GEOS-Chem Reference
2. Core Modules

GEOS-Chem Support Team

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Contents

1 GEOS-Chem header modules

Here follows a list modules that are used to define various global parameters and variables used by GEOS-Chem. These were formerly COMMON-block include files (*.h), but were converted to Fortran-90 modules as part of the GEOS-Chem HP (high-performance) project.

1.1 Fortran: Module Interface CMN_DIAG_mod.F

Module CMN_DIAG_mod contains size parameters and global variables for the GEOS-Chem diagnostic arrays. This is mostly historical baggage.

INTERFACE:

```
      MODULE CMN_DIAG_MOD
```

USES:

```
      USE CMN_SIZE_MOD
      USE CMN_FJX_MOD,   ONLY : W_
      USE PRECISION_MOD, ONLY : fpp => fp    ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PUBLIC
```

DEFINED PARAMETERS:

```
      INTEGER, PARAMETER :: PD05=14
      INTEGER, PARAMETER :: PD06=NDSTBIN
      ! +3 for SEAC4RS SOA tracers (jaf, 6/25/13)
      INTEGER, PARAMETER :: PD07=15
      INTEGER, PARAMETER :: PD08=4
      INTEGER, PARAMETER :: PD09=6
      INTEGER, PARAMETER :: PD10=20
      INTEGER, PARAMETER :: PD11=5
      INTEGER, PARAMETER :: PD16=2
      INTEGER, PARAMETER :: PD17=8
      INTEGER, PARAMETER :: PD18=8
      INTEGER, PARAMETER :: PD21=5+(NRHAER+NDUST)*3+(NRHAER*2)+
     &                           (NSTRATAER*3)
      INTEGER, PARAMETER :: PD22=28
      INTEGER, PARAMETER :: PD40=4
      INTEGER, PARAMETER :: PD43=7
      INTEGER, PARAMETER :: PD55=3
      ! Potential temperature diagnostic (hotp 7/31/09)
      INTEGER, PARAMETER :: PD57=1
      INTEGER, PARAMETER :: PD58=12
#if    defined( TOMAS )
      ! Special settings for TOMAS aerosol microphysics (win, bmy, 1/22/10)
      INTEGER, PARAMETER :: PD59=TOMASBIN*TOMASSPEC
      INTEGER, PARAMETER :: PD60=TOMASBIN*TOMASSPEC
```

```
      INTEGER, PARAMETER :: PD61=2
#else
      ! Normal settings for non-TOMAS simulations
      INTEGER, PARAMETER :: PD59=0
      INTEGER, PARAMETER :: PD60=1
      INTEGER, PARAMETER :: PD61=0
#endif
      INTEGER, PARAMETER :: PD64=W_
      INTEGER            :: PD65
      INTEGER, PARAMETER :: PD66=6
      INTEGER, PARAMETER :: PD67=23 ! (Lin, 31/03/09)
      INTEGER, PARAMETER :: PD68=8
      INTEGER, PARAMETER :: PD69=1

      !number of rad flux and optics output types
      !8 flux and 3*3=9 optics
      INTEGER, PARAMETER :: PD72R=17
      !total number of possible rad outputs (types*specs)
      !there are 11 possible flux output 'species' but
      !only 8 possible optics output 'species'
      !for simplicity we take the largest and put up with
      !some redundancy (should be 88+72=160)
      INTEGER, PARAMETER :: PD72=187 ! Radiation (Ridley 10/2012)

      !=================================================================
      ! Variables for printing out selected tracers in diagnostic output
      !=================================================================
#if   defined( RRTMG )
      INTEGER, PARAMETER :: MAX_DIAG   = 187
#else
      ! SDE 2013-11-17: Increased to 80 for UCX
      INTEGER, PARAMETER :: MAX_DIAG   = 80
#endif
#if   defined( TOMAS )
      INTEGER, PARAMETER :: MAX_TRACER = NNPAR+1   ! For TOMAS (win, 1/25/10)
#else
      INTEGER, PARAMETER :: MAX_TRACER = NNPAR+6   ! For non-TOMAS simulations
#endif
```

PUBLIC DATA MEMBERS:

```
      !=================================================================
      ! Diagnostic counters & time variables
      !=================================================================
      INTEGER :: KDA48, NJDAY(366)

      !=================================================================
      ! Variables for the number of levels in multi-level diagnostics
```

```
! Removed LD03 -- this is now in diag03_mod.f (bmy, 1/21/05)
! Added LD09 (bmy, 6/27/05)
! Added LD54 (phs, 9/22/06)
! Added LD10 (phs, 9/18/07)
! Added LD31 (bmy, 5/8/07)
! Added LD52 (jaegle, 02/26/09)
! Added LD59, LD60, LD61 (bmy, 1/22/10)
! Added LD57 (hotp 7/31/09)
!=================================================================
INTEGER :: LD12, LD13, LD14, LD15, LD16, LD17, LD18, LD21, LD22
INTEGER :: LD24, LD25, LD26, LD37, LD38, LD39, LD43, LD45, LD47
INTEGER :: LD54, LD64, LD65, LD66, LD68, LD01, LD02, LD05, LD07
INTEGER :: LD09, LD10, LD31, LD52, LD19, LD57, LD58, LD59, LD60
INTEGER :: LD61, LD62

!=================================================================
! NDxx diagnostic flags
!=================================================================
INTEGER :: ND01, ND02, ND05, ND06, ND07, ND08, ND09, ND10, ND11
INTEGER :: ND12, ND13, ND14, ND15, ND16, ND17, ND18, ND19, ND20
INTEGER :: ND21, ND22, ND23, ND24, ND25, ND26, ND27, ND28, ND29
INTEGER :: ND30, ND31, ND32, ND33, ND34, ND35, ND36, ND37, ND38
INTEGER :: ND39, ND40, ND43, ND44, ND45, ND46, ND47, ND48, ND49
INTEGER :: ND50, ND51, ND52, ND54, ND55, ND57, ND58, ND59
INTEGER :: ND60, ND61, ND62, ND63, ND64, ND65, ND66, ND67, ND68
INTEGER :: ND69, ND70, ND71, ND72, ND73, ND74, ND75

!=================================================================
! Variables for printing out selected tracers in diagnostic output
!=================================================================
INTEGER :: TINDEX(MAX_DIAG,MAX_TRACER)
INTEGER :: TCOUNT(MAX_DIAG)
INTEGER :: TMAX(MAX_DIAG)

!=================================================================
! OH, J-Value, and 2-PM diagnostic arrays (bmy, 9/25/98)
! Move this here for now (bmy, 7/20/04)
! Removed HR1_NO and HR2_NO (mpayer, 11/8/13)
!=================================================================
REAL(fpp)  :: HR1_JV, HR2_JV
REAL(fpp)  :: HR1_OH, HR2_OH, HR1_OTH, HR2_OTH
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  NOTE: THIS MODULE IS DEPRECATED.  MANY OF THE QUANTITIES STORED  %%%
%%%  in CMN_DIAG_MOD ARE NOW INCLUDED IN THE INPUT OPTIONS OBJECT,    %%%
%%%  BASED ON THE DERIVED TYPE IN Headers/input_opt_mod.F90.          %%%
%%%  (bmy, 11/19/12)                                                 %%%
```

```
%%%                                                                    %%%
%%%  ALSO NOTE: IN GEOS-CHEM v11-01, WE WILL BE RETIRING THE BPCH      %%%
%%%  DIAGNOSTICS.  MANY OF THESE PARAMETERS CAN THEN BE REMOVED.       %%%
%%%  (bmy, 6/24/16)                                                    %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
(1 ) Changed RCS ID tag comment character from "C" to "!" to allow freeform
      compilation.  Also added & continuation characters in column 73
      to allow header files to be included in F90 freeform files.
      Also converted PARAMETER statements to F90 syntax. (bmy, 6/25/02)
(2 ) Add LD05 for sulfate prod/loss (rjp, bdf, bmy, 9/20/02)
(3 )  Removed obsolete variables NTAU0, IDAY0, JDATE0, JYEAR0, KDACC,
       KDADYN, KDACONV, KDASRCE, KDACHEM, KDA3FLDS, KDA6FLDS, KDI6FLDS,
       KDKZZFLDS (bmy, 2/11/03)
(4 ) Fix for LINUX - remove & from column 73 (bmy, 6/27/03)
(5 ) Added LD03 for Kr85 Prod/loss diagnostic (bmy, 8/20/03)
(6 ) Removed obsolete arrays (bmy, 1/21/05)
(7 ) Rename MAXDIAG to MAX_DIAG and MAXTRACER to MAX_TRACER in order to
      avoid name conflicts with "gamap_mod.f" (bmy, 5/3/05)
(8 ) Remove reference to TRCOFFSET (bmy, 5/16/06)
(9 ) Added multi level LD54 to common CDIAG1 (phs, 9/22/06)
(10) Added multi level LD10 to common CDIAG1. Set PD10 to 20.  Set
      PD66 to 6. (phs, 9/18/07)
(11) Added LD52 to common CDIAG1 (jaegle, 02/26/09)
(12) Add GLYX, MGLY, SOAG, SOAM, and a few other tracers to AD17, AD18
      for archiving rainout and washout fraction. (tmf, 1/7/09)
(13) Add GLYX, MGLY J value archive. (tmf, 1/7/09)
(14) Add GLYX, MGLY, SOAG, SOAM, and a few other tracers to AD37, AD38,
      AD39
      for archiving rainout and washout flux. (tmf, 1/7/09)
(15) Add GLYX, MGLY, GLYC, 6 PANs, SOAG, SOAM dry dep,
      PD44 = 41.(tmf, 1/7/09)
(16) Add biogenic C2H4 emission, PD46 = 6. (tmf, 1/20/09)
(17) Add one met field to ND67 (EFLUX). (ccc, 5/14/09)
(18) Add declarations for PD58 and PD60, LD19, LD58. (kjw,8/18/09)
(19) Redimension PD59, PD60, PD61 for TOMAS microphysics.  Added LD59, LD60,
      LD61 to common block.  Reset MAX_TRACER to NNPAR+1 for TOMAS.
      (win, bmy, 1/22/10)
(20) Add LD57 and PD57 (potential temperature) (hotp, 3/15/10)
03 Aug 2010 - R. Yantosca - Added ProTeX headers
03 Aug 2010 - P. Kasibhatla & R. Yantosca - Now set MAX_TRACER to NNPAR+6
                                            to match ND09 diagnostic
09 Mar 2011 - R. Yantosca - Updated MAX_TRACER for APM (G. Luo)
03 Aug 2011 - M. Long     - Converted from Header file to Module
08 Nov 2013 - M. Sulprizio- Remove HR1_NO and HR2_NO. They are no longer
                            needed for ND43 because NO, NO2, and NO3 are now
                            tracers.
```

```
02 Dec 2014 - M. Yannetti - Added PRECISION_MOD
15 Dec 2014 - M. Sulprizio- Moved radiation diagnostic from ND72 to ND72 to
                            avoid conflicts with hourly max ppbv diagnostic.
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
21 Jul 2016 - R. Yantosca - Remove instances of NNPAR & obsolete parameters
```

1.1.1 Init_Cmn_Diag

Subroutine INIT_CMN_DIAG initializes quantities based on the grid-independent size parameters.

INTERFACE:

```
SUBROUTINE Init_CMN_DIAG( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
19 Nov 2012 - R. Yantosca - Added ProTeX headers
```

1.2 Fortran: Module Interface CMN_FJX_mod.F

Module CMN_FJX_MOD contains parameters and global variables used to interface between Harvard chemistry and UC-Irvine photolysis programs (Fast-J/Fast-JX), along with all Fast-J(X) global variables and some physical constants for the GEOS-Chem chemistry code.

INTERFACE:

```
MODULE CMN_FJX_MOD
```

USES:

```
USE CMN_SIZE_MOD,      ONLY : IIPAR, JJPAR, LLPAR, LLCHEM
USE CMN_SIZE_MOD,      ONLY : NDUST, NAER, NRHAER, NSTRATAER, NRH

USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PUBLIC
```

DEFINED PARAMETERS:

```
      ! New (SDE 03/28/13)
      ! Index in RAA & QAA of 999 nm wavelength
      INTEGER, PARAMETER :: IND999  = 5

      ! Required size of aerosol arrays
      INTEGER            :: L_             ! Number of CTM layers

      INTEGER            :: L1_            ! Number of CTM layer edges

      INTEGER            :: L2_            ! Number of levels in FJX grid that
                                           ! inc. both edges and mid-points

      INTEGER            :: JVL_           ! Vertical levels for J-values

      INTEGER, PARAMETER :: JVN_ = 121     ! Max number of J-values

#if defined( UCX )
      INTEGER, PARAMETER :: AN_  = 37      ! Including PSCs
#else
      INTEGER, PARAMETER :: AN_  = 35      ! # of separate aerosols per layer
#endif

      ! Variables used to interface GEOS-Chem and Fast-JX at runtime
      ! Branches for photolysis species
      INTEGER            :: BRANCH(JVN_)

      ! Names of photolysis species
      CHARACTER (LEN=10) :: RNAMES(JVN_)

      ! Mapping array from Harvard species names to UCI species names
      INTEGER            :: RINDEX(JVN_)

      ! Output J values
      REAL(fp), ALLOCATABLE :: ZPJ(:,:,:,:)

      !-----------------------------------------------------------------------
      ! variables used to map fast-JX J's onto CTM J's
      !-----------------------------------------------------------------------

      ! Multiplication factor for fast-JX calculated J
      REAL(fp)             :: JFACTA(JVN_)

      ! Index arrays that map Jvalue(j) onto rates
      INTEGER            :: JIND(JVN_)

      ! Mumber of Photolysis reactions in CTM chemistry, derived here NRATJ
```

```
      ! must be .le. JVN_
      INTEGER            :: NRATJ

      ! Label of J-value used in the main chem model
      CHARACTER*50       :: JLABEL(JVN_)

      ! JXL_: vertical(levels) dim for J-values computed within fast-JX
      INTEGER            ::  JXL_
      INTEGER            ::  JXL1_

      ! JXL2_: 2*JXL_ + 2 = mx no. levels in the basic Fast-JX grid (mid-level)
      INTEGER            ::  JXL2_

      ! WX_  = dim = no. of wavelengths in input file
      INTEGER, PARAMETER ::  WX_   = 18

      ! X_   = dim = max no. of X-section data sets (input data)
      INTEGER, PARAMETER ::  X_    = 72

      ! A_   = dim = no. of Aerosol/cloud Mie sets (input data)
      INTEGER, PARAMETER ::  A_    = 56

      ! W_   = dim = no. of Wavelength bins:  =18 std, =12 trop only
#if defined( UCX )
      INTEGER, PARAMETER ::  W_    = 18
#else
      INTEGER, PARAMETER ::  W_    = 12
#endif

      ! N_  = no. of levels in Mie scattering arrays
      !     = 2*NC+1 = 4*(L_+1) + 1 + 2*sum(JADDLV)
      INTEGER, PARAMETER ::  N_    = 601

      ! M_  = no. of Gauss points used, must = 4 in fast_JX (no option)
      INTEGER, PARAMETER ::  M_    = 4

      ! M2_ = 2*M_ = 8, replaces MFIT
      INTEGER, PARAMETER ::  M2_   = 2*M_

      !-----------------------------------------------------------------------
      ! 4 Gauss pts = 8-stream
      REAL(fp), DIMENSION(M_), PARAMETER  ::
     &             EMU = [.06943184420297e+0_fp, .33000947820757e+0_fp,
     &                    .66999052179243e+0_fp, .93056815579703e+0_fp]
      REAL(fp), DIMENSION(M_), PARAMETER  ::
     &             WT  = [.17392742256873e+0_fp, .32607257743127e+0_fp,
     &                    .32607257743127e+0_fp, .17392742256873e+0_fp]
      !-----------------------------------------------------------------------
```

```
! ZZHT: scale height (cm)
REAL(fp), PARAMETER  :: ZZHT   = 5.e+5_fp

! RAD: Radius of Earth (cm)
REAL(fp), PARAMETER  :: RAD    = 6375.e+5_fp

! ATAU: heating rate (factor increase from one layer to the next)
REAL(fp), PARAMETER  :: ATAU   = 1.120e+0_fp

! ATAU0: minimum heating rate
REAL(fp), PARAMETER  :: ATAU0  = 0.010e+0_fp

! JTAUMX = maximum number of divisions (i.e., may not get to ATAUMN)
INTEGER              :: JTAUMX

! Physical constants
REAL(fp), PARAMETER  :: UVXPLANCK = 6.62606957e-34
REAL(fp), PARAMETER  :: UVXCCONST = 2.99792458e8

! Conversion factors from photons/cm2s to W/m2
REAL(fp), DIMENSION(WX_) :: UVXFACTOR

!-----------------------------------------------------------------------
! Variables in file 'FJX_spec.dat' (RD_XXX)
!-----------------------------------------------------------------------

! WBIN: Boundaries of wavelength bins
REAL(fp)             :: WBIN(WX_+1)

! WL: Centres of wavelength bins - 'effective wavelength'
REAL(fp)             :: WL(WX_)

! FL: Solar flux incident on top of atmosphere (cm-2.s-1)
REAL(fp)             :: FL(WX_)

REAL(fp)             :: QO2(WX_,3)   ! QO2: O2 cross-sections
REAL(fp)             :: QO3(WX_,3)   ! QO3: O3 cross-sections
REAL(fp)             :: Q1D(WX_,3)   ! Q1D: O3 => O(1D) quantum yield

! QQQ: Supplied cross sections in each wavelength bin (cm2)
REAL(fp)             :: QQQ(WX_,3,X_)

! QRAYL: Rayleigh parameters (effective cross-section) (cm2)
REAL(fp)             :: QRAYL(WX_+1)

! TQQ: Temperature for supplied cross sections
REAL(fp)             :: TQQ(3,X_)
```

```
! LQQ = 1, 2, or 3 to determine interpolation with T or P
INTEGER            :: LQQ(X_)

! TITLEJX: Title for supplied cross sections, from 'FJX_spec.dat'
CHARACTER*6        :: TITLEJX(X_)

! SQQ: Flag for supplied cross sections, from 'FJX_spec.dat'
CHARACTER*1        :: SQQ(X_)

!-----------------------------------------------------------------------
! Variables in file 'jv_spec_mie.dat' (RD_MIE)
!-----------------------------------------------------------------------

! QAA: Aerosol scattering phase functions
REAL(fp)           :: QAA(5,A_)

! WAA: 5 Wavelengths for the supplied phase functions
REAL(fp)           :: WAA(5,A_)

! PAA: Phase function: first 8 terms of expansion
REAL(fp)           :: PAA(8,5,A_)

! RAA: Effective radius associated with aerosol type
REAL(fp)           :: RAA(5,A_)

! SAA: Single scattering albedo
REAL(fp)           :: SAA(5,A_)

! NAA: Number of categories for scattering phase functions
INTEGER            :: NAA

!-----------------------------------------------------------------------
! Variables in file 'jv_spec_aod.dat' (RD_AOD)
!-----------------------------------------------------------------------

! QAA_AOD: Aerosol scattering phase functions
REAL(fp)           :: QAA_AOD(A_)

! WAA: 5 Wavelengths for the supplied phase functions
REAL(fp)           :: WAA_AOD(A_)

! PAA: Phase function: first 8 terms of expansion
REAL(fp)           :: PAA_AOD(8,A_)

! RAA: Effective radius associated with aerosol type
REAL(fp)           :: RAA_AOD(A_)
```

```
      ! SAA: Single scattering albedo
      REAL(fp)             :: SAA_AOD(A_)

      !-----------------------------------------------------------------------
      ! Variables in file 'atmos_std.dat' (RD_PROF)
      !-----------------------------------------------------------------------

      ! T and O3 reference profiles
      REAL(fp), DIMENSION(51,18,12) :: TREF, OREF

      ! Interfacing indices for GC and FJX aerosols
      INTEGER, DIMENSION(AN_)     :: MIEDX

      ! TITLEAA: Title for scattering data
      CHARACTER*20, DIMENSION(A_) :: TITLEAA

      ! Dust and aerosol optical depths
      REAL(fp), ALLOCATABLE :: ODMDUST(:,:,:,:,:)
      REAL(fp), ALLOCATABLE :: ODAER(:,:,:,:,:)

      INTEGER NJX,NW1,NW2

      !-----------------------------------------------------------------------
      !  Variables added for RRTMG (dar, mps, 12/5/14)
      !-----------------------------------------------------------------------

      INTEGER, PARAMETER :: NWVAA   = 41     !number of wavelengths in LUT
      INTEGER, PARAMETER :: NWVAA0  = 11     !number of non-RRTMG wavelengths
      INTEGER, PARAMETER :: NWVAART = NWVAA-NWVAA0 !number of RRTMG wvs
      INTEGER, PARAMETER :: NRAA    = 7      !number of aer sizes in LUT
#if defined( UCX )
      INTEGER, PARAMETER :: NSPAA   = 8      !number of species in LUT
      INTEGER, PARAMETER :: NASPECRAD = 16   !aerosol species in RT
      INTEGER, PARAMETER :: NSPECRAD  = 18   !aerosol+gas species in RT
      INTEGER, PARAMETER :: NSPECRADMENU = 11!number of choices for RT flux
#else
      INTEGER, PARAMETER :: NSPAA     = 6    !number of species in LUT
      INTEGER, PARAMETER :: NASPECRAD = 14   !aerosol species in RT
      INTEGER, PARAMETER :: NSPECRAD  = 16   !aerosol+gas species in RT
      INTEGER, PARAMETER :: NSPECRADMENU = 10!number of choices for RT flux
#endif
      INTEGER, PARAMETER :: NALBD   = 2
      INTEGER, PARAMETER :: NEMISS  = 16

      ! New optical arrays
      REAL*8  :: WVAA(NWVAA,NSPAA)
      REAL*8  :: RHAA(NRAA,NSPAA)
      REAL*8  :: NRLAA(NWVAA,NRAA,NSPAA)
```

```
      REAL*8  :: NCMAA(NWVAA,NRAA,NSPAA)
      REAL*8  :: RDAA(NRAA,NSPAA)
      REAL*8  :: RWAA(NRAA,NSPAA)
      REAL*8  :: SGAA(NRAA,NSPAA)
      REAL*8  :: QQAA(NWVAA,NRAA,NSPAA)
      REAL*8  :: ALPHAA(NWVAA,NRAA,NSPAA)
      REAL*8  :: REAA(NRAA,NSPAA)
      REAL*8  :: SSAA(NWVAA,NRAA,NSPAA)
      REAL*8  :: ASYMAA(NWVAA,NRAA,NSPAA)
      REAL*8  :: PHAA(NWVAA,NRAA,NSPAA,8)
      REAL*8  :: WVSELECT(3)  !wavelengths requested by user
      INTEGER :: IWVSELECT(2,3) !index of requested wavelengths
      INTEGER :: IRTWVSELECT(2,3) !index of requested RT wavelengths

      ! max of 3 but need 2 per wavelength if interpolating
      INTEGER :: NWVSELECT !number of selected AOD output wavelengths
                           !(max=3)
      INTEGER :: NWVREQUIRED !number of wvs required for interpolation
      INTEGER :: IWVREQUIRED(6) !index of wavelengths for interpo.
      INTEGER :: NRTWVREQUIRED !number of wvs required for RT interpolation
      INTEGER :: IRTWVREQUIRED(6) !index of wavelengths for RT interpo.
      ! list of required wavelengths, up to max of 3 x 2

      INTEGER :: IWV1000 !Store the wavelength index for 1000nm for Fast-J

      !coefficients for interpolation of wavelength (and for RT too)
      REAL*8      :: ACOEF_WV(3),BCOEF_WV(3),CCOEF_WV(3)
      REAL*8      :: ACOEF_RTWV(3),BCOEF_RTWV(3),CCOEF_RTWV(3)
      CHARACTER*5 :: STRWVSELECT(3) !String array of requested wavelengths
      INTEGER     :: LSPECRADMENU(NSPECRADMENU) !indices for number of species on input menu
      INTEGER     :: SPECMASK(NSPECRAD) !list of binary switches for different
                                        !species flux output

      ! RH indices
      INTEGER, ALLOCATABLE :: IRHARR(:,:,:)

#if defined( RRTMG )
      !to pass to RT code
      !one for each hydrophilic/hydrophobic aerosol and optical dust bin
      !and also sulfate, nitrate and ammonia are separate too
      REAL*8, ALLOCATABLE :: RTODAER(:,:,:,:,:)
      REAL*8, ALLOCATABLE :: RTSSAER(:,:,:,:,:)
      REAL*8, ALLOCATABLE :: RTASYMAER(:,:,:,:,:)
#endif

      CONTAINS
 EOC
 ------------------------------------------------------------------------------
```

```
                  GEOS-Chem Global Chemical Transport Model                  !
  ------------------------------------------------------------------------------
%//////////////////////////////////////////////////////////////

\mbox{}\hrulefill\


  \subsubsection [Init\_Cmn\_Fjx] {Init\_Cmn\_Fjx}


  Routine INIT\_CMN\_FJX initializes quantities based on
    the grid-independent size parameters.
  \\
  \\{\bf INTERFACE:}
\begin{verbatim}
       SUBROUTINE Init_CMN_FJX( am_I_Root, RC )
```

USES:

```
       USE ErrCode_Mod
```

INPUT PARAMETERS:

```
       LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
       INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    21 Feb 2014 - M. Sulprizio- Renamed from Set_CMN_FJX_MOD to Init_CMN_FJX.
                                We now set several variables here that depend on
                                LLPAR, since LLPAR is no longer a parameter and
                                can't be used to define a parameter.
```

1.2.1 Cleanup_Cmn_Fjx

Subroutine CLEANUP_CMN_FJX deallocates all module arrays.

INTERFACE:

```
       SUBROUTINE Cleanup_CMN_FJX( am_I_Root, RC )
```

USES:

```
       USE ErrCode_Mod
```

INPUT PARAMETERS:

```
       LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
21 Feb 2014 - M. Sulprizio- Initial version
```

1.3 Fortran: Module Interface CMN_O3_mod.F

Common blocks for anthro emissions (via SMVGEAR!)

INTERFACE:

```
MODULE CMN_O3_MOD
```

USES:

```
USE CMN_SIZE_MOD, ONLY : IIPAR, JJPAR, LLPAR
USE PRECISION_MOD

IMPLICIT NONE
PUBLIC
```

PUBLIC DATA MEMBERS:

```
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!%%% NOTE: THESE ARE USED FOR DIAGNOSTICS WHICH ARE OBSOLETE %%%
!%%% WE WILL EVENTUALLY REMOVE THESE IN THE NEAR FUTURE.     %%%
!%%% (bmy, 5/22/15)                                          %%%
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

! SAVEOH  = array to save OH  fields
! SAVEHO2 = array to save HO2 fields (rvm, bmy, 2/27/02)
REAL(fp), ALLOCATABLE ::   SAVEOH(:,:,:)
REAL(fp), ALLOCATABLE ::   SAVEHO2(:,:,:)
REAL(fp), ALLOCATABLE ::   SAVEO1D(:,:,:)
REAL(fp), ALLOCATABLE ::   SAVEO3P(:,:,:)
```

REMARKS:

```
NOTE: Now NEMPARA = max no. of anthropogenic emissions
          NEMPARB = max no. of biogenic emissions

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  NOTE: THIS MODULE IS NOW DEPRECATED.  IT WILL BE REMOVED WHEN  %%%
%%%  THE GEOS-CHEM EMISSIONS MODULE IS UPDATED (SOMETIME SOON)      %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
23 Aug 2011 - M. Long   - Converted to Module from Header file
29 Mar 2013 - M. Payer    - Removed FRACO3, FRACNO, FRACNO2, SAVENO, SAVENO2,
                            and SAVENO3. They are no longer needed because
                            O3, NO, NO2, and NO3 are now tracers.
13 Aug 2013 - M. Sulprizio- Increase last dimension of EMISS_BVOC to include
                            sesquiterpenes and add EMISTNAP for SOA +
                            semivolatile POA simulation (H. Pye)
21 Feb 2014 - M. Sulprizio- Added SAVEO1D and SAVEO3P for UCX (S.D. Eastham)
03 Dec 2014 - M. Yannetti - Added PRECISION_MOD
22 May 2015 - R. Yantosca - Remove arrays made obsolete by HEMCO
```

1.3.1 Init_Cmn_O3

Subroutine INIT_CMN_O3 allocates all module arrays.

INTERFACE:

```
SUBROUTINE Init_CMN_O3( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
19 Nov 2012 - R. Yantosca - Added ProTeX headers
01 Feb 2013 - R. Yantosca - Now allocate EMISS_BVOC to 19 emission species
29 Mar 2013 - M. Payer    - Removed FRACO3, FRACNO, FRACNO2, SAVENO, SAVENO2,
                            and SAVENO3. They are no longer needed because
                            O3, NO, NO2, and NO3 are now tracers.
13 Aug 2013 - M. Sulprizio- Increase last dimension of EMISS_BVOC to include
                            sesquiterpenes and add EMISTNAP for SOA +
                            semivolatile POA simulation (H. Pye)
22 May 2015 - R. Yantosca - Remove arrays made obsolete by HEMCO
```

1.3.2 Cleanup_Cmn_O3

Subroutine CLEANUP_CMN_O3 allocates all module arrays.

INTERFACE:

```
      SUBROUTINE Cleanup_CMN_O3( am_I_Root, RC )
```

USES:

```
      USE ErrCode_Mod
```

INPUT PARAMETERS:

```
      LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
      INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    19 Nov 2012 - R. Yantosca - Added ProTeX headers
    29 Mar 2013 - M. Payer    - Removed FRACO3, FRACNO, FRACNO2, SAVENO, SAVENO2,
                                and SAVENO3. They are no longer needed because
                                O3, NO, NO2, and NO3 are now tracers.
    22 May 2015 - R. Yantosca - Remove arrays made obsolete by HEMCO
```

1.4 Fortran: Module Interface CMN_SIZE_mod.F

CMN_SIZE contains size parameters for GEOS-Chem arrays.

INTERFACE:

```
      MODULE CMN_SIZE_MOD
```

USES:

```
      USE PRECISION_MOD, ONLY : fpp => fp    ! For GEOS-Chem Precision (fpp)

      IMPLICIT NONE
      PUBLIC
```

DEFINED PARAMETERS:

```
      !=================================================================
      ! DISIZE = size (in degrees) of a longitude grid box
      ! DJSIZE = size (in degrees) of a latitude  grid box
      ! NOTE: DISIZE and DJSIZE are only needed for "GEOS-Chem Classic",
      ! as these are used to define the Delta-Lon and Delta-Lat values
      ! that need to get saved to the binary punch files.  If you are
      ! using "GEOS-Chem HP", then you can set this to a dummy value.
      ! (mlong, bmy, 5/22/15)
      !=================================================================
#if   defined( GRID4x5 )
      REAL(fpp), PARAMETER :: DISIZE = 5.0e+0_fpp
```

```
      REAL(fpp), PARAMETER :: DJSIZE = 4.0e+0_fpp
#elif defined( GRID2x25 )
      REAL(fpp), PARAMETER :: DISIZE = 2.5e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 2.0e+0_fpp
#elif defined( GRID1x125 )
      REAL(fpp), PARAMETER :: DISIZE = 1.25e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 1.0e+0_fpp
#elif defined( GRID1x1 )
      REAL(fpp), PARAMETER :: DISIZE = 1.0e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 1.0e+0_fpp
#elif defined( GRID05x0666 )
      REAL(fpp), PARAMETER :: DISIZE = 2e+0_fpp/3e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 0.5e+0_fpp
#elif defined( GRID05x0625 )
      REAL(fpp), PARAMETER :: DISIZE = 0.625e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 0.5e+0_fpp
#elif defined( GRID025x03125)
      REAL(fpp), PARAMETER :: DISIZE = 0.3125e+0_fpp
      REAL(fpp), PARAMETER :: DJSIZE = 0.25e+0_fpp
#elif defined( EXTERNAL_GRID )
      REAL(fpp)            :: DISIZE
      REAL(fpp)            :: DJSIZE
#endif

      !=================================================================
      ! GRID SETTINGS #1: Necessary for the grid-independent GEOS-Chem
      !=================================================================
      INTEGER                :: I_LO         ! Minimum lon index on this CPU
      INTEGER                :: J_LO         ! Minimum lat index on this CPU
      INTEGER                :: I_HI         ! Maximum lon index on this CPU
      INTEGER                :: J_HI         ! Maximum lat index on this CPU
      INTEGER                :: IM_WORLD     ! # of lons in the global grid
      INTEGER                :: JM_WORLD     ! # of lats in the global grid
      INTEGER                :: LM_WORLD     ! # of levs in the global grid
      REAL(fpp), ALLOCATABLE :: DLON(:,:,:)  ! Array of delta-lon [degrees]
      REAL(fpp), ALLOCATABLE :: DLAT(:,:,:)  ! Array of delta-lat [degrees]

      !=================================================================
      ! GRID SETTINGS #2: Mostly historical declarations (keep for now)
      ! IGLOB      = global longitude dimension
      ! JGLOB      = global latitude dimension
      ! LGLOB      = max number of sigma levels
      ! IIPAR      = window longitude dimension
      ! JJPAR      = window latitude dimension
      ! LLPAR      = window vertical dimension
      ! LLTROP     = maximum number of tropospheric levels for variable
      !              tropopause
      ! LLTROP_FIX = number of tropospheric levels for offline simulations
```

```
      ! LLSTRAT    = maximum number of levels below stratopause
      ! LLCHEM     = maximum number of levels included in chemistry grid
      ! LLCHEM_FIX = number of chemgrid levels for offline simulations
      ! PTOP       = model top pressure (mb)
      ! Most of the time, GEOS-CHEM is used for global simulations.
      ! In this case, then IIPAR=IGLOB, JJPAR=JGLOB, LLPAR=LGLOB.
      ! For nested grids, then IIPAR<IGLOB, JJPAR<JGLOB, LLPAR<LGLOB.
      !=================================================================

      ! IIPAR and JJPAR are always set at runtime
      ! for both GEOS-Chem HP and GEOS-Chem Classic
      INTEGER               :: IIPAR
      INTEGER               :: JJPAR

#if defined ( EXTERNAL_GRID ) || defined( EXTERNAL_FORCING ) || defined( ESMF_ )
      !-----------------------------------------------------------------
      !         %%%%%%% GEOS-Chem HP (with ESMF & MPI) %%%%%%%
      ! We need to make all of these be variables rather than
      ! parameters, so that they can be defined directly from the
      ! ESMF interface. (bmy, 10/11/12)
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB
      INTEGER               :: JGLOB
      INTEGER               :: LGLOB
      INTEGER               :: LLPAR
      INTEGER               :: LLTROP_FIX
      INTEGER               :: LLTROP
      INTEGER               :: LLSTRAT
      REAL*8,     PARAMETER :: PTOP       = 0.01d0
#else

      !-----------------------------------------------------------------
      !         %%%%%%% GEOS-Chem CLASSIC (with OpenMP) %%%%%%%
      ! For GEOS-Chem "Classic", we can preset the values of IGLOB,
      ! JGLOB, LGLOB, LLTROP, LLTROP_FIX, LLSTRAT, (bmy, 5/22/15)
      !-----------------------------------------------------------------

#if   defined( GCAP ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! GCAP: 4 x 5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 45
      INTEGER               :: LGLOB      = 23
      INTEGER               :: LLPAR
      INTEGER,    PARAMETER :: LLTROP     = 12
      INTEGER,    PARAMETER :: LLTROP_FIX = LLTROP
```

```
      INTEGER,    PARAMETER :: LLSTRAT    = 20
      REAL(fpp),  PARAMETER :: PTOP       = 0.002e+0_fpp

#elif defined( GEOS_4 ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! GEOS-4: 4 x 5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 46
      INTEGER               :: LGLOB      = 55
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 30        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 22        !  -- 30 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 27
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 23        !  -- 55 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 42
#endif
      INTEGER,    PARAMETER :: LLTROP_FIX = 17
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_4 ) && defined( GRID2x25 )

      !-----------------------------------------------------------------
      ! GEOS-4: 2 x 2.5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 144
      INTEGER               :: JGLOB      = 91
      INTEGER               :: LGLOB      = 55
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 30        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 22        !  -- 30 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 27
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 23        !  -- 55 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 42
#endif
      INTEGER,    PARAMETER :: LLTROP_FIX = 17
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_4 ) && defined( GRID1x125 )

      !-----------------------------------------------------------------
      ! GEOS-4: 1 x 1.2.5
      !-----------------------------------------------------------------
```

```
      INTEGER               :: IGLOB      = 288
      INTEGER               :: JGLOB      = 181
      INTEGER               :: LGLOB      = 55
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 30        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 22        !  -- 30 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 27
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP     = 23        !  -- 55 levels
      INTEGER,    PARAMETER :: LLSTRAT    = 42
#endif
      INTEGER,    PARAMETER :: LLTROP_FIX = 17
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_5 ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! GEOS-5: 4 x 5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 46
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_5 ) && defined( GRID2x25 )

      !-----------------------------------------------------------------
      ! GEOS-5: 2 x 2.5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 144
      INTEGER               :: JGLOB      = 91
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
```

```
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                 ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40       !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_5 ) && defined( GRID1x125 )
      !-----------------------------------------------------------------
      ! GEOS-5: 1 x 1.25
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 288
      INTEGER               :: JGLOB      = 181
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47       ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38       !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                 ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40       !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_5 ) && defined( GRID05x0666 )

      !-----------------------------------------------------------------
      ! GEOS-5: 0.5 x 0.666
      !-----------------------------------------------------------------
#if   defined( NESTED_CH )
      INTEGER               :: IGLOB      = 121      ! NESTED CH 0.5x0.666
      INTEGER               :: JGLOB      = 133
      INTEGER               :: LGLOB      = 72
#elif defined( NESTED_NA )
      INTEGER               :: IGLOB      = 151      ! NESTED NA 0.5x0.666
      INTEGER               :: JGLOB      = 121
      INTEGER               :: LGLOB      = 72
#elif defined( NESTED_EU )
      INTEGER               :: IGLOB      = 121      ! NESTED EU 0.5x0.666
      INTEGER               :: JGLOB      = 81
      INTEGER               :: LGLOB      = 72
#endif
#if   defined( GRIDREDUCED )
```

```
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA ) && defined( GRID2x25 )

      !-----------------------------------------------------------------
      ! MERRA: 2 x 2.5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 144
      INTEGER               :: JGLOB      = 91
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! MERRA: 4 x 5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 46
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
```

```
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_FP ) && defined( GRID025x03125 ) && defined( NESTED_CH )

      !-----------------------------------------------------------------
      ! GEOS-FP: Nested China Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 225
      INTEGER               :: JGLOB      = 161
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_FP ) && defined( GRID025x03125 ) && defined( NESTED_NA)

      !-----------------------------------------------------------------
      ! GEOS-FP Nested NA Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 225
      INTEGER               :: JGLOB      = 202
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp
```

```
      !Anna Prot added the following sizes for nesting EU, 7 May 2015
#elif defined( GEOS_FP ) && defined( GRID025x03125 ) && defined( NESTED_EU)

      !-----------------------------------------------------------------
      ! GEOS-FP Nested EU Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 177
      INTEGER               :: JGLOB      = 115
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_FP ) && defined( GRID2x25 )

      !-----------------------------------------------------------------
      ! GEOS-FP: 2 x 2.5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 144
      INTEGER               :: JGLOB      = 91
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( GEOS_FP ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! GEOS-FP: 4 x 5
      !-----------------------------------------------------------------
```

```
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 46
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA2 ) && defined( GRID05x0625 ) && defined( NESTED_AS )

      !-----------------------------------------------------------------
      ! MERRA2: Nested China Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 145
      INTEGER               :: JGLOB      = 133
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA2 ) && defined( GRID05x0625 ) && defined( NESTED_NA)

      !-----------------------------------------------------------------
      ! MERRA2: Nested NA Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 161
      INTEGER               :: JGLOB      = 121
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
```

```
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40      !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA2 ) && defined( GRID05x0625 ) && defined( NESTED_EU)

      !-----------------------------------------------------------------
      ! MERRA2: Nested EU Grid
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 129
      INTEGER               :: JGLOB      = 81
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA2 ) && defined( GRID2x25 )

      !-----------------------------------------------------------------
      ! MERRA2: 2 x 2.5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 144
      INTEGER               :: JGLOB      = 91
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
```

```
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#elif defined( MERRA2 ) && defined( GRID4x5 )

      !-----------------------------------------------------------------
      ! MERRA2: 4 x 5
      !-----------------------------------------------------------------
      INTEGER               :: IGLOB      = 72
      INTEGER               :: JGLOB      = 46
      INTEGER               :: LGLOB      = 72
#if   defined( GRIDREDUCED )
      INTEGER               :: LLPAR      = 47        ! Reduced vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 38        !  -- 47 levels
      INTEGER,    PARAMETER :: LLTROP     = 38
      INTEGER,    PARAMETER :: LLSTRAT    = 44
#else
      INTEGER               :: LLPAR                  ! Full vertical grid
      INTEGER,    PARAMETER :: LLTROP_FIX = 40        !  -- 72 levels
      INTEGER,    PARAMETER :: LLTROP     = 40
      INTEGER,    PARAMETER :: LLSTRAT    = 59
#endif
      REAL(fpp),  PARAMETER :: PTOP       = 0.01e+0_fpp

#endif
#endif

      !-----------------------------------------------------------------
      ! For stratospheric chemistry
      !-----------------------------------------------------------------
      INTEGER               :: LLCHEM
      INTEGER               :: LLCHEM_FIX

      !=================================================================
      ! TRACER & EMISSION SPECIES PARAMETERS
      ! NNPAR   = max number of tracers
      ! NEMPARA = max number of anthropogenic emission species
      ! NEMPARB = max number of biogenic      emission species
      !=================================================================
      ! increase NNPAR and NEMPARA an extra amount (hotp 7/31/09)
#if   defined( TOMAS )
# if    defined( TOMAS40 )
      INTEGER,    PARAMETER :: NNPAR   = 430   ! For TOMAS40 (sfarina 6/11/13)
# elif  defined( TOMAS15 )
      INTEGER,    PARAMETER :: NNPAR   = 205   ! For TOMAS15 (sfarina 6/11/13)
# elif  defined( TOMAS12 )
      INTEGER,    PARAMETER :: NNPAR   = 178   ! For TOMAS12 (sfarina 6/11/13)
```

```
# else
      INTEGER,    PARAMETER :: NNPAR   = 340   ! For TOMAS (win, bmy, sfarina 6/11/13)f
# endif
#else
      INTEGER,    PARAMETER :: NNPAR   = 150   ! For non-TOMAS simulations
#endif

      !=================================================================
      ! OTHER PARAMETERS
      !=================================================================

      ! NVEGTYPE - Maximum number of surface types: 74 olson
      ! NTYPE    - Maximum number of veg types in a CTM grid box
      ! NPOLY    - Number of coefficients for polynomial fits
      INTEGER,    PARAMETER :: NVEGTYPE = 74
#if defined( EXTERNAL_GRID ) || defined( EXTERNAL_TYPE )
      !-----------------------------------------------------------------
      !         %%%%%%% GEOS-Chem HP (with ESMF & MPI) %%%%%%%
      ! For testing the ESMF interface to GEOS-Chem with a grid that
      ! is smaller than the usual 72x46, increase NTYPE (bmy, 12/4/12)
      !-----------------------------------------------------------------
      INTEGER,    PARAMETER :: NTYPE    = 50
#else
      !-----------------------------------------------------------------
      !         %%%%%%% GEOS-Chem CLASSIC (with OpenMP) %%%%%%%
      ! Current practice in the std GEOS-Chem is to set NTYPE to 25,
      ! which is large enough if using the Olson 2001 land map at
      ! 0.25 x 0.25 resolution. (bmy, 12/4/12)
      !-----------------------------------------------------------------
      INTEGER,    PARAMETER :: NTYPE    = 25
#endif
      INTEGER,    PARAMETER :: NPOLY    = 20

      ! LLCONVM - Max number of layers for convection
      INTEGER               :: LLCONVM

      ! MAXFAM -- Max number of families for prod and loss output
      INTEGER,    PARAMETER :: MAXFAM = 40

      ! MAXMEM is maximum number of families of prod and loss
      ! moved from input_mod and diag_pl_mod to here (hotp 7/31/09)
      ! MAXMEM also increased from 10 to 20 by FP
      ! MAXMEM increased from 20 to 22 for bromine (jpp, mpayer, 12/28/11)
      INTEGER,    PARAMETER :: MAXMEM = 22

      ! MAXPL increased from 100 to 500 and moved from diag_pl_mod
      ! to here by FP (hotp 7/31/09)
      INTEGER,    PARAMETER :: MAXPL = 500
```

```
      ! NDUST -- Number of FAST-J aerosol size bins (rvm, bmy, 11/15/01)
      INTEGER,    PARAMETER :: NDUST = 7

      ! NRHAER -- Number of aerosols undergoing hygroscopic growth
      INTEGER,    PARAMETER :: NRHAER = 5

      ! NSTRATAER -- Number of stratospheric aerosols (SDE 04/17/13)
#if defined( UCX )
      INTEGER,    PARAMETER :: NSTRATAER = 2
#else
      INTEGER,    PARAMETER :: NSTRATAER = 0
#endif

      ! NAER -- number of other aerosol categories (rvm, bmy, 2/27/02)
      INTEGER,    PARAMETER :: NAER = NRHAER + NSTRATAER

      ! NRH -- number of relative humidity bins (rvm, bmy, 2/27/02)
      INTEGER,    PARAMETER :: NRH = 5

#if   defined( TOMAS )
      INTEGER,    PARAMETER :: TOMASSPEC = 8

# if  defined( TOMAS40 )
      INTEGER,    PARAMETER :: NDSTBIN   = 40
      INTEGER,    PARAMETER :: TOMASBIN  = 40
# elif  defined( TOMAS15 )
      INTEGER,    PARAMETER :: NDSTBIN   = 15
      INTEGER,    PARAMETER :: TOMASBIN  = 15
# elif  defined( TOMAS12 )
      INTEGER,    PARAMETER :: NDSTBIN   = 12
      INTEGER,    PARAMETER :: TOMASBIN  = 12
# else
      ! NDSTBIN -- redimensioned for TOMAS (dwest, bmy, 2/1/10)
      INTEGER,    PARAMETER :: NDSTBIN   = 30
      INTEGER,    PARAMETER :: TOMASBIN  = 30 ! Number of TOMAS bins
# endif

#else
      ! NDSTBIN -- number of dust size bins for transport (tdf, bmy, 3/31/04)
      INTEGER,    PARAMETER :: NDSTBIN   = 4
#endif
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% NOTE: THIS WAS MADE INTO A MODULE IN ORDER TO REMOVE COMMON BLOCKS  %%%
%%% WE WILL KEEP THIS FOR NOW.  EVENTUALLY WE MIGHT MIGRATE THESE DATA  %%%
%%% INTO A DERIVED TYPE OBJECT. (bmy, 12/3/12)                          %%%
```

%%%

REVISION HISTORY:

(1) Now set LLTROP = 20 for GEOS-3 (bmy, 4/12/01)
(2) Eliminated obsolete commented-out code (bmy, 4/20/01)
(3) Now set MAXFAM = 12 for more P-L families (bmy, 6/28/01)
(4) Comment out {IJL}GCMPAR -- these are obosolete (bmy, 9/24/01)
(5) Also set LLPAR = 30 for GEOS-3, will regrid online (bmy, 9/24/01)
(6) Removed obsolete code from 9/01 (bmy, 10/23/01)
(7) Removed NAIR, LAIREMS, these are now defined
in "aircraft_nox_mod.f" (bmy, 2/14/02)
(8) Eliminated commented-out code from 2/14/02. Also added NAER
and NRH parameters for aerosols. (rvm, bmy, 2/27/02)
(9) Removed IM, JM, IMX, JMX to avoid namespace pollution. This
is needed to get the new TPCORE to work. Also changed RCS
ID tag comment character from "C" to "!" to allow freeform
compilation. (bmy, 6/25/02)
(10) Removed obsolete code from 6/02 (bmy, 8/26/02)
(11) Added NUMDEP_SULF in a common block for sulfate dry deposition.
Also set MAXDEP=31 and NNPAR=31 for coupled fullchem/sulfate
simulations. (rjp, bdf, bmy, 11/15/02)
(12) Removed I0, J0; these are now superseded by "grid_mod.f"
(bmy, 2/11/03)
(13) Added parameters for GEOS-4 (bmy, 6/18/03)
(14) Now defines both 55 level and 30 level GEOS-4 grids. Also
define LLTROP=19 for GEOS-4 grids. Also remove obsolete
GEOS-2 grid declarations. (bmy, 10/31/03)
(15) LLTROP should be 17 for GEOS-4...based on the ND55 diagnostic
when computed for 2003 met fields (bmy, 2/18/04)
(16) Increase NNPAR from 31 to 39 for carbon & dust tracers. Also
declare NDSTBIN as # of dust bins. (rvm, tdf, bmy, 4/1/04)
(17) Increase NNPAR to 41 for seasalt tracers (rjp, bec, bmy, 4/20/04)
(18) Increase NNPAR to 50 for SOA tracers (rjp, bmy, 7/15/04)
(19) Now use NESTED_CH and NESTED_NA cpp switches to define
parameters for 1x1 nested grids. Also add parameters for
the 1 x 1.25 global grid. (bmy, 12/1/04)
(20) Now add parameters for GCAP and GEOS-5 grids. Remove references
to obsolete LGEOSCO and FULLCHEM Cpp switches (bmy, 6/24/05)
(21) Now add I1x1 and J1x1 parameters for data on the 1x1 GEOS
grid. (bmy, 10/24/05)
(22) Increase NNPAR to 52 (bmy, 12/6/05)
(23) Increase NNPAR to 54 (dkh, bmy, 5/22/06)
(24) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(25) Added variable tropopause case (bmy, phs, bdf, 8/21/06)
(26) Set LLTROP to level of first box entirely above 20km for GEOS-3
and GEOS-4 (phS, 9/14/06)
(27) Bug fix: set LLTROP_FIX = LLPAR for GCAP (bmy, 11/29/06)
(28) Reset vertical coordinates for GEOS-5. Also renamed GRID30LEV

```
      to GRIDREDUCED (bmy, 4/3/07)
(29) New parameters for GEOS-5 nested grid (yxw, dan, bmy, 11/6/08)
(30) NEMPARA set to 12 to emit O3 and HNO3 (phs, 4/3/08)
(31) Add tracers to NNPAR = 73. (tmf, 1/7/09)
(32) NEMPARA set to 21 to emit new tracers for GLYX chemistry
     (tmf, ccc, 3/2/09)
(33) NEMPARB set to 3 to emit MBO, MONX (tmf, ccc, 3/2/09)
(34) Added EUROPE grid parameters (amv, 10/19/09)
18 Dec 2009 - Aaron van D - Added NESTED_EU grid parameters
18 Dec 2009 - R. Yantosca - Added ProTeX headers
25 Jan 2010 - R. Yantosca - Set NNPAR=320 for TOMAS simulations
25 Jan 2010 - R. Yantosca - Define TOMASBIN and TOMASSPEC for TOMAS sims
08 Feb 2010 - F. Paulot   - Increase NNPAR, NEMPARA and NEMPARB
08 Feb 2010 - F. Paulot   - Move MAXMEM and MAXPL from diag_pl_mod.
30 Nov 2010 - R. Yantosca - Increase LLTROP (from 38 to 40) for GEOS-5 and
                            MERRA for the full 72-layer grids (i.e. when
                            the Cpp switch GRIDREDUCED is not set).
09 Mar 2011 - R. Yantosca - Updated NNPAR for APM (G. Luo)
23 Aug 2011 - M. Long     - Converted to Module from Header file
27 Dec 2011 - M. Payer    - Updated NNPAR, NEMPARB, MAXMEM for bromine
                            chemistry (J. Parrella)
10 Feb 2012 - R. Yantosca - Added #if blocks for GEOS-5.7.x nested CH grid
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
27 Mar 2012 - R. Yantosca - Increase NTYPE from 15 to 25 for Olson 2001 map
22 Oct 2012 - M. Payer    - Increase NNPAR to 100 for tagged Hg simulation
                            (E. Corbitt)
25 Oct 2012 - R. Yantosca - Now also set LLPAR, LLTROP, LLTROP_FIX to
                            LGLOB for grid-independent simulation
19 Nov 2012 - R. Yantosca - Renamed to INIT_CMN_SIZE, to better follow
                            adopted GEOS-Chem naming convention
27 Nov 2012 - R. Yantosca - Removed commented out code
05 Jun 2013 - R. Yantosca - Now define GEOS-5 0.25x0.3125 nested NA grid
13 Aug 2013 - M. Sulprizio- Increase NNPAR & NBIOMAX for updated SOA and
                            SOA + semivolatile POA simulations (H. Pye)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
03 Dec 2014 - M. Yannetti - Added PRECISION_MOD
22 May 2015 - R. Yantosca - Updated comments, cosmetic changes
22 May 2015 - R. Yantosca - Removed variables made obsolete by HEMCO
28 Jan 2016 - M. Sulprizio- Remove NBIOMAX made obsolete by HEMCO
18 May 2016 - M. Sulprizio- Remove MAXIJ made obsolete by FlexChem
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
```

1.4.1 Init_Cmn_Size

Routine INIT_CMN_SIZE initializes the grid dimension values in module CMN_SIZE_mod.F.

INTERFACE:

```
 SUBROUTINE Init_CMN_SIZE( am_I_Root,      RC,
&                          value_I_LO,     value_J_LO,
&                          value_I_HI,     value_J_HI,
&                          value_IM,       value_JM,
&                          value_LM,       value_IM_WORLD,
&                          value_JM_WORLD, value_LM_WORLD,
&                          value_LLTROP,   value_LLSTRAT  )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root        ! Are we on the root CPU?
INTEGER, OPTIONAL    :: value_I_LO       ! Lower lon index on this CPU
INTEGER, OPTIONAL    :: value_J_LO       ! Lower lat index on this CPU
INTEGER, OPTIONAL    :: value_I_HI       ! Upper lon index on this CPU
INTEGER, OPTIONAL    :: value_J_HI       ! Upper lat index on this CPU
INTEGER, OPTIONAL    :: value_IM         ! # of lons   on this CPU
INTEGER, OPTIONAL    :: value_JM         ! # of lats   on this CPU
INTEGER, OPTIONAL    :: value_LM         ! # of levels on this CPU
INTEGER, OPTIONAL    :: value_IM_WORLD   ! # of lons in the global grid
INTEGER, OPTIONAL    :: value_JM_WORLD   ! # of lats in the global grid
INTEGER, OPTIONAL    :: value_LM_WORLD   ! # of levs in the global grid
INTEGER, OPTIONAL    :: value_LLTROP     ! # of levs in troposphere
INTEGER, OPTIONAL    :: value_LLSTRAT    ! # of levs in stratosphere
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
15 Oct 2012 - M. Long     - Initial version
15 Oct 2012 - R. Yantosca - Added ProTeX Headers, use F90 format/indents
22 Oct 2012 - R. Yantosca - Renamed to GIGC_Init_Dimensions
03 Dec 2012 - R. Yantosca - Rewritten for clarity.  Also pass optional
                            arguments to carry values from ESMF environment
03 Dec 2012 - R. Yantosca - Now allocate DLON, DLAT arrays here.
04 Aug 2015 - C. Keller   - Added value_LLTROP and value_LLSTRAT.
```

1.4.2 Cleanup_Cmn_Size

Subroutine CLEANUP_CMN_SIZE deallocates all module arrays.

INTERFACE:

```
SUBROUTINE Cleanup_CMN_SIZE( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
3 Dec 2012 - R. Yantosca - Initial version
```

1.5 Fortran: Module Interface errcode_mod.F90

Module ERRCODE_MOD contains the error codes (i.e. that report success or failure) returned by GEOS-Chem routines.

INTERFACE:

```
MODULE ErrCode_Mod
```

USES:

```
IMPLICIT NONE
PRIVATE
```

DEFINED PARAMETERS:

```
INTEGER, PUBLIC, PARAMETER :: GC_SUCCESS =  0   ! Routine returns success
INTEGER, PUBLIC, PARAMETER :: GC_FAILURE = -1   ! Routine returns failure
```

REMARKS:

```
The error codes are returned by routines at various levels of the
Grid-Independent GEOS-Chem implementation.
```

REVISION HISTORY:

```
19 Oct 2012 - R. Yantosca - Initial version
16 Aug 2016 - M. Sulprizio- Rename from gigc_errcode_mod.F90 to
                            errcode_mod.F90. The "gigc" nomenclature is
                            no longer used.
```

1.6 Fortran: Module Interface input_opt_mod.F90

Module INPUT_OPT_MOD contains the derived type for GEOS-Chem options and logical switches.

INTERFACE:

```
MODULE Input_Opt_Mod
```

USES:

```
  USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC :: Set_Input_Opt
  PUBLIC :: Cleanup_Input_Opt
```

PUBLIC DATA MEMBERS:

```
  !=========================================================================
  ! Derived type for Input Options
  !=========================================================================
  TYPE, PUBLIC :: OptInput

     !-------------------------------------
     ! General Runtime & Distributed Comp Info
     !-------------------------------------
     INTEGER                     :: NPES      ! Number of MPI procs
     INTEGER                     :: myCpu     ! Local MPI process handle
     INTEGER                     :: MPICOMM   ! MPI Communicator Handle
     LOGICAL                     :: HPC       ! Is this an HPC (ESMF or otherwise) sim?
     LOGICAL                     :: RootCPU   ! Is this the root cpu?

     !-------------------------------------
     ! SIZE PARAMETER fields
     !-------------------------------------
     INTEGER                     :: MAX_DIAG
     INTEGER                     :: MAX_TRCS
     INTEGER                     :: MAX_MEMB
     INTEGER                     :: MAX_FAMS
     INTEGER                     :: MAX_DEP

     !-------------------------------------
     ! SIMULATION MENU fields
     !-------------------------------------
     INTEGER                     :: NYMDb
     INTEGER                     :: NHMSb
```

```
INTEGER                     :: NYMDe
INTEGER                     :: NHMSe
CHARACTER(LEN=255)          :: RUN_DIR
CHARACTER(LEN=255)          :: IN_RST_FILE
CHARACTER(LEN=255)          :: DATA_DIR
CHARACTER(LEN=255)          :: CHEM_INPUTS_DIR
CHARACTER(LEN=255)          :: RES_DIR
CHARACTER(LEN=255)          :: GCAP_DIR
CHARACTER(LEN=255)          :: GEOS_4_DIR
CHARACTER(LEN=255)          :: GEOS_5_DIR
CHARACTER(LEN=255)          :: GEOS_FP_DIR
CHARACTER(LEN=255)          :: MERRA_DIR
CHARACTER(LEN=255)          :: MERRA2_DIR
CHARACTER(LEN=255)          :: DATA_DIR_1x1
CHARACTER(LEN=255)          :: TEMP_DIR
LOGICAL                     :: LUNZIP
LOGICAL                     :: LWAIT
LOGICAL                     :: LVARTROP
LOGICAL                     :: LCAPTROP
REAL(fp)                    :: OZONOPAUSE
INTEGER                     :: NESTED_I0
INTEGER                     :: NESTED_J0
CHARACTER(LEN=255)          :: HcoConfigFile

!--------------------------------------
! ADVECTED SPECIES MENU fields
!--------------------------------------
INTEGER                     :: N_ADVECT
CHARACTER(LEN=255), POINTER :: AdvectSpc_Name(:)
INTEGER                     :: SIM_TYPE
CHARACTER(LEN=255)          :: SIM_NAME
LOGICAL                     :: LSPLIT
LOGICAL                     :: ITS_A_RnPbBe_SIM
LOGICAL                     :: ITS_A_CH3I_SIM
LOGICAL                     :: ITS_A_FULLCHEM_SIM
LOGICAL                     :: ITS_A_HCN_SIM
LOGICAL                     :: ITS_A_TAGO3_SIM
LOGICAL                     :: ITS_A_TAGCO_SIM
LOGICAL                     :: ITS_A_C2H6_SIM
LOGICAL                     :: ITS_A_CH4_SIM
LOGICAL                     :: ITS_AN_AEROSOL_SIM
LOGICAL                     :: ITS_A_MERCURY_SIM
LOGICAL                     :: ITS_A_CO2_SIM
LOGICAL                     :: ITS_A_H2HD_SIM
LOGICAL                     :: ITS_A_POPS_SIM
LOGICAL                     :: ITS_A_SPECIALTY_SIM
LOGICAL                     :: ITS_NOT_COPARAM_OR_CH4
```

```
!--------------------------------------
! AEROSOL MENU fields
!--------------------------------------
LOGICAL                     :: LSULF
LOGICAL                     :: LCRYST
LOGICAL                     :: LCARB
LOGICAL                     :: LBRC
LOGICAL                     :: LSOA
LOGICAL                     :: LMPOA
LOGICAL                     :: LSVPOA
LOGICAL                     :: LDUST
LOGICAL                     :: LDEAD
LOGICAL                     :: LSSALT
LOGICAL                     :: LDSTUP
LOGICAL                     :: LDICARB
REAL(fp),           POINTER :: SALA_REDGE_um(:)
REAL(fp),           POINTER :: SALC_REDGE_um(:)
LOGICAL                     :: LGRAVSTRAT
LOGICAL                     :: LSOLIDPSC
LOGICAL                     :: LHOMNUCNAT
REAL(fp)                    :: T_NAT_SUPERCOOL
REAL(fp)                    :: P_ICE_SUPERSAT
LOGICAL                     :: LPSCCHEM
LOGICAL                     :: LSTRATOD

!--------------------------------------
! EMISSIONS MENU fields
!--------------------------------------
LOGICAL                     :: LEMIS
INTEGER                     :: TS_EMIS
INTEGER                     :: LBIOFUEL
LOGICAL                     :: LOTDLOC
LOGICAL                     :: LSOILNOX
LOGICAL                     :: LWARWICK_VSLS
LOGICAL                     :: LSSABr2
LOGICAL                     :: LFIX_PBL_BRO
LOGICAL                     :: LCH4EMIS
LOGICAL                     :: LCH4SBC
LOGICAL                     :: LOCSEMIS
LOGICAL                     :: LCFCEMIS
LOGICAL                     :: LCLEMIS
LOGICAL                     :: LBREMIS
LOGICAL                     :: LN2OEMIS
LOGICAL                     :: LBASICEMIS
LOGICAL                     :: LSETH2O
LOGICAL                     :: LSETCH4
LOGICAL                     :: LSETOCS
LOGICAL                     :: LSETCFC
```

```
LOGICAL                     :: LSETCL
LOGICAL                     :: LBRGCCM
LOGICAL                     :: LSETBR
LOGICAL                     :: LSETBRSTRAT
LOGICAL                     :: LSETNOYSTRAT
LOGICAL                     :: LSETN2O
LOGICAL                     :: LSETH2SO4
INTEGER                     :: CFCYEAR
LOGICAL                     :: LFUTURECFC

!--------------------------------------
! CO2 MENU fields
!--------------------------------------
LOGICAL                     :: LFOSSIL
LOGICAL                     :: LCHEMCO2
LOGICAL                     :: LBIODIURNAL
LOGICAL                     :: LBIONETCLIM
LOGICAL                     :: LOCEAN
LOGICAL                     :: LSHIP
LOGICAL                     :: LPLANE
LOGICAL                     :: LFFBKGRD
LOGICAL                     :: LBIOSPHTAG
LOGICAL                     :: LFOSSILTAG
LOGICAL                     :: LSHIPTAG
LOGICAL                     :: LPLANETAG

!--------------------------------------
! FUTURE MENU fields
!--------------------------------------
LOGICAL                     :: LFUTURE
INTEGER                     :: FUTURE_YEAR
CHARACTER(LEN=255)          :: FUTURE_SCEN

!--------------------------------------
! CHEMISTRY MENU fields
!--------------------------------------
LOGICAL                     :: LCHEM
LOGICAL                     :: LSCHEM
LOGICAL                     :: LLINOZ
LOGICAL                     :: LSYNOZ
INTEGER                     :: TS_CHEM
REAL(fp)                    :: GAMMA_HO2
LOGICAL                     :: LUCX
LOGICAL                     :: LCH4CHEM
LOGICAL                     :: LACTIVEH2O
LOGICAL                     :: LO3FJX
LOGICAL                     :: LINITSPEC
INTEGER, POINTER            :: NTLOOPNCS(:)
```

```
!--------------------------------------
! RADIATION MENU fields
!--------------------------------------
LOGICAL                     :: LRAD
LOGICAL                     :: LLWRAD
LOGICAL                     :: LSWRAD
LOGICAL, POINTER            :: LSKYRAD(:)
INTEGER                     :: TS_RAD

!--------------------------------------
! TRANSPORT MENU fields
!--------------------------------------
LOGICAL                     :: LTRAN
LOGICAL                     :: LFILL
LOGICAL                     :: TPCORE_IORD
LOGICAL                     :: TPCORE_JORD
LOGICAL                     :: TPCORE_KORD
INTEGER                     :: TS_DYN

!--------------------------------------
! CONVECTION MENU fields
!--------------------------------------
LOGICAL                     :: LCONV
LOGICAL                     :: LTURB
LOGICAL                     :: LNLPBL
INTEGER                     :: TS_CONV

!--------------------------------------
! DEPOSITION MENU fields
!--------------------------------------
LOGICAL                     :: LDRYD
LOGICAL                     :: LWETD
REAL(fp)                    :: WETD_CONV_SCAL
LOGICAL                     :: USE_OLSON_2001
LOGICAL                     :: PBL_DRYDEP

!--------------------------------------
! GAMAP MENU fields
!--------------------------------------
CHARACTER(LEN=255)          :: GAMAP_DIAGINFO
CHARACTER(LEN=255)          :: GAMAP_TRACERINFO

!--------------------------------------
! OUTPUT MENU fields
!--------------------------------------
INTEGER,            POINTER :: NJDAY(:)
```

```
!--------------------------------------
! DIAGNOSTIC MENU fields
!--------------------------------------
INTEGER                       :: ND01,            LD01
INTEGER                       :: ND02,            LD02
INTEGER                       :: ND03,            LD03
INTEGER                       :: ND04,            LD04
INTEGER                       :: ND05,            LD05
INTEGER                       :: ND06,            LD06
INTEGER                       :: ND07,            LD07
INTEGER                       :: ND08,            LD08
INTEGER                       :: ND09,            LD09
INTEGER                       :: ND10,            LD10
INTEGER                       :: ND11,            LD11
INTEGER                       :: ND12,            LD12
INTEGER                       :: ND13,            LD13
INTEGER                       :: ND14,            LD14
INTEGER                       :: ND15,            LD15
INTEGER                       :: ND16,            LD16
INTEGER                       :: ND17,            LD17
INTEGER                       :: ND18,            LD18
INTEGER                       :: ND19,            LD19
INTEGER                       :: ND20,            LD20
INTEGER                       :: ND21,            LD21
INTEGER                       :: ND22,            LD22
INTEGER                       :: ND23,            LD23
INTEGER                       :: ND24,            LD24
INTEGER                       :: ND25,            LD25
INTEGER                       :: ND26,            LD26
INTEGER                       :: ND27,            LD27
INTEGER                       :: ND28,            LD28
INTEGER                       :: ND29,            LD29
INTEGER                       :: ND30,            LD30
INTEGER                       :: ND31,            LD31
INTEGER                       :: ND32,            LD32
INTEGER                       :: ND33,            LD33
INTEGER                       :: ND34,            LD34
INTEGER                       :: ND35,            LD35
INTEGER                       :: ND36,            LD36
INTEGER                       :: ND37,            LD37
INTEGER                       :: ND38,            LD38
INTEGER                       :: ND39,            LD39
INTEGER                       :: ND40,            LD40
INTEGER                       :: ND41,            LD41
INTEGER                       :: ND42,            LD42
INTEGER                       :: ND43,            LD43
INTEGER                       :: ND44,            LD44
INTEGER                       :: ND45,            LD45
```

```
      INTEGER                   :: ND46,            LD46
      INTEGER                   :: ND47,            LD47
      INTEGER                   :: ND48,            LD48
      INTEGER                   :: ND49,            LD49
      INTEGER                   :: ND50,            LD50
      INTEGER                   :: ND51,            LD51
      INTEGER                   :: ND52,            LD52
      INTEGER                   :: ND53,            LD53
      INTEGER                   :: ND54,            LD54
      INTEGER                   :: ND55,            LD55
      INTEGER                   :: ND56,            LD56
      INTEGER                   :: ND57,            LD57
      INTEGER                   :: ND58,            LD58
      INTEGER                   :: ND59,            LD59
      INTEGER                   :: ND60,            LD60
      INTEGER                   :: ND61,            LD61
      INTEGER                   :: ND62,            LD62
      INTEGER                   :: ND63,            LD63
      INTEGER                   :: ND64,            LD64
      INTEGER                   :: ND66,            LD66
      INTEGER                   :: ND67,            LD67
      INTEGER                   :: ND68,            LD68
      INTEGER                   :: ND69,            LD69
      INTEGER                   :: ND70,            LD70
      INTEGER                   :: ND71,            LD71
      INTEGER                   :: ND72,            LD72

      INTEGER                   :: TS_DIAG
      LOGICAL                   :: LPRT
      INTEGER,          POINTER :: TINDEX(:,:)
      INTEGER,          POINTER :: TCOUNT(:)
      INTEGER,          POINTER :: TMAX(:)
      LOGICAL                   :: DO_DIAG_WRITE

      ! Collection ids
      INTEGER                   :: DIAG_COLLECTION
      INTEGER                   :: GC_RST_COLLECTION ! Used only for NetCDF

#if defined( NC_DIAG )
      ! New diagnostic group output types (e.g. 'mean')
      CHARACTER(LEN=15)         :: TRANSPORT_OUTPUT_TYPE
      CHARACTER(LEN=15)         :: WETSCAV_OUTPUT_TYPE
      CHARACTER(LEN=15)         :: DRYDEP_OUTPUT_TYPE
      CHARACTER(LEN=15)         :: SPECIES_CONC_OUTPUT_TYPE
      CHARACTER(LEN=15)         :: SPECIES_EMIS_OUTPUT_TYPE
      CHARACTER(LEN=15)         :: MET_OUTPUT_TYPE

      ! Placeholders pending grouping of diagnostics
```

```
      CHARACTER(LEN=15)           :: ND01_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND02_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND12_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND14_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND15_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND16_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND17_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND18_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND19_OUTPUT_TYPE
      CHARACTER(LEN=15)           :: ND30_OUTPUT_TYPE
#endif

      !--------------------------------------
      ! PLANEFLIGHT MENU fields
      !--------------------------------------
      LOGICAL                     :: DO_PF
      CHARACTER(LEN=255)          :: PF_IFILE
      CHARACTER(LEN=255)          :: PF_OFILE

      !--------------------------------------
      ! ND48 MENU fields
      !--------------------------------------
      LOGICAL                     :: DO_ND48
      CHARACTER(LEN=255)          :: ND48_FILE
      INTEGER                     :: ND48_FREQ
      INTEGER                     :: ND48_N_STA
      INTEGER,            POINTER :: ND48_IARR(:)
      INTEGER,            POINTER :: ND48_JARR(:)
      INTEGER,            POINTER :: ND48_LARR(:)
      INTEGER,            POINTER :: ND48_NARR(:)

      !--------------------------------------
      ! ND49 MENU fields
      !--------------------------------------
      LOGICAL                     :: DO_ND49
      CHARACTER(LEN=255)          :: ND49_FILE
      INTEGER,            POINTER :: ND49_TRACERS(:)
      INTEGER                     :: ND49_FREQ
      INTEGER                     :: ND49_IMIN
      INTEGER                     :: ND49_IMAX
      INTEGER                     :: ND49_JMIN
      INTEGER                     :: ND49_JMAX
      INTEGER                     :: ND49_LMIN
      INTEGER                     :: ND49_LMAX

      !--------------------------------------
      ! ND50 MENU fields
      !--------------------------------------
```

```
LOGICAL                     :: DO_ND50
CHARACTER(LEN=255)          :: ND50_FILE
LOGICAL                     :: LND50_HDF
INTEGER,            POINTER :: ND50_TRACERS(:)
INTEGER                     :: ND50_IMIN
INTEGER                     :: ND50_IMAX
INTEGER                     :: ND50_JMIN
INTEGER                     :: ND50_JMAX
INTEGER                     :: ND50_LMIN
INTEGER                     :: ND50_LMAX

!--------------------------------------
! ND51 MENU fields
!--------------------------------------
LOGICAL                     :: DO_ND51
CHARACTER(LEN=255)          :: ND51_FILE
LOGICAL                     :: LND51_HDF
INTEGER,            POINTER :: ND51_TRACERS(:)
REAL(fp)                    :: ND51_HR_WRITE
REAL(fp)                    :: ND51_HR1
REAL(fp)                    :: ND51_HR2
INTEGER                     :: ND51_IMIN
INTEGER                     :: ND51_IMAX
INTEGER                     :: ND51_JMIN
INTEGER                     :: ND51_JMAX
INTEGER                     :: ND51_LMIN
INTEGER                     :: ND51_LMAX

!--------------------------------------
! ND51b MENU fields
!--------------------------------------
LOGICAL                     :: DO_ND51b
CHARACTER(LEN=255)          :: ND51b_FILE
LOGICAL                     :: LND51b_HDF
INTEGER,            POINTER :: ND51b_TRACERS(:)
REAL(fp)                    :: ND51b_HR_WRITE
REAL(fp)                    :: ND51b_HR1
REAL(fp)                    :: ND51b_HR2
INTEGER                     :: ND51b_IMIN
INTEGER                     :: ND51b_IMAX
INTEGER                     :: ND51b_JMIN
INTEGER                     :: ND51b_JMAX
INTEGER                     :: ND51b_LMIN
INTEGER                     :: ND51b_LMAX

!--------------------------------------
! ND63 MENU fields
!--------------------------------------
```

```
LOGICAL                     :: DO_ND63
CHARACTER(LEN=255)          :: ND63_FILE
INTEGER,            POINTER :: ND63_TRACERS(:)
INTEGER                     :: ND63_FREQ
INTEGER                     :: ND63_IMIN
INTEGER                     :: ND63_IMAX
INTEGER                     :: ND63_JMIN
INTEGER                     :: ND63_JMAX

!--------------------------------------
! PROD LOSS MENU fields
!--------------------------------------
LOGICAL                     :: DO_SAVE_PL
LOGICAL                     :: LFAMILY
INTEGER                     :: ND65, LD65
LOGICAL                     :: DO_SAVE_O3
INTEGER                     :: NFAM
REAL(fp),           POINTER :: FAM_COEF(:,:)
CHARACTER(LEN=255), POINTER :: FAM_MEMB(:,:)
CHARACTER(LEN=255), POINTER :: FAM_NAME(:  )
INTEGER,            POINTER :: FAM_NMEM(:  )
CHARACTER(LEN=255), POINTER :: FAM_TYPE(:  )

!--------------------------------------
! UNIX CMDS fields
!--------------------------------------
CHARACTER(LEN=255)          :: BACKGROUND
CHARACTER(LEN=255)          :: REDIRECT
CHARACTER(LEN=255)          :: REMOVE_CMD
CHARACTER(LEN=255)          :: SEPARATOR
CHARACTER(LEN=255)          :: WILD_CARD
CHARACTER(LEN=255)          :: UNZIP_CMD
CHARACTER(LEN=255)          :: ZIP_SUFFIX
CHARACTER(LEN=1)            :: SPACE

!--------------------------------------
! NESTED GRID MENU fields
!--------------------------------------
LOGICAL                     :: ITS_A_NESTED_GRID
LOGICAL                     :: LWINDO
LOGICAL                     :: LWINDO2x25
LOGICAL                     :: LWINDO_NA
CHARACTER(LEN=255)          :: TPBC_DIR_NA
LOGICAL                     :: LWINDO_EU
CHARACTER(LEN=255)          :: TPBC_DIR_EU
LOGICAL                     :: LWINDO_CH
CHARACTER(LEN=255)          :: TPBC_DIR_CH
LOGICAL                     :: LWINDO_AS
```

```
CHARACTER(LEN=255)          :: TPBC_DIR_AS
LOGICAL                     :: LWINDO_CU
CHARACTER(LEN=255)          :: TPBC_DIR
INTEGER                     :: NESTED_TS
INTEGER                     :: NESTED_I1
INTEGER                     :: NESTED_J1
INTEGER                     :: NESTED_I2
INTEGER                     :: NESTED_J2
INTEGER                     :: NESTED_IOW
INTEGER                     :: NESTED_JOW
INTEGER                     :: NESTED_IOE
INTEGER                     :: NESTED_JOE

!---------------------------------------
! BENCHMARK MENU fields
!---------------------------------------
LOGICAL                     :: LSTDRUN
CHARACTER(LEN=255)          :: STDRUN_INIT_FILE
CHARACTER(LEN=255)          :: STDRUN_FINAL_FILE

!---------------------------------------
! MERCURY MENU fields
!---------------------------------------
INTEGER                     :: ANTHRO_Hg_YEAR
CHARACTER(LEN=255)          :: HG_SCENARIO
LOGICAL                     :: USE_CHECKS
LOGICAL                     :: LDYNOCEAN
LOGICAL                     :: LPREINDHG
LOGICAL                     :: LGTMM
CHARACTER(LEN=255)          :: GTMM_RST_FILE
LOGICAL                     :: LARCTICRIV
LOGICAL                     :: LKRedUV

!---------------------------------------
! CH4 MENU fields
!---------------------------------------
LOGICAL                     :: LCH4BUD
LOGICAL                     :: LGAO
LOGICAL                     :: LCOL
LOGICAL                     :: LLIV
LOGICAL                     :: LWAST
LOGICAL                     :: LBFCH4
LOGICAL                     :: LRICE
LOGICAL                     :: LOTANT
LOGICAL                     :: LBMCH4
LOGICAL                     :: LWETL
LOGICAL                     :: LSOABS
LOGICAL                     :: LOTNAT
```

```
!--------------------------------------
! POPS MENU fields
!--------------------------------------
CHARACTER(LEN=3)            :: POP_TYPE
LOGICAL                     :: CHEM_PROCESS
REAL(fp)                    :: POP_XMW
REAL(fp)                    :: POP_KOA
REAL(fp)                    :: POP_KBC
REAL(fp)                    :: POP_K_POPG_OH
REAL(fp)                    :: POP_K_POPP_O3A
REAL(fp)                    :: POP_K_POPP_O3B
REAL(fp)                    :: POP_HSTAR
REAL(fp)                    :: POP_DEL_H
REAL(fp)                    :: POP_DEL_Hw

!--------------------------------------
! Fields for drydep and dust.  These get
! set in the init stage based on info
! from file "input.geos". (mlong, 1/5/13)
!--------------------------------------
INTEGER                     :: N_DUST_BINS
INTEGER,            POINTER :: NTRAIND(:)
INTEGER,            POINTER :: IDDEP(:)
INTEGER,            POINTER :: IDEP(:)
REAL(fp),           POINTER :: DUSTREFF(:)
REAL(fp),           POINTER :: DUSTDEN(:)
CHARACTER(LEN=14),  POINTER :: DEPNAME(:)

!--------------------------------------
! Fields for interface to GEOS-5 GCM
!--------------------------------------
LOGICAL                     :: haveImpRst

!--------------------------------------
! Fields for LINOZ strat chem
!--------------------------------------
INTEGER                     :: LINOZ_NLEVELS
INTEGER                     :: LINOZ_NLAT
INTEGER                     :: LINOZ_NMONTHS
INTEGER                     :: LINOZ_NFIELDS
REAL(fp),           POINTER :: LINOZ_TPARM(:,:,:,:)

!--------------------------------------
! Fields for overhead O3
! This gets set in main.F based on met
! field and year (mpayer, 12/13/13)
!--------------------------------------
```

```
    LOGICAL                       :: USE_O3_FROM_MET

  END TYPE OptInput
```

REMARKS:

This will eventually replace the switches in logical_mod.F.

REVISION HISTORY:

```
01 Nov 2012 - R. Yantosca - Initial version, based on logical_mod.F
                            newer Olson 2001 land map & drydep inputs
07 Nov 2012 - R. Yantosca - Added Input_Opt%ITS_A_*_SIM fields
08 Nov 2012 - R. Yantosca - Added APM MENU fields
09 Nov 2012 - R. Yantosca - Added LD* variables for diagnostic levels
28 Nov 2012 - R. Yantosca - Add USE_OLSON_2001 logical flag
22 May 2013 - M. Payer    - Add GAMMA_HO2 variable for chemistry menu
26 Feb 2013 - M. Long     - Add extra fields from input.geos
26 Feb 2013 - M. Long     - Bug fix: timesteps are now INTEGER, not LOGICAL
28 Feb 2013 - R. Yantosca - Add haveImpRst field for GEOS-5 GCM interface
08 Mar 2013 - R. Yantosca - Add myCpu field to pass CPU # to GEOS-Chem
15 Mar 2013 - R. Yantosca - Add fields for LINOZ strat chemistry
27 Mar 2013 - R. Yantosca - Add extra fields for tagged CO2
27 Mar 2013 - R. Yantosca - Add extra fields for tagged EDGAR
29 Mar 2013 - R. Yantosca - Add DO_DIAG_WRITE field (to shut diags in MPI)
22 Jul 2013 - M. Sulprizio- Add extra fields for RCP emissions
31 Jul 2013 - M. Sulprizio- Add extra field for AEIC aircraft emissions and
                            remove LAIRNOX field
13 Aug 2013 - M. Sulprizio- Add extra fields for semivolatile POA (H. Pye)
22 Aug 2013 - R. Yantosca - Add fields for soil NOx & species restart files
17 Sep 2013 - M. Sulprizio- Add LDSTUP flag for acid uptake on dust aerosols
26 Sep 2013 - R. Yantosca - Renamed GEOS_57_DIR to GEOS_FP_DIR
03 Oct 2013 - M. Sulprizio- Removed obsolete LMFCT for flux correction
03 Oct 2013 - M. Sulprizio- Removed obsolete LAVHRRLAI and LMODISLAI
13 Dec 2013 - M. Sulprizio- Add USE_O3_FROM_MET logical flag
16 Apr 2014 - M. Sulprizio- Add field for PSC restart file
23 Jun 2014 - R. Yantosca - Add POP_EMISDIR field for POPs simlulation
25 Jun 2014 - R. Yantosca - Now add Input_Opt%SIM_TYPE field
29 Sep 2014 - R. Yantosca - Now add Input_Opt%N_DUST_BINS field
03 Dec 2014 - M. Yannetti - Added PRECISION_MOD
03 Dec 2014 - M. Sulprizio- Add fields for Radiation Menu
16 Dec 2014 - R. Yantosca - Removed JLOP, JLOP_PREV; these are in State_Chm
01 Apr 2015 - R. Yantosca - Add extra nested-grid fields
09 Apr 2015 - M. Sulprizio- Removed fields for NAPEMISS, POAEMISSSCALE,
                            and PST_RST_FILE. These options are now handled
                            by HEMCO.
11 Aug 2015 - R. Yantosca - Add MERRA2_DIR field to OptInput
26 Jan 2016 - E. Lundgren - Add fields for netcdf diagnostics
04 Feb 2016 - C. Keller   - Add LINITSPEC. Used in ESMF to initialize species
```

```
                              concentrations from globchem.dat.
    04 Feb 2016 - M. Sulprizio- Add Hg_CAT and Hg_CAT_FULL arrays for tagged Hg
                              simulations
    27 Apr 2016 - R. Yantosca - Remove Hg_Cat, Hg_Cat_Full fields
    17 May 2016 - R. Yantosca - Remove TRACER_N_CONST, TRACER_CONST, ID_EMITTED,
                              TRACER_COEFF
    31 May 2016 - E. Lundgren - Remove TRACER_MW_KG, TRACER_MW_G, and XNUMOL
    23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                              compatible with the FlexChem implementation
    13 Jul 2016 - R. Yantosca - Remove some unused drydep fields
    16 Aug 2016 - M. Sulprizio- Rename from gigc_input_opt_mod.F90 to
                              input_opt_mod.F90. The "gigc" nomenclature is
                              no longer used.
    29 Aug 2016 - M. Sulprizio- Rename N_TRACERS to N_ADVECT and TRACER_NAME to
                              AdvectSpc_Name to reflect that we now refer to
                              tracers as advected species
    20 Sep 2016 - R. Yantosca - LND51_HDF and LND51b_HDF are now declared
                              as LOGICAL, not INTEGER.  This chokes Gfortran.
    03 Oct 2016 - R. Yantosca - LWINDO_CU has to be LOGICAL, not INTEGER
```

1.6.1 Set_Input_Opt

Subroutine SET_INPUT_OPT intializes all GEOS-Chem options carried in Input Options derived type object.

INTERFACE:

```
SUBROUTINE Set_Input_Opt( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE CMN_SIZE_Mod,     ONLY : NDSTBIN, NVEGTYPE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Set the following fields of Input_Opt outside of this routine:
(1 ) Input_Opt%MAX_DIAG      : Max # of diagnostics
(2 ) Input_Opt%MAX_TRCS      : Max # of tracers
```

```
(3 ) Input_Opt%MAX_MEMB      : Max # of members per family tracer
(4 ) Input_Opt%MAX_FAMS      : Max # of P/L diagnostic families
(5 ) Input_Opt%MAX_DEP       : Max # of dry depositing species
(6 ) Input_Opt%LINOZ_NLEVELS : Number of levels    in LINOZ climatology
(7 ) Input_Opt%LINOZ_NLAT    : Number of latitudes in LINOZ climatology
(8 ) Input_Opt%LINOZ_NMONTHS : Number of months    in LINOZ climatology
(9 ) Input_Opt%LINOZ_NFIELDS : Number of species   in LINOZ climatology
                                                                        .
We also need to implement better error checking.
```

REVISION HISTORY:

```
01 Nov 2012 - R. Yantosca - Initial version
07 Nov 2012 - R. Yantosca - Now add size parameter fields to Input_Opt
                            that can be set prior to calling this routine
09 Nov 2012 - R. Yantosca - Now zero LD* fields for diagnostic levels
28 Nov 2012 - R. Yantosca - Now set USE_OLSON_2001 logical flag
29 Nov 2012 - M. Payer    - Add Input_Opt%ITS_A_POPS_SIM
26 Feb 2013 - M. Long     - Add extra fields from input.geos
28 Feb 2013 - R. Yantosca - Add haveImpRst field for GEOS-5 GCM interface
08 Mar 2013 - R. Yantosca - Now initialize the myCpu field
15 Mar 2013 - R. Yantosca - Now initialize the LINOZ_TPARM field
27 Mar 2013 - R. Yantosca - Add extra fields for tagged CO2
27 Mar 2013 - R. Yantosca - Add extra fields for EDGAR
29 Mar 2013 - R. Yantosca - Add DO_DIAG_WRITE field (to shut diags in MPI)
22 Apr 2013 - R. Yantosca - Now dimension ND48_*ARR to 1000 so that we are
                            consistent with the settings in diag48_mod.F
22 Jul 2013 - M. Sulprizio- Add extra fields for RCP emissions
07 Aug 2013 - M. Sulprizio- Add extra fields for SOA + SVPOA simulation
22 Aug 2013 - R. Yantosca - Add fields for soil NOx & species restart files
12 Sep 2013 - M. Sulprizio- Double size of IDDEP to account for dust
                            alkalinity (tdf 04/10/08)
17 Sep 2013 - M. Sulprizio- Add LDSTUP flag for acid uptake on dust aerosols
26 Sep 2013 - R. Yantosca - Renamed GEOS_57_DIR to GEOS_FP_DIR
25 Jun 2014 - R. Yantosca - Now initialize Input_Opt%SIM_TYPE field
03 Dec 2014 - M. Yannetti - Added PRECISION_MOD
05 Mar 2015 - R. Yantosca - Added RES_DIR, CHEM_INPUTS_DIR fields
06 Mar 2015 - R. Yantosca - Now initialize directory names with './'
01 Apr 2015 - R. Yantosca - Now initialize extra nested-grid fields
04 Mar 2016 - C. Keller   - Added WETD_CONV_SCAL, LSYNOZ, LCAPTROP, and
                            OZONOPAUSE. These are only used within ESMF.
17 May 2016 - R. Yantosca - Remove TRACER_N_CONST, TRACER_CONST, ID_EMITTED,
                            TRACER_COEFF
31 May 2016 - E. Lundgren - Remove TRACER_MW_G, TRACER_MW_KG, and XNUMOL
13 Jul 2016 - R. Yantosca - Remove some obsolete drydep fields
13 Jul 2016 - R. Yantosca - Remove ID_TRACER, NUMDEP
```

1.6.2 Cleanup_Input_Opt

Subroutine CLEANUP_INPUT_OPT deallocates all allocatable fields of the Input Options object.

INTERFACE:

```
SUBROUTINE Cleanup_Input_Opt( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
02 Nov 2012 - R. Yantosca - Initial version
07 Nov 2012 - R. Yantosca - Now deallocate fields from prod/loss menu
26 Feb 2013 - M. Long     - Now deallocate extra fields from input.geos
15 Mar 2013 - R. Yantosca - Now deallocate the LINOZ_TPARM field
17 May 2016 - R. Yantosca - Remove TRACER_N_CONST, TRACER_CONST, ID_EMITTED,
                            TRACER_COEFF
31 May 2016 - E. Lundgren - Remove TRACER_MW_G, TRACER_MW_KG, and XNUMOL
13 Jul 2016 - R. Yantosca - Remove ID_TRACER
```

1.7 Fortran: Module Interface passive_tracer_mod.F90

Module passive_tracer_mod.F90 contains variables and routines for using passive tracers in GEOS-Chem. Passive tracers are tracers that are passively transported by GEOS-Chem, with a simple first order loss rate being applied to each tracer. The number of passive tracers, corresponding tracer properties as well as loss rates and default initial concentrations can be specified by the user via the GEOS-Chem input file (input.geos).
The passive tracer module is designed to work in combination with any existing GEOS-Chem simulation type, even though it has only been tested with the Radon simulation at this point. **REMARKS:**

```
Passive tracers are defined in input.geos in the PASSIVE TRACERS menu. For
instance, to use the Radon simulation with two passive tracers ('Rn_ps' and
'Dummy') with atmospheric lifetimes of 3.8 days and 1 hour, respectively,
add the following entries to input.geos:
%%% PASSIVE TRACERS %%% :
```

```
    Number of pass. tracers : 2
    Passive tracer #1       : Rn_ps 328320.0 1.0e-20
    Passive tracer #2       : Dummy 3600.0   1.0e-20
    The 3rd column of the tracer definition denotes the default initial
    concentration (in v/v) of the species of interest (1.0e-20 v/v in this
    case). This value will be used if the GEOS-Chem tracer restart file has
    no concentration field for the given tracer.
    There must be a matching entry in the tracers menu for every passive tracer
    defined in the passive tracers menu:
    %%% TRACER MENU %%%     :
    Type of simulation      : 1
    Number of Tracers       : 4
    Tracer Entries -------> : TR#   Name  g/mole   Tracer Members; () = emitted
    Tracer #1               :   1   Rn     222.0
    Tracer #2               :   2   Pb     210.0
    Tracer #3               :   3   Be7      7.0
    Tracer #4               :   4   Rn_ps  222.0
    Tracer #5               :   5   Dummy  100.0

    In this example, tracers 1-3 are the default tracers for this simulation type
    while tracers 4-5 are the user-specific passive tracers.
    As for regular GEOS-Chem tracers, emissions can be assigned to passive
    tracers via the HEMCO configuration file. For example, to assign a uniform
    flux of 0.1 kg/m2/s to passive tracer 'Dummy', add the following line to
    section base emissions of your HEMCO_Config.rc:
    0 DUMMY_EMIS 0.1 - - - xy kg/m2/s Dummy - 1 1
  \\
  \\
```

INTERFACE:

```
 MODULE PASSIVE_TRACER_MOD
```

USES:

```
   USE PRECISION_MOD

   IMPLICIT NONE
   PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
   PUBLIC :: INIT_PASSIVE_TRACER
   PUBLIC :: ADD_PASSIVE_TRACER
   PUBLIC :: PASSIVE_TRACER_GETRATE
   PUBLIC :: PASSIVE_TRACER_INQUIRE
   PUBLIC :: CLEANUP_PASSIVE_TRACER
```

PRIVATE MEMBER FUNCTIONS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller   - Initial version.
```

1.7.1 Init_Passive_Tracer

Subroutine INIT_PASSIVE_TRACER initializes the passive tracers arrays.

INTERFACE:

```
SUBROUTINE INIT_PASSIVE_TRACER ( am_I_Root, NPT, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
INTEGER,          INTENT(IN   )  :: NPT        ! # of passive tracers
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
```

REMARKS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller    - Initial version
```

1.7.2 Add_Passive_Tracer

Subroutine ADD_PASSIVE_TRACER registers a passive tracer based on the passed input arguments.

INTERFACE:

```
SUBROUTINE ADD_PASSIVE_TRACER ( am_I_Root,   TrcName, TrcTau, &
                                TrcInitConc, TrcMW,   RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root   ! root CPU?
CHARACTER(LEN=*), INTENT(IN   )  :: TrcName     ! Tracer name
REAL(fp),         INTENT(IN   )  :: TrcTau      ! Tracer lifetime (s)
REAL(fp),         INTENT(IN   )  :: TrcInitConc ! Tracer default init conc (v/v)
REAL(fp),         INTENT(IN   )  :: TrcMW       ! Tracer molec. weight (g/mol)
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,          INTENT(INOUT)  :: RC          ! Failure or success
```

REMARKS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller    - Initial version
```

1.7.3 Passive_Tracer_Getrate

Subroutine PASSIVE_TRACER_GETRATE returns the unitless decay rate for the given tracer and chemistry time step. on all passive tracers.

INTERFACE:

```
SUBROUTINE PASSIVE_TRACER_GETRATE ( am_I_Root, TrcName, DT, Rate, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
CHARACTER(LEN=*), INTENT(IN   )  :: TrcName    ! Passive tracer name
REAL(fp),         INTENT(IN   )  :: DT         ! Time step in s
```

OUTPUT PARAMETERS:

```
REAL(fp),         INTENT(  OUT)  :: Rate       ! Decay rate (unitless
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
```

REMARKS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller    - Initial version
```

1.7.4 Passive_Tracer_Inquire

Function PASSIVE_TRACER_INQUIRE is a wrapper routine to inquire information about a passive tracer.

INTERFACE:

```
SUBROUTINE PASSIVE_TRACER_INQUIRE ( TrcName, IsPassive, MW, InitConc )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*),   INTENT(IN   )  :: TrcName    ! GC tracer name
```

OUTPUT PARAMETERS:

```
LOGICAL,  OPTIONAL, INTENT(  OUT)  :: IsPassive  ! Is TrcID a passive tracer?
REAL(fp), OPTIONAL, INTENT(  OUT)  :: MW         ! Molecular weight (g/mol)
REAL(fp), OPTIONAL, INTENT(  OUT)  :: InitConc   ! Initial concentration (v/v)
```

REMARKS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller    - Initial version
```

1.7.5 Cleanup_Passive_Tracer

Subroutine CLEANUP_PASSIVE_TRACER finalizes the passive tracers arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_PASSIVE_TRACER ( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
```

REMARKS:

REVISION HISTORY:

```
04 Sep 2015 - C. Keller    - Initial version
```

1.8 Fortran: Module Interface physconstants.F

PhysConstants contains GEOS-Chem specific PHYSICAL CONSTANTS and DERIVED QUANTITIES.

INTERFACE:

```
MODULE PHYSCONSTANTS
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PUBLIC
```

DEFINED PARAMETERS:

```
! AIRMW : Average molecular weight of dry air [g/mol]
REAL(fp), PARAMETER :: AIRMW    = 28.97e+0_fp

! H2OMW : Molecular weight of water [g/mol]
REAL(fp), PARAMETER :: H2OMW   = 18.016e+0_fp

! AVO   : Avogadro's number [particles/mol]
! Now use more precise value 6.022140857e+23 instead of 6.022e+23?
! Source: NIST, 2014 (ewl, 1/7/16) (NEED TO CHANGE HEMCO)
REAL(fp), PARAMETER :: AVO      = 6.022140857e+23_fp

! g0    : Acceleration due to gravity at earth's surface [m/s^2]
! Now use more precise value of 9.80665 instead of 9.8 (ewl, 1/7/16)
! Source: NIST, 2014 (NEED TO CHANGE HEMCO)
REAL(fp), PARAMETER :: g0       =   9.80665e+0_fp

! g0_100 : 100 / g0
REAL(fp), PARAMETER :: g0_100   = 100.e+0_fp / g0

! PI    : Double-Precision value of PI
REAL(fp), PARAMETER :: PI       = 3.14159265358979323e+0_fp

! PI_180 : Number of radians per degree
REAL(fp), PARAMETER :: PI_180   = PI / 180e+0_fp

! Re    : Radius of Earth [m]
REAL(fp), PARAMETER :: Re       = 6.375e+6_fp

! Rd    : Gas Constant in Dry Air [J/K/kg]
REAL(fp), PARAMETER :: Rd       = 287.0e+0_fp

! Rv    : Gas Constant for water vapor [J/K/kg]
```

```
      REAL(fp), PARAMETER :: Rv       = 461.0e+0_fp

      ! Rdg0   = Rd    / g0
      REAL(fp), PARAMETER :: Rdg0     = Rd / g0

      ! SCALE_HEIGHT : Scale height of atmosphere [m]
      REAL(fp), PARAMETER :: SCALE_HEIGHT = 7600.e+0_fp

      ! VON_KARMAN : Von Karman's constant [.]
      REAL(fp), PARAMETER :: VON_KARMAN   = 0.4e+0_fp

      ! RSTARG : Molar gas constant [J/K/mol]
      ! Now use more precise value 8.3144598 instead of 8.31450? (ewl, 1/7/16)
      ! Source: NIST, 2014 (NEED TO CHANGE HEMCO)
      REAL(fp), PARAMETER :: RSTARG   = 8.3144598e+0_fp

      ! XNUMOLAIR : Molecules dry air per kg dry air
      REAL(fp), PARAMETER :: XNUMOLAIR = AVO / ( AIRMW * 1.e-3_fp)

      ! BOLTZ : Boltzmann's constant [J/K]  (Source: NIST, 2014)
      REAL(fp), PARAMETER :: BOLTZ   = 1.38064852e-23_fp

      ! ATM : Standard atmosphere [Pa]  (Source: NIST, 2014)
      REAL(fp), PARAMETER :: ATM     = 1.01325e+5_fp

      ! Condensation vapor pressure
      ! ** NEED SOURCE **
      !  We think 6.1078 hPa is the saturation vapor pressure at 273.16 K, the
      !   triple point of water, but this needs to be confirmed (mps, 4/21/16)
      !  Use BOLTZ [J/K] rather than BOLTG [ergs/K] from comode_loop_mod
      !   (ewl, 1/4/16)
      REAL(fp), PARAMETER :: CONSVAP  = 6.1078e+03_fp /
     &                                  ( BOLTZ * 1e+7_fp )
   !REFERENCES:
   (1) NIST, 2014. Website: http://physics.nist.gov/cuu/Constants/index.html
```

REVISION HISTORY:

```
 25 Jun 2002 - R. Yantosca - Initial version
 23 Aug 2011 - M. Long     - Converted to Module from Header file
 23 Jul 2014 - R. Yantosca - Add Von Karman's constant here
 23 Jul 2014 - R. Yantosca - Add Avogadro's number here
 23 Jul 2014 - R. Yantosca - List constants in alphabetical order
 02 Dec 2014 - M. Yannetti - Added PRECISION_MOD
 06 Jan 2014 - E. Lundgren - Added constants and clarified comments
 24 Mar 2015 - E. Lundgren - Add xnumolair, previously in tracer_mod
 08 Jan 2016 - E. Lundgren - Update values to NIST 2014 and use AIRMW in
                             definition of XNUMOLAIR. Add BOLTZ.
 08 Jan 2016 - E. Lundgren - Rename this file to physconstants.F. Previously
```

```
                              it was called CMN_GCTM_mod.F
   21 Apr 2016 - M. Sulprizio- Move CONSVAP here from comode_loop_mod.F
```

1.9 Fortran: Module Interface precision_mod.F

Module PRECISION_MOD is used to change the precision of many variables throughout GEOS-Chem at compile-time.

INTERFACE:

```
      MODULE PRECISION_MOD
```

USES:

```
      IMPLICIT NONE
      PRIVATE
```

DEFINED PARAMETERS:

```
      !=================================================================
      ! Set parameters for floating precision
      ! FP will be set to either 4-byte or 8-byte precision at compile
      ! time.  Most variables can now  declared with REAL(fp).
      !=================================================================
#if defined( USE_REAL8 )

      ! Use 8-byte floating point precision when asked.
      INTEGER, PARAMETER, PUBLIC :: fp = KIND( REAL( 0.0, 8 ) )

#else

      ! Use 4-byte floating point by default.
      INTEGER, PARAMETER, PUBLIC :: fp = KIND( REAL( 0.0, 4 ) )

#endif

      !=================================================================
      ! Set parameters for fixed precision
      ! Not all variables can be converted into the flexible precision.
      ! Some may have to be still declared as either 4-byte or 8-byte
      ! floating point.  Use these parameters for such variables.
      !=================================================================

      ! KIND parameter for 4-byte precision
      INTEGER, PARAMETER, PUBLIC :: f4 = KIND( REAL( 0.0, 4 ) )

      ! KIND parameter for 8-byte precision
      INTEGER, PARAMETER, PUBLIC :: f8 = KIND( REAL( 0.0, 8 ) )
```

REMARKS:

```
This module is designed to help avoid hard-coding precision.
```

REVISION HISTORY:

```
(1 ) Created. (myannetti, 11/04/14)
23 Nov 2016 - R. Yantosca - Now rewrite KIND definitions to prevent 4-byte
                            and 8-byte variables from being elevated
                            when using -r8 (or equivalent flags)
```

1.10 Fortran: Module Interface species_database_mod.F90

Module SPECIES_DATABASE_MOD contains routines to set up a database object containing physical properties for each GEOS-Chem species. This allows us to consolidate all species properties into a single data structure, for convenience.

INTERFACE:

```
MODULE Species_Database_Mod
```

USES:

```
USE Precision_Mod

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: Init_Species_Database
PUBLIC  :: Cleanup_Species_Database
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: TranUc

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Uncomment this if you want to use the new henry's law constants
%%% compiled by Katie Travis and posted on this wiki page:
%%% http://wiki.geos-chem.org/Physical_properties_of_GEOS-Chem_species
#define NEW_HENRY_CONSTANTS 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REMARKS:

REVISION HISTORY:

```
28 Aug 2015 - R. Yantosca - Initial version
02 Aug 2016 - M. Sulprizio- Add KppSpcId to store all KPP species incices.
```

1.10.1 Init_Species_Database

Initializes the GEOS-Chem species database object. You can add information about new species to this routine.

INTERFACE:

```
SUBROUTINE Init_Species_Database( am_I_Root, Input_Opt, SpcData, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod, ONLY : OptInput
USE Passive_Tracer_Mod, ONLY : PASSIVE_TRACER_INQUIRE
USE Species_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root    ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt    ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(SpcPtr),   POINTER     :: SpcData(:)   ! Vector with species info
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC           ! Success or failure?
```

REMARKS:

```
For detailed information about the species database (and the physical
properties that are specified there), please see the following GEOS-Chem
wiki pages:
  (1) wiki.geos-chem.org/GEOS_Chem_species_database
  (2) wiki.geos-chem.org/Physical_properties_of_GEOS-Chem_species
References for the new Henry's law constants:
  (1) Sander et al [2015]: http://henrys-law.org
The Hcp (aka K0) parameter listed on the wiki page:
   http://wiki.geos-chem.org/Physical_properties_of_GEOS-Chem_species
have units of [mol m-3 Pa-1].  But the GEOS-Chem species object expects
this parameter to have units of [M atm-1].  Therefore, when we pass the
Hcp paramter to routine Spc_Create via the HENRY_K0 argument, we will
multiply by the proper conversion factor (9.86923e-3) to convert
[mol m-3 Pa-1] to [M atm-1].
```

REVISION HISTORY:

```
22 Jul 2015 - R. Yantosca - Initial version
01 Sep 2015 - R. Yantosca - Add Henry K0, CR constants for DMS, ACET
02 Sep 2015 - R. Yantosca - Corrected typos for some SOA species
24 Sep 2015 - R. Yantosca - WD_RainoutEff is now a 3-element vector
24 Sep 2015 - R. Yantosca - Add WD_KcScaleFAc, a 3-element vector
```

```
30 Sep 2015 - R. Yantosca - DD_A_Density is renamed to Density
30 Sep 2015 - R. Yantosca - DD_A_Radius is renamed to Radius
01 Oct 2015 - R. Yantosca - Added DD_DvzMinVal field to put a minimum
                            deposition velocity for sulfate aerosols
14 Oct 2015 - E. Lundgren - Treat H2SO4 as an aerosol for TOMAS
18 Nov 2015 - M. Sulprizio- Add passive tracers PASV to RnPbBe simulation
16 Dec 2015 - R. Yantosca - Use MW_g = 31.4 g/mol for SO4s and NITs
15 Mar 2016 - R. Yantosca - Added tagged CO tracer names
22 Apr 2016 - R. Yantosca - Now define Is_Hg0, Is_Hg2, Is_HgP fields
19 May 2016 - R. Yantosca - Remove DryDepId_PAN and DryDepId_HNO3; we shall
                            now explicitly compute a drydep velocity for
                            all GEOS-Chem species.
21 Jun 2016 - M. Sulprizio- Set Is_Photolysis to T for all species included
                            in FAST-JX photolysis. Also added new species
                            that are in FAST-JX photolysis but not already
                            defined here.
18 Jul 2016 - M. Sulprizio- Remove family tracers ISOPN, MMN, CFCX, HCFCX
                            and replace with their constituents.
02 Aug 2016 - M. Sulprizio- Add KppSpcId as argument passed to Spc_Create
11 Aug 2016 - E. Lundgren - Define special background conc for some species
22 Nov 2016 - M. Sulprizio- Move aerosol densities for BC, OC, and SO4 here
                            from aerosol_mod.F
```

1.10.2 Cleanup_Species_Database

Finalizes the vector with species information.

INTERFACE:

```
SUBROUTINE Cleanup_Species_Database( am_I_Root, SpcData, RC )
```

USES:

```
USE ErrCode_Mod
USE Species_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root    ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(SpcPtr),   POINTER     :: SpcData(:)   ! Species database object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC           ! Success or failure?
```

REMARKS:

REVISION HISTORY:

```
22 Jul 2015 - R. Yantosca - Initial version
```

1.10.3 TranUc

Tranlate a character variable to all upper case letters. Non-alphabetic characters are not affected. The original "text" is destroyed.

INTERFACE:

```
SUBROUTINE TranUc( text )
```

INPUT/OUTPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(INOUT) :: text
```

AUTHOR:

```
Robert D. Stewart, May 19, 1992 (part of CHARPAK)
```

REMARKS:

```
Keep a private shadow copy of this routine here so as not to
incur a dependency with GeosUtil/charpak_mod.F.  This lets us
keep species_datbase_mod.F90 in the Headers/ folder together
with state_chm_mod.F90 and species_mod.F90.
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
```

1.10.4 Unique_Species_Names

Stores the list of unique species names (i.e. removing duplicates from the list of advected species and the the list of KPP species) for later use. Also computes the corresponding indices for the KPP variable and fixed species arrays (VAR and FIX, respectively).

INTERFACE:

```
SUBROUTINE Unique_Species_Names( am_I_Root, Input_Opt, nSpecies, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod, ONLY : OptInput
USE GcKpp_Monitor,      ONLY : Spc_Names
USE GcKpp_Parameters,   ONLY : NFIX, NSPEC, NVAR
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: nSpecies    ! Number of unique species
INTEGER,        INTENT(OUT) :: RC          ! Success or failure
```

REMARKS:

```
This may not be the fastest search algorithm (because it relies on string
comparisons).  But it is only executed at startup so we can live with it.
We could make it faster by hashing but that seems like overkill.
```

REVISION HISTORY:

```
09 May 2016 - R. Yantosca - Initial version
02 Aug 2016 - M. Sulprizio- Add KppSpcId; Also only set KppVarId if loop
                            indexis <= NVAR.
```

1.10.5 Cleanup_Work_Arrays

Stores the list of unique species names (i.e. removing duplicates from the list of advected species and the the list of KPP species) for later use. Also computes the indices for KPP variable and fixed indices.

INTERFACE:

```
SUBROUTINE Cleanup_Work_Arrays()
```

REMARKS:

```
This may not be the fastest search algorithm, but it is only executed
once, at startup.
```

REVISION HISTORY:

```
06 May 2016 - R. Yantosca - Initial version
```

1.11 Fortran: Module Interface species_mod.F90

Module SPECIES_MOD contains types and routines to define the GEOS-Chem species object.

INTERFACE:

```
MODULE Species_Mod
  USES:
  USE Precision_Mod

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: Str2Hash
PUBLIC :: SpcData_Init
PUBLIC :: SpcData_Cleanup
PUBLIC :: Spc_Create
PUBLIC :: Spc_GetIndx
PUBLIC :: Spc_GetNumSpecies
PUBLIC :: Spc_Print
```

PUBLIC TYPES:

```
!=========================================================================
! Counters for the species indices
!=========================================================================
INTEGER, PRIVATE :: AdvectCount = 0       ! Counter of advected species
INTEGER, PRIVATE :: DryDepCount = 0       ! Counter of dry-deposited species
INTEGER, PRIVATE :: KppSpcCount = 0       ! Counter of species in KPP matrix
INTEGER, PRIVATE :: WetDepCount = 0       ! Counter of wet-deposited species
INTEGER, PRIVATE :: ActiveCount = 0       ! Counter of active chem species
INTEGER, PRIVATE :: FixedCount  = 0       ! Counter of fixed chem species
INTEGER, PRIVATE :: PhotolCount = 0       ! Counter of photolysis species
INTEGER, PRIVATE :: Hg0Count    = 0       ! Number  of Hg0 tracers
INTEGER, PRIVATE :: Hg2Count    = 0       ! Number  of Hg2 tracers
INTEGER, PRIVATE :: HgPCount    = 0       ! Number  of HgP tracers

!=========================================================================
! Type for the Species Database object (vector of type Species)
!=========================================================================
TYPE, PUBLIC :: SpcPtr
   TYPE(Species), POINTER :: Info         ! Single entry of Species Database
END TYPE SpcPtr

!=========================================================================
! Type for individual species information
! (i.e. this is a single entry in the Species Database)
!=========================================================================
TYPE, PUBLIC :: Species

   ! Indices
   INTEGER            :: ModelID          ! Model species ID
   INTEGER            :: AdvectID         ! Advection index
   INTEGER            :: DryDepID         ! Dry deposition index
   INTEGER            :: WetDepID         ! Wet deposition index
   INTEGER            :: KppSpcID         ! KPP species index
   INTEGER            :: KppVarId         ! KPP variable species index
   INTEGER            :: KppFixId         ! KPP fixed spcecies index
   INTEGER            :: PhotolID         ! Photolysis index

   ! Names
   CHARACTER(LEN=31)  :: Name             ! Short name
```

```
      CHARACTER(LEN=80)  :: FullName         ! Long name
      INTEGER            :: NameHash         ! Integer hash for short name

      ! Logical switches
      LOGICAL            :: Is_Gas           ! Is it a gas?  If not, aerosol.
      LOGICAL            :: Is_Advected      ! Is it advected?
      LOGICAL            :: Is_DryDep        ! Is it dry-deposited?
      LOGICAL            :: Is_WetDep        ! Is it wet-deposited?
      LOGICAL            :: Is_Kpp           ! Is it in the KPP mechanism?
      LOGICAL            :: Is_ActiveChem    ! Is it an active chemical species?
      LOGICAL            :: Is_FixedChem     ! Is it a fixed chemical species?
      LOGICAL            :: Is_Photolysis    ! Is it an photolysis species?
      LOGICAL            :: Is_InRestart     ! Is it in the restart file?

      ! Molecular weights
      REAL(fp)           :: MW_g             ! Species molecular weight [g/mol]
      REAL(fp)           :: EmMW_g           ! Emitted molecular weight [g/mol]
      REAL(fp)           :: MolecRatio       ! Mol carbon / mol species [1    ]

      ! Default background concentration
      REAL(fp)           :: BackgroundVV     ! Background conc [v/v]

      ! Density and radius
      REAL(fp)           :: Density          ! Density [kg/m3]
      REAL(fp)           :: Radius           ! Radius  [m]

      ! Henry's law parameters
      REAL(f8)           :: Henry_K0         ! Liq./gas Henry const [M/atm ]
      REAL(f8)           :: Henry_CR         ! d(ln K0) / d(1/T)    [K     ]
      REAL(f8)           :: Henry_PKA        ! pKa for Henry const. correction

      ! Drydep parameters
      LOGICAL            :: DD_AeroDryDep    ! Use AERO_SFCRSII for drydep?
      LOGICAL            :: DD_DustDryDep    ! Use DUST_SFCRSII for drydep?
      REAL(fp)           :: DD_DvzAerSnow    ! Vd for aerosols on snow [cm/s]
      REAL(fp)           :: DD_DvzMinVal(2)  ! Min Vd for aerosols [cm/s]
      REAL(fp)           :: DD_F0            ! F0 (reactivity) factor [1]
      REAL(fp)           :: DD_KOA           ! KOA factor for POPG
      !%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      !%%% NOTE: We will eventually replace this with the common Henry's law
      !%%% parameters.  But in order to replicate the prior behavior,
      !%%% we will need to supply the dry deposition code with the same
      !%%% HSTAR values that are currently set in INIT_DRYDEP.  Therefore,
      !%%% add this field as a temporary placeholder for the Hstar quantity
      !%%% from drydep_mod.F.  We will remove this later on. (bmy, 8/24/15)
      !%%%
      REAL(fp)           :: DD_Hstar_Old     ! HSTAR value in drydep_mod [M/atm]
      !%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
   ! Wetdep parameters, gas-phase species
   LOGICAL            :: WD_LiqAndGas     ! Consider liquid and gas phases?
   REAL(fp)           :: WD_ConvFacI2G    ! Conv. factor for ice/gas ratio
   REAL(fp)           :: WD_RetFactor     ! Retention factor [1]

   ! Wetdep parameters, aerosol-phase species
   LOGICAL            :: WD_Is_H2SO4      ! Flag to denote H2SO4 wetdep
   LOGICAL            :: WD_Is_HNO3       ! Flag to denote HNO3 wetdep
   LOGICAL            :: WD_Is_SO2        ! Flag to denote SO2 wetdep
   LOGICAL            :: WD_CoarseAer     ! T=coarse aerosol; F=fine aerosol
   REAL(fp)           :: WD_AerScavEff    ! Aerosol scavenging efficiency
   REAL(fp)           :: WD_KcScaleFac(3) ! Temperature-dependent scale
                                          !  factors to multiply Kc rate
                                          !  (conv of condensate -> precip)
                                          !  in F_AEROSOL (wetscav_mod.F)
   REAL(fp)           :: WD_RainoutEff(3) ! Temperature-dependent scale
                                          !  factors for rainout efficiency

   ! Microphysics parameters
   LOGICAL            :: MP_SizeResAer    ! T=size-resolved aerosol (TOMAS)
   LOGICAL            :: MP_SizeResNum    ! T=size-resolved aerosol number

   ! Tagged mercury parameters
   LOGICAL            :: Is_Hg0           ! T=total or tagged Hg0 species
   LOGICAL            :: Is_Hg2           ! T=total or tagged Hg2 species
   LOGICAL            :: Is_HgP           ! T=total or tagged HgP species
   INTEGER            :: Hg_Cat           ! Tagged Hg category number

END TYPE Species
!DEFINED PARAMETERS
!=============================================================================
! Missing value parameters
!=============================================================================
INTEGER,  PARAMETER  :: MISSING_INT = -999         ! Integer
REAL(fp), PARAMETER  :: MISSING     = -999e+0_fp   ! Flexible precision
REAL(f8), PARAMETER  :: MISSING_R8  = -999e+0_f8   ! 8-byte precision
REAL(fp), PARAMETER  :: ZERO        =  0.0e+0_fp   ! Flexible precision
REAL(f8), PARAMETER  :: ZERO_R8     =  0.0e+0_f8   ! 8-byte precision

REAL(fp), PARAMETER  :: MISSING_MW  = -1.0_fp      ! Missing MW values

!=============================================================================
! Missing species concentration value if not in restart file and special
! background value not defined
!=============================================================================
REAL(fp), PARAMETER, PUBLIC :: MISSING_VV  = 1.0e-20_fp ! Missing spc conc
```

REMARKS:

```
(1) The emission molecular weight is the molecular weight of the emitted
    compound. This value is only different to MW_g if the emitted compound
    does not correspond to the transported species, e.g. if emissions are
    in kg C4H10 but the corresponding species is transported as mass Carbon.
(2) MolecRatio is the ratio between # of species molecules per emitted
    molecule, e.g. 4 if emissions are kg C4H10 but model species are kg C.
```

REVISION HISTORY:

```
 28 Feb 2014 - C. Keller   - Initial version
 22 Jul 2015 - R. Yantosca - Updated and cleaned up a bit
 18 Aug 2015 - R. Yantosca - Added indices for drydep, wetdep, transport
 18 Aug 2015 - R. Yantosca - Added missing value parameters
 31 Aug 2015 - R. Yantosca - Add AdvectId
 24 Sep 2015 - R. Yantosca - Make WD_RainoutEff a 3-element vector:
                             (1) T < 237K; (2) 237K < T < 258 K (3) T > 258K
 24 Sep 2015 - R. Yantosca - Rename WD_ConvFactor to WD_ConvFacI2G
 25 Sep 2015 - R. Yantosca - Rename WD_SizeResAer to MP_SizeResAer
 25 Sep 2015 - R. Yantosca - Add MP_SizeResBin for microphysics size bins
 30 Sep 2015 - R. Yantosca - Renamed DD_A_Density to Density
 30 Sep 2015 - R. Yantosca - Renamed DD_A_Radius to Radius
 30 Sep 2015 - R. Yantosca - Added WD_Is_HNO3 and WD_Is_SO2 fields to flag
                             special cases of HNO3 and SO2 wet deposition
 01 Oct 2015 - R. Yantosca - Add field DD_DvzMinVal
 16 Oct 2015 - E. Lundgren - Add WD_Is_H2SO4 field to flag special case of
                             H2SO4 wet deposition for microphysics
 22 Apr 2016 - R. Yantosca - Added Is_Hg0, Is_Hg2, Is_HgP species
 04 May 2016 - R. Yantosca - Added fast name lookup via hashing
 09 May 2016 - R. Yantosca - Add Is_Kpp, KppVarId, KppFixId to type Species
 21 Jun 2016 - M. Sulprizio- Add Is_Photolysis, Is_ActiveChem, and
                             Is_FixedChem to type Species
 25 Jul 2016 - E. Lundgren - Add Is_InRestart to track which species are
                             read in versus set to default background values
 02 Aug 2016 - M. Sulprizio- Remove function Get_KPPIndx, it is not used.
                             KppSpcId is set in species_database_mod.F90 where
                             KppVarId and KppFixId are set.
 04 Aug 2016 - R. Yantosca - Add parameter MISSING_MW = -1.0
 10 Aug 2016 - E. Lundgren - Add BackgroundVV field for default background
                             and missing background concentration param [v/v]
```

1.11.1 Str2Hash

Returns a unique integer hash for a given character string. This allows us to implement a fast name lookup algorithm.

INTERFACE:

```
FUNCTION Str2Hash( Str ) RESULT( Hash )
```

INPUT PARAMETERS:

```
CHARACTER(LEN=14), INTENT(IN) :: Str    ! String (14 chars long)
```

RETURN VALUE:

```
INTEGER                       :: Hash   ! Hash value from string
```

REMARKS:

```
(1) Algorithm taken from this web page:
    https://fortrandev.wordpress.com/2013/07/06/fortran-hashing-algorithm/
(2) For now, we only use the first 14 characers of the character string
    to compute the hash value.  Most GEOS-Chem species names only use
    at most 14 unique characters.  We can change this later if need be.
```

REVISION HISTORY:

```
04 May 2016 - R. Yantosca - Initial version
05 May 2016 - R. Yantosca - Now make the input string 14 chars long
```

1.11.2 SpcData_Init

Routine SpcData_Init initializes species database object. This is an array where each element is of type Species. This object holds the metadata for each species (name, molecular weight, Henry's law constants, drydep info, wetdep info, etc.

INTERFACE:

```
SUBROUTINE SpcData_Init( am_I_Root, nSpecies, SpecDB, RC )
```

INPUT PARAMETERS:

```
LOGICAL,             INTENT(IN)    :: am_I_Root    ! root CPU?
INTEGER,             INTENT(IN)    :: nSpecies     ! # of species
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(SpcPtr),        POINTER       :: SpecDB(:)    ! Species database
INTEGER,             INTENT(INOUT) :: RC           ! Return code
```

REVISION HISTORY:

```
20 Aug 2013 - C. Keller   - Adapted from gigc_state_chm_mod.F90
22 Jul 2015 - R. Yantosca - Cosmetic changes
```

1.11.3 Spc_GetIndx

Function Spc_GetIndx returns the index of a given species in the species data base object. You can search by the short name or the full name of the species.

INTERFACE:

```
FUNCTION Spc_GetIndx( Name, SpecDB ) RESULT( Indx )
```

USES:

```
USE CHARPAK_MOD, ONLY : TRANUC
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN) :: Name       ! Species name
TYPE(SpcPtr),     POINTER    :: SpecDB(:)  ! Species Database object
```

RETURN VALUE:

```
INTEGER                      :: Indx       ! Index of this species
```

REMARKS:

```
The input name field has will get copied to an internal string that is
14 characters long, for input into the Str2Hash function.  14 characters
is about the longest species name for GEOS-Chem.  We can modify this
if need be.
```

REVISION HISTORY:

```
09 Oct 2012 - M. Long     - Initial version, based on gc_esmf_utils_mod.F90
22 Jul 2015 - R. Yantosca - Cosmetic changes
04 May 2016 - R. Yantosca - Now use hash comparison, it's faster
04 May 2016 - R. Yantosca - Renamed to Spc_GetIndx
05 May 2016 - R. Yantosca - The NAME argument is now of variable length
15 Jun 2016 - M. Sulprizio- Make species name uppercase before computing hash
```

1.11.4 SpcData_Cleanup

Routine SpcData_Cleanup cleans up the passed species collection object

INTERFACE:

```
SUBROUTINE SpcData_Cleanup( SpecDB )
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(SpcPtr), POINTER :: SpecDB(:)  ! Species database object
```

REVISION HISTORY:

```
20 Aug 2013 - C. Keller   - Adapted from gigc_state_chm_mod.F90
22 Jul 2015 - R. Yantosca - Cosmetic changes
08 Oct 2015 - R. Yantosca - Bug fix, make sure the size of SpecDb
                            is zero before deallocating each element
```

1.11.5 Spc_Create

Routine Spc_Create creates a new object that holds information about a given species, and assigns values to it.

INTERFACE:

```
SUBROUTINE Spc_Create( am_I_Root,     ThisSpc,       ModelID,        &
                      DryDepID,       Name,          FullName,       &
                      MW_g,           EmMW_g,        MolecRatio,     &
                      BackgroundVV,   Henry_K0,      Henry_CR,       &
                      Henry_PKA,      Density,       Radius,         &
                      DD_AeroDryDep,  DD_DustDryDep, DD_DvzAerSnow,  &
                      DD_DvzMinVal,   DD_F0,         DD_KOA,         &
                      DD_HStar_Old,   MP_SizeResAer, MP_SizeResNum,  &
                      WD_RetFactor,   WD_LiqAndGas,  WD_ConvFacI2G,  &
                      WD_AerScavEff,  WD_KcScaleFac, WD_RainoutEff,  &
                      WD_CoarseAer,   Is_Advected,   Is_Gas,         &
                      Is_Drydep,      Is_Wetdep,     Is_Photolysis,  &
                      Is_InRestart,   Is_Hg0,        Is_Hg2,         &
                      Is_HgP,         KppSpcId,      KppVarId,       &
                      KppFixId,       RC             )
```

USES:

```
USE CHARPAK_MOD,        ONLY : TRANUC             ! String manipulation
USE PhysConstants,      ONLY : AIRMW, AVO         ! Physical constants
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN)  :: am_I_Root        ! Are we on the root CPU?
INTEGER,          OPTIONAL    :: ModelID          ! Model ID number
INTEGER,          OPTIONAL    :: DryDepID         ! Drydep ID number
CHARACTER(LEN=*), OPTIONAL    :: Name             ! Short name of species
CHARACTER(LEN=*), OPTIONAL    :: FullName         ! Long name of species
REAL(fp),         OPTIONAL    :: MW_g             ! Molecular weight [g]
REAL(fp),         OPTIONAL    :: EmMW_g           ! Emissions mol. wt [g]
REAL(fp),         OPTIONAL    :: MolecRatio       ! Molec ratio
REAL(fp),         OPTIONAL    :: BackgroundVV     ! Background conc [v/v]
REAL(f8),         OPTIONAL    :: Henry_K0         ! Henry's law K0 [M/atm]
REAL(f8),         OPTIONAL    :: Henry_CR         ! Henry's law CR [K]
REAL(f8),         OPTIONAL    :: Henry_PKA        ! Henry's law pKa [1]
REAL(fp),         OPTIONAL    :: Density          ! Density [kg/m3]
REAL(fp),         OPTIONAL    :: Radius           ! Radius [m]
LOGICAL,          OPTIONAL    :: DD_AeroDryDep    ! Use AERO_SFCRSII?
LOGICAL,          OPTIONAL    :: DD_DustDryDep    ! Use DUST_SFCRSII?
REAL(fp),         OPTIONAL    :: DD_DvzAerSnow    ! Vd for aerosols
                                                  !  on snow/ice [cm/s]
REAL(fp),         OPTIONAL    :: DD_DvzMinVal(2)  ! Min Vd for aerosols
                                                  !  (cf GOCART) [cm/s]
```

```
REAL(fp),         OPTIONAL    :: DD_F0            ! Drydep reactivity [1]
REAL(fp),         OPTIONAL    :: DD_KOA           ! Drydep KOA parameter
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!%%% NOTE: We will eventually replace this with the common Henry's law
!%%% parameters.  But in order to replicate the prior behavior,
!%%% we will need to supply the dry deposition code with the same
!%%% HSTAR values that are currently set in INIT_DRYDEP.  Therefore,
!%%% add this field as a temporary placeholder for the Hstar quantity
!%%% from drydep_mod.F.  We will remove this later on. (bmy, 8/24/15)
!%%%
REAL(fp),         OPTIONAL    :: DD_Hstar_Old     ! HSTAR, drydep [M/atm]
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
LOGICAL,          OPTIONAL    :: MP_SizeResAer    ! Size resolved aerosol?
LOGICAL,          OPTIONAL    :: MP_SizeResNum    ! Size resolved aer #?
REAL(fp),         OPTIONAL    :: WD_RetFactor     ! Wetdep retention factor
LOGICAL,          OPTIONAL    :: WD_LiqAndGas     ! Liquid and gas phases?
REAL(fp),         OPTIONAL    :: WD_ConvFacI2G    ! Factor for ice/gas ratio
REAL(fp),         OPTIONAL    :: WD_AerScavEff    ! Aerosol scavenging eff.
REAL(fp),         OPTIONAL    :: WD_KcScaleFac(3) ! Factor to multiply Kc
                                                  !  rate in F_AEROSOL
REAL(fp),         OPTIONAL    :: WD_RainoutEff(3) ! Rainout efficiency
LOGICAL,          OPTIONAL    :: WD_CoarseAer     ! Coarse aerosol?
LOGICAL,          OPTIONAL    :: Is_Advected      ! Is it advected?
LOGICAL,          OPTIONAL    :: Is_Gas           ! Gas (T) or aerosol (F)?
LOGICAL,          OPTIONAL    :: Is_Drydep        ! Is it dry deposited?
LOGICAL,          OPTIONAL    :: Is_Wetdep        ! Is it wet deposited?
LOGICAL,          OPTIONAL    :: Is_Photolysis    ! Is it photolysis spc?
LOGICAL,          OPTIONAL    :: Is_InRestart     ! Is it in restart file?
LOGICAL,          OPTIONAL    :: Is_Hg0           ! Denotes Hg0 species
LOGICAL,          OPTIONAL    :: Is_Hg2           ! Denotes Hg2 species
LOGICAL,          OPTIONAL    :: Is_HgP           ! Denotes HgP species
INTEGER,          OPTIONAL    :: KppSpcId         ! KPP species ID
INTEGER,          OPTIONAL    :: KppVarId         ! KPP variable species ID
INTEGER,          OPTIONAL    :: KppFixId         ! KPP fixed species ID
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(Species),    POINTER     :: ThisSpc       ! Object w/ species info
```

OUTPUT PARAMETERS:

```
INTEGER,          INTENT(OUT) :: RC            ! Return code
```

REMARKS:

(1) If Fullname is not specified, it will use the value assigned to Name.
(2) If EmMw_g is not specified, it will use the value assigned to MW_g.
(3) If MolecRatio is not specified, it will be set to 1.
(4) WD_Is_HNO3 is automatically set according to Name.

```
(5 ) WD_Is_SO2 is automatically set according to Name.
(6 ) All other fields, if not specified, will be set to MISSING
(7 ) If Is_Gas = T, aerosol-specific fields will be set to MISSING.
     (except for HNO3 and SO2, which wet scavenge as aerosols).
(8 ) If Is_Gas = F, gas-phase specific-fields will be set to MISSING.
(9 ) If Is_Advected = T, this will automatically update AdvectId.
(10) If Is_Drydep = T, this will automatically update DryDepId.
(11) If Is_Wetdep = T, this will automatically update WetDepId.
```

REVISION HISTORY:

```
20 Aug 2013 - C. Keller   - Adapted from gigc_state_chm_mod.F90
22 Jul 2015 - R. Yantosca - Added RetFactor and drydep parameters
31 Aug 2015 - R. Yantosca - Now also compute AdvectId
04 Sep 2015 - R. Yantosca - Add arguments WD_RainoutEff, WD_CoarseAer,
                            and WD_SizeResAer
24 Sep 2015 - R. Yantosca - Added WD_KcScaleFac argument
22 Apr 2016 - R. Yantosca - Added Is_Hg0, Is_Hg2, Is_HgP
04 May 2016 - R. Yantosca - Now construct hash value from short name
15 Jun 2016 - M. Sulprizio- Make species name uppercase before computing hash
21 Jun 2016 - M. Sulprizio- Add optional argument Is_Photolysis. Also set
                            Is_ActiveChem and Is_Fixed Chem according to
                            KppVarId and KPPFixId.
06 Jul 2016 - R. Yantosca - Add more error checks to avoid uninit'd fields
18 Jul 2016 - M. Sulprizio- Remove special handling of ISOPN and MMN for
                            DryDepCount. Family tracers have been eliminated.
25 Jul 2016 - E. Lundgren - Add optional argument Is_InRestart
02 Aug 2016 - M. Sulprizio- Add optional argument KppSpcId
04 Aug 2016 - R. Yantosca - Now set missing molecular weights to -1,
                            which seems to avoid numerical roundoff
10 Aug 2016 - E. Lundgren - Add default background concentration argument
```

1.11.6 Spc_Print

Routine Spc_Create prints the fields of the species object.

INTERFACE:

```
SUBROUTINE Spc_Print( am_I_Root, ThisSpc, RC )
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN)    :: am_I_Root    ! Are we on the root CPU?
TYPE(Species),    POINTER       :: ThisSpc      ! Object w/ species info
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,          INTENT(INOUT) :: RC           ! Return code
```

REMARKS:

```
Optional fields are not printed out if they are not defined (i.e. if they
have a "missing data value" of -999).
```

REVISION HISTORY:

```
27 Jul 2015 - R. Yantosca - Initial version
```

1.11.7 Spc_GetNumSpecies

Routine Spc_GetNumSpecies returns the number of advected, dry-deposited, and wet-deposited species to an external routine.

INTERFACE:

```
SUBROUTINE Spc_GetNumSpecies( nAdvect,  nDryDep,  nKppSpc, nWetDep,  &
                              nHg0Cats, nHg2Cats, nHgPCats          )
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: nAdvect   ! # of advected species
INTEGER, INTENT(OUT) :: nDryDep   ! # of dry-deposited species
INTEGER, INTENT(OUT) :: nKppSpc   ! # of species in the KPP mechanism
INTEGER, INTENT(OUT) :: nWetDep   ! # of wet-deposited species
INTEGER, INTENT(OUT) :: nHg0Cats  ! # of Hg0 categories
INTEGER, INTENT(OUT) :: nHg2Cats  ! # of Hg0 categories
INTEGER, INTENT(OUT) :: nHgPCats  ! # of Hg0 categories
```

REVISION HISTORY:

```
02 Sep 2015 - R. Yantosca - Initial version
25 Apr 2016 - R. Yantosca - Also return the # of Hg0, Hg2, HgP categories
18 May 2016 - R. Yantosca - Also return the # of KPP chemical species
```

1.12 Fortran: Module Interface state_chm_mod.F90

Module STATE_CHM_MOD contains the derived type used to define the Chemistry State object for GEOS-Chem.

This module also contains the routines that allocate and deallocate memory to the Chemistry State object. The chemistry state object is not defined in this module. It must be be declared as variable in the top-level driver routine, and then passed to lower-level routines as an argument.

INTERFACE:

```
MODULE State_Chm_Mod
  USES:
  USE PhysConstants    ! Physical constants
  USE Precision_Mod    ! GEOS-Chem precision types
  USE Species_Mod      ! For species database object

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC :: Ind_
  PUBLIC :: Init_State_Chm
  PUBLIC :: Cleanup_State_Chm
  !PRIVATE DATA MEMBERS:
  TYPE(SpcPtr), PRIVATE, POINTER :: SpcDataLocal(:)  ! Local version of StateChm for
```

PUBLIC DATA MEMBERS:

```
  !=========================================================================
  ! Derived type for Chemistry State
  !=========================================================================
  TYPE, PUBLIC :: ChmState

     ! Count of each type of species
     INTEGER                   :: nSpecies            ! # of species
     INTEGER                   :: nAdvect             ! # of advected species
     INTEGER                   :: nDryDep             ! # of drydep species
     INTEGER                   :: nKppSpc             ! # of KPP chem species
     INTEGER                   :: nWetDep             ! # of wetdep species

     ! Mapping vectors to subset types of species
     INTEGER,           POINTER :: Map_Advect (:      ) ! Advected species ID's
     INTEGER,           POINTER :: Map_DryDep (:      ) ! Drydep species ID's
     INTEGER,           POINTER :: Map_KppSpc (:      ) ! KPP chem species ID's
     INTEGER,           POINTER :: Map_WetDep (:      ) ! Wetdep species IDs'

     ! Physical properties & indices for each species
     TYPE(SpcPtr),      POINTER :: SpcData    (:      ) ! GC Species database

     ! Chemical species
     INTEGER,           POINTER :: Spec_Id    (:      ) ! Species ID #
     CHARACTER(LEN=14), POINTER :: Spec_Name  (:      ) ! Species names
     REAL(fp),          POINTER :: Species    (:,:,:,:) ! Species [molec/cm3]
     CHARACTER(LEN=20)          :: Spc_Units            ! Species units

     ! Aerosol quantities
     INTEGER                   :: nAero                ! # of Aerosol Types
     REAL(fp),          POINTER :: AeroArea   (:,:,:,:) ! Aerosol Area [cm2/cm3]
```

```
     REAL(fp),          POINTER :: AeroRadi   (:,:,:,:) ! Aerosol Radius [cm]
     REAL(fp),          POINTER :: WetAeroArea(:,:,:,:) ! Aerosol Area [cm2/cm3]
     REAL(fp),          POINTER :: WetAeroRadi(:,:,:,:) ! Aerosol Radius [cm]

#if defined( ESMF_ )
     ! Chemical rates & rate parameters
     INTEGER,           POINTER :: JLOP       (:,:,:  ) ! 1-D SMVGEAR index
     INTEGER,           POINTER :: JLOP_PREV  (:,:,:  ) ! JLOP, prev timestep
#endif

     ! Fields for UCX mechanism
     REAL(f4),          POINTER :: STATE_PSC  (:,:,:  ) ! PSC type (see Kirner
                                                        !  et al. 2011, GMD)
     REAL(fp),          POINTER :: KHETI_SLA  (:,:,:,:) ! Strat. liquid aerosol
                                                        !  reaction cofactors
     ! For the tagged Hg simulation
     INTEGER                    :: N_HG_CATS            ! # of Hg categories
     INTEGER,           POINTER :: Hg0_Id_List(:      ) ! Hg0 cat <-> tracer #
     INTEGER,           POINTER :: Hg2_Id_List(:      ) ! Hg2 cat <-> tracer #
     INTEGER,           POINTER :: HgP_Id_List(:      ) ! HgP cat <-> tracer #
     CHARACTER(LEN=4),  POINTER :: Hg_Cat_Name(:      ) ! Category names

   END TYPE ChmState
```

REMARKS:

REVISION HISTORY:

```
   19 Oct 2012 - R. Yantosca - Initial version, based on "gc_type2_mod.F90"
   26 Oct 2012 - R. Yantosca - Add fields for stratospheric chemistry
   26 Feb 2013 - M. Long     - Add DEPSAV to derived type ChmState
   07 Mar 2013 - R. Yantosca - Add Register_Tracer subroutine
   07 Mar 2013 - R. Yantosca - Now make POSITION a locally SAVEd variable
   20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
   19 May 2014 - C. Keller   - Removed Trac_Btend. DepSav array covers now
                               all species.
   03 Dec 2014 - M. Yannetti - Added PRECISION_MOD
   11 Dec 2014 - R. Yantosca - Keep JLOP and JLOP_PREV for ESMF runs only
   17 Feb 2015 - E. Lundgren - New tracer units kg/kg dry air (previously kg)
   13 Aug 2015 - E. Lundgren - Add tracer units string to ChmState derived type
   28 Aug 2015 - R. Yantosca - Remove strat chemistry fields, these are now
                               handled by the HEMCO component
   05 Jan 2016 - E. Lundgren - Use global physical constants
   28 Jan 2016 - M. Sulprizio- Add STATE_PSC, KHETI_SLA. These were previously
                               local arrays in ucx_mod.F, but now need to be
                               accessed in gckpp_HetRates.F90.
   12 May 2016 - M. Sulprizio- Add WetAeroArea, WetAeroRadi to replace 1D arrays
```

```
                              WTARE, WERADIUS previously in comode_mod.F
   18 May 2016 - R. Yantosca - Add mapping vectors for subsetting species
   07 Jun 2016 - M. Sulprizio- Remove routines Get_Indx, Register_Species, and
                              Register_Tracer made obsolete by the species
                              database.
   22 Jun 2016 - R. Yantosca - Rename Id_Hg0 to Hg0_Id_List, Id_Hg2 to
                              Hg2_Id_List, and Id_HgP to HgP_Id_List
   16 Aug 2016 - M. Sulprizio- Rename from gigc_state_chm_mod.F90 to
                              state_chm_mod.F90. The "gigc" nomenclature is
                              no longer used.
   23 Aug 2016 - M. Sulprizio- Remove tracer fields from State_Chm. These are
                              now entirely replaced with the species fields.
```

1.12.1 Ind_

Function IND_ returns the index of an advected species or chemical species contained in the chemistry state object by name.

INTERFACE:

```
  FUNCTION Ind_( name, flag ) RESULT( Indx )
```

USES:

```
    USE CHARPAK_MOD, ONLY : TRANUC
```

INPUT PARAMETERS:

```
    CHARACTER(LEN=*),           INTENT(IN) :: name  ! Species name
    CHARACTER(LEN=*), OPTIONAL, INTENT(IN) :: flag  ! Species type
```

RETURN VALUE:

```
    INTEGER                                :: Indx  ! Index of this species
  !REMARKS
```

REVISION HISTORY:

```
   07 Oct 2016 - M. Long     - Initial version
   15 Jun 2016 - M. Sulprizio- Make species name uppercase before computing hash
   17 Aug 2016 - M. Sulprizio- Tracer flag 'T' is now advected species flag 'A'
```

1.12.2 Init_State_Chm

Routine INIT_STATE_CHM allocates and initializes the pointer fields of the chemistry state object.

INTERFACE:

```
SUBROUTINE Init_State_Chm( am_I_Root, IM,        JM,         &
                           LM,        Input_Opt, State_Chm,  &
                           nAerosol,  RC         )
```

USES:

```
USE ErrCode_Mod
USE GCKPP_Parameters,     ONLY : NSPEC
USE Input_Opt_Mod,        ONLY : OptInput
USE Species_Mod,          ONLY : Species
USE Species_Mod,          ONLY : Spc_GetNumSpecies
USE Species_Database_Mod, ONLY : Init_Species_Database
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
INTEGER,        INTENT(IN)    :: IM          ! # longitudes on this PET
INTEGER,        INTENT(IN)    :: JM          ! # longitudes on this PET
INTEGER,        INTENT(IN)    :: LM          ! # longitudes on this PET
INTEGER,        INTENT(IN)    :: nAerosol    ! # aerosol species
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Return code
```

REMARKS:

```
In the near future we will put some error trapping on the allocations
so that we can stop the simulation if the allocations cannot be made.
```

REVISION HISTORY:

```
19 Oct 2012 - R. Yantosca - Renamed from gc_type2_mod.F90
19 Oct 2012 - R. Yantosca - Now pass all dimensions as arguments
26 Oct 2012 - R. Yantosca - Now allocate Strat_P, Strat_k fields
26 Oct 2012 - R. Yantosca - Add nSchem, nSchemBry as arguments
01 Nov 2012 - R. Yantosca - Don't allocate strat chem fields if nSchm=0
                            and nSchmBry=0 (i.e. strat chem is turned off)
26 Feb 2013 - M. Long     - Now pass Input_Opt via the argument list
26 Feb 2013 - M. Long     - Now allocate the State_Chm%DEPSAV field
11 Dec 2014 - R. Yantosca - Remove TRAC_TEND and DEPSAV fields
13 Aug 2015 - E. Lundgren - Initialize trac_units to ''
28 Aug 2015 - R. Yantosca - Remove stratospheric chemistry fields;
                            these are all now read in via HEMCO
28 Aug 2015 - R. Yantosca - Also initialize the species database object
09 Oct 2015 - R. Yantosca - Bug fix: set State_Chm%SpcData to NULL
```

```
16 Dec 2015 - R. Yantosca - Now overwrite the Input_Opt%TRACER_MW_G and
                            related fields w/ info from species database
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
02 May 2016 - R. Yantosca - Nullify Hg index fields for safety's sake
18 May 2016 - R. Yantosca - Now determine the # of each species first,
                            then allocate fields of State_Chm
18 May 2016 - R. Yantosca - Now populate the species mapping vectors
30 Jun 2016 - M. Sulprizio- Remove nSpecies as an input argument. This is now
                            initialized as the size of SpcData.
22 Jul 2016 - E. Lundgren - Initialize spc_units to ''
28 Nov 2016 - R. Yantosca - Only allocate STATE_PSC and KHETI_SLA for UCX
                            simulations; set to NULL otherwise
28 Nov 2016 - R. Yantosca - Only allocate State_Chm%*Aero* fields for
                            fullchem and/or aerosol-only simulations
```

1.12.3 Cleanup_State_Chm

Routine CLEANUP_STATE_CHM deallocates all fields of the chemistry state object.

INTERFACE:

```
SUBROUTINE Cleanup_State_Chm( am_I_Root, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE Species_Database_Mod, ONLY : Cleanup_Species_Database
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root    ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm    ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC           ! Return code
```

REMARKS:

```
For now the am_I_Root and RC arguments are not used.  We include these
for consistency and also to facilitate future expansion. (bmy, 10/16/12)
```

REVISION HISTORY:

```
15 Oct 2012 - R. Yantosca - Initial version
26 Oct 2012 - R. Yantosca - Now deallocate Strat_P, Strat_k fields
26 Feb 2013 - M. Long     - Now deallocate State_Chm%DEPSAV
11 Dec 2014 - R. Yantosca - Remove TRAC_TEND and DEPSAV fields
28 Aug 2015 - R. Yantosca - Remove stratospheric chemistry fields;
                            these are all now read in via HEMCO
28 Aug 2015 - R. Yantosca - Also initialize the species database object
```

1.13 Fortran: Module Interface state_met_mod.F90

Module STATE_MET_MOD contains the derived type used to define the Meteorology State object for GEOS-Chem.

This module also contains the routines that allocate and deallocate memory to the Meteorology State object. The Meteorology State object is not defined in this module. It must be be declared as variable in the top-level driver routine, and then passed to lower-level routines as an argument.

INTERFACE:

```
MODULE State_Met_Mod
  USES:
  USE PRECISION_MOD

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC :: Init_State_Met
  PUBLIC :: Cleanup_State_Met
```

PUBLIC DATA MEMBERS:

```
  !=========================================================================
  ! Derived type for Meteorology State
  !=========================================================================
  TYPE, PUBLIC :: MetState

     !------------------------------------------------------------------------
     ! Surface fields
     !------------------------------------------------------------------------
     REAL(fp), POINTER :: ALBD      (:,:  ) ! Visible surface albedo [1]
     REAL(fp), POINTER :: CLDFRC    (:,:  ) ! Column cloud fraction [1]
     INTEGER,  POINTER :: CLDTOPS   (:,:  ) ! Max cloud top height [levels]
     REAL(fp), POINTER :: EFLUX     (:,:  ) ! Latent heat flux [W/m2]
     REAL(fp), POINTER :: EVAP      (:,:  ) ! Surface evap [kg/m2/s]
     REAL(fp), POINTER :: FRCLND    (:,:  ) ! Olson land fraction [1]
     REAL(fp), POINTER :: FRLAKE    (:,:  ) ! Fraction of lake [1]
     REAL(fp), POINTER :: FRLAND    (:,:  ) ! Fraction of land [1]
     REAL(fp), POINTER :: FRLANDIC  (:,:  ) ! Fraction of land ice [1]
     REAL(fp), POINTER :: FROCEAN   (:,:  ) ! Fraction of ocean [1]
     REAL(fp), POINTER :: FRSEAICE  (:,:  ) ! Sfc sea ice fraction
     REAL(fp), POINTER :: FRSNO     (:,:  ) ! Sfc snow fraction
     REAL(fp), POINTER :: GRN       (:,:  ) ! Greenness fraction
     REAL(fp), POINTER :: GWETROOT  (:,:  ) ! Root soil wetness [1]
     REAL(fp), POINTER :: GWETTOP   (:,:  ) ! Top soil moisture [1]
     REAL(fp), POINTER :: HFLUX     (:,:  ) ! Sensible heat flux [W/m2]
```

```
REAL(fp), POINTER :: LAI       (:,:  ) ! Leaf area index [m2/m2]
REAL(fp), POINTER :: ITY       (:,:  ) ! Land surface type index
REAL(fp), POINTER :: LWI       (:,:  ) ! Land/water indices [1]
REAL(fp), POINTER :: LWI_GISS  (:,:  ) ! Land fraction [1]
REAL(fp), POINTER :: MOLENGTH  (:,:  ) ! Monin-Obhukov length [m]
REAL(fp), POINTER :: OICE      (:,:  ) ! Fraction of ocean ice [1]
REAL(fp), POINTER :: PARDR     (:,:  ) ! Direct  photsyn active rad [W/m2]
REAL(fp), POINTER :: PARDF     (:,:  ) ! Diffuse photsyn active rad [W/m2]
REAL(fp), POINTER :: PBLH      (:,:  ) ! PBL height [m]
INTEGER,  POINTER :: PBL_TOP_L (:,:  ) ! PBL top layer [1]
REAL(fp), POINTER :: PHIS      (:,:  ) ! Sfc geopotential height [m2/s2]
REAL(fp), POINTER :: PRECANV   (:,:  ) ! Anvil previp @ ground [kg/m2/s]
REAL(fp), POINTER :: PRECCON   (:,:  ) ! Conv  precip @ ground [kg/m2/s]
REAL(fp), POINTER :: PRECTOT   (:,:  ) ! Total precip @ ground [kg/m2/s]
REAL(fp), POINTER :: PRECLSC   (:,:  ) ! LS precip @ ground [kg/m2/s]
REAL(fp), POINTER :: PRECSNO   (:,:  ) ! Snow precip [kg/m2/s]
REAL(fp), POINTER :: PS1_WET   (:,:  ) ! Wet sfc press at dt start[hPa]
REAL(fp), POINTER :: PS2_WET   (:,:  ) ! Wet sfc press at dt end [hPa]
REAL(fp), POINTER :: PSC2_WET  (:,:  ) ! Wet interpolated sfc press [hPa]
REAL(fp), POINTER :: PS1_DRY   (:,:  ) ! Dry sfc press at dt start[hPa]
REAL(fp), POINTER :: PS2_DRY   (:,:  ) ! Dry sfc press at dt end [hPa]
REAL(fp), POINTER :: PSC2_DRY  (:,:  ) ! Dry interpolated sfc press [hPa]
REAL(fp), POINTER :: RADLWG    (:,:  ) ! Net LW radiation @ ground [W/m2]
REAL(fp), POINTER :: RADSWG    (:,:  ) ! Solar radiation @ ground [W/m2]
REAL(fp), POINTER :: SEAICE00  (:,:  ) ! Sea ice coverage 00-10%
REAL(fp), POINTER :: SEAICE10  (:,:  ) ! Sea ice coverage 10-20%
REAL(fp), POINTER :: SEAICE20  (:,:  ) !  Sea ice coverage 20-30%
REAL(fp), POINTER :: SEAICE30  (:,:  ) ! Sea ice coverage 30-40%
REAL(fp), POINTER :: SEAICE40  (:,:  ) ! Sea ice coverage 40-50%
REAL(fp), POINTER :: SEAICE50  (:,:  ) ! Sea ice coverage 50-60%
REAL(fp), POINTER :: SEAICE60  (:,:  ) ! Sea ice coverage 60-70%
REAL(fp), POINTER :: SEAICE70  (:,:  ) ! Sea ice coverage 70-80%
REAL(fp), POINTER :: SEAICE80  (:,:  ) ! Sea ice coverage 80-90%
REAL(fp), POINTER :: SEAICE90  (:,:  ) ! Sea ice coverage 90-100%
REAL(fp), POINTER :: SLP       (:,:  ) ! Sea level pressure [hPa]
REAL(fp), POINTER :: SNICE     (:,:  ) ! Fraction of snow/ice [1]
REAL(fp), POINTER :: SNODP     (:,:  ) ! Snow depth [m]
REAL(fp), POINTER :: SNOMAS    (:,:  ) ! Snow mass [kg/m2]
REAL(fp), POINTER :: SNOW      (:,:  ) ! Snow depth (H2O equiv) [mm H2O]
REAL(fp), POINTER :: SST       (:,:  ) ! Sea surface temperature [K]
REAL(fp), POINTER :: SUNCOS    (:,:  ) ! COS(SZA), current time
REAL(fp), POINTER :: SUNCOSmid (:,:  ) ! COS(SZA), midpt of chem timestep
 REAL(fp), POINTER :: SUNCOSmid5(:,:  ) ! COS(SZA), midpt of chem timestep
                                        !  5 hrs ago (for PARANOX)
REAL(fp), POINTER :: SWGDN     (:,:  ) ! Incident radiation @ grnd [W/m2]
REAL(fp), POINTER :: TO3       (:,:  ) ! Total overhead O3 column [DU]
REAL(fp), POINTER :: TO31      (:,:  ) ! Total O3 at timestep start [DU]
REAL(fp), POINTER :: TO32      (:,:  ) ! Total O3 at timestep end [DU]
```

```
REAL(fp), POINTER :: TROPP     (:,:  ) ! Tropopause pressure [hPa]
REAL(fp), POINTER :: TROPP1    (:,:  ) ! Trop P at timestep start [hPa]
REAL(fp), POINTER :: TROPP2    (:,:  ) ! Trop P at timestep end [hPa]
REAL(fp), POINTER :: TS        (:,:  ) ! Surface temperature [K]
REAL(fp), POINTER :: TSKIN     (:,:  ) ! Surface skin temperature [K]
REAL(fp), POINTER :: TTO3      (:,:  ) ! Tropospheric ozone column [DU]
REAL(fp), POINTER :: U10M      (:,:  ) ! E/W wind speed @ 10m height [m/s]
REAL(fp), POINTER :: USTAR     (:,:  ) ! Friction velocity [m/s]
REAL(fp), POINTER :: UVALBEDO  (:,:  ) ! UV surface albedo [1]
REAL(fp), POINTER :: V10M      (:,:  ) ! N/S wind speed @ 10m height [m/s]
REAL(fp), POINTER :: Z0        (:,:  ) ! Surface roughness height [m]
REAL(fp), POINTER :: CNV_FRC   (:,:  ) ! Convective fraction [1]

!-----------------------------------------------------------------------
! 3-D Fields
!-----------------------------------------------------------------------
REAL(fp), POINTER :: AREA_M2   (:,:,:) ! Grid box surface area [cm2]
REAL(fp), POINTER :: CLDF      (:,:,:) ! 3-D cloud fraction [1]
REAL(fp), POINTER :: CMFMC     (:,:,:) ! Cloud mass flux [kg/m2/s]
REAL(fp), POINTER :: DETRAINE  (:,:,:) ! Detrainment (entrain plume)[Pa/s]
REAL(fp), POINTER :: DETRAINN  (:,:,:) ! Detrainment (non-entr plume)[Pa/s]
REAL(fp), POINTER :: DNDE      (:,:,:) ! Downdraft (entr plume) [Pa/s]
REAL(fp), POINTER :: DNDN      (:,:,:) ! Downdraft (non-entr plume) [Pa/s]
REAL(fp), POINTER :: DQRCU     (:,:,:) ! Conv precip prod rate [kg/kg/s]
                                       ! (assume per dry air)
REAL(fp), POINTER :: DQRLSAN   (:,:,:) ! LS precip prod rate [kg/kg/s]
                                       ! (assume per dry air)
REAL(fp), POINTER :: DQIDTMST  (:,:,:) ! Ice tendency, mst proc [kg/kg/s]
REAL(fp), POINTER :: DQLDTMST  (:,:,:) ! H2O tendency, mst proc [kg/kg/s]
REAL(fp), POINTER :: DQVDTMST  (:,:,:) ! Vapor tendency, mst proc [kg/kg/s]
REAL(fp), POINTER :: DTRAIN    (:,:,:) ! Detrainment flux [kg/m2/s]
REAL(fp), POINTER :: ENTRAIN   (:,:,:) ! GCAP entrainment [Pa/s]
REAL(fp), POINTER :: HKBETA    (:,:,:) ! Hack overshoot parameter [1]
REAL(fp), POINTER :: HKETA     (:,:,:) ! Hack conv mass flux [kg/m2/s]
REAL(fp), POINTER :: MOISTQ    (:,:,:) ! Tendency in sp. humidity
                                       ! [kg/kg tot air/s]
REAL(fp), POINTER :: OPTD      (:,:,:) ! Visible optical depth [1]
REAL(fp), POINTER :: PEDGE     (:,:,:) ! Wet air press @ level edges [hPa]
REAL(fp), POINTER :: PFICU     (:,:,:) ! Dwn flux ice prec:conv [kg/m2/s]
REAL(fp), POINTER :: PFILSAN   (:,:,:) ! Dwn flux ice prec:LS+anv [kg/m2/s]
REAL(fp), POINTER :: PFLCU     (:,:,:) ! Dwn flux liq prec:conv [kg/m2/s]
REAL(fp), POINTER :: PFLLSAN   (:,:,:) ! Dwn flux ice prec:LS+anv [kg/m2/s]
REAL(fp), POINTER :: PV        (:,:,:) ! Potential vort [kg*m2/kg/s]
REAL(fp), POINTER :: QI        (:,:,:) ! Ice mixing ratio [kg/kg dry air]
REAL(fp), POINTER :: QL        (:,:,:) ! Water mixing ratio [kg/kg dry air]
REAL(fp), POINTER :: REEVAPCN  (:,:,:) ! Evap of precip conv [kg/kg/s]
                                       ! (assume per dry air)
REAL(fp), POINTER :: REEVAPLS  (:,:,:) ! Evap of precip LS+anvil [kg/kg/s]
```

```
                                        ! (assume per dry air)
REAL(fp), POINTER :: RH        (:,:,:) ! Relative humidity [%]
REAL(fp), POINTER :: RH1       (:,:,:) ! RH at timestep start [%]
REAL(fp), POINTER :: RH2       (:,:,:) ! RH at timestep end [%]
REAL(fp), POINTER :: SPHU      (:,:,:) ! Spcfc humidity [g H2O/kg tot air]
REAL(fp), POINTER :: SPHU1     (:,:,:) ! Spec hum at timestep start [g/kg]
REAL(fp), POINTER :: SPHU2     (:,:,:) ! Spec hum at timestep end [g/kg]
REAL(fp), POINTER :: T         (:,:,:) ! Temperature [K]
REAL(fp), POINTER :: TAUCLI    (:,:,:) ! Opt depth of ice clouds [1]
REAL(fp), POINTER :: TAUCLW    (:,:,:) ! Opt depth of H2O clouds [1]
REAL(fp), POINTER :: TMPU1     (:,:,:) ! Temperature at timestep start [K]
REAL(fp), POINTER :: TMPU2     (:,:,:) ! Temperature at timestep end [K]
REAL(fp), POINTER :: U         (:,:,:) ! E/W component of wind [m s-1]
REAL(fp), POINTER :: UPDE      (:,:,:) ! Updraft (entraining plume) [Pa/s]
REAL(fp), POINTER :: UPDN      (:,:,:) ! Updraft (non-entr'n plume) [Pa/s]
REAL(fp), POINTER :: UPDVVEL   (:,:,:) ! Updraft vertical velocity [hPa/s]
REAL(fp), POINTER :: V         (:,:,:) ! N/S component of wind [m s-1]
REAL(fp), POINTER :: ZMEU      (:,:,:) ! Z/M updraft entrainment [Pa/s]
REAL(fp), POINTER :: ZMMD      (:,:,:) ! Z/M downdraft mass flux [Pa/s]
REAL(fp), POINTER :: ZMMU      (:,:,:) ! Z/M updraft   mass flux [Pa/s]

!-----------------------------------------------------------------------
! Air quantities assigned in AIRQNT
!-----------------------------------------------------------------------
! Note on pressures: PMID is calculated from PEDGE,
! and dry air pressures assume constant RH and T across grid box
REAL(fp), POINTER :: PEDGE_DRY (:,:,:) ! Dry air partial pressure [hPa]
                                        ! @ level edges [hPa]
REAL(fp), POINTER :: PMID      (:,:,:) ! Average wet air pressure [hPa]
                                        ! defined as arithmetic
                                        ! average of edge pressures
REAL(fp), POINTER :: PMID_DRY  (:,:,:) ! Dry air partial pressure [hPa]
                                        ! defined as arithmetic average
                                        ! of edge pressures
REAL(fp), POINTER :: TV        (:,:,:) ! Virtual temperature [K]
REAL(fp), POINTER :: MAIRDEN   (:,:,:) ! Moist air density [kg/m3]
REAL(fp), POINTER :: AIRDEN    (:,:,:) ! Dry air density [kg/m3]
REAL(fp), POINTER :: AIRNUMDEN (:,:,:) ! Dry air density [molec/m3]
REAL(fp), POINTER :: AVGW      (:,:,:) ! Water vapor volume mixing ratio
                                        ! [vol H2O / vol dry air]
REAL(fp), POINTER :: BXHEIGHT  (:,:,:) ! Grid box height [m] (dry air)
REAL(fp), POINTER :: DELP      (:,:,:) ! Delta-P (wet) across box [hPa]
REAL(fp), POINTER :: DELP_DRY  (:,:,:) ! Delta-P (dry) across box [hPa]
REAL(fp), POINTER :: AD        (:,:,:) ! Dry air mass [kg] in grid box
REAL(fp), POINTER :: AIRVOL    (:,:,:) ! Grid box volume [m3] (dry air)
REAL(fp), POINTER :: DELP_PREV (:,:,:) ! Previous State_Met%DELP
REAL(fp), POINTER :: DP_DRY_PREV (:,:,:) ! Previous State_Met%DELP_DRY
REAL(fp), POINTER :: SPHU_PREV (:,:,:) ! Previous State_Met%SPHU
```

```
!-------------------------------------------------------------------------
! Land type and leaf area index (LAI) fields for dry deposition
!-------------------------------------------------------------------------
INTEGER,  POINTER :: IREG      (:,:  ) ! # of landtypes in grid box (I,J)
INTEGER,  POINTER :: ILAND     (:,:,:) ! Land type at (I,J); 1..IREG(I,J)
INTEGER,  POINTER :: IUSE      (:,:,:) ! Fraction (per mil) of grid box
                                       !  (I,J) occupied by each land type
REAL(fp), POINTER :: XLAI      (:,:,:) ! LAI per land type, this month
REAL(fp), POINTER :: XLAI2     (:,:,:) ! LAI per land type, next month
REAL(fp), POINTER :: XCHLR     (:,:,:) ! CHLR per land type, this month
REAL(fp), POINTER :: XCHLR2    (:,:,:) ! CHLR per land type, next month



END TYPE MetState
```

REMARKS:

In MERRA2, PS and SLP are kept in Pa (not converted to hPa).

REVISION HISTORY:

```
19 Oct 2012 - R. Yantosca - Initial version, split off from gc_type_mod.F90
23 Oct 2012 - R. Yantosca - Added QI, QL met fields to the derived type
15 Nov 2012 - M. Payer    - Added all remaining met fields
12 Dec 2012 - R. Yantosca - Add IREG, ILAND, IUSE fields for dry deposition
13 Dec 2012 - R. Yantosca - Add XLAI, XLAI2 fields for dry deposition
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
15 Nov 2013 - R. Yantosca - Now denote that RH fields have units of [%]
10 Oct 2014 - C. Keller   - Added ITY (needed for GIGC). For now, this value
                            is just initialized to 1.0 and not modified any
                            more.
05 Nov 2014 - M. Yannetti - Changed REAL*8 to REAL(fp)
12 Feb 2015 - C. Keller   - Added UPDVVEL (for use in wet scavenging).
24 Feb 2015 - E. Lundgren - Add PEDGE_DRY, PMID_DRY, and MAIRDEN
03 Mar 2015 - E. Lundgren - Add TV (virtual temperature)
16 Apr 2015 - E. Lundgren - Add mean pressures PMEAN and PMEAN_DRY. Clarify
                            definition of PMID as arithmetic average P.
                            Add MOISTMW to use TCVV with moist mixing ratio.
25 May 2015 - C. Keller   - Removed SUNCOSmid5 (now calculated by HEMCO).
08 Jul 2015 - E. Lundgren - Add XCHLR and XCHLR2 for organic marine aerosols
11 Aug 2015 - R. Yantosca - Extend #ifdefs for MERRA2 met fields
22 Sep 2015 - E. Lundgren - Add SWGDN for incident radiation at ground
28 Oct 2015 - E. Lundgren - Add previous delta-P and specific humidity for
                            tracer mass conservation in mixing ratio update
04 Mar 2016 - C. Keller   - Add CNV_FRC for convective fraction. Currently
                            not a standard GEOS-FP output, only used in
                            online model (ESMF).
```

```
21 Dec 2015 - M. Sulprizio- Add AIRNUMDEN, which is the same as AIRDEN but
                            has units molec/cm3 for the chemistry routines.
17 Mar 2016 - M. Sulprizio- Remove OPTDEP. Instead, we now solely use OPTD.
03 May 2016 - E. Lundgren - Add PSC2_DRY, PS1_DRY, and PS2_DRY
06 Jul 2016 - E. Lundgren - Rename PS1, PS2, and PSC1: add '_WET' suffix
06 Jul 2016 - E. Lundgren - Add DELP_DRY and DP_DRY_PREV
19 Jul 2016 - E. Lundgren - Remove PMEAN, PMEAN_DRY, MOISTMW, and ADMOIST
16 Aug 2016 - M. Sulprizio- Rename from gigc_state_chm_mod.F90 to
                            state_chm_mod.F90. The "gigc" nomenclature is
                            no longer used.
```

1.13.1 Init_State_Met

Subroutine INIT_STATE_MET allocates all fields of the meteorology state object.

INTERFACE:

```
SUBROUTINE Init_State_Met( am_I_Root, IM, JM, LM, State_Met, RC )
```

USES:

```
USE ErrCode_Mod                              ! Error codes
USE CMN_SIZE_MOD,    ONLY : NTYPE            ! # of land types
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
INTEGER,        INTENT(IN)    :: IM          ! # longitudes on this PET
INTEGER,        INTENT(IN)    :: JM          ! # longitudes on this PET
INTEGER,        INTENT(IN)    :: LM          ! # longitudes on this PET
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Obj for meteorology state
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Return code
```

REMARKS:

```
For consistency, maybe this should be moved to a different module.
```

REVISION HISTORY:

```
19 Oct 2012 - R. Yantosca - Initial version, based on gc_environment_mod.F90
19 Oct 2012 - R. Yantosca - Now pass all dimensions as arguments
23 Oct 2012 - R. Yantosca - Now allocate QI, QL fields
15 Nov 2012 - M. Payer    - Added all remaining met fields
16 Nov 2012 - R. Yantosca - Now zero all fields after allocating
27 Nov 2012 - R. Yantosca - Now allocate SUNCOS fields (IM,JM)
```

```
12 Dec 2012 - R. Yantosca - Now allocate the IREG, ILAND, IUSE fields
13 Dec 2012 - R. Yantosca - Now allocate the XLAI, XLAI2 fields
07 Mar 2013 - R. Yantosca - Now allocate PF*LSAN, PF*CU fields properly
                            for GEOS-5.7.x met (they are edged)
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
22 Aug 2014 - R. Yantosca - Allocate PBL_TOP_L field
05 Nov 2014 - R. Yantosca - Now use 0.0_fp instead of 0d0
06 Nov 2014 - R. Yantosca - Now make all fields (IM,JM,LM) instead of
                            (LM,JM,IM), to facilitate use w/in GEOS-5 GCM
05 Oct 2016 - R. Yantosca - Swapped order of HKETA and HKBETA allocation
28 Nov 2016 - R. Yantosca - Nullify fields that may or may not be allocated
```

1.13.2 Cleanup_State_Met

Subroutine CLEANUP_STATE_MET deallocates all fields of the meteorology state object.

INTERFACE:

```
SUBROUTINE Cleanup_State_Met( am_I_Root, State_Met, RC )
```

USES:

```
USE ErrCode_Mod                          ! Error codes
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Obj for meteorology state
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Return code
```

REVISION HISTORY:

```
19 Oct 2012 - R. Yantosca - Initial version, based on gc_environment_mod.F90
23 Oct 2012 - R. Yantosca - Now deallocate QI, QL fields
15 Nov 2012 - M. Payer    - Added all remaining met fields
19 Nov 2012 - R. Yantosca - Segregate DEALLOCATE statements w/ #ifdefs
                            for each met field data product type
27 Nov 2012 - R. Yantosca - Now deallocate the SUNCOS fields
12 Dec 2012 - R. Yantosca - Now deallocate the IREG, ILAND, IUSE fields
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
22 Aug 2014 - R. Yantosca - Deallocate PBL_TOP_L field
```

2 GEOS-Chem driver and other operations

These modules contain routines to perform core operations such as initializing a GEOS-Chem simulation, timestepping, reading data from restart files, and cleanup.

2.1 Fortran: Module Interface main.F

Program GEOS_CHEM is the main level driver program for the GEOS-Chem model of atmospheric chemistry and composition.

INTERFACE:

```
PROGRAM GEOS_CHEM
```

USES:

```
!-----------------------------------------------------------------
! Parameters to define floating-point variables
!-----------------------------------------------------------------
USE PRECISION_MOD,   ONLY : fpp => fp  ! Flexible precision
USE PRECISION_MOD,   ONLY : f4         ! 4-byte floating point
USE PRECISION_MOD,   ONLY : f8         ! 8-byte floating point

!-----------------------------------------------------------------
! Basic GEOS-Chem modules
!-----------------------------------------------------------------
USE CMN_SIZE_MOD          ! Size parameters
USE ErrCode_Mod           ! Error codes for success or failure
USE ERROR_MOD             ! For error checking
USE FILE_MOD              ! For file I/O
USE GEOS_TIMERS_MOD       ! For GEOS-Chem timers (optional)
USE GC_Environment_Mod    ! For allocating derived type objects
USE GC_GRID_MOD           ! For defining the lons/lats/areas of the grid
USE Input_Opt_Mod         ! Derived type for Input Options
USE INPUT_MOD             ! For reading settings from "input.geos"
USE MAPPING_MOD           ! For regridding MODIS LAI
USE OLSON_LANDMAP_MOD     ! Computes IREG, ILAND, IUSE from Olson map
USE PhysConstants         ! Physical constants
USE PRESSURE_MOD          ! For computing pressure at grid boxes
USE REGRID_A2A_MOD        ! For horizontal regridding
USE RESTART_MOD           ! For restart file I/O
USE State_Chm_Mod         ! Derived type for Chemistry State object
USE State_Met_Mod         ! Derived type for Meteorology State object
USE TIME_MOD              ! For computing date & time
USE UnitConv_Mod          ! For gas concentration unit conversion

!-----------------------------------------------------------------
! GEOS-Chem chemistry modules
!-----------------------------------------------------------------
USE CARBON_MOD            ! For SOA simulation
USE CHEMISTRY_MOD         ! Driver routines for chemistry
USE GLOBAL_CH4_MOD        ! For offline CH4 simulation
USE MERCURY_MOD           ! For offline Hg simulation (driver)
USE OCEAN_MERCURY_MOD     ! For offline Hg simulation (ocean model)
USE STRAT_CHEM_MOD        ! For linearized stratospheric chemistry
```

```
USE TOMS_MOD              ! For overhead O3 columns (for FAST-J)
USE UCX_MOD               ! For unified trop-strat chemistry (SDE)
USE UVALBEDO_MOD          ! For reading UV albedoes (for FAST-J)

!-----------------------------------------------------------------
! GEOS-Chem deposition modules
!-----------------------------------------------------------------
USE DEPO_MERCURY_MOD      ! Deposition for offline Hg simulation
USE DRYDEP_MOD            ! For dry deposition
USE WETSCAV_MOD           ! For wet deposition (rainout & washout)

!-----------------------------------------------------------------
! GEOS-Chem diagnostics modules
!-----------------------------------------------------------------
USE BENCHMARK_MOD         ! For the 1-month benchmark simulations
USE CMN_DIAG_MOD          ! Logical switches for G-C diagnostics
USE DIAG_MOD              ! G-C diagnostic arrays & counters
USE DIAG41_MOD            ! For ND41  (afternoon PBL       ) diag
USE DIAG42_MOD            ! For ND42  (SOA products        ) diag
USE DIAG48_MOD            ! For ND48  (station timeseries  ) diag
USE DIAG49_MOD            ! For ND49  (inst. timeseries    ) diag
USE DIAG50_MOD            ! For ND50  (24h avg timeseries  ) diag
USE DIAG51_MOD            ! For ND51  (satellite timeseries) diag
USE DIAG51b_MOD           ! For ND51b (satellite timeseries) diag
USE DIAG63_MOD            ! For ND63  (PARANOX timeseries  ) diag
USE DIAG_OH_MOD           ! For ND43  (OH,HO2,etc. prod    ) diag
USE DIAGNOSTICS_MOD       ! NetCDF diagnostics module (C. Keller)
USE PLANEFLIGHT_MOD       ! For ND40  (plane flight track  ) diag

!-----------------------------------------------------------------
! GEOS-Chem dynamics modules
!-----------------------------------------------------------------
USE CHEMGRID_MOD          ! For the dynamic tropopause
USE CONVECTION_MOD        ! For deep cloud convection
USE LINOZ_MOD             ! For LINOX linear strat chemistry
USE PBL_MIX_MOD           ! To compute PBL height
USE TPCORE_BC_MOD         ! For nested-grid boundary conditions
USE TRANSPORT_MOD         ! Driver routines for advection
USE VDIFF_MOD             ! For non-local PBL mixing (J. Lin)

!-----------------------------------------------------------------
! GEOS-Chem emissions modules
!-----------------------------------------------------------------
USE EMISSIONS_MOD         ! For interfacing with HEMCO emissions
USE MIXING_MOD            ! performs tracer mixing
USE MODIS_LAI_MOD         ! For MODIS leaf area indices (replacement)

!-----------------------------------------------------------------
```

```
      ! GEOS-Chem met field I/O modules
      !-----------------------------------------------------------------
      USE DAO_MOD               ! Met field definitions
      USE GCAP_READ_MOD         ! For reading GCAP met data
      USE GEOSFP_READ_MOD       ! For reading GEOS-FP data
      USE MERRA2_READ_MOD       ! For reading MERRA2 data
      USE MERRA_A1_MOD          ! For reading MERRA A1 data
      USE MERRA_A3_MOD          ! For reading MERRA A3 data
      USE MERRA_CN_MOD          ! For reading MERRA CN data
      USE MERRA_I6_MOD          ! For reading MERRA I6 data
      USE A3_READ_MOD           ! For reading A3 data (all other met)
      USE A6_READ_MOD           ! For reading A6 data (all other met)
      USE I6_READ_MOD           ! For reading I6 data (all other met)
#if defined( EXCHANGE )
      USE EXCHANGE_MOD          ! For two-way coupled simulations
#endif

#if defined( RRTMG )
      !-----------------------------------------------------------------
      ! Radiation modules
      !-----------------------------------------------------------------
      USE RRTMG_RAD_TRANSFER_MOD, ONLY: DO_RRTMG_RAD_TRANSFER,
     &                                  LW_UFLUX, LW_DFLUX,
     &                                  SW_UFLUX, SW_DFLUX,
     &                                  LW_UFLUXC, LW_DFLUXC,
     &                                  SW_UFLUXC, SW_DFLUXC,
     &                                  INIT_SURFACE_RAD,
     &                                  READ_SURFACE_RAD,
     &                                  INIT_STRAT_CLIM,
     &                                  READ_STRAT_CLIM,
     &                                  INIT_MCICA_CLOUDS,
     &                                  SET_SPECMASK
      USE CMN_FJX_MOD,            ONLY: NSPECRADMENU,
     &                                  LSPECRADMENU
      USE rrtmg_lw_init,  ONLY : rrtmg_lw_ini
      USE rrtmg_sw_init,  ONLY : rrtmg_sw_ini

#endif

      IMPLICIT NONE
```

REMARKS:

```
      GGGGGG  EEEEEEE  OOOOO  SSSSSSS       CCCCCC H     H EEEEEEE M     M
     G        E       O     O S           C       H     H E       M M M M
     G   GGG  EEEEEE  O     O SSSSSSS     C       HHHHHHH EEEEEE  M  M  M
     G     G  E       O     O       S     C       H     H E       M     M
      GGGGGG  EEEEEEE  OOOOO  SSSSSSS       CCCCCC H     H EEEEEEE M     M
```

```
.
.
              (formerly known as the Harvard-GEOS model)
          for 4 x 5, 2 x 2.5 global grids and hi-res nested grids
.
     Contact: GEOS-Chem Support Team (geos-chem-support@as.harvard.edu)

.
See the GEOS-Chem Web Site:
.
   http://acmg.seas.harvard.edu/geos/
.
and the GEOS-Chem User's Guide:
.
   http://acmg.seas.harvard.edu/geos/doc/man/
.
and the GEOS-Chem wiki:
.
   http://wiki.seas.harvard.edu/geos-chem/
.
for the most up-to-date GEOS-Chem documentation on the following topics:
.
   - installation, compilation, and execution
   - coding practice and style
   - input files and met field data files
   - horizontal and vertical resolution
   - modification history
```

REVISION HISTORY:

```
13 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2010 - R. Yantosca - Add modifications for MERRA (treat like GEOS-5)
19 Aug 2010 - R. Yantosca - Now call MERRA met field reader routines
02 Feb 2011 - S. Kim      - Call Compute_OD after wet deposition
05 Oct 2011 - R. Yantosca - Now get SUNCOS30 array from routine COSSZA
07 Oct 2011 - R. Yantosca - Rename SUNCOS30 to SUNCOS_MID, which is the
                            cos(SZA) at the midpt of the chemistry timestep
02 Feb 2012 - R. Yantosca - Added modifications for GEOS-5.7.x met fields
06 Feb 2012 - R. Yantosca - Reorganize USE statements for clarity
06 Feb 2012 - R. Yantosca - Renamed NN to NNN to avoid name confusion
07 Feb 2012 - R. Yantosca - Split off met field I/O into internal routines
                            READ_INITIAL_MET_FIELDS and READ_MET_FIELDS
07 Feb 2012 - M. Payer    - Replace call to COSSZA with GET_COSINE_SZA
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
06 Mar 2012 - R. Yantosca - Now call READ_TOMS every month (this was
                            formerly done within routine "fast_j.F")
06 Mar 2012 - R. Yantosca - Add subroutine GET_OVERHEAD_O3_FOR_FASTJ
                            which calls COMPUTE_OVERHEAD_O3 (in toms_mod.F)
                            to pre-compute the overhead O3 columsn for
```

```
                            FAST-J photolysis.  This removes code from
                            "set_prof.F" to facilitate the GI model.
19 Mar 2012 - R. Yantosca - Now call routines from olson_landmap_mod.F90
                            to read the Olson land map data
04 Apr 2012 - R. Yantosca - Now call updated LAI routines from new module
                            modis_lai_mod.F90.  Retire routine RDLAI.
05 Apr 2012 - R. Yantosca - Removed reference to LXTRA, it's obsolete
11 Apr 2012 - R. Yantosca - Replace lai_mod.F with modis_lai_mod.F90
11 Apr 2012 - R. Yantosca - Now call INIT_MODIS_LAI (in modis_lai_mod.F90)
                            here so that we don't have to call it from
                            megan_mod.F and mercury_mod.F separately.
17 Apr 2012 - R. Yantosca - Need to set the mapping variable to NULL()
10 Jun 2012 - L. Murray   - Remove references to UPBDFLX_MOD.F
31 Jul 2012 - R. Yantosca - Now pass am_I_Root variable to lower-level
                            routines in order to allow PRINT and WRITE
                            statements to execute on the root CPU.  This
                            is needed for compatibility w/ the GEOS-5 GCM.
13 Aug 2012 - R. Yantosca - Now call FILL_CHEM_STATE_IDs to populate
                            the CHEM_STATE object ID and name fields
18 Oct 2012 - R. Yantosca - Rename LOCAL_MET object to State_Met
18 Oct 2012 - R. Yantosca - Rename CHEM_STATE object to State_Chm
18 Oct 2012 - R. Yantosca - Now pass am_I_Root, RC arguments to routines
                            ALLOCATE_ALL, INIT_ALL when using -DDEVEL
19 Oct 2012 - R. Yantosca - Now reference gigc_state_chm_mod.F90
19 Oct 2012 - R. Yantosca - Now reference gigc_state_met_mod.F90
25 Oct 2012 - R. Yantosca - Define logical doDebugPrt for ND70 output
25 Oct 2012 - R. Yantosca - Add descriptive comments for DEVEL #ifdefs
25 Oct 2012 - R. Yantosca - Now reference gigc_errcode_mod.F90
01 Nov 2012 - R. Yantosca - Now read soil NOx restart file
01 Nov 2012 - R. Yantosca - Now reference gigc_input_opt_mod.F90
08 Nov 2012 - R. Yantosca - Now pass Input_Opt as an arg to DO_CHEMISTRY
01 Nov 2012 - R. Yantosca - Now read soil NOx restart file
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
                            to various subroutines
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
15 Nov 2012 - R. Yantosca - Bring Input_Opt out of the DEVEL tags
26 Feb 2013 - R. Yantosca - Add placeholder tag for Input_Opt%MAX_DEP
05 Mar 2013 - R. Yantosca - Now pass am_I_Root, Input_Opt, RC to routine
                            DO_PBL_MIX_2 (for non-local PBL mixing)
15 Mar 2013 - R. Yantosca - Now set Input_Opt%LINOZ_N* fields here
26 Mar 2013 - S.D. Eastham- Added initialization of rare tracers
29 Mar 2013 - R. Yantosca - Bring code out of DEVEL blocks
30 May 2013 - R. Yantosca - Now pass Input_Opt object to STDRUN routine
03 Jun 2013 - R. Yanosca - Use routines from updated mercury_mod.F
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
23 Oct 2013 - R. Yantosca - Now pass am_I_root, Input_Opt, RC to INIT_DAO
13 Dec 2013 - M. Sulprizio- Now set USE_O3_FROM_MET logical flag during
```

```
                            initialization stage
   11 Apr 2014 - R. Yantosca - Now remove call to INIT_GLOBAL_CH4; this is
                               now done from routine GIGC_Init_Extra
   19 May 2014 - C. Keller   - Added INIT_CHEMISTRY
   19 May 2014 - C. Keller   - Added HEMCO
   23 Jun 2014 - R. Yantosca - Removed references to unix_cmds_mod.F
   23 Jun 2014 - R. Yantosca - Removed references to directory_mod.F
   23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
   15 Jul 2014 - R. Yantosca - Now reference grid_mod.F90, regrid_a2a_mod.F90
   15 Jul 2014 - R. Yantosca - Now call Init_Map_A2A to store shadow variables
                               within regrid_a2a_mod.F90.  This helps to
                               break dependencies for the HEMCO implementation.
   25 Jul 2014 - R. Yantosca - Remove reference to commsoil_mod.F90
   22 Aug 2014 - R. Yantosca - Now save areas [m2] in State_Met%AREA_M2
   15 Dec 2014 - M. Yannetti - Added PRECISION_MOD
   06 Jan 2015 - R. Yantosca - Added two-way coupled simulation options
   17 Feb 2015 - E. Lundgren - Remove STT and TCVV pointers
   25 Feb 2015 - E. Lundgren - Remove MAKE-RH call since now in AIRQNT
   16 Mar 2015 - E. Lundgren - Change tracer main units from kg to kg/kg
   24 Mar 2015 - E. Lundgren - Now pass Input_Opt to Check_STT
   31 Mar 2015 - E. Lundgren - Move post-transport AIRQNT call to transport_mod
   16 Apr 2015 - R. Yantosca - Remove call to INIT_DAO; it's obsolete
   12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
   03 Sep 2015 - R. Yantosca - Now call SETUP_WETSCAV instead of INIT_WETSCAV
   25 Jan 2016 - R. Yantosca - Call LINE_BUFFER to force PGI compiler to flush
                               STDOUT (unit=6) output to disk during a run
   03 Feb 2016 - E. Lundgren - Use routine MAKE_RESTART_FILES for all GC rsts
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   02 May 2016 - R. Yantosca - Now pass Input_Opt to cleanup_gigc_state_chm
   18 May 2016 - M. Sulprizio- Remove call to INIT_COMODE; it's obsolete
   06 Jun 2016 - M. Sulprizio- Remove call to FILL_CHEM_STATE_IDs; this routine
                               was made obsolete by the species database
   22 Jun 2016 - R. Yantosca - Add error checks to prevent calling UCX routines
                               when we are running specialty simulations
   12 Jul 2016 - E. Lundgren - Remove binary punch restart file option
   29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

2.1.1 display_grid_and_model

Internal Subroutine DISPLAY_GRID_AND_MODEL displays the appropriate messages for the given model grid and machine type. It also prints the starting time and date (local time) of the GEOS-Chem simulation.

INTERFACE:

```
SUBROUTINE DISPLAY_GRID_AND_MODEL
```

REVISION HISTORY:

```
02 Dec 2003 - R. Yantosca - Initial version
13 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2010 - R. Yantosca - Added extra output
02 Feb 2012 - R. Yantosca - Added output for GEOS-5.7.x met fields
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
19 Mar 2012 - R. Yantosca - Now echo info for 0.25 x 0.3125 runs
19 Mar 2012 - R. Yantosca - Now echo info if ISORROPIA is turned off
22 Oct 2012 - R. Yantosca - Now echo info if -DDEVEL is used
```

2.1.2 ctm_flush

Internal subroutine CTM_FLUSH flushes certain diagnostic file buffers to disk.

CTM_FLUSH should normally be called after each diagnostic output, so that in case the run dies, the output files from the last diagnostic timestep will not be lost.

FLUSH is an intrinsic FORTRAN subroutine and takes as input the unit number of the file to be flushed to disk.

INTERFACE:

```
SUBROUTINE CTM_FLUSH
```

REVISION HISTORY:

```
31 Aug 2000 - R. Yantosca - Initial version
13 Aug 2010 - R. Yantosca - Added ProTeX headers
06 Aug 2012 - R. Yantosca - IU_BPCH is only global file LUN still needed
```

2.1.3 display_end_time

Internal subroutine DISPLAY_END_TIME prints the ending time of the GEOS-Chem simulation.

INTERFACE:

```
SUBROUTINE DISPLAY_END_TIME
```

REVISION HISTORY:

```
03 May 2005 - R. Yantosca - Initial version
13 Aug 2010 - R. Yantosca - Added ProTeX headers
```

2.1.4 read_initial_met_fields

Internal subroutine READ_INITIAL_MET_FIELDS calls the various routines to read met fields at the beginning of a GEOS-Chem simulation. This code was moved out of the main routine for clarity, due to the many #if defined() blocks that are required.

INTERFACE:

```
SUBROUTINE READ_INITIAL_MET_FIELDS()
```

REMARKS:

```
All variables used in this routine are declared above in the main
program, and as such, are visible here.

Also calls the following routines:
(1) AVGPOLE   (average pressure @ poles) when I3 or I6 fields are read
(2) LIGHTNING (lightning NOx emissions)  when A3 or A6 fields are read
```

REVISION HISTORY:

```
07 Feb 2012 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
23 Oct 2013 - R. Yantosca - Now pass Input_Opt to GET_A6_FIELDS
23 Oct 2013 - R. Yantosca - Now pass Input_Opt to GET_MERRA_A3_FIELDS
24 Jun 2014 - R. Yantosca - Now pass Input_Opt to other routines
24 Jun 2014 - R. Yantosca - Cosmetic changes, line up arguments
12 Aug 2015 - R. Yantosca - Call routines for reading MERRA2 fields
```

2.1.5 read_met_fields

Internal subroutine READ_MET_FIELDS calls the various routines to read met fields in the main GEOS-Chem timestepping loop. This code was moved out of the main routine for clarity, due to the many #if defined() blocks that are required.

INTERFACE:

```
SUBROUTINE READ_MET_FIELDS()
```

REMARKS:

```
All variables used in this routine are declared above in the main
program, and as such, are visible here.

Also calls the following routines:
(1) AVGPOLE   (average pressure @ poles) when I3 or I6 fields are read
(2) LIGHTNING (lightning NOx emissions)  when A3 or A6 fields are read
```

REVISION HISTORY:

```
07 Feb 2012 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
04 Jan 2013 - M. Payer    - Call UPDATE_T_DAY for MERRA and GEOS-5.7.2 (tmf)
23 Oct 2013 - R. Yantosca - Now pass Input_Opt to GET_A6_FIELDS
24 Jun 2014 - R. Yantosca - Now pass Input_Opt to other routines
24 Jun 2014 - R. Yantosca - Cosmetic changes, line up arguments
12 Aug 2015 - R. Yantosca - Now call routines to read MERRA2 met data
```

2.1.6 get_overhead_o3_for_fastj

Internal subroutine GET_OVERHEAD_O3_FOR_FASTJ

INTERFACE:

```
    SUBROUTINE GET_OVERHEAD_O3_FOR_FASTJ( am_I_Root )
INPUT ARGUMENTS:

    LOGICAL, INTENT(IN   )   :: am_I_Root   ! Root CPU?
```

REMARKS:

```
This routine makes use of variables declared in above in the main program
(which are visible in all sub-programs below the CONTAINS statement).

The original code was done in FAST-J routine "set_prof.F", but has been
split off to facilitate development of the grid-independent model.
```

REVISION HISTORY:

```
07 Mar 2012 - R. Yantosca - Initial version
14 Nov 2013 - R. Yantosca - For GEOS-FP, read O3 from met field files
13 Dec 2013 - M. Sulprizio- Moved USE_O3_FROM_MET to the Input_Opt object and
                            set in initialization stage of GEOS_CHEM
22 Oct 2014 - C. Keller   - Added am_I_Root
```

2.1.7 initialize_regridding

Internal subroutine Initialize_Regridding passes several variables to regrid_a2a_mod.F90, where they are locally shadowed.

INTERFACE:

```
    SUBROUTINE Initialize_Regridding( am_I_Root, Input_Opt, RC )
```

INPUT PARAMETERS:

```
    LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
    TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
This routine is a wrapper for Init_Map_A2A in regrid_a2a_mod.F90.
Passing variables via Init_Map_A2A helps us to remove dependencies on
other GEOS-Chem routines from regrid_a2a_mod.F90.  This in turn
facilitates the implementation of the HEMCO emissions package.
```

REVISION HISTORY:

```
15 Jul 2014 - R. Yantosca - Initial version
05 Mar 2015 - R. Yantosca - Now read data w/r/t ExtData/HEMCO
```

2.2 Fortran: Module Interface input_mod.F

Module INPUT_MOD contains routines that read the GEOS-Chem input file at the start of the run and pass the information to several other GEOS-Chem F90 modules.

INTERFACE:

```
MODULE INPUT_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: INITIALIZE_GEOS_GRID
PUBLIC  :: READ_INPUT_FILE
PUBLIC  :: GC_Init_Extra
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: READ_ONE_LINE
PRIVATE :: SPLIT_ONE_LINE
PRIVATE :: READ_SIMULATION_MENU
PRIVATE :: READ_ADVECTED_SPECIES_MENU
PRIVATE :: READ_AEROSOL_MENU
PRIVATE :: READ_EMISSIONS_MENU
PRIVATE :: READ_FUTURE_MENU
PRIVATE :: READ_CHEMISTRY_MENU
PRIVATE :: READ_RADIATION_MENU
```

```
      PRIVATE :: READ_TRANSPORT_MENU
      PRIVATE :: READ_CONVECTION_MENU
      PRIVATE :: READ_DEPOSITION_MENU
      PRIVATE :: READ_OUTPUT_MENU
      PRIVATE :: READ_DIAGNOSTIC_MENU
      PRIVATE :: SET_TINDEX
      PRIVATE :: READ_ND49_MENU
      PRIVATE :: READ_ND50_MENU
      PRIVATE :: READ_ND51_MENU
      PRIVATE :: READ_ND51b_MENU
      PRIVATE :: READ_ND63_MENU
      PRIVATE :: READ_PROD_LOSS_MENU
      PRIVATE :: READ_UNIX_CMDS_MENU
      PRIVATE :: READ_NESTED_GRID_MENU
      PRIVATE :: READ_BENCHMARK_MENU
      PRIVATE :: READ_CH4_MENU
      PRIVATE :: READ_PASSIVE_TRACER_MENU
      PRIVATE :: VALIDATE_DIRECTORIES
      PRIVATE :: CHECK_DIRECTORY
      PRIVATE :: CHECK_TIME_STEPS
      PRIVATE :: IS_LAST_DAY_GOOD
#if defined( TOMAS )
      PRIVATE :: INIT_TOMAS_MICROPHYSICS
#endif
```

REVISION HISTORY:

```
   20 Jul 2004 - R. Yantosca - Initial version
   (1 ) Now references LSOA in READ_AEROSOL_MENU (bmy, 9/28/04)
   (2 ) Fixed error checks and assign LSPLIT for tagged Hg.  Also now
        refernces LAVHRRLAI from "logical_mod.f" (eck, bmy, 12/20/04)
   (3 ) Updated for crystalline/aqueous aerosol tracers.  Also moved routine
        IS_LAST_DAY_GOOD here from "main.f".  Also now references
        "ocean_mercury_mod.f".  Also now open the bpch file for output in
        READ_DIAGNOSTIC_MENU instead of in "main.f".  (cas, sas, bmy, 2/3/05)
   (4 ) Now references "diag03_mod.f" and "diag41_mod.f".  Fixed minor
        bugs.  Now references FILE_EXISTS from "file_mod.f".  Updated
        comments. (bmy, 3/28/05)
   (5 ) Now modified for GEOS-5 and GCAP met fields.  Also now set LSPLIT
        correctly for HCN/CH3CN simulation. (swu, xyp, bmy, 6/30/05)
   (6 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
   (7 ) Now read LMEGAN switch for MEGAN biogenics.  Now read variable
        DATA_DIR_1x1 for 1x1 emissions files, etc.  Now reference XNUMOL and
        XNUMOLAIR from "tracer_mod.f" (tmf, bmy, 10/25/05)
   (8 ) Now read LEMEP switch for EMEP emissions (bdf, bmy, 11/1/05)
   (9 ) Now added MERCURY MENU section.  Also fixed bug in READ_ND48_MENU.
        (eck, cdh, bmy, 3/6/06)
   (10) Now read LGFED2BB switch for GFED2 biomass emissions (bmy, 4/5/06)
```

```
(11) Bug fix for GCAP in IS_LAST_DAY_GOOD.  Also now read LCTH, LMFLUX,
     LPRECON in READ_EMISSIONS_MENU. (bmy, 5/10/06)
(12) Updated for ND42 SOA concentration diagnostic (dkh, bmy, 5/22/06)
(13) Modified for future emissions (swu, bmy, 6/1/06)
(14) Modified for BRAVO emissions (rjp, kfb, bmy, 6/26/06)
(15) Remove support for GEOS-1 and GEOS-STRAT met fields.  Also modified
     for David Streets' emissions. (bmy, 8/17/06)
(16) Modified for variable tropopause.  Also set dimension of ND28 diag
     for GFED2 or default biomass burning.  Now read if Time Spent in
     Troposphere is wanted (phs, bmy, 10/17/06)
(17) Now modified for OTD-LIS local redistribution.  Remove references
     to GEOS-1 and GEOS-STRAT run dirs. (bmy, 11/5/07)
(18) New error traps for OTD-LIS scaling, dependent on met field type.
     Bug fix, create string variables for ERROR_STOP.  Bug fix: use ND52
     in call to SET_TINDEX in READ_DIAGNOSTIC_MENU. (ltm, bmy, 2/11/08)
(19) Bug fix: use (0,0) in call to INIT_TRANSFER (phs, 6/17/08)
(20) Minor fix in READ_TRANSPORT_MENU (cdh, bmy, 7/7/08)
(21) Fixed typo READ_EMISSIONS_MENU for GEOS-3 (bmy, 10/30/08)
(22) Set upper limit on dynamic timestep for 0.5 x 0.666 nested
     grids (yxw, bmy, dan, 11/6/08)
(23) Now read LCAC switch for CAC emissions (amv, 1/09/2008)
(24) Move the call to NDXX_SETUP (phs, 11/18/08)
(25) Minor bug fix in READ_DIAGNOSTIC_MENU (tmf, 2/10/09)
(26) Add LMEGANMONO switch in emission menu (ccc, 3/2/09)
(27) Add LDICARB switch in aerosol menu (ccc, tmf, 3/10/09)
(28) Now read LCOOKE in aerosol menu (phs, 5/18/09)
(29) Add CH4_MENU in input.geos (kjw, 8/18/09)
(30) Corrected typos in CHECK_TIME_STEPS (bmy, 8/21/09)
(31) Now read LLINOZ in READ_SIMULATION_MENU (dbm, bmy, 10/16/09)
(32) Remove reference to obsolete embedded chemistry stuff (bmy, 2/25/10)
(33) Remove depreciated lightning options (ltm, bmy, 1/24/11)
25 Aug 2010 - R. Yantosca - Added modifications for MERRA
27 Aug 2010 - R. Yantosca - Added ProTeX headers
16 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
29 Jul 2011 - R. Yantosca - Bug fix in READ_EMISSIONS_MENU for nested NA
07 Sep 2011 - P. Kasibhatla - Modified to include monthly GFED3
17 Jan 2012 - P. Kasibhatla - Modified to include daily and 3-hourly GFED3
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x met data
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
30 Jul 2012 - R. Yantosca - READ_INPUT_FILE now accepts am_I_Root from
                            both the ESMF interface and main.F
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
03 Aug 2012 - R. Yantosca - Now make IU_GEOS a global module variable
                            so that we can define it with findFreeLun
02 Nov 2012 - R. Yantosca - Now pass the Input Options object to routines;
                            this will eventually replace logical_mod, etc.
26 Feb 2013 - M. Long     - Now make INITIALIZE_GEOS_GRID a public routine
```

```
04 Mar 2013 - R. Yantosca - Add routine GIGC_Init_Extra to move some init
                            calls out of the run stage when using ESMF
23 Apr 2013 - R. Yantosca - For TOMAS, rename READ_MICROPHYSICS_MENU to
                            INIT_TOMAS_MICROPHYSICS
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Sep 2013 - R. Yantosca - Increase MAXDIM from 255 to 500 for more tracers
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP everywhere
26 Sep 2013 - R. Yantosca - Now read GEOS_FP_DIR from Input_Opt everywhere
23 Jun 2014 - R. Yantosca - Remove references to logical_mod.F
23 Jun 2014 - R. Yantosca - Removed INIT_INPUT routine
14 Nov 2014 - M. Yannetti - Added PRECISION_MOD
24 Nov 2014 - C. Keller   - Updates on timestep handling in ESMF environment
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
28 Jul 2016 - M. Sulprizio- Rename subroutine READ_TRACER_MENU to
                            READ_ADVECTED_SPECIES_MENU
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

2.2.1 read_input_file

Subroutine READ_INPUT_FILE is the driver program for reading the GEOS-Chem input file "input.geos" from disk.

In an ESMF environment, all time steps (chemistry, convection, emissions, dynamics) must be specified externally before calling this routine. This is done in routine GIGC_Init_Simulation (gigc_initialization_mod.F90). The time steps specified in input.geos are ignored.

INTERFACE:

```
SUBROUTINE READ_INPUT_FILE( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE CHARPAK_MOD,        ONLY : STRREPL
USE ErrCode_Mod
USE FILE_MOD,           ONLY : IOERROR
USE GAMAP_MOD,          ONLY : DO_GAMAP
USE Input_Opt_Mod,      ONLY : OptInput
USE SEASALT_MOD,        ONLY : INIT_SEASALT
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now call DO_GAMAP from "gamap_mod.f" to create "diaginfo.dat" and
     "tracerinfo.dat" files after all diagnostic menus have been read in
(2 ) Now call NDXX_setup from this routine (phs, 11/18/08)
(3 ) Now call READ_ND51b_MENU (amv, bmy, 12/18/09)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root from main.F, so that we
                            can get rid of duplicate code in DEVEL blocks
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
03 Aug 2012 - R. Yantosca - Now make IU_GEOS a global module variable
                            so that we can define it with findFreeLun
15 Oct 2012 - R. Yantosca - Add EXTERNAL_GRID, XTERNAL_FORCING to #ifdef
16 Oct 2012 - R. Yantosca - Don't call CHECK_TIME_STEPS if we are calling
                            READ_INPUT_FILE from the ESMF interface
09 Nov 2012 - R. Yantosca - Now pass Input_Opt to lower-level routines
06 Dec 2012 - R. Yantosca - Now call CHECK_TIME_STEPS when we are connecting
                            to the GEOS-5 GCM via the ESMF environment,
19 Mar 2013 - R. Yantosca - When using ESMF interface to GEOS-5, append
                            ".rc" to input.geos (instead of ___.rc)
04 Apr 2013 - R. Yantosca - Now pass objects to DO_GAMAP routine
23 Jun 2014 - R. Yantosca - Now do not call INIT_INPUT, this is replaced
                            by the INIT_GIGC_INPUT_OPT routine
15 Apr 2015 - R. Yantosca - Also define Input_Opt%ITS_A_NESTED_GRID here
                            so that we can pass it to INITIALIZE_GEOS_GRID
04 Aug 2015 - M. Long     - Removed ".rc" file specifier. Not necessary.
16 Dec 2015 - R. Yantosca - Now pass State_Chm to READ_TRACER_MENU
04 Sep 2015 - C. Keller   - Added passive tracer menu
16 Jun 2016 - E. Lundgren - Move TOMAS init to GIGC_INIT_EXTRA
```

2.2.2 read_one_line

Subroutine READ_ONE_LINE reads a line from the input file. If the global variable VERBOSE is set, the line will be printed to stdout. READ_ONE_LINE can trap an unexpected EOF if LOCATION is passed. Otherwise, it will pass a logical flag back to the calling routine, where the error trapping will be done.

INTERFACE:

```
FUNCTION READ_ONE_LINE( EOF, LOCATION ) RESULT( LINE )
```

USES:

```
USE FILE_MOD, ONLY : IOERROR
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN), OPTIONAL :: LOCATION    ! Msg to display
```

OUTPUT PARAMETERS:

```
LOGICAL,          INTENT(OUT)          :: EOF         ! Denotes EOF
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
03 Aug 2012 - R. Yantosca - Now make IU_GEOS a global module variable
                            so that we can define it with findFreeLun
17 Sep 2013 - R. Yantosca - Extend line length to read in more tracers
```

2.2.3 split_one_line

Subroutine SPLIT_ONE_LINE reads a line from the input file (via routine READ_ONE_LINE), and separates it into substrings.

SPLIT_ONE_LINE also checks to see if the number of substrings found is equal to the number of substrings that we expected to find. However, if you don't know a-priori how many substrings to expect a-priori, you can skip the error check.

INTERFACE:

```
SUBROUTINE SPLIT_ONE_LINE( SUBSTRS, N_SUBSTRS, N_EXP, LOCATION )
```

USES:

```
USE CHARPAK_MOD, ONLY: STRSPLIT
```

INPUT PARAMETERS:

```
! Number of substrings we expect to find
INTEGER,            INTENT(IN)  :: N_EXP

! Name of routine that called SPLIT_ONE_LINE
CHARACTER(LEN=*),   INTENT(IN)  :: LOCATION
```

OUTPUT PARAMETERS:

```
! Array of substrings (separated by " ")
CHARACTER(LEN=255), INTENT(OUT) :: SUBSTRS(MAXDIM)

! Number of substrings actually found
INTEGER,            INTENT(OUT) :: N_SUBSTRS
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
17 Sep 2013 - R. Yantosca - Extend LINE to 500 chars to allow more tracers
```

2.2.4 read_simulation_menu

Subroutine READ_SIMULATION_MENU reads the SIMULATION MENU section of the GEOS-Chem input file.

INTERFACE:

```
      SUBROUTINE READ_SIMULATION_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE GC_GRID_MOD,        ONLY : SET_XOFFSET, SET_YOFFSET
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_BEGIN_TIME,   SET_END_TIME
      USE TIME_MOD,           ONLY : SET_CURRENT_TIME, SET_DIAGb
      USE TIME_MOD,           ONLY : SET_NDIAGTIME,    GET_TAU
      USE TRANSFER_MOD,       ONLY : INIT_TRANSFER
#if defined( EXTERNAL_GRID ) || defined( EXTERNAL_FORCING )
      USE TIME_MOD,           ONLY : Accept_External_Date_Time
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Bug fix: Read LSVGLB w/ the * format and not w/ '(a)'. (bmy, 2/23/05)
(2 ) Now read GEOS_5_DIR and GCAP_DIR from input.geos (swu, bmy, 5/25/05)
(3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4 ) Now references DATA_DIR_1x1 for 1x1 emissions files (bmy, 10/24/05)
(5 ) Now read switch for using variable tropopause or not (phs, 9/14/06)
(6 ) Remove references to GEOS-1 and GEOS-STRAT run dirs.  Now calls
```

```
      INIT_TRANSFER (bmy, 11/5/07)
(7 ) Fix typo in "print to screen" section  (phs, 6/1/08)
(8 ) Call INIT_TRANSFER w/ (0,0) instead of (I0,J0) (phs, 6/17/08)
(10) Now read LLINOZ switch from input.geos file (dbm, bmy, 10/16/09)
13 Aug 2010 - R. Yantosca - Now read MERRA_DIR
19 Aug 2010 - R. Yantosca - Set LUNZIP=F for MERRA met fields.
27 Aug 2010 - R. Yantosca - Added ProTeX headers
01 Feb 2012 - R. Yantosca - Now read GEOS_57_DIR for GEOS-5.7.x met
08 Feb 2012 - R. Yantosca - Set LUNZIP=F for GEOS-5.7.x met fields
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now call routine INITIALIZE_GEOS_GRID to
                            initialize horizontal grid parameters
10 Jun 2012 - L. Murray   - Move Linoz to chemistry menu
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
06 Dec 2012 - R. Yantosca - Now get NYMDb, NHMSb, NYMDe, NHMSe from the ESMF
                            environment when connecting to the GEOS-5 GCM
11 Dec 2012 - R. Yantosca - ACCEPT_DATE_TIME_FROM_ESMF has now been renamed
                            to ACCEPT_EXTERNAL_DATE_TIME
19 May 2014 - C. Keller   - Now read HEMCO configuration file.
23 Jun 2014 - R. Yantosca - Remove references to logical_mod.F
12 Aug 2015 - R. Yantosca - Add support for MERRA2
12 Aug 2015 - R. Yantosca - Add support for 05x0625 grids
13 Aug 2015 - R. Yantosca - Bug fix: prefix RES_DIR in front of MERRA2_DIR
27 Jul 2016 - M. Sulprizio- Remove LSVGLB and OUT_RST_FILE options. Restart
                            files are now always saved out and the output
                            restart file name is hardcoded in restart_mod.F.
09 Aug 2016 - E. Lundgren - Remove call to routine set_restart; use input
                            rst filename directly in restart_mod.F.
```

2.2.5 initialize_geos_grid

Subroutine INITIALIZE_GEOS_GRID calls routines from grid_mod.F90 to initialize the horizontal grid parameters.

INTERFACE:

```
SUBROUTINE INITIALIZE_GEOS_GRID( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD,        ONLY : COMPUTE_GRID
USE GC_GRID_MOD,        ONLY : INIT_GRID
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
The module grid_mod.F90 has been modified to save grid parameters in 3D
format, which will facilitate interfacing GEOS-Chem to a GCM.

.

The module global_grid_mod.F90 contains several of the global grid arrays
(*_g) originally in grid_mod.F. These arrays are used in regridding GFED3
biomass emissions, which are available on a 0.5x0.5 global grid. The global
arrays may need to be used in the future for regridding other emissions for
nested grids.

.
```

REVISION HISTORY:

```
01 Mar 2012 - R. Yantosca - Initial version
01 May 2012 - M. Payer    - Add call to COMPUTE_GLOBAL_GRID for nested grids
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
30 Nov 2012 - R. Yantosca - Accept external DLON, DLAT from ESMF interface
26 Feb 2013 - R. Yantosca - Now pass I_LO, J_LO to COMPUTE_GRID
28 Feb 2013 - R. Yantosca - Bug fix for GEOS-5 interface: Now call
                            Compute_Grid with 1..IIPAR, I..JJPAR
01 Jul 2013 - R. Yantosca - Don't use 1/2 sized polar boxes for GCAP
25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
23 Jul 2014 - R. Yantosca - Remove reference to obsolete global_grid_mod
```

2.2.6 read_advected_species_menu

Subroutine READ_ADVECTED_SPECIES_MENU reads the ADVECTED SPECIES MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ADVECTED_SPECIES_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CHARPAK_MOD,        ONLY : ISDIGIT
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now set LSPLIT correctly for Tagged Hg simulation (eck, bmy, 12/13/04)
(2 ) Now initialize ocean mercury module (sas, bmy, 1/20/05)
(3 ) Now set LSPLIT correctly for Tagged HCN/CH3CN sim (xyp, bmy, 6/30/05)
(4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(5 ) Now reference XNUMOLAIR from "tracer_mod.f" (bmy, 10/25/05)
(6 ) Now move call to INIT_OCEAN_MERCURY to READ_MERCURY_MENU (bmy, 2/24/06)
(7 ) Now do not call SET_BIOTRCE anymore; it's obsolete (bmy, 4/5/06)
(8 ) Add SET_BIOTRCE to initialize IDBxxxs. (fp, 2/26/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2012 - R. Yantosca - Now pass CHEM_STATE as an argument (DEVEL only)
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
07 Nov 2012 - R. Yantosca - Now define Input_Opt%ITS_A_*_SIM fields
28 Oct 2013 - R. Yantosca - Set Input_Opt%ITS_A_SPECIALTY_SIM = .FALSE.
                            when running GEOS-Chem in an ESMF environment
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
21 Aug 2014 - R. Yantosca - Bug fix: add ITS_A_RnPbBe_SIM to the test
                            that defines the ITS_A_SPECIALTY_SIM flag
24 Mar 2015 - E. Lundgren - Move init_tracer to within APM ifdef block
23 Jun 2016 - R. Yantosca - Remove call to TRACERID, it's obsolete
28 Jul 2016 - M. Sulprizio- Rename TRACER MENU to ADVECTED SPECIES MENU;
                            Remove ID, MW, and member columns from menu
```

2.2.7 read_aerosol_menu

Subroutine READ_AEROSOL_MENU reads the AEROSOL MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_AEROSOL_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE UCX_MOD,            ONLY : T_NAT_SUPERCOOL, P_ICE_SUPERSAT
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
    Move error checks that depend on species indices to the subroutine
    DO_ERROR_CHECKS.  This is now called from GC_INIT_EXTRA, after the
    initialization of the species database.
```

REVISION HISTORY:

```
    20 Jul 2004 - R. Yantosca - Initial version
    (1 ) Now reference LSOA (bmy, 9/28/04)
    (2 ) Now stop run if LSOA=T and SOA tracers are undefined (bmy, 11/19/04)
    (3 ) Now reference LCRYST from "logical_mod.f".  Also now check to make
         prevent aerosol tracers from being undefined if the corresponding
         logical switch is set. (cas, bmy, 1/14/05)
    (4 ) Now also require LSSALT=T when LSULF=T, since we now compute the
         production of SO4 and NIT w/in the seasalt aerosol (bec, bmy, 4/13/05)
    (5 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (6 ) Now update error check for SOG4, SOA4 (dkh, bmy, 6/1/06)
    (7 ) Add LDICARB switch to cancel SOG condensation onto OC aerosols.
        (ccc, tmf, 3/10/09)
    27 Aug 2010 - R. Yantosca - Added ProTeX headers
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
    11 Apr 2013 - S.D. Eastham- Added gravitational settling flag
    13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                                semivolatile POA simulations (H. Pye)
    12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                                aerosols (T.D. Fairlie)
    16 Apr 2014 - M. Sulprizio- Now read path for PSC restart file
    23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
    25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
    09 Apr 2015 - M. Sulprizio- Removed options for DEAD dust emissions, NAP
                                emissions, POA emissions scale, and the PSC
```

```
                              restart file. These options are now handled
                              by HEMCO.
  08 Jul 2015 - E. Lundgren - Added LMPOA option for marine organic aerosols
  16 Jun 2016 - K. Travis   - Now define species ID's with the Ind_ function
  22 Jun 2016 - R. Yantosca - Move error checks to DO_ERROR_CHECKS routine
------------------------------------------------------------------------------
BOC
```

LOCAL VARIABLES:

```
      ! Scalars
      LOGICAL            :: LSULF,      LCARB,      LBRC,  LSOA
      LOGICAL            :: LSVPOA,     LDUST,      LDSTUP
      LOGICAL            :: LSSALT,     LCRYST,     LDICARB
      LOGICAL            :: LGRAVSTRAT, LHOMNUCNAT, LSOLIDPSC
      LOGICAL            :: LPSCCHEM,   LSTRATOD,   LMPOA
      INTEGER            :: N,          T,          I
      CHARACTER(LEN=255) :: MSG,        LOCATION

      ! Arrays
      CHARACTER(LEN=255) :: SUBSTRS(MAXDIM)

      !=================================================================
      ! READ_AEROSOL_MENU begins here!
      !=================================================================

      ! Location string for ERROR_STOP
      LOCATION = 'READ_AEROSOL_MENU ("input_mod.f")'

      ! Error check
      IF ( CT1 /= 2 ) THEN
         MSG = 'SIMULATION MENU & ADVECTED SPECIES MENU ' //
     &         'must be read in first!'
         CALL ERROR_STOP( MSG, LOCATION )
      ENDIF

      ! Use online sulfate aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:1' )
      READ( SUBSTRS(1:N), * ) LSULF

      ! Use crystalline sulfate aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:2' )
      READ( SUBSTRS(1:N), * ) LCRYST

      ! Use online carbon aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:3' )
      READ( SUBSTRS(1:N), * ) LCARB

      ! Use brown carbon aerosols?
```

```
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:4' )
      READ( SUBSTRS(1:N), * ) LBRC

      ! Use secondary organic aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:5' )
      READ( SUBSTRS(1:N), * ) LSOA

      ! SOAupdate: Add Semi-volatile POA switch (hotp 8/9/09)
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:6' )
      READ( SUBSTRS(1:N), * ) LSVPOA

      ! Use online dust aerosols ?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:7' )
      READ( SUBSTRS(1:N), * ) LDUST

      !tdf
      ! Use SO2 and HNO3 uptake on dust aerosols
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:9.5' )
      READ( SUBSTRS(1:N), * ) LDSTUP

      ! Use online sea-salt aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:8' )
      READ( SUBSTRS(1:N), * ) LSSALT

      ! Accum mode seasalt radii bin edges [um]
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 2, 'read_aerosol_menu:9' )
      DO T = 1, N
         READ( SUBSTRS(T), * ) Input_Opt%SALA_REDGE_um(T)
      ENDDO

      ! Coarse mode seasalt radii bin edges [um]
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 2, 'read_aerosol_menu:10' )
      DO T = 1, N
         READ( SUBSTRS(T), * ) Input_Opt%SALC_REDGE_um(T)
      ENDDO

      ! Use marine organic aerosols?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:11' )
      READ( SUBSTRS(1:N), * ) LMPOA

      ! Switch to comment the SOG condensation in carbon_mod.f (ccc, 3/10/09)
      ! Use online dicarbonyl chemistry
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:12' )
      READ( SUBSTRS(1:N), * ) LDICARB

      ! Apply gravitational settling in stratosphere?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:13' )
      READ( SUBSTRS(1:N), * ) LGRAVSTRAT
```

```
      ! Use solid polar stratospheric clouds (PSCs)?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:14' )
      READ( SUBSTRS(1:N), * ) LSOLIDPSC

      ! Allow homogeneous nucleation of NAT?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:15' )
      READ( SUBSTRS(1:N), * ) LHOMNUCNAT

      ! NAT supercooling requirement (K)
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:16' )
      READ( SUBSTRS(1:N), * ) T_NAT_SUPERCOOL

      ! Ice supersaturation ratio requirement
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:17' )
      READ( SUBSTRS(1:N), * ) P_ICE_SUPERSAT

      ! Perform PSC-related heterogeneous chemistry?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:18' )
      READ( SUBSTRS(1:N), * ) LPSCCHEM

      ! Include stratospheric aerosols optical depths?
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:19' )
      READ( SUBSTRS(1:N), * ) LSTRATOD

      ! Separator line
      CALL SPLIT_ONE_LINE( SUBSTRS, N, 1, 'read_aerosol_menu:20' )

      !=================================================================
      ! Error checks
      !=================================================================

      ! Make sure that SALA, SALC bins are contiguous
      IF ( Input_Opt%SALA_REDGE_um(2) /=
     &     Input_Opt%SALC_REDGE_um(1)     ) THEN
         MSG = 'SALA and SALC bin edges are not contiguous!'
         CALL ERROR_STOP( MSG, LOCATION )
      ENDIF

      ! Turn off switches for simulations that don't use aerosols
      IF ( ( .not. Input_Opt%ITS_A_FULLCHEM_SIM )  .and.
     &     ( .not. Input_OPt%ITS_AN_AEROSOL_SIM ) ) THEN
         LSULF  = .FALSE.
         LCRYST = .FALSE.
         LCARB  = .FALSE.
         LBRC   = .FALSE.
         LSOA   = .FALSE.
         LDUST  = .FALSE.
```

```
      LSSALT = .FALSE.
      LMPOA  = .FALSE.
      LSVPOA = .FALSE.
   ENDIF

   !%%% The cryst/aq code is currently under development so make
   !%%% sure that LCRYST = FALSE for now until further notice
   !%%% (rjp, bmy, 3/15/05)
   LCRYST = .FALSE.

   !=================================================================
   ! Set fields of Input Options object
   !=================================================================
   Input_Opt%LSULF              = LSULF
   Input_Opt%LCRYST             = LCRYST
   Input_Opt%LCARB              = LCARB
   Input_Opt%LBRC               = LBRC
   Input_Opt%LSOA               = LSOA
   Input_Opt%LSVPOA             = LSVPOA
   Input_Opt%LDUST              = LDUST
   Input_Opt%LDSTUP             = LDSTUP
   Input_Opt%LSSALT             = LSSALT
   Input_Opt%LMPOA              = LMPOA
   Input_Opt%LDICARB            = LDICARB
   Input_Opt%LGRAVSTRAT         = LGRAVSTRAT
   Input_Opt%LSOLIDPSC          = LSOLIDPSC
   Input_Opt%LHOMNUCNAT         = LHOMNUCNAT
   Input_Opt%T_NAT_SUPERCOOL    = T_NAT_SUPERCOOL
   Input_Opt%P_ICE_SUPERSAT     = P_ICE_SUPERSAT
   Input_Opt%LPSCCHEM           = LPSCCHEM
   Input_Opt%LSTRATOD           = LSTRATOD

   ! Return success
   RC = GC_SUCCESS

   !=================================================================
   ! Print to screen
   !=================================================================
   IF ( am_I_Root ) THEN
      WRITE( 6, '(/,a)' ) 'AEROSOL MENU'
      WRITE( 6, '(  a)' ) '------------'
      WRITE( 6, 100     ) 'Online SULFATE AEROSOLS?    : ', LSULF
      WRITE( 6, 100     ) 'Online CRYST & AQ AEROSOLS? : ', LCRYST
      WRITE( 6, 100     ) 'Online CARBON AEROSOLS?     : ', LCARB
      WRITE( 6, 100     ) 'Brown Carbon Aerosol?       : ', LBRC
      WRITE( 6, 100     ) 'Online 2dy ORGANIC AEROSOLS?: ', LSOA
      WRITE( 6, 100     ) 'Semivolatile POA?           : ', LSVPOA
      WRITE( 6, 100     ) 'Online DUST AEROSOLS?       : ', LDUST
```

```
          WRITE( 6, 100     ) 'Acid uptake on dust?        : ', LDSTUP

          WRITE( 6, 100     ) 'Online SEA SALT AEROSOLS?   : ', LSSALT
          WRITE( 6, 110     ) 'Accum  SEA SALT radii [um]  : ',
     &                         Input_Opt%SALA_REDGE_um(1),
     &                         Input_Opt%SALA_REDGE_um(2)
          WRITE( 6, 110     ) 'Coarse SEA SALT radii [um]  : ',
     &                         Input_Opt%SALC_REDGE_um(1),
     &                         Input_Opt%SALC_REDGE_um(2)
          WRITE( 6, 100     ) 'MARINE ORGANIC AEROSOLS?    : ', LMPOA
          WRITE( 6, 100     ) 'Settle strat. aerosols?     : ',LGRAVSTRAT
          WRITE( 6, 100     ) 'Online SOLID PSC aerosols?  : ',LSOLIDPSC
          WRITE( 6, 100     ) 'Allow hom. NAT nucleation?  : ',LHOMNUCNAT
          WRITE( 6, 120     ) 'NAT supercooling requirement: ',
     &                                                 T_NAT_SUPERCOOL
          WRITE( 6, 120     ) 'Ice supersaturation req.    : ',
     &                                    ((P_ICE_SUPERSAT-1)*1.e+2_fp)
          WRITE( 6, 100     ) 'Perform PSC het. chemistry? : ',LPSCCHEM
          WRITE( 6, 100     ) 'Use strat. aerosol OD?      : ', LSTRATOD
       ENDIF

  100  FORMAT( A, L5     )
  110  FORMAT( A, f6.2, ' - ', f6.2 )
  120  FORMAT( A, f6.2, 'K' )
  105  FORMAT( A, f6.2 )
  130  FORMAT( A, A   )

       END SUBROUTINE READ_AEROSOL_MENU
  EOC
 #if defined( TOMAS )
  ------------------------------------------------------------------------------
                   GEOS-Chem Global Chemical Transport Model                  !
  ------------------------------------------------------------------------------
%//////////////////////////////////////////////////////////

\mbox{}\hrulefill\


  \subsubsection [init\_tomas\_microphys] {init\_tomas\_microphys}


  Subroutine INIT\_TOMAS\_MICROPHYS will initialize the
    TOMAS microphysics package.  This replaces the former subroutine
    READ\_MICROPHYSICS\_MENU.
  \\
  \\{\bf INTERFACE:}
\begin{verbatim}       SUBROUTINE INIT_TOMAS_MICROPHYSICS( am_I_Root, Input_Opt,
     &                                    State_Chm, RC )
```

USES:

```
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE TOMAS_MOD,          ONLY : INIT_TOMAS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry state
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

We now invoke TOMAS by compiling GEOS-Chem and setting either the TOMAS=yes (30 bins, default) or TOMAS40=yes (40 bins, optional) switches. The old LTOMAS logical switch is now obsolete because all of the TOMAS code is segregated from the rest of GEOS-Chem with #ifdef blocks. Therefore, we no longer need to read the microphysics menu, but we still need to apply some error checks and then call INIT_TOMAS. (bmy, 4/23/13)

The Ind_() function now defines all species ID's. It returns -1 if a species cannot be found. The prior behavior was to return 0 if a species wasn't found. Therefore, in order to preserve the logic of the error checks, we must force any -1's returned by Ind_() to 0's in this subroutine.

REVISION HISTORY:

20 Jul 2004 - R. Yantosca - Initial version
(1) Now read LNEI99 -- switch for EPA/NEI99 emissions (bmy, 11/5/04)
(2) Now read LAVHRRLAI-switch for using AVHRR-derived LAI (bmy, 12/20/04)
(3) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4) Now read LMEGAN -- switch for MEGAN biogenics (tmf, bmy, 10/20/05)
(5) Now read LEMEP -- switch for EMEP emissions (bdf, bmy, 11/1/05)
(6) Now read LGFED2BB -- switch for GFED2 biomass emissions (bmy, 4/5/06)
(7) Now read LOTDLIS, LCTH, LMFLUX, LPRECON for lightning options
(bmy, 5/10/06)
(8) Now read LBRAVO for BRAVO Mexican emissions (rjp, kfb, bmy, 6/26/06)
(9) Now read LEDGAR for EDGAR emissions (avd, bmy, 7/11/06)
(10) Now read LSTREETS for David Streets' emissions (bmy, 8/17/06)
(11) Kludge: Reset LMFLUX or LPRECON to LCTH, as the MFLUX and PRECON

```
      lightning schemes have not yet been implemented.  Rename LOTDLIS
      to LOTDREG.  Also read LOTDLOC for the OTD-LIS local redistribution
      of lightning flashes (cf B. Sauvage).  Make sure LOTDREG and
      LOTDLOC are not both turned on at the same time. (bmy, 1/31/07)
(12) Add LOTDSCALE to the list of LNOx options (ltm, bmy, 9/24/07)
(13) Add new error traps for OTD-LIS options, dependent on met field type
      (ltm, bmy, 11/29/07)
(14) Bug fix, create string variables for ERROR_STOP (bmy, 1/24/08)
(15) Now read LCAC for CAC emissions (amv, 1/09/2008)
(16) Now read LEDGARSHIP, LARCSHIP and LEMEPSHIP (phs, 12/5/08)
(17) Fixed typo in message for GEOS-3 (bmy, 10/30/08)
(18) Now read LVISTAS (amv, 12/2/08)
(19) Now read L8DAYBB, L3HRBB and LSYNOPBB for GFED2 8-days and 3hr
      emissions, and LICARTT for corrected EPA (phs, yc, 12/17/08)
(20) Add a specific switch for MEGAN emissions for monoterpenes and MBO
     (ccc, 2/2/09)
(21) Now read LICOADSSHIP (cklee, 6/30/09)
(22) Bug fix: for now, if LEMEPSHIP is turned on but LEMEP is turned off,
      just turn off LEMEPSHIP and print a warning msg. (mak, bmy, 10/18/09)
(23) Now accounts for NEI2005 (amv, phs, 10/9/09)
(24) Included optional flag for using MODIS LAI data (mpb,2009).
(25) Included optional flag for using PCEEA model (mpb, 2009)
(26) Now force settings for EU, NA, CC nested grids (amv, bmy, 12/18/09)
(27) Now force MEGAN to use MODIS LAI (ccarouge, bmy, 2/24/10)
(28) Add separate switch for NOx fertilizer. (fp, 2/29/10)
(29) Add scaling for isoprene and NOx emissions. (fp, 2/29/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
23 Apr 2013 - R. Yantosca - Renamed to INIT_TOMAS_MICROPHYS
30 Jan 2014 - R. Yantosca - INIT_TOMAS accepts am_I_Root, Input_Opt, RC
16 Jun 2016 - K. Travis   - Now define species ID's with the Ind_ function
16 Jun 2016 - E. Lundgren - INIT_TOMAS now accepts State_Chm
22 Jun 2016 - R. Yantosca - Force -1's returned by Ind_() to zeroes,
                            in order to preserve the program logic
```

2.2.8 read_emissions_menu

Subroutine READ_EMISSIONS_MENU reads the EMISSIONS MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_EMISSIONS_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_O3_MOD
```

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_HISTYR
      USE UCX_MOD,            ONLY : CFCYEAR
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
    The Ind_() function now defines all species ID's.  It returns -1 if
    a species cannot be found.  Therefore now test for Ind_() > 0  for a
    valid species.
```

REVISION HISTORY:

```
    20 Jul 2004 - R. Yantosca - Initial version
    (1 ) Now read LNEI99 -- switch for EPA/NEI99 emissions (bmy, 11/5/04)
    (2 ) Now read LAVHRRLAI-switch for using AVHRR-derived LAI (bmy, 12/20/04)
    (3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (4 ) Now read LMEGAN -- switch for MEGAN biogenics (tmf, bmy, 10/20/05)
    (5 ) Now read LEMEP -- switch for EMEP emissions (bdf, bmy, 11/1/05)
    (6 ) Now read LGFED2BB -- switch for GFED2 biomass emissions (bmy, 4/5/06)
    (7 ) Now read LOTDLIS, LCTH, LMFLUX, LPRECON for lightning options
         (bmy, 5/10/06)
    (8 ) Now read LBRAVO for BRAVO Mexican emissions (rjp, kfb, bmy, 6/26/06)
    (9 ) Now read LEDGAR for EDGAR emissions (avd, bmy, 7/11/06)
    (10) Now read LSTREETS for David Streets' emissions (bmy, 8/17/06)
    (11) Kludge: Reset LMFLUX or LPRECON to LCTH, as the MFLUX and PRECON
         lightning schemes have not yet been implemented.  Rename LOTDLIS
         to LOTDREG.  Also read LOTDLOC for the OTD-LIS local redistribution
         of lightning flashes (cf B. Sauvage).  Make sure LOTDREG and
         LOTDLOC are not both turned on at the same time. (bmy, 1/31/07)
    (12) Add LOTDSCALE to the list of LNOx options (ltm, bmy, 9/24/07)
    (13) Add new error traps for OTD-LIS options, dependent on met field type
         (ltm, bmy, 11/29/07)
    (14) Bug fix, create string variables for ERROR_STOP (bmy, 1/24/08)
    (15) Now read LCAC for CAC emissions (amv, 1/09/2008)
    (16) Now read LEDGARSHIP, LARCSHIP and LEMEPSHIP (phs, 12/5/08)
    (17) Fixed typo in message for GEOS-3 (bmy, 10/30/08)
```

```
(18) Now read LVISTAS (amv, 12/2/08)
(19) Now read L8DAYBB, L3HRBB and LSYNOPBB for GFED2 8-days and 3hr
      emissions, and LICARTT for corrected EPA (phs, yc, 12/17/08)
(20) Add a specific switch for MEGAN emissions for monoterpenes and MBO
     (ccc, 2/2/09)
(21) Now read LICOADSSHIP (cklee, 6/30/09)
(22) Bug fix: for now, if LEMEPSHIP is turned on but LEMEP is turned off,
      just turn off LEMEPSHIP and print a warning msg. (mak, bmy, 10/18/09)
(23) Now accounts for NEI2005 (amv, phs, 10/9/09)
(24) Included optional flag for using MODIS LAI data (mpb,2009).
(25) Included optional flag for using PCEEA model (mpb, 2009)
(26) Now force settings for EU, NA, CC nested grids (amv, bmy, 12/18/09)
(27) Now force MEGAN to use MODIS LAI (ccarouge, bmy, 2/24/10)
(28) Add separate switch for NOx fertilizer. (fp, 2/29/10)
(29) Add scaling for isoprene and NOx emissions. (fp, 2/29/10)
(30) Remove depreciated lightning options. (ltm, 1/25,11)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
27 Aug 2010 - R. Yantosca - Added warning msg for MERRA
29 Jul 2011 - L. Zhang    - Fix bug that turns off CAC/BRAVO emissions
                            inadvertently during nested NA simulations
11 Aug 2011 - E. Leibensperger - Added flag for historical emissions and
                                 base year
07 Sep 2011 - P. Kasibhatla - Add modifications for GFED3
14 Feb 2012 - R. Yantosca - Reorganize error checks for logical switches
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
05 Apr 2012 - R. Yantosca - Now call INIT_MODIS_LAI
05 Apr 2012 - R. Yantosca - Reorganized USE statements for clarity
10 Apr 2012 - R. Yantosca - Bug fix: do not turn off LAVHRRLAI or LMODISLAI
                            when emissions are turned off.  LAI is used
                            in other areas of the code.
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
22 Jul 2013 - M. Sulprizio- Now copy LRCP, LRCPSHIP, LRCPAIR to Input_Opt
31 Jul 2013 - M. Sulprizio- Now copy LAEIC to Input_Opt; Add check to
                            make sure LAEIC and LRCPAIR are not both on
22 Aug 2013 - R. Yantosca - Now read path for soil NOx restart file
26 Sep 2013 - R. Yantosca - Remove SEAC4RS C-preprocessor switch
03 Oct 2013 - M. Sulprizio- Removed obsolete options for LAVHRRLAI and
                            LMODISLAI. MODIS LAI data are now read from
                            netCDF files.
03 Jun 2014 - R. Yantosca - Radically simplify this routine since most
                            emissions options are now specified in HEMCO
23 Jun 2014 - R. Yantosca - Remove reference to logical_mod.F
25 Jun 2014 - R. Yantosca - Move call to INIT_MODIS_LAIT to GIGC_INIT_EXTRA
04 Sep 2014 - R. Yantosca - Bug fix: Now use Input_Opt%OTDLOC since we have
                            now removed logical_mod.F
24 Jun 2015 - R. Yantosca - Now always turn off emissions for mass cons test
```

```
16 Jun 2016 - K. Travis   - Now define species ID's with the Ind_ function
22 Jun 2016 - R. Yantosca - Move some error checks to DO_ERROR_CHECKS
20 Sep 2016 - R. Yantosca - Use "I4" format to read in CFCYEAR
```

2.2.9 read_co2_sim_menu

Subroutine READ_CO2_SIM_MENU reads the CO2 SIM MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_CO2_SIM_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_O3_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
02 Mar 2009 - R. Nassar   - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
07 Sep 2011 - P. Kasibhatla - Modified for GFED3
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
03 Jun 2014 - R. Yantosca - Now specify biomass, biofuel options in HEMCO
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
13 Apr 2015 - R. Nassar - Simplified CO2 menu since options are now in HEMCO
```

2.2.10 read_future_menu

Subroutine READ_FUTURE_MENU reads the FUTURE MENU section of the GEOS-Chem input file; this defines IPCC future emissions options.

INTERFACE:

```
SUBROUTINE READ_FUTURE_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE FUTURE_EMISSIONS_MOD, ONLY : DO_FUTURE_EMISSIONS
USE Input_Opt_Mod,        ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
01 Jun 2006 - S. Wu       - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
23 Jun 2014 - R. Yantosca - Removed reference to logical_mod.F
```

2.2.11 read_chemistry_menu

Subroutine READ_CHEMISTRY_MENU reads the CHEMISTRY MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_CHEMISTRY_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : SET_CT_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1) added optional test on KPPTRACER (phs, 6/17/09)
(2) Remove reference to obsolete embedded chemistry stuff in "CMN"
    (bmy, 2/25/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
10 Jun 2012 - L. Murray   - Move all strat chemistry switches here
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
06 Dec 2012 - R. Yantosca - Now get TS_CHEM from the ESMF environment
                            when we are connecting to the GEOS-5 GCM
11 Dec 2012 - R. Yantosca - ACCEPT_DATE_TIME_FROM_ESMF has now been renamed
                            to ACCEPT_EXTERNAL_DATE_TIME
22 May 2013 - M. Payer    - Now read in GAMMA_HO2. Recommended value is 0.2
                            based on Jacon et al (2000) and Mao et al (2013).
22 Aug 2013 - R. Yantosca - Now read in path for species restart file
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
27 Jul 2016 - M. Sulprizio- Remove LSVCSPEC and SPEC_RST_FILE. Restart files
                            are now always saved out and the output restart
                            file name is hardcoded in restart_mod.F.
```

2.2.12 read_radiation_menu

Subroutine READ_RADIATION_MENU reads the RADIATION MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_RADIATION_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_FJX_MOD              ! Fast-JX flux diagnostics
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : SET_CT_RAD
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
   18 Jun 2013 - D. Ridley   - Initial version
   03 Dec 2014 - M. Sulprizio- Now save fields to the Input_Opt object
   10 Dec 2014 - M. Sulprizio- Add error checks for RRTMG switches
```

2.2.13 read_transport_menu

Subroutine READ_TRANSPORT_MENU reads the TRANSPORT MENU section of the GEOS-Chem input file.

INTERFACE:

```
      SUBROUTINE READ_TRANSPORT_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
#if !defined( ESMF_ )
      USE TRANSPORT_MOD,      ONLY : SET_TRANSPORT
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now define MAX_DYN for 1 x 1.25 grid (bmy, 12/1/04)
(2 ) Update text in error message (bmy, 2/23/05)
(3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4 ) Don't stop run if TS_DYN > MAX_DYN but transport is turned off
     (cdh, bmy, 7/7/08)
(5 ) Set MAX_DYN for the 0.5 x 0.666 nested grid (yxw, dan, bmy, 11/6/08)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
10 Jun 2012 - L. Murray - Move strat to chemistry menu
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
06 Dec 2012 - R. Yantosca - Now get TS_DYN from the ESMF environment, if
                            we are connecting to the GEOS-5 GCM
11 Dec 2012 - R. Yantosca - ACCEPT_DATE_TIME_FROM_ESMF has now been renamed
                            to ACCEPT_EXTERNAL_DATE_TIME
03 Oct 2013 - M. Sulprizio- Removed obsolete option for flux correction. This
                            was used for GEOS-3, which has been retired.
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
20 Sep 2016 - R. Yantosca - Use "I8" format for write statement
```

2.2.14 read_convection_menu

Subroutine READ_CONVECTION_MENU reads the CONVECTION MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_CONVECTION_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FVDAS_CONVECT_MOD,  ONLY : INIT_FVDAS_CONVECT
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Add option for new non-local PBL scheme. And a check on GEOS-5,
      LNLPBL turned to false if GEOS-5 is not used (lin, ccc 5/13/09)
27 Aug 2010 - R. Yantosca - Now allow non-local PBL for MERRA met data
27 Aug 2010 - R. Yantosca - Added ProTeX headers
02 Feb 2012 - R. Yantosca - Added modifications for MERRA met data
13 Apr 2012 - R. Yantosca - Fixed typo ( defined( GEOS_FP ) should have
                            been !defined( GEOS_FP ) )
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
01 Mar 2013 - R. Yantosca - Now set TS_CONV to the same value as TS_DYN
                            when connecting to the GEOS-5 GCM.
12 Aug 2015 - R. Yantosca - Now allow non-local PBL mixing for MERRA2 met
```

2.2.15 read_deposition_menu

Subroutine READ_DEPOSITION_MENU reads the DEPOSITION MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_DEPOSITION_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now print an informational message for tagged Hg (bmy, 12/15/04)
(2 ) We need to call WETDEPID for both wetdep and cloud convection
      since this sets up the list of soluble tracers (bmy, 3/1/05)
```

```
(3 ) Remove references to obsolete CO_OH simulation (bmy, 6/24/05)
(4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
16 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
31 Jul 2012 - R. Yantosca - Now pass am_I_Root to INIT_DRYDEP
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
26 Feb 2013 - R. Yantosca - Now call INIT_DUST jere to facilitate
                            connecting to the GEOS-5 GCM
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
25 Jun 2014 - R. Yantosca - Now set USE_OLSON_2001 = T for GEOS-FP met;
                            this was originally done in INIT_INPUT
05 Mar 2015 - C. Keller   - Added PBL_DRYDEP to define if dry
                            deposition rates are calculated over
                            full PBL or 1st model level only.
                            Set to .TRUE. (full PBL) if full PBL
                            mixing is used, to false otherwise.
```

2.2.16 read_gamap_menu

Subroutine READ_GAMAP_MENU reads the GAMAP MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_GAMAP_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
25 Apr 2005 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
```

2.2.17 read_output_menu

Subroutine READ_OUTPUT_MENU reads the OUTPUT MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_OUTPUT_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_DIAG_MOD         ! NJDAY
USE CMN_SIZE_MOD         ! Size parameters
USE ErrCode_Mod
USE FILE_MOD,       ONLY : IOERROR
USE Input_Opt_Mod,  ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
03 Aug 2012 - R. Yantosca - IU_GEOS is now a global module variable
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
28 Feb 2013 - R. Yantosca - Don't call IS_LAST_DAY_GOOD when using ESMF
```

2.2.18 read_diagnostic_menu

Subroutine READ_DIAGNOSTIC_MENU reads the DIAGNOSTIC MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_DIAGNOSTIC_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE BPCH2_MOD,     ONLY : OPEN_BPCH2_FOR_WRITE
USE CMN_DIAG_MOD        ! NDxx flags, TINDEX, TCOUNT, TMAX
USE CMN_SIZE_MOD        ! Size parameters
USE DIAG03_MOD,    ONLY : ND03,      PD03
USE DIAG03_MOD,    ONLY : PD03_PL    !eds 9/9/10
USE DIAG04_MOD,    ONLY : ND04,      PD04,      INIT_DIAG04
USE DIAG41_MOD,    ONLY : ND41,      PD41,      INIT_DIAG41
USE DIAG42_MOD,    ONLY : ND42,      PD42,      INIT_DIAG42
USE DIAG53_MOD,    ONLY : ND53,      PD53,      INIT_DIAG53
USE DIAG56_MOD,    ONLY : ND56,      PD56,      INIT_DIAG56
USE DRYDEP_MOD,    ONLY : NUMDEP
USE ErrCode_Mod
USE ERROR_MOD,     ONLY : ERROR_STOP
USE FILE_MOD,      ONLY : IU_BPCH
USE Input_Opt_Mod, ONLY : OptInput
USE TIME_MOD,      ONLY : GET_NYMDb, GET_NHMSb, EXPAND_DATE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now reference IU_BPCH from "file_mod.f" and OPEN_BPCH2_FOR_WRITE
     from "bpch2_mod.f".  Now opens the bpch file for output here
     instead of w/in "main.f" (bmy, 2/3/05)
(2 ) Now references "diag03_mod.f" and "diag41_mod.f".  Now turn off ND38
     when both LWETD=F and LCONV=F.  Now calls EXPAND_DATE to replace
     YYYYMMDD and HHMMSS tokens in the bpch file name with the actual
     starting date & time of the run. (bmy, 3/25/05)
(3 ) Now get diag info for ND09 for HCN/CH3CN sim (bmy, 6/27/05)
(4 ) Now references "diag04_mod.f" (bmy, 7/26/05)
```

```
(5 ) Now make sure all USE statements are USE, ONLY.  Also remove reference
     to DIAG_MOD, it's not needed. (bmy, 10/3/05)
(6 ) Now remove reference to NBIOTRCE; Replace w/ NBIOMAX. (bmy, 4/5/06)
(7 ) Now reference ND56, PD56, INIT_DIAG56 from "diag56_mod.f"
     (bmy, 5/10/06)
(8 ) Now reference ND42, PD42, INIT_DIAG42 from "diag42_mod.f"
     (dkh, bmy, 5/22/06)
(9 ) Now set max dimension for GFED2 or default biomass (bmy, 9/22/06)
(10) Bug fix: Should use ND52 in call to SET_TINDEX (cdh, bmy, 2/11/08)
(11) Remove call to NDXX_SETUP; this is now called in READ_INPUT_FILE.
     (phs, 11/18/08)
(12) Now set TINDEX with PD45=NNPAR+1 tracers instead of N_TRACERS.
     (tmf, 2/10/09)
(13) NBIOMAX now in CMN_SIZE (fp, 6/2009)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
26 May 2011 - R. Yantosca - For ND17, ND18, ND37, ND38, ND39, we need to
                            set N_TMP = N_TRACERS, or else wetdep tracers
                            with indices higher than #32 won't print out.
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
06 Mar 2013 - H. Amos     - merge C. Friedman's POP code
08 Nov 2013 - M. Sulprizio- Remove HR1_NO, and HR2_NO from ND43 diagnostic.
03 Feb 2014 - R. Yantosca - Remove references to TINDEX, TCOUNT, and TMAX
                            from diag_mod.  They are in CMN_SIZE_mod.F.
                            Lee Murray reports this causes the compilation
                            to choke on Macintosh platforms.
23 Jun 2014 - R. Yantosca - Now pass Input_Opt, RC to INIT_DIAG_OH
24 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
15 Dec 2014 - M. Sulprizio- Moved radiation diagnostic from ND71 to ND72 to
                            avoid conflicts with hourly max ppbv diagnostic.
15 Jan 2015 - R. Yantosca - Now define Input_Opt%DIAG_COLLECTION
22 May 2015 - R. Yantosca - Remove variables made obsolete by HEMCO
23 Jun 2016 - R. Yantosca - Now call INIT_DIAG_OH from GIGC_Init_Extra
20 Jul 2016 - R. Yantosca - Remove references to NNPAR
```

2.2.19 set_tindex

Subroutine SET_TINDEX sets the TINDEX and TMAX arrays, which determine how many tracers to print to the punch file.

INTERFACE:

```
      SUBROUTINE SET_TINDEX( am_I_Root,
     &                       N_DIAG, L_DIAG, SUBSTRS, N, NMAX )
```

USES:

```
#if   defined( TOMAS )
      USE CHARPAK_MOD, ONLY : TXTEXT   ! (win, 7/14/09)
#endif
      USE CMN_DIAG_MOD                                ! TMAX, TINDEX
      USE CMN_SIZE_MOD                                ! Size parameters
```

INPUT PARAMETERS:

```
      INTEGER,            INTENT(IN) :: N_DIAG      ! GEOS-Chem diagnostic #
      INTEGER,            INTENT(IN) :: N           ! # of valid substrs passed
      INTEGER,            INTENT(IN) :: NMAX        ! Max # of tracers allowed
      INTEGER,            INTENT(IN) :: L_DIAG      ! # of levels to save
      CHARACTER(LEN=255), INTENT(IN) :: SUBSTRS(N)  ! Substrs passed from
                                                    !  READ_DIAGNOSTIC_MENU
      LOGICAL,            INTENT(IN) :: am_I_Root   ! Is this the root CPU?
```

REVISION HISTORY:

```
   20 Jul 2004 - R. Yantosca - Initial version
   (1 ) Bug fix: now do not drop the last tracer number if "all" is not
        explicitly specified (tmf, bmy, 11/15/04)
   27 Aug 2010 - R. Yantosca - Added ProTeX headers
```

2.2.20 read_planeflight_menu

Subroutine READ_PLANEFLIGHT_MENU reads the PLANEFLIGHT MENU section of the GEOS-Chem input file. This turns on the ND40 flight track diagnostic.

INTERFACE:

```
      SUBROUTINE READ_PLANEFLIGHT_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE CMN_DIAG_MOD          ! ND40
      USE CMN_SIZE_MOD          ! MAXFAM
      USE ErrCode_Mod
      USE ERROR_MOD,       ONLY : ERROR_STOP
      USE Input_Opt_Mod,   ONLY : OptInput
      USE PLANEFLIGHT_MOD, ONLY : SET_PLANEFLIGHT
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
```

2.2.21 read_nd48_menu

Subroutine READ_ND48_MENU reads the ND48 MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ND48_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE DIAG48_MOD, ONLY : INIT_DIAG48, ND48_MAX_STATIONS
USE ErrCode_Mod
USE ERROR_MOD,  ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Bug fix: ND48 stations should now be read correctly. (bmy, 3/6/06)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
```

2.2.22 read_nd49_menu

Subroutine READ_ND49_MENU reads the ND49 MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ND49_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DIAG49_MOD,         ONLY : INIT_DIAG49
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
```

2.2.23 read_nd50_menu

Subroutine READ_ND50_MENU reads the ND50 MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ND50_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE DIAG50_MOD,         ONLY : INIT_DIAG50
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now include option to save ND51 diagnostic to HDF5 file format
     (amv, bmy, 12/21/09)
(2 ) Increase tracer number to 121. (ccc, 4/20/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.24 read_nd51_menu

Subroutine READ_ND51_MENU reads the ND51 MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ND51_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG51_MOD,         ONLY : INIT_DIAG51
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now include option to save ND51 diagnostic to HDF5 file format
     (amv, bmy, 12/21/09)
(2 ) Increase # of tracers to 121 (ccc, 4/20/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.25 read_nd51b_menu

Subroutine READ_ND51b_MENU reads the ND51 MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_ND51b_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG51b_MOD,        ONLY : INIT_DIAG51b
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
21 Dec 2009 - Aaron van D - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.26 read_nd63_menu

Subroutine READ_ND63_MENU reads the ND63 MENU section of the GEOS-Chem input file. (gvinken, 02/25/11)

INTERFACE:

```
SUBROUTINE READ_ND63_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DIAG63_MOD,         ONLY : INIT_DIAG63
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
25 Feb 2011 - G. Vinken   - Initial version
07 Feb 2012 - M. Payer    - Added ProTeX headers
24 Feb 2012 - M. Payer    - Renamed routine from READ_ND59_MENU to
                            READ_ND63 MENU. ND59 is used by TOMAS.
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
20 Sep 2016 - R. Yantosca - Fixed typo (N_ND63 instead of ND63) when
                            saving to Input_Opt%ND63_TRACERS
```

2.2.27 read_prod_loss_menu

Subroutine READ_PROD_LOSS_MENU reads the PROD AND LOSS MENU section of the GEOS-Chem input file

INTERFACE:

```
SUBROUTINE READ_PROD_LOSS_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE CHARPAK_MOD,        ONLY : ISDIGIT,         STRSPLIT
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE gckpp_Parameters,   ONLY : NFAM
USE gckpp_Monitor,      ONLY : FAM_NAMES
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Bug fixes.  Only error check # of prod/loss families for TagOx and
     TagCO runs if DO_SAVE_PL=T.  Also turn off this diagnostic for
     the offline aerosol run. (bmy, 10/29/04)
(2 ) Add error trap is P/L families are asked when using KPP. (ccc, 3/10/10)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
08 Nov 2012 - R. Yantosca - Now save fields to the Input_Opt object
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
14 Jan 2016 - C. Keller   - Now refer to Input_Opt%LKPP instead of LKPP
```

2.2.28 read_unix_cmds_menu

Subroutine READ_UNIX_CMDS_MENU reads the UNIX CMDS MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_UNIX_CMDS_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CHARPAK_MOD,   ONLY : STRSQUEEZE
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
20 Jun 2014 - R. Yantosca - Remove reference to unix_cmds_mod.F
```

2.2.29 read_nested_grid_menu

Subroutine READ_NESTED_GRID_MENU reads the NESTED GRID MENU section of the GEOS-CHEM input file.

INTERFACE:

```
SUBROUTINE READ_NESTED_GRID_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now give user the option of saving out nested grid boundary conditions
      at 2 x 2.5 resolution for the EU, CH, or NA grids (amv, bmy, 12/18/09)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.30 read_benchmark_menu

Subroutine READ_BENCHMARK_MENU reads the BENCHMARK MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_BENCHMARK_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE BENCHMARK_MOD,      ONLY : INITIAL_FILE, FINAL_FILE
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.31 read_mercury_menu

Subroutine READ_MERCURY_MENU reads the BENCHMARK MENU section of the GEOS-Chem input file.

INTERFACE:

```
SUBROUTINE READ_MERCURY_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
24 Feb 2006 - R. Yantosca - Initial version
( 1) Update for Chris Holmes's mercury version. (ccc, 5/6/10)
( 2) Add options to use GTMM for mercury soil emissions (ccc, 9/16/09)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
25 Apr 2016 - R. Yantosca - Now init mercury modules from GIGC_INIT_EXTRA
27 Jul 2016 - M. Sulprizio- Remove IN_HG_RST_FILE and OUT_HG_RST_FILE.
                            Hg restart fields are now stored in the GEOS-Chem
                            netCDF restart file.
```

2.2.32 read_ch4_menu

Subroutine READ_CH4_MENU reads the CH4 MENU section of the GEOS-Chem input file; this defines emissions options for CH4 tagged simulations.

INTERFACE:

```
SUBROUTINE READ_CH4_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
03 Aug 2009 - K. Wecht, C. Pickett-Heaps - Initial version
27 Aug 2010 - R. Yantosca - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
01 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC as arguments
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
19 Feb 2014 - R. Yantosca - Add warning for CH4 budget (which is now
                            controlled by an #ifdef in global_ch4_mod.F)
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
20 Sep 2016 - R. Yantosca - Rewrote IF statement to avoid Gfortran error
```

2.2.33 read_pops_menu

Subroutine READ_POPS_MENU reads the POPS MENU section of the GEOS-Chem input file; this defines emissions options for POPs simulations.

INTERFACE:

```
SUBROUTINE READ_POPS_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,        ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)           :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
01 Oct 2012 - C. Friedman - Initial version
26 Nov 2012 - M. Payer    - Added ProTeX headers
29 Nov 2012 - M. Payer    - Now pass Input_Opt, RC as arguments
26 Mar 2013 - R. Yantosca - Now pass Input_Opt to INIT_POPS
14 Apr 2014 - R. Yantosca - Now echo all POPs parameters to log file
23 Jun 2014 - R. Yantosca - Now use Input_Opt%POP_EMISDIR
25 Aug 2014 - M. Sulprizio- Move call to INIT_POPs to GIGC_Init_Extra
27 Aug 2014 - M. Sulprizio- Remove POP_EMISDIR, emissions are now handled
                            by HEMCO
```

2.2.34 read_passive_tracer_menu

Subroutine READ_PASSIVE_TRACER_MENU reads the passive tracer MENU section of the GEOS-Chem input file; this defines passive tracers to be used for this simulation.

INTERFACE:

```
SUBROUTINE READ_PASSIVE_TRACER_MENU( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,        ONLY : OptInput
USE PASSIVE_TRACER_MOD,   ONLY : INIT_PASSIVE_TRACER
USE PASSIVE_TRACER_MOD,   ONLY : ADD_PASSIVE_TRACER
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)           :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input options
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
04 Sep 2015 - C. Keller   - Initial version
```

2.2.35 validate_directories

Subroutine VALIDATE_DIRECTORIES makes sure that each of the directories that we have read from the GEOS-Chem input file are valid. Also, trailing separator characters will be added.

INTERFACE:

```
SUBROUTINE VALIDATE_DIRECTORIES( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE GC_GRID_MOD,        ONLY : ITS_A_NESTED_GRID
USE TIME_MOD,           ONLY : EXPAND_DATE
USE TIME_MOD,           ONLY : GET_NYMDb
USE TIME_MOD,           ONLY : GET_NYMDe
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) Now make sure all USE statements are USE, ONLY.  Now also validate
     GCAP and GEOS-5 directories. (bmy, 10/3/05)
(2 ) Now references DATA_DIR_1x1 from directory_mod.f (bmy, 10/24/05)
(3 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(4 ) Now check TPBC_DIR_NA, TPBC_DIR_CH, TPBC_DIR_EU (amv, bmy, 12/18/09)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
27 Aug 2010 - R. Yantosca -  Now check MERRA directory
08 Feb 2012 - R. Yantosca - Now check GEOS-5.7.x directory
09 Feb 2012 - R. Yantosca - Rewrote USE statements for clarity
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
20 Jun 2014 - R. Yantosca - Now use fields from Input_Opt
05 Mar 2015 - R. Yantosca - Now also check CHEM_INPUTS_DIR
12 Aug 2015 - R. Yantosca - Now validate Input_Opt%MERRA2_DIR
```

2.2.36 check_directory

Subroutine CHECK_DIRECTORY makes sure that the given directory is valid. Also a trailing slash character will be added if necessary.

INTERFACE:

```
SUBROUTINE CHECK_DIRECTORY( Input_Opt, DIR )
```

USES:

```
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : FILE_EXISTS
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput),   INTENT(INOUT) :: Input_Opt   ! Input Options object
CHARACTER(LEN=*), INTENT(INOUT) :: DIR         ! Dir to be checked
```

REVISION HISTORY:

```
20 Mar 2003 - R. Yantosca - Initial version
(1 ) Now references FILE_EXISTS from "file_mod.f" (bmy, 3/23/05)
27 Aug 2010 - R. Yantosca - Added ProTeX headers
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
20 Jun 2014 - R. Yantosca - Now added Input_Opt object via arg list
```

2.2.37 check_time_steps

Subroutine CHECK_TIME_STEPS computes the smallest dynamic time step for the model, based on which operation are turned on. This is called from routine READ_INPUT_FILE, after all of the timesteps and logical flags have been read from "input.geos".

INTERFACE:

```
SUBROUTINE CHECK_TIME_STEPS( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : SET_TIMESTEPS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    20 Jul 2004 - R. Yantosca - Initial version
    (1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (2 ) Add TS_DIAG, the largest time steps used for diagnostics.
         And test that all time steps are multiple of the smallest one.
         (ccc, 5/13/09)
    (3 ) Corrected typos -99999 instead of -999999 (phs, bmy, 8/21/09)
    (4 ) Now compute TS_SUN_2 which is 1/2 of the chemistry timestep (or
         smallest timestep if LCHEM=LEMIS=LDRYD=F).  This is used to compute
         SUNCOS at the midpoint of the timestep instead of the beginning.
         (bmy, 4/27/10)
    27 Aug 2010 - R. Yantosca - Added ProTeX headers
    07 Oct 2011 - R. Yantosca - Add extra error checks for centralizing
                                chemistry timestep algorithm
    07 Oct 2011 - R. Yantosca - Remove TS_SUN_2 from call to SET_TIMESTEPS
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
```

2.2.38 is_last_day_good

Suborutine IS_LAST_DAY_GOOD tests to see if there is output scheduled on the last day of the run.

INTERFACE:

```
      SUBROUTINE IS_LAST_DAY_GOOD
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE ERROR_MOD,  ONLY : ERROR_STOP
      USE JULDAY_MOD, ONLY : JULDAY
      USE TIME_MOD,   ONLY : GET_NYMDe, ITS_A_LEAPYEAR, YMD_EXTRACT
```

REVISION HISTORY:

```
    20 Jul 2004 - R. Yantosca - Initial version
    (1 ) Moved to "input_mod.f" from "main.f" (bmy, 1/11/05)
    (2 ) Now call ITS_A_LEAPYEAR with FORCE=.TRUE. to always return whether
         the year Y would be a leap year, regardless of met field type.
         (swu, bmy, 4/24/06)
    27 Aug 2010 - R. Yantosca - Added ProTeX headers
```

2.2.39 gc_init_extra

Suborutine GC_INIT_EXTRA initializes other GEOS-Chem modules that have not been initialized in either GC_Allocate_All or GC_Init_all.

INTERFACE:

```
SUBROUTINE GC_Init_Extra( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE Aerosol_Mod,        ONLY : Init_Aerosol
USE Carbon_Mod,         ONLY : Init_Carbon
USE CO2_Mod,            ONLY : Init_CO2
USE C2H6_Mod,           ONLY : Init_C2H6
USE Chemgrid_Mod,       ONLY : Init_Chemgrid
USE Depo_Mercury_Mod,   ONLY : Init_Depo_Mercury
USE Diag03_Mod,         ONLY : Init_Diag03
USE Diag20_Mod,         ONLY : Init_Diag20
USE Diag_OH_Mod,        ONLY : Init_Diag_OH
USE Drydep_Mod,         ONLY : Init_Drydep
USE Dust_Mod,           ONLY : Init_Dust
USE ErrCode_Mod
USE Error_Mod,          ONLY : Debug_Msg
USE Gamap_Mod,          ONLY : Do_Gamap
USE Get_Ndep_Mod,       ONLY : Init_Get_Ndep
USE Global_CH4_Mod,     ONLY : Init_Global_CH4
USE Input_Opt_Mod,      ONLY : OptInput
USE Linoz_Mod,          ONLY : Init_Linoz
USE Land_Mercury_Mod,   ONLY : Init_Land_Mercury
USE Mercury_Mod,        ONLY : Init_Mercury
USE Modis_Lai_Mod,      ONLY : Init_Modis_Lai
USE Ocean_Mercury_Mod,  ONLY : Init_Ocean_Mercury
USE POPs_Mod,           ONLY : Init_POPs
USE Seasalt_Mod,        ONLY : Init_SeaSalt
USE State_Chm_Mod,      ONLY : ChmState
USE Sulfate_Mod,        ONLY : Init_Sulfate
USE Tagged_CO_Mod,      ONLY : Init_Tagged_CO
USE Tagged_O3_Mod,      ONLY : Init_Tagged_O3
USE Toms_Mod,           ONLY : Init_Toms
USE TPCORE_BC_Mod,      ONLY : Init_TPCORE_BC
USE Vdiff_Pre_Mod,      ONLY : Set_Vdiff_Values
USE WetScav_Mod,        ONLY : Init_WetScav
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry state object
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Several of the INIT routines now called within GC_Init_Extra had
originally been called from the Run method.  We now gather these INIT
routines here so that they may be called from the Initialization method.
This is necessary when connecting GEOS-Chem to the GEOS-5 GCM via ESMF.

                                                                             .
GC_Init_Extra should be called after the call to DO_DRYDEP, since
these routines depend on dry deposition parameters being set up first.
```

REVISION HISTORY:

```
04 Mar 2013 - R. Yantosca - Initial revision
05 Mar 2013 - R. Yantosca - Now call INIT_AEROSOL (GeosCore/aerosol_mod.F)
15 Mar 2013 - R. Yantosca - Now call INIT_LINOZ (GeosCore/linoz_mod.F)
29 Mar 2013 - R. Yantosca - Now call INIT_TROPOPAUSE (so that we can pass
                            a LVARTROP from Input_Opt and not logical_mod.F)
10 Apr 2014 - R. Yantosca - Now call INIT_TAGGED_CO
10 Apr 2014 - R. Yantosca - Now call INIT_TAGGED_OX and INIT_GLOBAL_CH4
11 Apr 2014 - R. Yantosca - Now call INIT_C2H6 and INIT_HCN_CH3CN
14 Apr 2014 - R. Yantosca - Also call INIT_C2H6 if it's a fullchem sim
                            since we read C2H6 emissions from c2h6_mod.F
25 Jun 2014 - R. Yantosca - Now call INIT_MODIS_LAI
25 Jun 2014 - R. Yantosca - Now call SET_VDIFF_VALUES (vdiff_pre_mod.F90)
25 Aug 2014 - M. Sulprizio- Now call INIT_POPS
16 Mar 2015 - R. Yantosca - Now call INIT_TOMS here
28 Aug 2015 - R. Yantosca - Now initialize drydep & wetdep here, so that
                            we can take advantage of the species database
03 Sep 2015 - R. Yantosca - Now call INIT_WETSCAV instead of WETDEPID
21 Sep 2015 - R. Yantosca - Now pass State_Chm to INIT_POPS
22 Sep 2015 - R. Yantosca - Bug fix: only call INIT_WETSCAV if convection,
                            wetdep, or chemistry ist turned on.  This
                            replicates the prior behavior,
23 Sep 2015 - R. Yantosca - Now pass State_Chm to INIT_SEASALT
23 Sep 2015 - R. Yantosca - Now pass State_Chm to INIT_SULFATE
25 Apr 2016 - R. Yantosca - Now call INIT_DIAG03 here
25 Apr 2016 - R. Yantosca - Now initialize all mercury modules from here
23 Jun 2016 - R. Yantosca - Now call INIT_DIAG_OH from here
16 Aug 2016 - M. Sulprizio- Rename from GIGC_Init_Extra to GC_Init_Extra.
                            The "gigc" nomenclature is no longer used.
```

2.2.40 do_error_checks

Makes sure that certain species are defined in order to proceed with a certain option. Halts the simulation with an error message if incorrect inputs would have caused a simulation to

crash.

INTERFACE:

```
SUBROUTINE Do_Error_Checks( am_I_root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Error_Mod,          ONLY : Error_Stop
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC
```

REMARKS:

```
These error checks were originally called when the various menus were
read in from disk.  However, in order to use the Ind_() function to look
up given species indices, we need to call this after the Species Database
(which is in State_Chm) is initialized.  Therefore, we have now moved these
error checks to this routine, which is now called from GC_Init_Extra.

The Ind_() function now defines all species ID's.  It returns -1 if
a species cannot be found.  The prior behavior was to return 0 if a
species wasn't found.  Therefore, in order to preserve the logic of the
error checks, we must force any -1's returned by Ind_() to 0's in
this subroutine.
```

REVISION HISTORY:

```
22 Jun 2016 - R. Yantosca - Initial version
```

2.3 Fortran: Module Interface gc_environment_mod.F90

Module GC_ENVIRONMENT_MOD establishes the runtime environment for the GEOS-Chem. It is designed to receive model parameter and geophysical environment information and allocate memory based upon it.

It provides routines to do the following:

- Allocate geo-spatial arrays

- Initialize met. field derived type.
- Initialize Chemistry, Metorology, Emissions, and Physics States

INTERFACE:

```
MODULE GC_Environment_Mod
  !USES

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: GC_Allocate_All
  PUBLIC  :: GC_Init_All
```

REMARKS:

```
   For consistency, we should probably move the met state initialization
   to the same module where the met state derived type is contained.
```

REVISION HISTORY:

```
   26 Jan 2012 - M. Long     - Created module file
   13 Aug 2012 - R. Yantosca - Added ProTeX headers
   19 Oct 2012 - R. Yantosca - Removed routine INIT_LOCAL_MET, this is now
                               handled in Headers/gigc_state_met_mod.F90
   22 Oct 2012 - R. Yantosca - Renamed to gigc_environment_mod.F90
   20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
   28 Aug 2015 - R. Yantosca - Remove Get_nSchm_nSchmBry; stratospheric
                               chemistry fields are now read by HEMCO
   16 Aug 2016 - M. Sulprizio- Rename from gigc_environment_mod.F90 to
                               gc_environment_mod.F90. The "gigc" nomenclature
                               is no longer used.
```

2.3.1 gc_allocate_all

Subroutine GC_ALLOCATE_ALL allocates all LAT/LON ALLOCATABLE arrays for global use by the GEOS-Chem either as a standalone program or module.

INTERFACE:

```
  SUBROUTINE GC_Allocate_All( am_I_Root,       Input_Opt,       &
                              RC,              value_I_LO,      &
                              value_J_LO,      value_I_HI,      &
                              value_J_HI,      value_IM,        &
                              value_JM,        value_LM,        &
                              value_IM_WORLD,  value_JM_WORLD,  &
                              value_LM_WORLD )
```

USES:

```
USE CMN_DIAG_Mod,       ONLY : Init_CMN_DIAG
USE CMN_FJX_MOD,        ONLY : Init_CMN_FJX
USE CMN_O3_Mod,         ONLY : Init_CMN_O3
USE CMN_SIZE_Mod,       ONLY : Init_CMN_SIZE
USE ErrCode_Mod
USE Input_Opt_Mod
USE VDIFF_PRE_Mod,      ONLY : Init_Vdiff_Pre

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root        ! Are we on the root CPU?
INTEGER,        OPTIONAL      :: value_I_LO       ! Min local lon index
INTEGER,        OPTIONAL      :: value_J_LO       ! Min local lat index
INTEGER,        OPTIONAL      :: value_I_HI       ! Max local lon index
INTEGER,        OPTIONAL      :: value_J_HI       ! Max local lat index
INTEGER,        OPTIONAL      :: value_IM         ! Local # of lons
INTEGER,        OPTIONAL      :: value_JM         ! Local # of lats
INTEGER,        OPTIONAL      :: value_LM         ! Local # of levels
INTEGER,        OPTIONAL      :: value_IM_WORLD   ! Global # of lons
INTEGER,        OPTIONAL      :: value_JM_WORLD   ! Global # of lats
INTEGER,        OPTIONAL      :: value_LM_WORLD   ! Global # of levels
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt        ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC               ! Success or failure?
```

REMARKS:

```
For error checking, return up to the main routine w/ an error code.
This can be improved upon later.
```

REVISION HISTORY:

```
26 Jan 2012 - M. Long     - Initial version
13 Aug 2012 - R. Yantosca - Added ProTeX headers
17 Oct 2012 - R. Yantosca - Add am_I_Root, RC as arguments
22 Oct 2012 - R. Yantosca - Renamed to GIGC_Allocate_All
30 Oct 2012 - R. Yantosca - Now pass am_I_Root, RC to SET_COMMSOIL_MOD
01 Nov 2012 - R. Yantosca - Now zero the fields of the Input Options object
16 Nov 2012 - R. Yantosca - Remove this routine from the #ifdef DEVEL block
27 Nov 2012 - R. Yantosca - Now pass Input_Opt to INIT_COMODE_LOOP
03 Dec 2012 - R. Yantosca - Now pass am_I_Root, RC to INIT_CMN_SIZE
03 Dec 2012 - R. Yantosca - Add optional arguments to accept dimension
                            size information from the ESMF interface
```

```
13 Dec 2012 - R. Yantosca - Remove reference to obsolete CMN_DEP_mod.F
13 Dec 2012 - R. Yantosca - Remove reference to obsolete CMN_mod.F
23 Jul 2014 - R. Yantosca - Remove reference to obsolete CMN_NOX_mod.F
25 Jul 2014 - R. Yantosca - Remove reference to obsolete commsoil_mod.F90
25 Jul 2014 - R. Yantosca - Now call INIT_GET_NDEP (GeosCore/get_ndep_mod.F)
04 Aug 2015 - C. Keller   - Now pass LLTROP and LLSTRAT to INIT_CMN_SIZE.
17 Jun 2016 - R. Yantosca - Move call to INIT_GET_NDEP to GIGC_INIT_EXTRA
                            which is called after species database init
30 Jun 2016 - M. Sulprizio- Remove call to INIT_COMODE_LOOP; it's obsolete
```

2.3.2 gc_init_all

Subroutine GC_INIT_ALL initializes the top-level data structures that are either passed to/from GC or between GC components (emis-¿transport-¿chem-¿etc)

INTERFACE:

```
SUBROUTINE GC_Init_All( am_I_Root, Input_Opt, State_Chm, State_Met, RC )
```

USES:

```
USE CMN_Size_Mod,       ONLY : IIPAR, JJPAR, LLPAR
USE CMN_SIZE_Mod,       ONLY : NDUST, NAER
USE ErrCode_Mod
USE Input_Opt_Mod
USE State_Chm_Mod
USE State_Met_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
Need to add better error checking, currently we just return upon error.
```

REVISION HISTORY:

```
26 Jan 2012 - M. Long     - Initial version
13 Aug 2012 - R. Yantosca - Added ProTeX headers
16 Oct 2012 - R. Yantosca - Renamed LOCAL_MET argument to State_Met
16 Oct 2012 - R. Yantosca - Renamed GC_STATE  argument to State_Chm
```

```
16 Oct 2012 - R. Yantosca - Call Init_Chemistry_State (in gc_type2_mod.F90,
                            which was renamed from INIT_CHEMSTATE)
19 Oct 2012 - R. Yantosca - Now reference gigc_state_met_mod.F90
19 Oct 2012 - R. Yantosca - Now reference gigc_state_chm_mod.F90
19 Oct 2012 - R. Yantosca - Now reference gigc_errcode_mod.F90
19 Oct 2012 - R. Yantosca - Now reference IGAS in Headers/comode_loop_mod.F
22 Oct 2012 - R. Yantosca - Renamed to GIGC_Init_All
26 Oct 2012 - R. Yantosca - Now call Get_nSchm, nSchmBry to find out the
                            number of strat chem species and Bry species
01 Nov 2012 - R. Yantosca - Now use LSCHEM from logical_mod.F
09 Nov 2012 - R. Yantosca - Now pass Input Options object for GIGC
26 Feb 2013 - R. Yantosca - Now pass Input_Opt to Init_GIGC_State_Chm
28 Aug 2015 - R. Yantosca - Remove strat-chem options from call to
                            Init_GIGC_State_Chm; this is done by HEMCO
25 Jan 2016 - R. Yantosca - Bug fix: Declare Input_Opt as INTENT(INOUT),
                            to match the declaration in INIT_GIGC_STATE_CHM
28 Jan 2016 - M. Sulprizio- Remove NBIOMAX from call to Init_GIGC_State_Chm
30 Jun 2016 - M. Sulprizio- Remove nSpecies from call to Init_GIGC_State_Chm
```

2.4 Fortran: Module Interface restart_mod.F

Module RESTART_MOD contains variables and routines which are used to read and write restart files for GEOS-Chem species in units of [v/v] dry mixing ratio, which represents mol species per mol dry air.

INTERFACE:

```
      MODULE RESTART_MOD
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE inquireMod,    ONLY : findFreeLUN
      USE PhysConstants
      USE Precision_Mod
      USE UnitConv_Mod

      IMPLICIT NONE
      PRIVATE
  !PUBLIC MEMBER FUNCTIONS
      PUBLIC  :: READ_GC_RESTART
      PUBLIC  :: WRITE_GC_RESTART
      PUBLIC  :: INIT_GC_RESTART
      PUBLIC  :: COMPARE_TRC_SPC ! temporary for tracer removal debugging
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: CHECK_RST_DIMENSIONS
```

DEFINED PARAMETERS:

```
      ! Prefix of GEOS-Chem output restart filename
      CHARACTER(LEN=255), PARAMETER :: Output_GC_Rst_Prefix =
     &                                 'GEOSChem_restart'
```

REVISION HISTORY:

```
    25 Jun 2002 - R. Yantosca - Initial version
    (1 ) Moved routines "make_restart_file.f"" and "read_restart_file.f" into
         this module.  Also now internal routines to "read_restart_file.f"
         are now a part of this module.  Now reference "file_mod.f" to get
         file unit numbers and error checking routines. (bmy, 6/25/02)
    (2 ) Now reference AD from "dao_mod.f".  Now reference "error_mod.f".
         Also added minor bug fix for ALPHA platform. (bmy, 10/15/02)
    (3 ) Now references "grid_mod.f" and the new "time_mod.f" (bmy, 2/11/03)
    (4 ) Added error-check and cosmetic changes (bmy, 4/29/03)
    (5 ) Removed call to COPY_STT_FOR_OX, it's obsolete (bmy, 8/18/03)
    (6 ) Add fancy output (bmy, 4/26/04)
    (7 ) Added routine SET_RESTART.  Now reference "logical_mod.f" and
         "tracer_mod.f" (bmy, 7/20/04)
    (8 ) Removed obsolete routines TRUE_TRACER_INDEX and COPY_DATA_FOR_CO_OH
         (bmy, 6/28/05)
    (9 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (10) Now pass TAU via the arg list in MAKE_RESTART_FILE (bmy, 12/15/05)
    (11) Add MAKE_CSPEC_FILE and READ_CSPEC_FILE routines to save and read
         CSPEC_FULL restart files (dkh, 02/12/09)
    11 Jul 2011 - R. Yantosca - Corrected mis-indexing problem w/ the
                                CSPEC restart file
    21 Jul 2011 - M. Long     - Now include F77_CMN_SIZE instead of CMN_SIZE
    03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
    20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
    19 Nov 2014 - M. Yannetti - Added PRECISION_MOD
    09 Feb 2016 - E. Lundgren - Add NetCDF restart file routines
    11 Jul 2016 - E. Lundgren - Store only species in restart files
    12 Jul 2016 - E. Lundgren - Remove bpch restart file format option and
                                associated routines
    09 Aug 2016 - E. Lundgren - Remove obsolete routines convert_tracer_to_vv
                                and set_restart and associated module vars;
                                replace all tracer language to species; rename
                                OUTPUT_RESTART_FILE to OUTPUT_GC_RST_PREFIX
    29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

2.4.1 init_gc_restart

Subroutine INIT_GC_RESTART initializes the GEOS-Chem restart file collection and populates it with containers. This collection includes restart concentrations for each species as

well as additional data if running the mercury simulation.

INTERFACE:

```
SUBROUTINE INIT_GC_RESTART( am_I_Root, Input_Opt,
&                           State_Chm, RC         )
```

USES:

```
USE GC_GRID_MOD,        ONLY : AREA_M2
USE HCO_Error_Mod
USE HCO_Diagn_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput),   INTENT(INOUT) :: Input_Opt   ! Input Options object
TYPE(ChmState),   INTENT(INOUT) :: State_Chm   ! Chemistry state object
```

OUTPUT PARAMETERS:

```
INTEGER,          INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
09 Feb 2016 - E. Lundgren - Initial version
20 Apr 2016 - E. Lundgren - Implement ocean and snow Hg variables
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies and
                            NAMEGAS with SpcInfo%Name from species database
11 Jul 2016 - E. Lundgren - Remove tracer container; now only use species
12 Jul 2016 - E. Lundgren - Rename routine from init_gc_restart_nc
```

2.4.2 read_gc_restart

Subroutine READ_GC_RESTART reads species concentrations [mol/mol] from the GEOS-Chem restart file and uses them to initialize species concentrations in [kg/kg dry]. If species data are missing from the restart file, pre-configured background values are used. If using the mercury simulation, additional restart data are read from file.

INTERFACE:

```
SUBROUTINE READ_GC_RESTART( am_I_Root,  YYYYMMDD,  HHMMSS,
&                           Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE m_netcdf_io_open                          ! netCDF file open
USE m_netcdf_io_read                          ! netCDF read
USE m_netcdf_io_readattr                      ! netCDF attribute reads
USE m_netcdf_io_get_dimlen                    ! netCDF get dimensions
USE m_netcdf_io_close                         ! netCDF file close
USE PHYSCONSTANTS,      ONLY : BOLTZ
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : EXPAND_DATE

! For Hg simulation restart file
USE OCEAN_MERCURY_MOD,  ONLY : Hg0aq, Hg2aq, HgPaq, Hgaq_tot
USE OCEAN_MERCURY_MOD,  ONLY : CHECK_OCEAN_MERCURY
USE DEPO_MERCURY_MOD,   ONLY : SNOW_HG_OC,  SNOW_HG_STORED_OC
USE DEPO_MERCURY_MOD,   ONLY : SNOW_HG_LN,  SNOW_HG_STORED_LN
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root  ! Are we on the root CPU?
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! YYYY/MM/DD GMT date
INTEGER,        INTENT(IN)    :: HHMMSS     ! hh:mm:ss   GMT time
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met  ! Meteorology State object
include "netcdf.inc"
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC         ! Success or failure?
```

REVISION HISTORY:

```
09 Feb 2016 - E. Lundgren - Initial version
20 Apr 2016 - E. Lundgren - Implement ocean and snow Hg variables
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
31 May 2016 - E. Lundgren - Replace Input_Opt%TRACER_MW_G with species
                            database field emMW_g (emitted species g/mol)
06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies and
                            NAMEGAS with SpcInfo%Name from species database
22 Jun 2016 - R. Yantosca - Now refer to Hg0_Id_List, Hg2_Id_List, and
                            HgP_Id_List fields of State_Chm
11 Jul 2016 - E. Lundgren - Remove tracers and read only species
12 Jul 2016 - E. Lundgren - Rename from read_gc_restart_nc
```

```
18 Jul 2016 - M. Sulprizio- Remove special handling of ISOPN, MMN, CFCX, and
                            HCFCX. Family tracers have been eliminated.
25 Jul 2016 - E. Lundgren - Store whether species in rst file in species db
                            rather than module-level variable
03 Aug 2016 - E. Lundgren - Remove tracers; now only use species
11 Aug 2016 - E. Lundgren - Move source of background values to spc database
```

2.4.3 write_gc_restart

Subroutine WRITE_GC_RESTART writes species concentrations [mol/mol] to the GEOS-Chem restart file in NetCDF format. If using the mercury simulation, additional data such as ocean mercury values are written to the restart file.

INTERFACE:

```
 SUBROUTINE WRITE_GC_RESTART( am_I_Root, YYYYMMDD,  HHMMSS,
&                             Input_Opt, State_Chm, State_Met,
&                             RC )
```

USES:

```
 USE Input_Opt_Mod,      ONLY : OptInput
 USE Species_Mod,        ONLY : Species
 USE State_Chm_Mod,      ONLY : ChmState
 USE State_Met_Mod,      ONLY : MetState
 USE TIME_MOD,           ONLY : EXPAND_DATE

 ! HEMCO
 USE HCO_Error_Mod
 USE HCO_Diagn_Mod,      ONLY : Diagn_Update
 USE HCOIO_Diagn_Mod,    ONLY : HCOIO_Diagn_WriteOut

 ! For Hg simulation
 USE OCEAN_MERCURY_MOD,  ONLY : Hg0aq, Hg2aq, HgPaq, Hgaq_tot
 USE OCEAN_MERCURY_MOD,  ONLY : CHECK_OCEAN_MERCURY
 USE DEPO_MERCURY_MOD,   ONLY : SNOW_HG_OC,  SNOW_HG_STORED_OC
 USE DEPO_MERCURY_MOD,   ONLY : SNOW_HG_LN,  SNOW_HG_STORED_LN
```

INPUT PARAMETERS:

```
 LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
 INTEGER,        INTENT(IN)    :: YYYYMMDD    ! YYYY/MM/DD GMT date
 INTEGER,        INTENT(IN)    :: HHMMSS      ! hh:mm:ss GMT time
 TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
 TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
 TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
09 Feb 2016 - E. Lundgren - Initial version
20 Apr 2016 - E. Lundgren - Implement ocean and snow Hg variables
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies and
                            NAMEGAS with SpcInfo%Name from species database
22 Jun 2016 - R. Yantosca - Now refer to Hg0_Id_List, Hg2_Id_List, and
                            HgP_Id_List fields of State_Chm
11 Jul 2016 - E. Lundgren - Remove tracers and write only species
12 Jul 2016 - E. Lundgren - Rename from write_gc_restart_nc
10 Aug 2016 - E. Lundgren - Input species concentrations are now kg/kg dry
```

2.4.4 check_rst_dimensions

Subroutine CHECK_RST_DIMENSIONS checks to see if dimensions read from the netCDF file match the defined GEOS-Chem dimensions. If not, then it will stop the GEOS-Chem simulation with an error message.

INTERFACE:

```
SUBROUTINE Check_Rst_Dimensions( lon, lat, lev, time,
&                                time_expected, LOC )
```

INPUT PARAMETERS:

```
INTEGER,          OPTIONAL, INTENT(IN)  :: lon           ! Lon dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: lat           ! Lat dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: lev           ! Alt dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: time          ! Time dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: time_expected ! Expected # of
                                                         !  time slots
CHARACTER(LEN=*), INTENT(IN)            :: LOC           ! Caller location
```

REMARKS:

```
Call this routine with keyword arguments, e.g
   CALL CHECK_RST_DIMENSION( lon=X,  lat=Y,           lev=Z,         &
                         time=T, time_expected=8, caller=caller )
```

REVISION HISTORY:

REVISION HISTORY:

```
(1 ) Added to "restart_mod.f".  Now no longer allow initialization with
     less than a globally-sized data block. (bmy, 6/25/02)
(2 ) Now reference GEOS_CHEM_STOP from "error_mod.f", which frees all
     allocated memory before stopping the run. (bmy, 10/15/02)
11 Jul 2011 - R. Yantosca - Added ProTeX headers
21 Jul 2011 - M. Long     - Now include F77_CMN_SIZE instead of CMN_SIZE
09 Feb 2016 - E. Lundgren - Add args and all args optional except location
01 Apr 2016 - E. Lundgren - Rename this subroutine from check_dimensions to
                            check_rst_dimensions for global clarity
```

2.4.5 compare_trc_spc

Subroutine COMPARE_TRC_SPC prints out species values to log in kg/kg dry for advected species, and prints out non-advected species molec/cm3. This can only be used where tracers were kg/kg dry.

INTERFACE:

```
SUBROUTINE COMPARE_TRC_SPC( am_I_Root, Input_Opt,
&                           State_Met, State_Chm, LOC, RC )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,            INTENT(IN) :: am_I_Root  ! Are we on the root CPU?
TYPE(OptInput),     INTENT(IN) :: Input_Opt   ! Input Options object
TYPE(MetState),     INTENT(IN) :: State_Met   ! Meteorology State object
CHARACTER(LEN=*),   INTENT(IN) :: LOC
include "netcdf.inc"
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC         ! Success or failure?
```

REVISION HISTORY:

```
08 Aug 2016 - E. Lundgren - Initial version
```

2.5 Fortran: Module Interface cleanup.F

Subroutine CLEANUP deallocates the memory assigned to dynamically allocatable arrays just before exiting a GEOS-Chem simulation.

INTERFACE:

```
SUBROUTINE CLEANUP( am_I_Root, ERROR, RC )
```

USES:

```
USE AEROSOL_MOD,             ONLY : CLEANUP_AEROSOL
USE C2H6_MOD,                ONLY : CLEANUP_C2H6
USE CARBON_MOD,              ONLY : CLEANUP_CARBON
USE CHEMGRID_MOD,            ONLY : CLEANUP_CHEMGRID
USE CO2_MOD,                 ONLY : CLEANUP_CO2
USE CMN_FJX_Mod,             ONLY : Cleanup_CMN_FJX
USE CMN_O3_Mod,              ONLY : Cleanup_CMN_O3
USE CMN_SIZE_Mod,            ONLY : Cleanup_CMN_SIZE
USE DIAG_MOD,                ONLY : CLEANUP_DIAG
USE DIAG03_MOD,              ONLY : CLEANUP_DIAG03
USE DIAG04_MOD,              ONLY : CLEANUP_DIAG04
USE DIAG20_MOD,              ONLY : CLEANUP_DIAG20
USE DIAG41_MOD,              ONLY : CLEANUP_DIAG41
USE DIAG50_MOD,              ONLY : CLEANUP_DIAG50
USE DIAG51_MOD,              ONLY : CLEANUP_DIAG51
USE DIAG53_MOD,              ONLY : CLEANUP_DIAG53 !(clf, 3/11/11)
USE DIAG_OH_MOD,             ONLY : CLEANUP_DIAG_OH
USE DRYDEP_MOD,              ONLY : CLEANUP_DRYDEP
USE DUST_MOD,                ONLY : CLEANUP_DUST
USE ERROR_MOD,               ONLY : DEBUG_MSG
USE FLEXCHEM_MOD,            ONLY : CLEANUP_FLEXCHEM
USE GEOSFP_READ_MOD,         ONLY : CLEANUP_GEOSFP_READ
USE GET_NDEP_MOD,            ONLY : CLEANUP_GET_NDEP
USE GLOBAL_CH4_MOD,          ONLY : CLEANUP_GLOBAL_CH4
USE GC_GRID_MOD,             ONLY : CLEANUP_GRID
USE HDF_MOD,                 ONLY : CLEANUP_HDF
USE Input_Opt_Mod,           ONLY : OptInput
USE ISOROPIAII_MOD,          ONLY : CLEANUP_ISOROPIAII
USE LINOZ_MOD,               ONLY : CLEANUP_LINOZ
USE MERCURY_MOD,             ONLY : CLEANUP_MERCURY
USE MODIS_LAI_MOD,           ONLY : CLEANUP_MODIS_LAI
USE OCEAN_MERCURY_MOD,       ONLY : CLEANUP_OCEAN_MERCURY
USE DEPO_MERCURY_MOD,        ONLY : CLEANUP_DEPO_MERCURY
USE LAND_MERCURY_MOD,        ONLY : CLEANUP_LAND_MERCURY
USE MERRA2_READ_MOD,         ONLY : CLEANUP_MERRA2_READ
USE PBL_MIX_MOD,             ONLY : CLEANUP_PBL_MIX
USE PJC_PFIX_MOD,            ONLY : CLEANUP_PJC_PFIX
USE PLANEFLIGHT_MOD,         ONLY : CLEANUP_PLANEFLIGHT
USE PRESSURE_MOD,            ONLY : CLEANUP_PRESSURE
```

```
      USE Regrid_A2A_Mod,          ONLY : Cleanup_Map_A2a
      USE SEASALT_MOD,             ONLY : CLEANUP_SEASALT
      USE SULFATE_MOD,             ONLY : CLEANUP_SULFATE
      USE STRAT_CHEM_MOD,          ONLY : CLEANUP_STRAT_CHEM
      USE TAGGED_CO_MOD,           ONLY : CLEANUP_TAGGED_CO
#if   defined( TOMAS )
      USE TOMAS_MOD,               ONLY : CLEANUP_TOMAS  !sfarina, 1/16/13
#endif
      USE TOMS_MOD,                ONLY : CLEANUP_TOMS
      USE TPCORE_FVDAS_MOD,        ONLY : EXIT_TPCORE
      USE TPCORE_WINDOW_MOD,       ONLY : EXIT_TPCORE_WINDOW
#if ! defined( ESMF_ )
      USE TRANSPORT_MOD,           ONLY : CLEANUP_TRANSPORT
#endif
      USE UCX_MOD,                 ONLY : CLEANUP_UCX
      USE VDIFF_PRE_Mod,           ONLY : Cleanup_VDIFF_PRE
      USE PASSIVE_TRACEr_MOD,      ONLY : Cleanup_Passive_Tracer
      USE WETSCAV_MOD,             ONLY : CLEANUP_WETSCAV

      ! HEMCO
 #if !defined(ESMF_)
      USE EMISSIONS_MOD,           ONLY : EMISSIONS_FINAL
 #endif

#if defined( NC_DIAG )
      ! Cleanup routine for netCDF diagnostics structure
      USE DIAGNOSTICS_MOD,         ONLY : DIAGNOSTICS_FINAL
#endif

#if   defined( RRTMG )
      USE RRTMG_RAD_TRANSFER_MOD,  ONLY : CLEANUP_SURFACE_RAD
      USE RRTMG_RAD_TRANSFER_MOD,  ONLY : CLEANUP_STRAT_CLIM
      USE RRTMG_RAD_TRANSFER_MOD,  ONLY : CLEANUP_MCICA_CLOUDS
#endif


      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root    ! Are we on the root CPU?
      LOGICAL,        INTENT(IN)  :: ERROR        ! Cleanup after error?
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC           ! Success or failure
```

REVISION HISTORY:

```
   29 Nov 1999 - R. Yantosca - Initial version
```

```
(1 ) CLEANUP is written in Fixed-Format F90.
(2 ) Now calls CLEANUP_WETSCAV, which deallocates arrays from
     "wetscav_mod.f". (bmy, 3/9/00)
(3 ) Add call to CLEANUP_SULFATE, which deallocates arrays from
     "sulfate_mod.f".  Also now deallocate ND32 arrays. (bmy, 6/6/00)
(4 ) Add call to CLEANUP_DAO, which deallocates arrays from "dao_mod.f".
     (bmy, 6/26/00)
(5 ) Add call to CLEANUP_TAGGED_CO and CLEANUP_COMODE, which deallocates
     arrays from and "comode_mod.f". (bmy, 7/19/00)
(6 ) Add call to CLEANUP_GLOBAL_OH and CLEANUP_COMODE, which deallocates
     arrays from "global_oh_mod.f". (bmy, 7/28/00)
(7 ) Add calls to CLEANUP_BIOMASS and CLEANUP_BIOFUEL, which deallocates
     arrays from "biomass_mod.f" and "biofuel_mod.f".  Also deallocate
     the AD32_bf array for the biofuel NOx diagnostic. (bmy, 9/12/00)
(8 ) Add call to CLEANUP_DIAG51, to deallocate module arrays from
     "diag51_mod.f" (bmy, 11/29/00)
(9 ) Removed obsolete code from 11/29/00 (bmy, 12/21/00)
(10) Add call to CLEANUP_CH4, to deallocate module arrays from
     "global_ch4_mod.f" (bmy, 1/16/01)
(11) Now deallocate the AD34 array.  Also updated comments and
     made some cosmetic changes. (bmy, 3/15/01)
(12) Now deallocate the AD12 array (bdf, bmy, 6/15/01)
(13) Add call to CLEANUP_ACETONE, to deallocate module arrays from
     "acetone_mod.f"  Also deallocate AD11 array.  Also deallocate
     variables from dao_mod.f last, to try to avoid bus error on
     SGI (bmy, 8/3/01)
(14) Added call to CLEANUP_UVALBEDO from "uvalbedo_mod.f".  Also removed
     obsolete code from 9/01.  Also only include references to CLEANUP_*
     subroutines in other modules for clarity. (bmy, 1/15/02)
(15) Added call to CLEANUP_C2H6 from "c2h6_mod.f" (bmy, 1/25/02)
(16) Added call to CLEANUP_AIRCRAFT_NOX from "aircraft_nox_mod.f"
     (bmy, 2/14/02)
(17) Now deallocate CTNO2, CTHO2, LTNO2, LTHO2 arrays (rvm, bmy, 2/27/02)
(18) Now reference CLEANUP_PLANEFLIGHT from "planeflight_mod.f".
     Now also deallocate AD01 and AD02 arrays. (mje, bmy, 8/7/02)
(19) Now reference cleanup routines from "global_nox_mod.f",
     "global_hno3_mod.f", "global_no3_mod.f", "drydep_mod.f", and
     "rpmares_mod.f". (bmy, 12/16/02)
(20) Now reference cleanup routine from "transport_mod.f" (bmy, 2/10/03)
(21) Now reference cleanup routine from "pjc_pfix_mod.f" and
     "tpcore_fvdas_mod.f90". (bmy, 5/9/03)
(22) Now reference cleanup routine from "toms_mod.f" (bmy, 7/14/03)
(23) Now reference cleanup routine from "carbon_mod.f", "dust_mod.f", and
     "dust_dead_mod.f". (bmy, 7/14/03)
(23) Now references cleanup routine from "lightning__nox_mod.f"
     (bmy, 4/14/04)
(24) Now references cleanup routine from "seasalt_mod.f" (bmy, 4/26/04)
(25) Now references cleanup routines from new modules (bmy, 7/20/04)
```

```
(26) Now calls cleanup routine from "epa_nei_mod.f" (bmy, 11/5/04)
(27) Now call CLEANUP_MERCURY from "mercury_mod.f" (eck, bmy, 12/7/04)
(28) Now call CLEANUP_OCEAN_MERCURY from "ocean_mercury_mod.f".  Also
     reordered the calling sequence. (sas, bmy, 1/21/05)
(29) Now call CLEANUP_PBL_MIX from "pbl_mix_mod.f".  Now call CLEANUP_DIAG41
     from "diag41_mod.f". (bmy, 2/17/05)
(30) Now calls CLEANUP_HCN_CH3CN from "hcn_ch3cn_mod.f (bmy, 6/23/05)
(31) Now calls CLEANUP_DIAG04, CLEANUP_CO2, and CLEANUP_TROPOPAUSE
      (bmy, 8/15/05)
(32) Now calls CLEANUP_LAI from "lai_mod.f", CLEANUP_MEGAN from
     "megan_mod.f" and CLEANUP_REGRID_1x1 from "regrid_1x1_mod.f"
     (tmf, bdf, bmy, 10/24/05)
(33) Now calls CLEANUP_EMEP from "emep_mod.f" (bdf, bmy, 11/1/05)
(34) Now calls CLEANUP_GC_BIOMASS and CLEANUP_GFED2_BIOMASS (bmy, 4/5/06)
(35) Now calls CLEANUP_DIAG56 from "diag56_mod.f" and
     CLEANUP_LIGHTNING_NOX_NL from "lightning_nox_nl_mod.f"
     (ltm, bmy, 5/5/06)
(36) Now references CLEANUP_BRAVO from "bravo_mod.f" and CLEANUP_EDGAR
     from "edgar_mod.f" (bmy, 7/6/06)
(37) Now calls CLEANUP_H2_HD from "h2_hd_mod.f" and CLEANUP_GLOBAL_O1D
     from "global_o1d_mod.f".  Remove call to CLEANUP_LIGHTNING_NOx_NL
     from "lightning_nox_nl_mod.f (hup, phs, bmy, 10/2/07)
(38) Now calls GEOS5_EXIT_TPCORE_WINDOW to finalize the TPCORE for
     GEOS-5 nested window simulations (yxw, dan, bmy, 11/6/08)
(39) Now references CLEANUP_CAC_ANTHRO (amv, phs, 3/10/08)
(40) Now references CLEANUP_ARCTAS_SHIP (phs, 3/10/08)
(41) Now references CLEANUP_VISTAS_ANTHRO (phs, 3/10/08)
(41) Now references CLEANUP_LINOZ (phs, 10/16/09)
(42) Now references CLEANUP_HDF (amv, bmy, 12/21/09)
(43) Now references CLEANUP_ISOROPIAII (ccc, bmy, 1/29/09)
(44) Now references CLEANUP_DEPO_MERCURY and CLEANUP_LAND_MERCURY
    (ccc, 5/6/10)
(45) Added call to CLEANUP_GLOBAL_OC, which deallocates arrays from
    "global_oc_mod.f"  (clf, 2/28/2011)
(46) Added call to CLEANUP_GLOBAL_BC, which deallocates arrays from
    "global_bc_mod.f"  (clf, 2/28/2011)
13 Aug 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2011 - C. Friedman - Added call to CLEANUP_GLOBAL_OC, which
                            deallocates arrays from "global_oc_mod.f"
22 Aug 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
07 Sep 2011 - P. Kasibhatla - Add modifications for GFED3
19 Mar 2012 - M. Payer    - Remove call to CLEANUP_ACETONE. It is no longer
                            needed after removal of JO1D and RESP routines.
05 Apr 2012 - R. Yantosca - Now call CLEANUP_MODIS_LAI
11 Apr 2012 - R. Yantosca - Remove reference to obsolete lai_mod.F
01 May 2012 - M. Payer    - Added calls for CLEANUP_GLOBAL_GRID and
                            CLEANUP_GRID
19 Nov 2012 - R. Yantosca - Add cleanup calls for modules in Headers;
```

```
                            these were omitted during development
28 Nov 2012 - R. Yantosca - Remove reference to CLEANUP_DAO; we have now
                            removed all allocatable arrays from dao_mod.F
03 Dec 2012 - R. Yantosca - Now call Cleanup_CMN_SIZE
13 Dec 2012 - R. Yantosca - Remove reference to obsolete CMN_DEP_mod.F
06 Mar 2013 - H. Amos     - Merge C. Friedman's PAH code
14 Mar 2013 - M. Payer    - Restore reference to CLEANUP_DAO. Some arrays
                            have been restored to dao_mod.F for use in
                            the vertical regridding of OH for offline
                            simulations.
24 Mar 2013 - S.D. Eastham- Switched TROPOPAUSE_MOD to CHEMGRID_MOD
04 Apr 2013 - S.D. Eastham- Added call for CLEANUP_UCX
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
26 Sep 2013 - R. Yantosca - Now reference EXIT_GEOSFP_TPCORE_WINDOW
29 Oct 2013 - R. Yantosca - Now call CLEANUP_DAO for all simulations (if
                            arrays are not allocated it'll exit gracefully)
03 Jun 2014 - R. Yantosca - Don't finalize HEMCO if emissions are turned
                            off.  This prevents a seg fault error.
03 Jun 2014 - R. Yantosca - Now pass Input_Opt via the argument list
03 Jun 2014 - R. Yantosca - Remove references to emissions modules that
                            HEMCO renders obsolete
24 Jun 2014 - R. Yantosca - Remove CLEANUP_BROMOCARB; HEMCO replaces this
25 Jun 2014 - R. Yantosca - Remove reference to tracer_mod.F
21 Jul 2014 - R. Yantosca - Remove reference to regrid_1x1_mod.F
23 Jul 2014 - R. Yantosca - Remove reference to obsolete CMN_mod.F
23 Jul 2014 - R. Yantosca - Remove reference to obsolete global_grid_mod.F
23 Jul 2014 - R. Yantosca - Remove reference to obsolete CMN_NOX_mod.F
25 Jul 2014 - R. Yantosca - Remove reference to commsoil_mod.F90
25 Jul 2014 - R. Yantosca - Now call CLEANUP_GET_NDEP
15 Aug 2014 - R. Yantosca - Remove reference to biofuel_mod.F
15 Aug 2014 - R. Yantosca - Remove reference to biomass_mod.F
10 Sep 2014 - M. Sulprizio- Remove references to global_oc_mod.F and
                            global_bc_mod.F
23 Sep 2014 - M. Sulprizio- Remove references to global_hno3_mod.F and
                            global_no3_mod.F
12 Jan 2015 - R. Yantosca - Remove CLEANUP_UVALBEDO routine
11 Mar 2015 - R. Yantosca - Remove call to CLEANUP_GLOBAL_OH
11 Mar 2015 - R. Yantosca - Remove call to CLEANUP_GLOBAL_NOX
16 Mar 2015 - R. Yantosca - Remove call to CLEANUP_HCN_CH3CN
25 Mar 2015 - C. Keller   - Now cleanup UCX before emissisions.
16 Apr 2015 - R. Yantosca - Remove call to CLEANUP_DAO; it's obsolete
24 Mar 2016 - C. Keller   - Remove input arg Input_Opt; this is cleaned
                            up before routine CLEANUP is called.
18 May 2016 - M. Sulprizio- Remove call to CLEANUP_COMODE; it's obsolete
30 Jun 2016 - M. Sulprizio- Remove call to CLEANUP_COMODE_LOOP; it's obsolete
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

3 Transport modules

These modules contain routines to advect GEOS-Chem speecies using assimilated meteorology fields.

3.1 Fortran: Module Interface transport_mod.F

Module TRANSPORT_MOD is used to call the proper version of the TPCORE advection scheme for GCAP, GEOS-4, GEOS-5, or GEOS-5.7 nested-grid or global simulations.

INTERFACE:

```
MODULE TRANSPORT_MOD
```

USES:

```
USE PRECISION_MOD      ! For GEOS-Chem Precision (fp)
USE PRESSURE_MOD

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CLEANUP_TRANSPORT
PUBLIC  :: DO_TRANSPORT
PUBLIC  :: INIT_TRANSPORT
PUBLIC  :: INIT_WINDOW_TRANSPORT
PUBLIC  :: SET_TRANSPORT
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: GEOS4_GEOS5_GLOBAL_ADV
PRIVATE :: GCAP_GLOBAL_ADV
PRIVATE :: DO_WINDOW_TRANSPORT
```

REVISION HISTORY:

```
10 Mar 2003 - Y. Wang, R. Yantosca - Initial version
(1 ) Now can select transport scheme for GEOS-3 winds.  Added code for PJC
     pressure fixer. (bdf, bmy, 5/8/03)
(2 ) Now delete DSIG array, it's obsolete.  Also added new PRIVATE function
     GET_AIR_MASS to compute air masses from the input/output pressures
     from the new GEOS-4/fvDAS TPCORE. (bmy, 6/24/03)
(3 ) Now references DEBUG_MSG from "error_mod.f". (bmy, 8/7/03)
(4 ) Bug fix in DO_GLOBAL_TRANSPORT (bmy, 10/21/03)
(5 ) IORD, JORD, KORD are now module variables.  Now references
     "logical_mod.f" and "tracer_mod.f" (bmy, 7/20/04)
(6 ) Add mass-flux diagnostics to TPCORE_FVDAS (bdf, bmy, 9/28/04)
(7 ) Now references "diag_mod.f" (bmy, 9/28/04)
```

```
(8 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(9 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(10) Now flip arrays in call to TPCORE_FVDAS (bmy, 6/16/06)
(11) Added modifications for SUN compiler (bmy, 7/12/06)
(12) Bug fixes in DO_GLOBAL_TRANSPORT (bmy, 11/29/06)
(13) Split off GCAP, GEOS-3, GEOS-4/GEOS-5 specific calling sequences
     into separate subroutines.  Also removed some obsolete module
     variables. (bmy, 10/30/07)
(14) Modifications for GEOS-5 nested grid (yxw, dan, bmy, 11/6/08)
(15) Bug fix in mass balance in GCAP_GLOBAL_ADV and GEOS4_GEOS5_GLOBAL_ADV.
     (ccc, 2/17/09)
26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
26 Feb 2010 - R. Yantosca - Added ProTex Headers
08 Mar 2010 - C. Carouge  - Modify call to tpcore_fvdas. We do not re-order
                            mass fluxes diagnostics anymore.
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
21 Jun 2012 - R. Yantosca - Now use pointers to flip arrays in vertical
21 Jun 2012 - R. Yantosca - Comment out GEOS-3 window subroutine
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Renamed "GEOS57" to "GEOSFP" in routine names
24 Nov 2014 - M. Yannetti - Added PRECISION_MOD
12 Feb 2015 - E. Lundgren - Added functionality for writing diags to netcdf
15 Apr 2015 - R. Yantosca - Add TARGET spec to A_M2 array
24 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                            (previously v/v) for advection
24 Jun 2015 - E. Lundgren - Remove post-advection residual mass correction
                            and GET_AIR_MASS function since no longer needed
                            when using kg/kg total air in advection
13 Aug 2015 - E. Lundgren - Tracer units are now input as kg/kg dry air
                            (previously v/v)
19 Jan 2016 - E. Lundgren - Move DiagnUpdate_Transport to diagnostics_mod
                            and consolidate netcdf and bpch diagnostic code
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

3.1.1 do_transport

Subroutine DO_TRANSPORT is the driver routine for the proper TPCORE program for GEOS-3, GEOS-4/GEOS-5, or window simulations.

INTERFACE:

```
      SUBROUTINE DO_TRANSPORT( am_I_Root, Input_Opt,
     &                         State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE GC_GRID_MOD,        ONLY : ITS_A_NESTED_GRID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TPCORE_BC_MOD,      ONLY : INIT_TPCORE_BC
      USE TIME_MOD,           ONLY : GET_TS_DYN
#if defined( USE_TEND )
      USE TENDENCIES_MOD
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    10 Mar 2003 - R. Yantosca - Initial version
    (1 ) Removed IORD, JORD, KORD from the arg list.  Also now removed
         reference to CMN, it's not needed. (bmy, 7/20/04)
    (2 ) Now call separate routines for different met fields. (bmy, 10/30/07)
    (3 ) Now references subroutine INIT_TPCORE_BC from tpcore_bc_mod.f and
         DO_GEOS5_FVDAS_WINDOW_TRANSPORT from
         "tpcore_geos5_fvdas_window_mod.f90". (yxw, dan, bmy, 11/6/08)
    26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
    26 Feb 2010 - R. Yantosca - Added ProTeX headers
    06 Oct 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5.
    28 Feb 2012 - R. Yantosca - Treat GEOS-5.7 in the same way as MERRA
    28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
    25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
    31 Mar 2015 - E. Lundgren - Make State_Met INTENT(INOUT) for AIRQNT calls
    19 Jul 2016 - R. Yantosca - Now bracket DO_TEND calls with #ifdef USE_TEND
```

3.1.2 geos4_geos5_global_adv

Subroutine GEOS4_GEOS5_GLOBAL_ADV is the driver routine for TPCORE with the GMAO GEOS-4 or GEOS-5 met fields.

INTERFACE:

```
      SUBROUTINE GEOS4_GEOS5_GLOBAL_ADV( am_I_Root, Input_Opt,
     &                                   State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD             ! NDxx flags
      USE CMN_SIZE_MOD             ! Size parameters
      USE DAO_MOD,            ONLY : AIRQNT
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : MASSFLEW,  MASSFLNS,  MASSFLUP
#elif defined( NC_DIAG )
      USE DIAGNOSTICS_MOD,    ONLY : DIAGNUPDATE_TRANSPORT_FLUX
#endif
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE State_Met_Mod,      ONLY : MetState
      USE PhysConstants            ! Physical constants
      USE PJC_PFIX_MOD,       ONLY : DO_PJC_PFIX
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE TPCORE_FVDAS_MOD,   ONLY : TPCORE_FVDAS
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    As of July 2016, we assume that all of the advected species are listed
    first in the species database.  This is the easiest way to pass a slab
    to the TPCORE routine.  This may change in the future. (bmy, 7/13/16)

    Note: the mass flux diagnostic arrays (MASSFLEW, MASSFLNS and MASSFLUP)
    are incremented upside-down (level 1 = top of the atmosphere).
    The levels order is reversed only when written out to diagnostic output.
```

REVISION HISTORY:

```
   30 Oct 2007 - R. Yantosca - Initial version
   (1 ) Split off the GEOS-4 & GEOS-5 relevant parts from the previous
        routine DO_GLOBAL_TRANSPORT (bmy, 10/30/07)
   (2 ) Activate the call to SAVE_GLOBAL_TPCORE_BC (yxw, dan, bmy, 11/6/08)
   (3 ) Bug fix in mass balance: only account for cells of STT with non-zero
        concentrations when doing the computation (ccc, bmy, 2/17/09)
   26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
   26 Feb 2010 - R. Yantosca - Added ProTeX headers
   16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
   21 Jun 2012 - R. Yantosca - Now use pointers to flip indices in vertical
   09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                               derived type object
   25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
   04 Jun 2013 - R. Yantosca - Replace pointer STT with State_Chm%Tracers
   26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
   31 Mar 2015 - E. Lundgren - Move AIRQNT call from main to within transport
   09 Jun 2015 - E. Lundgren - Remove dependency on tpcore_bc_mod since not used
   15 Jun 2015 - E. Lundgren - Tracer units in advection are now kg/kg total air
                               (previously v/v)
   15 Jun 2015 - E. Lundgren - Remove mass residual adjustment to tracer
                               concentration following advection
   13 Aug 2015 - E. lundgren - Remove v/v <-> kg/kg conversion
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                               species ID from State_Chm%Map_Advect.
   20 Jul 2016 - R. Yantosca - Add minor bug fixes for netCDF diagnostics
   20 Jul 2016 - R. Yantosca - Now replace NNPAR with State_Chm%nAdvect
   20 Jul 2016 - R. Yantosca - Now pass State_Chm to DiagnUpdate_Transport_Flux
   03 Aug 2016 - R. Yantosca - Removed temporary tracer-removal code
```

3.1.3 gcap_global_adv

Subroutine GCAP_GLOBAL_ADV is the driver routine for TPCORE with the GCAP/GISS met fields.

INTERFACE:

```
      SUBROUTINE GCAP_GLOBAL_ADV( am_I_Root, Input_Opt,
     &                            State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD             ! NDxx flags
      USE CMN_SIZE_MOD             ! Size parameters
      USE DAO_MOD,            ONLY : AIRQNT
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : MASSFLEW,  MASSFLNS,  MASSFLUP
#elif defined( NC_DIAG )
```

```
      USE DIAGNOSTICS_MOD,    ONLY : DIAGNUPDATE_TRANSPORT_FLUX
#endif
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE PhysConstants            ! Physical constants
      USE PJC_PFIX_MOD,       ONLY : DO_PJC_PFIX
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE TPCORE_FVDAS_MOD,   ONLY : TPCORE_FVDAS
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    As of July 2016, we assume that all of the advected species are listed
    first in the species database.  This is the easiest way to pass a slab
    to the TPCORE routine.  This may change in the future. (bmy, 7/13/16)
    Note: the mass flux diagnostic arrays (MASSFLEW, MASSFLNS and MASSFLUP)
    are incremented upside-down (level 1 = top of the atmosphere).
    The levels order is reversed only when written out to diagnostic output.
```

REVISION HISTORY:

```
    30 Oct 2007 - R. Yantosca - Initial version
    (1 ) Split off the GCAP relevant parts from the previous routine
         DO_GLOBAL_TRANSPORT (bmy, 10/30/07)
    (2 ) Bug fix in mass balance: only account for cells of STT with non-zero
         concentrations when doing the computation (ccc, bmy, 2/17/09)
    26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
    26 Feb 2010 - R. Yantosca - Added ProTeX headers
    16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
    21 Jun 2012 - R. Yantosca - Now use pointers to flip arrays in the vertical
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
    04 Jun 2013 - R. Yantosca - Replace pointer STT with State_Chm%Tracers
    04 Sep 2014 - R. Yantosca - Avoid div-by-zero errors in division w/ SUMADA
```

```
   26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
   31 Mar 2015 - E. Lundgren - Move AIRQNT call from main to within transport
   09 Jun 2015 - E. Lundgren - Remove dependency on tpcore_bc_mod since not used
   15 Jun 2015 - E. Lundgren - Tracer units in advection are now kg/kg total air
                               (previously v/v)
   15 Jun 2015 - E. Lundgren - Remove mass residual adjustment to tracer
                               concentration following advection
   13 Aug 2015 - E. lundgren - Remove v/v <-> kg/kg conversion
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                               species ID from State_Chm%Map_Advect.
   20 Jul 2016 - R. Yantosca - Add minor bug fixes for netCDF diagnostics
   20 Jul 2016 - R. Yantosca - Now replace NNPAR with State_Chm%nAdvect
   20 Jul 2016 - R. Yantosca - Now pass State_Chm to DiagnUpdate_Transport_Flux
   03 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

3.1.4 do_window_transport

Subroutine DO_WINDOW_TRANSPORT is the driver program for the proper TPCORE program for the GEOS-5/GEOS-FP/MERRA2 nested-grid simulations.

INTERFACE:

```
      SUBROUTINE DO_WINDOW_TRANSPORT( am_I_Root, Input_Opt,
     &                                State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD               ! NDxx flags
      USE CMN_SIZE_MOD               ! Size parameters
      USE DAO_MOD,              ONLY : AIRQNT
#if defined( BPCH_DIAG )
      USE DIAG_MOD,             ONLY : MASSFLEW, MASSFLNS, MASSFLUP
#elif defined( NC_DIAG )
      USE DIAGNOSTICS_MOD,      ONLY : DIAGNUPDATE_TRANSPORT_FLUX
#endif
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,          ONLY : GET_XOFFSET,   GET_YOFFSET
      USE Input_Opt_Mod,        ONLY : OptInput
      USE State_Chm_Mod,        ONLY : ChmState
      USE State_Met_Mod,        ONLY : MetState
      USE PhysConstants              ! Physical constants
      USE PJC_PFIX_WINDOW_MOD,  ONLY : DO_PJC_PFIX_WINDOW
      USE TIME_MOD,             ONLY : GET_TS_DYN
      USE TPCORE_BC_MOD,        ONLY : I0_W, J0_W, I1_W, J1_W
      USE TPCORE_BC_MOD,        ONLY : I2_W, J2_W, IM_W, JM_W, IGZD
      USE TPCORE_BC_MOD,        ONLY : DO_WINDOW_TPCORE_BC
```

```
USE TPCORE_WINDOW_MOD,    ONLY : TPCORE_WINDOW
USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
As of July 2016, we assume that all of the advected species are listed
first in the species database.  This is the easiest way to pass a slab
to the TPCORE routine.  This may change in the future. (bmy, 7/13/16)

Note: the mass flux diagnostic arrays (MASSFLEW, MASSFLNS and MASSFLUP)
are incremented upside-down (level 1 = top of the atmosphere).
The levels order is reversed only when written out to diagnostic output.
```

REVISION HISTORY:

```
10 Mar 2003 - R. Yantosca - Initial version
26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
26 Feb 2010 - R. Yantosca - Added ProTeX headers
16 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
21 Jun 2012 - R. Yantosca - Now use pointers to flip arrays in the vertical
04 Jun 2013 - R. Yantosca - Replace pointer STT with State_Chm%Tracers
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
31 Mar 2015 - E. Lundgren - Move AIRQNT call from main to within transport
01 Apr 2015 - L. Zhang    - Add updates to skip the window region
15 Apr 2015 - R. Yantosca - Add more pointers to avoid array temporaries
15 Jun 2015 - E. Lundgren - Tracer units in advection are now kg/kg total air
                            (previously v/v)
15 Jun 2015 - E. Lundgren - Remove mass residual adjustment to tracer
                            concentration prior to advection
13 Aug 2015 - E. lundgren - Remove v/v <-> kg/kg conversion
04 Nov 2015 - M. Sulprizio- Rename from DO_GEOSFP_WINDOW_TRANSPORT to
                            DO_WINDOW_TRANSPORT for use with all nested grids
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
20 Jul 2016 - R. Yantosca - Add minor bug fixes for netCDF diagnostics
20 Jul 2016 - R. Yantosca - Now replace NNPAR with State_Chm%nAdvect
20 Jul 2016 - R. Yantosca - Now pass State_Chm to DiagnUpdate_Transport_Flux
03 Aug 2016 - R. Yantosca - Removed temporary tracer-removal code
```

3.1.5 set_transport

Subroutine SET_TRANSPORT passes IORD, JORD, KORD values from "input_mod.f".

INTERFACE:

```
SUBROUTINE SET_TRANSPORT( I_ORD, J_ORD, K_ORD )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I_ORD  ! IORD option for E/W advection
INTEGER, INTENT(IN) :: J_ORD  ! JORD option for N/S advection
INTEGER, INTENT(IN) :: K_ORD  ! KORD option for vertical diffusion
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
26 Feb 2010 - R. Yantosca - Added ProTeX headers
```

3.1.6 init_transport

Subroutine INIT_TRANSPORT initializes all module variables and arrays.

INTERFACE:

```
SUBROUTINE INIT_TRANSPORT( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE GC_GRID_MOD,        ONLY : GET_AREA_M2, GET_YMID_R
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants            ! Re
USE TIME_MOD,           ONLY : GET_TS_DYN
USE TPCORE_FVDAS_MOD,   ONLY : INIT_TPCORE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
10 Mar 2003 - R. Yantosca - Initial version
(1 ) Now references GET_TS_DYN from "time_mod.f", INIT_TPCORE_FVDAS from
     "tpcore_fvdas_mod.f90", and GET_YMID_R from "grid_mod.f".  Now also
     include "CMN_SETUP".  (bdf, bmy, 4/28/03)
(2 ) Remove reference to DSIG, it's obsolete. (bmy, 6/24/03)
(3 ) Now references LEMBED & LTPFV from "logical_mod.f".  Now references
     N_TRACERS from "tracer_mod.f". (bmy, 7/20/04)
(4 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(5 ) Removed reference to USE_GEOS_4_TRANSPORT, STT_I1, STT_I2, STT_J1,
     STT_J2, variables (bmy, 10/30/07)
(6 ) Deleted reference to CMN, it's not needed anymore (bmy, 11/6/08)
26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
26 Feb 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R_W(I,J,L) from grid_mod.F90
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
05 Dec 2014 - M. Yannetti - Added REAL_N_DYN
```

3.1.7 init_window_transport

Subroutine INIT_WINDOW_TRANSPORT initializes all module variables and arrays for the GEOS-5/GEOS-FP/MERRA2 nested grid simulation.

INTERFACE:

```
SUBROUTINE INIT_WINDOW_TRANSPORT( am_I_Root,Input_Opt,RC )
```

USES:

```
USE CMN_SIZE_MOD                 ! Size parameters
USE ErrCode_Mod
USE ERROR_MOD,               ONLY : ALLOC_ERR, GC_Error
USE GC_GRID_MOD,             ONLY : GET_AREA_M2
USE GC_GRID_MOD,             ONLY : GET_YMID_R_W
USE Input_Opt_Mod,           ONLY : OptInput
USE PhysConstants                 ! Re
USE TIME_MOD,                ONLY : GET_TS_DYN
USE TPCORE_FVDAS_MOD,        ONLY : INIT_TPCORE
USE TPCORE_BC_MOD,           ONLY : I0_W, J0_W, I1_W, J1_W
USE TPCORE_BC_MOD,           ONLY : I2_W, J2_W, IM_W, JM_W
USE TPCORE_BC_MOD,           ONLY : IGZD, INIT_TPCORE_BC
USE TPCORE_WINDOW_MOD,       ONLY : INIT_WINDOW
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
06 Jun 2008 - D. Chen & R. Yantosca - Initial version
26 Feb 2010 - R. Yantosca - Removed references to obsolete LEMBED switch
26 Feb 2010 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R_W(I,J,L) from grid_mod.F90
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
26 Sep 2013 - R. Yantosca - Renamed to INIT_GEOSFP_WINDOW_TRANSPORT
05 Dec 2014 - M. Yannetti - Added REAL_N_DYN
04 Nov 2015 - M. Sulprizio- Renamed from INIT_GEOSFP_WINDOW_TRANSPORT to
                            INIT_WINDOW_TRANSPORT for use with all nested
                            grids
```

3.1.8 cleanup_transport

Subroutine CLEANUP_TRANSPORT deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_TRANSPORT
```

REVISION HISTORY:

```
10 Mar 2003 - R. Yantosca - Initial version
(1 ) Remove reference to DSIG, it's obsolete. (bmy, 6/24/03)
(2 ) Remove obsolete embedded chemistry arrays (bmy, 10/30/07)
26 Feb 2010 - R. Yantosca - Added ProTeX headers
12 Feb 2015 - E. Lundgren - Added new diagnostics arrays for netcdf output
```

3.2 Fortran: Module Interface pjc_pfix_mod.F

Module Pjc_Pfix_Mod contains routines which implements the Philip Cameron-Smith pressure fixer for the new fvDAS transport scheme. (bdf, bmy, 5/8/03, 10/27/03)

INTERFACE:

```
MODULE Pjc_Pfix_Mod
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: Do_Pjc_Pfix
PUBLIC  :: Cleanup_Pjc_Pfix
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: Calc_Pressure
PRIVATE :: Calc_Advection_Factors
PRIVATE :: Adjust_Press
PRIVATE :: Init_Press_Fix
PRIVATE :: Do_Press_Fix_LLNL
PRIVATE :: Average_Press_Poles
PRIVATE :: Convert_Winds
PRIVATE :: Calc_Horiz_Mass_Flux
PRIVATE :: Calc_Divergence
PRIVATE :: Set_Press_Terms
PRIVATE :: Do_Divergence_Pole_Sum
PRIVATE :: Xpavg
PRIVATE :: Init_Pjc_Pfix
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
Brendan Field and Bob Yantosca (5/8/03)
Modified for new GMI TPCORE by Claire Carouge (ccarouge@seas.harvard.edu)
```

REVISION HISTORY:

```
(1 ) Bug fix for Linux/PGI compiler in routines ADJUST_PRESS and
     INIT_PRESS_FIX. (bmy, 6/23/03)
(2 ) Now make P1, P2 true surface pressure in DO_PJC_PFIX (bmy, 10/27/03)
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
19 Nov 2014 - M. Yannetti - Added PRECISION_MOD
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

3.2.1 Do_Pjc_Pfix

Subroutine Do_Pjc_Pfix is the driver routine for the Philip Cameron-Smith pressure fixer for the fvDAS transport scheme. (bdf, bmy, 5/8/03, 3/5/07)

We assume that the winds are on the A-GRID, since this is the input that the fvDAS transport scheme takes. (bdf, bmy, 5/8/03)

INTERFACE:

```
SUBROUTINE Do_Pjc_Pfix( D_DYN, P1, P2, UWND, VWND, XMASS, YMASS )
```

USES:

```
USE CMN_SIZE_MOD    ! Size parameters
USE PhysConstants   ! Physical constants
```

INPUT PARAMETERS:

```
! Dynamic timestep [s]
REAL(fp),  INTENT(IN)  :: D_DYN

! True PSurface at middle of dynamic timestep [hPa]
REAL(fp),  INTENT(IN)  :: P1(:,:)

! True PSurface at end    of dynamic timestep [hPa]
REAL(fp),  INTENT(IN)  :: P2(:,:)

! Zonal (E-W) wind [m/s]
REAL(fp),  INTENT(IN)  :: UWND(IIPAR,JJPAR,LLPAR)

! Meridional (N-S) wind [m/s]
REAL(fp),  INTENT(IN)  :: VWND(IIPAR,JJPAR,LLPAR)
```

OUTPUT PARAMETERS:

```
! E-W mass fluxes [mixing ratio]
REAL(fp),  INTENT(OUT) :: XMASS(IIPAR,JJPAR,LLPAR)

! N-S mass fluxes [mixing ratio]
REAL(fp),  INTENT(OUT) :: YMASS(IIPAR,JJPAR,LLPAR)
```

AUTHOR:

Brendan Field and Bob Yantosca (5/8/03)

REMARKS:

(1) Now P1 and P2 are "true" surface pressures, and not PS-PTOP. If using this P-fixer w/ GEOS-3 winds, pass true surface pressure to this routine. (bmy, 10/27/03)
(2) Now define P2_TMP array for passing to ADJUST_PRESS (yxw, bmy, 3/5/07)

REVISION HISTORY:

02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers. Declare all REAL variables as REAL(fp).
04 Nov 2013 - M. Sulprizio- Eliminate array temporaries by accepting assumed-shape dummy arguments

---

3.2.2 Calc_Pressure

Subroutine Calc_Pressure recalculates the new surface pressure from the adjusted air masses XMASS and YMASS. This is useful for debugging purposes. (bdf, bmy, 5/8/03)

INTERFACE:

```
SUBROUTINE Calc_Pressure( XMASS, YMASS, RGW_FV, PS_NOW, PS_AFTER )
```

USES:

```
USE CMN_SIZE_MOD  ! Size parameters
```

INPUT PARAMETERS:

```
! E-W mass flux from pressure fixer
REAL(fp), INTENT(IN)  :: XMASS(IIPAR,JJPAR,LLPAR)

! N-S mass flux from pressure fixer
REAL(fp), INTENT(IN)  :: YMASS(IIPAR,JJPAR,LLPAR)

! Surface pressure - PTOP at current time
REAL(fp), INTENT(IN)  :: PS_NOW(IIPAR,JJPAR)

! 1 / ( SINE(J+1) - SINE(J) ) -- latitude factor
REAL(fp), INTENT(IN)  :: RGW_FV(JJPAR)
```

OUTPUT PARAMETERS:

```
! Surface pressure - PTOP adjusted by P-fixer
REAL(fp), INTENT(OUT) :: PS_AFTER(IIPAR,JJPAR)
```

AUTHOR:

```
Brendan Field and Bob Yantosca (5/8/03)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
23 Jul 2014 - R. Yantosca - Removed reference to obsolete CMN_mod.F
```

3.2.3 Calc_Advection_Factors

Subroutine Calc_Advection_Factors calculates the relative area of each grid box, and the geometrical factors used by this modified version of TPCORE. These geomoetrical DO assume that the space is regularly gridded, but do not assume any link between the surface area and the linear dimensions.

INTERFACE:

```
      SUBROUTINE Calc_Advection_Factors
     &  (mcor, rel_area, geofac, geofac_pc)
```

USES:

```
      USE CMN_SIZE_MOD   ! Size parameters
      USE PhysConstants  ! Physical constants
```

INPUT PARAMETERS:

```
      ! Area of grid box (m^2)
      REAL(fp), INTENT(IN)  :: mcor(i1_gl :i2_gl, ju1_gl:j2_gl)
```

OUTPUT PARAMETERS:

```
      ! relative surface area of grid box (fraction)
      REAL(fp), INTENT(OUT) :: rel_area(i1_gl :i2_gl, ju1_gl:j2_gl)

      ! Geometrical factor for meridional advection; geofac uses
      ! correct spherical geometry, and replaces acosp as the
      ! meridional geometrical factor in tpcore
      REAL(fp), INTENT(OUT) :: geofac(ju1_gl:j2_gl)

      ! Special geometrical factor (geofac) for Polar cap
      REAL(fp), INTENT(OUT) :: geofac_pc
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REMARKS:

```
Now reference PI from "CMN_GCTM" for consistency.  Also force
double-precision with the "D" exponent. (bmy, 5/6/03)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.4 Adjust_Press

Subroutine Adjust_Press initializes and calls the pressure fixer code.

INTERFACE:

```
      SUBROUTINE Adjust_Press
     &  (metdata_name_org, do_timinterp_winds, new_met_rec,
     &   met_grid_type, advec_consrv_opt, pmet2_opt, press_fix_opt,
     &   tdt, geofac_pc, geofac, cose, cosp, rel_area, dap, dbk,
     &   pctm1, pctm2, pmet2, uu, vv, xmass, ymass)
```

INPUT PARAMETERS:

```
! First  part of metdata_name, e.g., "NCAR"
CHARACTER(LEN=*) :: metdata_name_org

! Time interpolate wind fields?
LOGICAL :: do_timinterp_winds

! New met record?
LOGICAL :: new_met_rec

! Met grid type, A or C
INTEGER :: met_grid_type

! Advection_conserve option
INTEGER :: advec_consrv_opt

! pmet2 option
INTEGER :: pmet2_opt

! pressure fixer option
INTEGER :: press_fix_opt

! Model time step [s]
REAL(fp)  :: tdt

! Special geometrical factor (geofac) for Polar cap
REAL(fp)  :: geofac_pc

! Geometrical factor for meridional advection; geofac uses
! correct spherical geometry, and replaces acosp as the
! meridional geometrical factor in tpcore
REAL(fp)  :: geofac  (ju1_gl:j2_gl)

! Cosines of grid box edges and centers
REAL(fp)  :: cose    (ju1_gl:j2_gl)
REAL(fp)  :: cosp    (ju1_gl:j2_gl)

! Pressure difference across layer from (ai * pt) term [hPa]
REAL(fp)  :: dap     (k1:k2)

! Difference in bi across layer - the dSigma term
REAL(fp)  :: dbk     (k1:k2)

! Relative surface area of grid box (fraction)
REAL(fp)  :: rel_area( i1_gl:i2_gl,   ju1_gl:j2_gl)

! Metfield surface pressure at t1+tdt [hPa]
```

```
REAL(fp)  :: pmet2(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! CTM surface pressure at t1 [hPa]
REAL(fp)  :: pctm1(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! CTM surface pressure at t1+tdt [hPa]
REAL(fp)  :: pctm2(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! Wind velocity, x direction at t1+tdt/2 [m/s]
REAL(fp)  :: uu(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)

! Wind velocity, y direction at t1+tdt/2 [m/s]
REAL(fp)  :: vv(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)
```

INPUT/OUTPUT PARAMETERS:

```
! Horizontal mass flux in E-W direction [hPa]
REAL(fp)  :: xmass(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)

! Horizontal mass flux in N-S direction [hPa]
REAL(fp)  :: ymass(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)
```

AUTHOR:

Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.5 Init_Press_Fix

Subroutine Init_Press_Fix initializes the pressure fixer.

INTERFACE:

```
 SUBROUTINE Init_Press_Fix
&  (metdata_name_org, met_grid_type, tdt, geofac_pc, geofac,
&   cose, cosp, dap, dbk, dps, dps_ctm, rel_area, pctm1, pmet2,
&   uu, vv, xmass, ymass)
```

INPUT PARAMETERS:

```
! Model Time step [s]
REAL(fp) :: tdt

! First part of metdata_name, e.g., "NCAR"
CHARACTER(LEN=*) :: metdata_name_org
```

```
! Met grid type, A or C
INTEGER          :: met_grid_type

! Special geometrical factor (geofac) for Polar cap
REAL(fp)         :: geofac_pc

! Cosine of grid box edges and centers
REAL(fp)         :: cose(ju1_gl:j2_gl)
REAL(fp)         :: cosp(ju1_gl:j2_gl)

! Geometrical factor for meridional advection; geofac uses
! correct spherical geometry, and replaces acosp as the
! meridional geometrical factor in tpcore
REAL(fp)         :: geofac(ju1_gl:j2_gl)

! Pressure difference across layer from (ai * pt) term [hPa]
REAL(fp)         :: dap(k1:k2)

! Difference in bi across layer - the dSigma term
REAL(fp)         :: dbk(k1:k2)

! relative surface area of grid box (fraction)
REAL(fp)         :: rel_area( i1_gl:i2_gl, ju1_gl:j2_gl)

! Metfield surface pressure at t1 [hPa]
REAL(fp)         :: pmet2(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! CTM surface pressure at t1 [hPa]
REAL(fp)         :: pctm1(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! CTM surface pressure at t1+tdt [hPa]
REAL(fp)         :: pctm2(ilo_gl:ihi_gl, julo_gl:jhi_gl)

! Wind velocity, x direction at t1+tdt/2 [m/s]
REAL(fp)        :: uu(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)

! Wind velocity, y direction at t1+tdt/2 [m/s]
REAL(fp)        :: vv(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)
```

OUTPUT PARAMETERS:

```
! Horizontal mass flux in E-W direction [hPa]
REAL(fp)  :: xmass(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)

! Horizontal mass flux in N-S direction [hPa]
REAL(fp)  :: ymass(ilo_gl:ihi_gl, julo_gl:jhi_gl, k1_gl:k2_gl)

! Change of surface pressure from met field pressure [hPa]
```

```
      REAL(fp)  :: dps(i1_gl:i2_gl, ju1_gl:j2_gl)

      ! CTM surface pressure tendency [hPa]
      REAL(fp)  :: dps_ctm(i1_gl:i2_gl, ju1_gl:j2_gl)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.6 Do_Press_Fix_Llnl

Subroutine Do_Press_Fix_Llnl fixes the mass fluxes to match the met field pressure tendency.

INTERFACE:

```
      SUBROUTINE Do_Press_Fix_Llnl
     &  (geofac_pc, geofac, dbk, dps, dps_ctm, rel_area,
     &   xmass, ymass, xmass_fixed, ymass_fixed)
```

INPUT PARAMETERS:

```
      ! Special geometrical factor (geofac) for Polar cap
      REAL(fp), INTENT(IN)   :: geofac_pc

      ! Geometrical factor for meridional advection; geofac uses
      ! correct spherical geometry, and replaces acosp as the
      !  meridional geometrical factor in tpcore
      REAL(fp), INTENT(IN)   :: geofac(ju1_gl:j2_gl)

      ! Difference in bi across layer - the dSigma term
      REAL(fp), INTENT(IN)   :: dbk(k1:k2)

      ! Change of surface pressure from met field pressure [hPa]
      REAL(fp), INTENT(IN)   :: dps(i1:i2, ju1:j2)

      ! Relative surface area of grid box (fraction)
      REAL(fp), INTENT(IN)   :: rel_area(i1:i2, ju1:j2)

      ! Horizontal mass fluxes in E-W and N-S directions [hPa]
      REAL(fp), INTENT(IN)   :: xmass(ilo:ihi, julo:jhi, k1:k2)
      REAL(fp), INTENT(IN)   :: ymass(ilo:ihi, julo:jhi, k1:k2)
```

OUTPUT PARAMETERS:

```
! Sum over vertical of dpi calculated from original mass fluxes [hPa]
REAL(fp),  INTENT(OUT) :: dps_ctm(i1:i2, ju1:j2)

! Horizontal mass flux in E-W and N-S directions after fixing [hPa]
REAL(fp),  INTENT(OUT) :: xmass_fixed(ilo:ihi, julo:jhi, k1:k2)
REAL(fp),  INTENT(OUT) :: ymass_fixed(ilo:ihi, julo:jhi, k1:k2)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.7 Average_Press_Poles

Subroutine Average_Press_Poles averages pressure at the Poles when the Polar cap is enlarged. It makes the last two latitudes equal.

INTERFACE:

```
SUBROUTINE Average_Press_Poles
&  (rel_area, press)
```

INPUT PARAMETERS:

```
! Relative surface area of grid box (fraction)
REAL(fp), INTENT(IN)    :: rel_area(i1:i2, ju1:j2)
```

OUTPUT PARAMETERS:

```
! Surface pressure [hPa]
REAL(fp), INTENT(INOUT) :: press   (ilo:ihi, julo:jhi)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.8 Convert_Winds

Subroutine Convert_Winds converts winds on A or C grid to Courant # on C grid.

INTERFACE:

```
SUBROUTINE Convert_Winds
&  (igd, tdt, cosp, crx, cry, uu, vv)
```

USES:

```
USE CMN_SIZE_MOD ! Size parameters
USE PhysConstants! Re, PI
```

INPUT PARAMETERS:

```
! A or C grid
INTEGER, INTENT(IN)  :: igd

! Model time step [s]
REAL(fp),  INTENT(IN)  :: tdt

! Cosine of grid box centers
REAL(fp),  INTENT(IN)  :: cosp(ju1_gl:j2_gl)

! Wind velocity in E-W (UU) and N-S (VV) directions at t1+tdt/2 [m/s]
REAL(fp),  INTENT(IN)  :: uu  (ilo:ihi, julo:jhi, k1:k2)
REAL(fp),  INTENT(IN)  :: vv  (ilo:ihi, julo:jhi, k1:k2)
```

OUTPUT PARAMETERS:

```
! Courant number in E-W (CRX) and N-S (CRY) directions
REAL(fp),  INTENT(OUT) :: crx (ilo:ihi, julo:jhi, k1:k2)
REAL(fp),  INTENT(OUT) :: cry (ilo:ihi, julo:jhi, k1:k2)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REMARKS:

```
Use GEOS-CHEM physical constants Re, PI to be consistent with other
usage everywhere (bmy, 5/5/03)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.9 Calc_Horiz_Mass_Flux

Subroutine Calc_Horiz_Mass_Flux calculates the horizontal mass flux for non-GISS met data.

INTERFACE:

```
      SUBROUTINE Calc_Horiz_Mass_Flux
     &  (cose, delpm, uu, vv, xmass, ymass, tdt, cosp)
```

USES:

```
      USE CMN_SIZE_MOD ! Size parameters
      USE PhysConstants! Re, Pi
```

INPUT PARAMETERS:

```
      ! Timestep [s]
      REAL(fp), INTENT(IN)   :: tdt

      ! Cosine of grid box edges
      REAL(fp), INTENT(IN)   :: cose (ju1_gl:j2_gl)

      ! Cosine of grid box centers
      REAL(fp), INTENT(IN)   :: cosp (ju1_gl:j2_gl)

      ! Pressure thickness, the pseudo-density in a
      ! hdrostatic system  at t1+tdt/2 (approximate) [hPa]
      REAL(fp), INTENT(IN)   :: delpm(ilo:ihi, julo:jhi, k1:k2)

      ! E-W (UU) and N-S (VV) winds [m/s]
      REAL(fp), INTENT(IN)   :: uu  (ilo:ihi, julo:jhi, k1:k2)
      REAL(fp), INTENT(IN)   :: vv  (ilo:ihi, julo:jhi, k1:k2)
```

OUTPUT PARAMETERS:

```
      ! Horizontal mass flux in E-W and N-S directions [hPa]
      REAL(fp), INTENT(OUT)  :: xmass(ilo:ihi, julo:jhi, k1:k2)
      REAL(fp), INTENT(OUT)  :: ymass(ilo:ihi, julo:jhi, k1:k2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REMARKS:

```
Use GEOS-CHEM physical constants Re, PI to be consistent with other
usage everywhere (bmy, 5/5/03)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.10 Calc_Divergence

Subroutine Calc_Divergence calculates the divergence.

INTERFACE:

```
      SUBROUTINE Calc_Divergence
     &  (do_reduction, geofac_pc, geofac, dpi, xmass, ymass)
```

INPUT PARAMETERS:

```
      ! Set to F if called on Master; set to T if called by Slaves
      ! (NOTE: this doesn't seem to be used!)
      LOGICAL, INTENT(IN)    :: do_reduction

      ! Special geometrical factor (geofac) for Polar cap
      REAL(fp),  INTENT(IN)    :: geofac_pc

      ! geometrical factor for meridional advection; geofac uses
      ! correct spherical geometry, and replaces acosp as the
      ! meridional geometrical factor in tpcore
      REAL(fp),  INTENT(IN)    :: geofac(ju1_gl:j2_gl)

      ! horizontal mass fluxes in E-W and N-S directions [hPa]
      REAL(fp),  INTENT(IN)    :: xmass (ilo:ihi, julo:jhi, k1:k2)
      REAL(fp),  INTENT(IN)    :: ymass (ilo:ihi, julo:jhi, k1:k2)
```

INPUT/OUTPUT PARAMETERS:

```
      ! Divergence at a grid point; used to calculate vertical motion [hPa]
      REAL(fp),  INTENT(INOUT) :: dpi   (i1:i2, ju1:j2, k1:k2)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.11 Set_Press_Terms

Subroutine Set_Press_Terms sets the pressure terms.

INTERFACE:

```
 SUBROUTINE Set_Press_Terms
&  (dap, dbk, pres1, pres2, delp1, delpm, pu)
```

INPUT PARAMETERS:

```
! Pressure difference across layer from (ai * pt) term [hPa]
REAL(fp), INTENT(IN)  :: dap  (k1:k2)

! Difference in bi across layer - the dSigma term
REAL(fp), INTENT(IN)  :: dbk  (k1:k2)

! Surface pressure at t1 [hPa]
REAL(fp), INTENT(IN)  :: pres1(ilo:ihi, julo:jhi)

! Surface pressure at t1+tdt [hPa]
REAL(fp), INTENT(IN)  :: pres2(ilo:ihi, julo:jhi)
```

OUTPUT PARAMETERS:

```
! Pressure thickness, the psudo-density in a
! hydrostatic system at t1 [hPa]
REAL(fp), INTENT(OUT) :: delp1(ilo:ihi, julo:jhi, k1:k2)

! Pressure thickness, the psudo-density in a
! hydrostatic system at t1+tdt/2 (approximate)  [hPa]
REAL(fp), INTENT(OUT) :: delpm(ilo:ihi, julo:jhi, k1:k2)

! Pressure at edges in "u" [hPa]
REAL(fp), INTENT(OUT) :: pu   (ilo:ihi, julo:jhi, k1:k2)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).
```

3.2.12 Do_Divergence_Pole_Sum

Do_Divergence_Pole_Sum sets the divergence at the Poles.

INTERFACE:

```
      SUBROUTINE Do_Divergence_Pole_Sum
     &  (do_reduction, geofac_pc, dpi, ymass)
```

INPUT PARAMETERS:

```
      ! Set to T if called on Master; set to F if called by Slaves
      ! (NOTE: This does not seem to be used!)
      LOGICAL :: do_reduction

      ! Special geometrical factor (geofac) for Polar cap
      REAL(fp)  :: geofac_pc

      ! horizontal mass flux in N-S direction [hPa]
      REAL(fp)  :: ymass(ilo:ihi, julo:jhi, k1:k2)
```

OUTPUT PARAMETERS:

```
      ! Divergence at a grid point; used to calculate vertical motion [hPa]
      REAL(fp)  :: dpi  ( i1:i2,   ju1:j2,  k1:k2)
```

AUTHOR:

```
   Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
    02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                                Declare all REAL variables as REAL(fp).
```

3.2.13 Xpavg

!description: Subroutine Xpavg replaces each element of a vector with the average of the entire array. (bmy, 5/7/03)

INTERFACE:

```
      SUBROUTINE Xpavg( P, IM )
```

USES:

```
      ! References to F90 modules
      USE ERROR_MOD, ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      ! Dimension of P
      INTEGER, INTENT(IN)    :: IM
```

INPUT/OUTPUT PARAMETERS:

```
      ! 1-D vector to be averaged
      REAL(fp),  INTENT(INOUT) :: P(IM)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Now make all REAL variables REAL(fp).
```

3.2.14 Init_Pjc_Pfix

Subroutine Init_Pjc_Pfix allocates and initializes module arrays and variables. GMI dimension variables will be used for compatibility with the Phil Cameron-Smith P-fixer. (bdf, bmy, 5/8/03)

INTERFACE:

```
SUBROUTINE Init_Pjc_Pfix
```

USES:

```
! References to F90 modules
USE GC_GRID_MOD,  ONLY : GET_AREA_M2, GET_YMID_R
USE ERROR_MOD,    ONLY : ALLOC_ERR,   ERROR_STOP
USE PRESSURE_MOD, ONLY : GET_AP,      GET_BP

USE CMN_SIZE_MOD  ! Size parameters
USE PhysConstants ! Re, PI, etc...
```

AUTHOR:

```
Brendan Field and Bob Yantosca (5/8/03)
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R(I,J,L) from grid_mod.F90
```

3.2.15 Cleanup_Pjc_Pfix

Subroutine Cleanup_Pjc_Pfix deallocates all module arrays (bmy, 5/8/03)

INTERFACE:

```
SUBROUTINE Cleanup_Pjc_Pfix
```

REVISION HISTORY:

```
02 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
```

3.3 Fortran: Module Interface tpcore_bc_mod.F

Module TPCORE_BC_MOD contains modules and variables which are needed to save and read TPCORE nested-grid boundary conditions to/from disk.

INTERFACE:

```
MODULE TPCORE_BC_MOD
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)
IMPLICIT NONE
PRIVATE
```

PUBLIC DATA MEMBERS:

```
!-------------------------------------------------------------
! I0_W : Lon offset of TPCORE REGION [# boxes]
! J0_W : Lat offset of TPCORE REGION [# boxes]
! IM_W : Lon extent of TPCORE REGION [# boxes]
! JM_W : Lat extent of TPCORE REGION [# boxes]
! I1_W : Lower left-hand  (LL) lon index of NESTED WINDOW
! J1_W : Lower left-hand  (LL) lat index of NESTED WINDOW
! I2_W : Upper right-hand (UR) lon index of NESTED WINDOW
! J2_W : Upper right-hand (UR) lat index of NESTED WINDOW
! IGZD : ???
! Please also see the diagram in the REMARKS section.
!-------------------------------------------------------------
INTEGER, PUBLIC :: I0_W, J0_W
INTEGER, PUBLIC :: I0_E, J0_E
INTEGER, PUBLIC :: I1_W, J1_W
INTEGER, PUBLIC :: I2_W, J2_W
INTEGER, PUBLIC :: IM_W, JM_W
INTEGER, PUBLIC :: IGZD
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: INIT_TPCORE_BC
PUBLIC :: DO_WINDOW_TPCORE_BC
PUBLIC :: SET_CLEAN_BC
PUBLIC :: SAVE_GLOBAL_TPCORE_BC
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: OPEN_BC_FILE
PRIVATE :: CLEAN_WINDOW_TPCORE_BC
PRIVATE :: READ_WINDOW_TPCORE_BC
PRIVATE :: GET_4x5_BC
PRIVATE :: GET_4x5_BC_INIT
PRIVATE :: GET_2x25_BC
PRIVATE :: GET_2x25_BC_INIT
PRIVATE :: ITS_TIME_FOR_BC
PRIVATE :: CLEANUP_TPCORE_BC
```

REMARKS:

Reference Diagram:

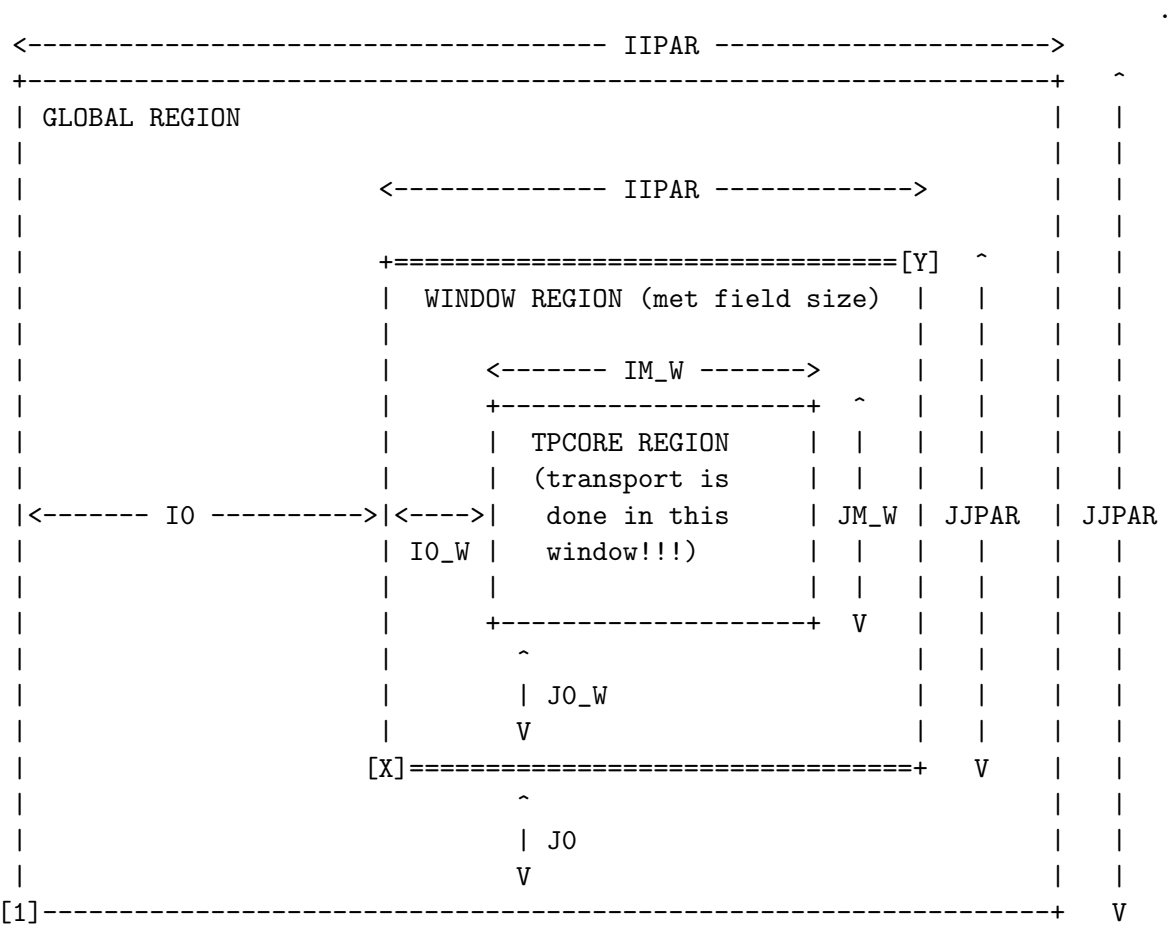


DIAGRAM NOTES:

(a) The outermost box ("Global Region") is the global grid size. This region has IIPAR boxes in longitude and JJPAR boxes in latitude. The origin of the "Global Region" is at the south pole, at the lower left-hand corner (point [1]).

(b) The next innermost box ("Window Region") is the nested-grid window. This region has IIPAR boxes in longitude and JJPAR boxes in latitude. This is the size of the trimmed met fields that will be used for a 1 x 1 "nested-grid" simulation.

(c) The innermost region ("TPCORE Region") is the actual area in which TPCORE transport will be performed. Note that this region is smaller than the "Window Region". It is set up this way since a cushion of grid boxes is needed TPCORE Region for boundary conditions.

(d) I0 is the longitude offset (# of boxes) and J0 is the latitude offset

```
      (# of boxes) which translate between the "Global Region" and the
      "Window Region".

                                                                      .
  (e) I0_W is the longitude offset (# of boxes), and J0_W is the latitude
      offset (# of boxes) which translate between the "Window Region"
      and the "TPCORE Region".

                                                                      .
  (f) The lower left-hand corner of the "Window Region" (point [X]) has
      longitude and latitude indices (I1_W, J1_W).  Similarly, the upper
      right-hand corner (point [Y]) has longitude and latitude indices
      (I2_W, J2_W).

                                                                      .
  (g) Note that if I0=0, J0=0, I0_W=0, J0_W=0, IIPAR=IIPAR, JJPAR=JJPAR
      specifies a global simulation.  In this case the "Window Region"
      totally coincides with the "Global Region".

                                                                      .
  (h) In order for the nested-grid to work we must save out concentrations
      over the WINDOW REGION from a coarse model (e.g. 4x5) corresponding to
      the same WINDOW REGION at 1x1.  These concentrations are copied along
      the edges of the 1x1 WINDOW REGION and are thus used as boundary
      conditions for TPCORE.
```

REVISION HISTORY:

```
  04 Mar 2003 - R. Yantosca - Initial version
  (1 ) Bug fix for LINUX w/ TIMESTAMP_STRING (bmy, 9/29/03)
  (2 ) Now references "tracer_mod.f", "directory_mod.f", and
       "logical_mod.f" (bmy, 7/20/04)
  (3 ) Now get HALFPOLAR for GEOS or GCAP grids (bmy, 6/28/05)
  (4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
  (5 ) Rename arguments in GET_4x5_BC to avoid name conflict (bmy, 10/24/05)
  (6 ) Now use EXPAND_DATE instead of obsolete DATE_STRING (bmy, 3/15/06)
  (7 ) Added 2x2.5 boundary condition output (created GET_2x25_BC).
       Added multi-boundary condition output (NA, EU, CH and Custom region).
       Unternally defined boundary condition regions for NA, EU and CH.
       (amv, bmy, 12/18/09)
  16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
  01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
  15 May 2012 - R. Yantosca - Added ProTeX headers
  06 Aug 2012 - R. Yantosca - Now make IU_BC, IU_BC_NA, IU_BC_EU, IU_BC_CH
                              local variables for findFreeLUN
  07 Sep 2012 - R. Yantosca - Minor fixes for numerical stability
  20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
  21 Nov 2014 - M. Yannetti - Added PRECISION_MOD
  01 Apr 2015 - R. Yantosca - Now add I0_E and J0_E
  03 Aug 2015 - M. Sulprizio- Now make BC and BC_CU separate arrays to avoid
                              confusion and error
  23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                              compatible with the FlexChem implementation
```

```
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

3.3.1 set_clean_bc

Subroutine SET_CLEAN_BC initializes the CLEAN_BC logical flag. CLEAN_BC decides whether or not we will zero the nested-grid tpcore boundary conditions.

INTERFACE:

```
SUBROUTINE SET_CLEAN_BC( THIS_CLEAN_BC )
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN) :: THIS_CLEAN_BC
```

REVISION HISTORY:

```
04 Mar 2003 - R. Yantosca - Initial versioni
15 May 2012 - R. Yantosca - Added ProTeX headers
```

3.3.2 open_bc_file

Subroutine OPEN_BC_FILE opens the file which contains boundary conditions saved from the coarse-grid WINDOW REGION for either reading or writing.

INTERFACE:

```
SUBROUTINE OPEN_BC_FILE( am_I_Root, Input_Opt, RC,
&                        WINDOW,    FOR_READ,  FOR_WRITE )
```

USES:

```
USE BPCH2_MOD,     ONLY : OPEN_BPCH2_FOR_WRITE
USE BPCH2_MOD,     ONLY : OPEN_BPCH2_FOR_READ
USE ErrCode_Mod
USE Input_Opt_Mod, ONLY : OptInput
USE inquireMod,    ONLY : findFreeLUN
USE TIME_MOD,      ONLY : EXPAND_DATE,  GET_NYMD
USE TIME_MOD,      ONLY : ITS_A_NEW_DAY
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
LOGICAL, INTENT(IN), OPTIONAL :: FOR_READ    ! Open file for read?
LOGICAL, INTENT(IN), OPTIONAL :: FOR_WRITE   ! Open file for write?
INTEGER, INTENT(IN)           :: WINDOW      ! Specifies nested region
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
 Pass these values via the WINDOW argument to do the following actions;
   WINDOW = 1 : Save BC's to file (Custom window,        aka "CU")
   WINDOW = 2 : Save BC's to file (North America window, aka "NA")
   WINDOW = 3 : Save BC's to file (Europe window,        aka "EU")
   WINDOW = 4 : Save BC's to file (China/SE Asia window, aka "CH")
   WINDOW = 5 : Read BC's from file
```

REVISION HISTORY:

```
07 Mar 2003 - R. Yantosca - Initial version
(1 ) Now use ITS_A_NEW_DAY from "time_mod.f".  Now references TPBC_DIR
     from "directory_mod.f" (bmy, 7/20/04)
(2 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(3 ) DATE_STRING is now obsolete; use EXPAND_DATE instead (bmy, 3/15/06)
(4 ) Can now read files from different directories (amv, bmy, 12/18/09)
15 May 2012 - R. Yantosca - Added ProTeX headers
06 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
06 Aug 2012 - R. Yantosca - Cleaned up IF statement, added comments
06 Aug 2012 - R. Yantosca - Close existing files before opening new files
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Removed SEAC4RS C-preprocessor switch
```

3.3.3 save_global_tpcore_bc

Subroutine SAVE_GLOBAL_TPCORE_BC saves concentrations from the WINDOW REGION of a coarse-resolution model run to a bpch file. A new boundary conditions file is created for each day.

INTERFACE:

```
      SUBROUTINE SAVE_GLOBAL_TPCORE_BC( am_I_Root, Input_Opt,
     &                                  State_Chm, RC         )
```

USES:

```
      USE BPCH2_MOD
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_NYMD,  GET_NHMS
      USE TIME_MOD,           ONLY : GET_TAU,   TIMESTAMP_STRING
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
04 Mar 2003 - Y. Wang     - Initial version
(1 ) Now references N_TRACERS and STT from "tracer_mod.f".  Also now
     references TIMESTAMP_STRING from "time_mod.f".  (bmy, 7/20/04)
(2 ) Now call GET_HALFPOLAR from "bpch2_mod.f" to get the HALFPOLAR flag
     value for GEOS or GCAP grids (bmy, 6/28/05)
(3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4 ) Can now save files to different directories (amv, bmy, 12/18/09)
16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
15 May 2012 - R. Yantosca - Added ProTeX headers
06 Aug 2012 - R. Yantosca - Added comments & cosmetic changes
06 Aug 2012 - R. Yantosca - Now use file unit variables from this module
                            instead of from GeosUtil/file_mod.F
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
17 Feb 2014 - E. Lundgren - Move temporary unit change to vol/vol to within
                            this subroutine
13 Aug 2015 - E. Lundgren - Tracer units are now [kg/kg dry air]
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
03 Aug 2016 - R. Yantosca - Remove temporary tracer removal code
```

3.3.4 do_window_tpcore_bc

Subroutine DO_WINDOW_TPCORE_BC is a driver routine for assigning TPCORE boundary conditions to the tracer array Spc.

INTERFACE:

```
SUBROUTINE DO_WINDOW_TPCORE_BC( am_I_Root, Input_Opt,
&                               State_Chm, RC         )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
07 Mar 2003 - R. Yantosca - Initial version
(1 ) Now references N_TRACERS and STT from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now can use 2 x 2.5 BC's (amv, bmy, 12/18/09)
16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
08 Dec 2009 - R. Yantosca - Added ProTeX headers
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
13 Aug 2014 - E. Lundgren - Tracer units are now [kg/kg dry air]
03 Aug 2016 - R. Yantosca - Remove temporary tracer removal code
```

3.3.5 clean_window_tpcore_bc

Subroutine CLEAN_WINDOW_TPCORE_BC zeroes the boundary conditions array BC at each timestep. (bmy, 3/7/03, 12/18/09)

INTERFACE:

```
SUBROUTINE CLEAN_WINDOW_TPCORE_BC( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
07 Mar 2003 - M. Prather  - Initial version
(1 ) Now references N_TRACERS from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now zeroes the arrays for the different regions (amv, bmy, 12/18/09)
16 Feb 2011 - R. Yantosca - Add modifications for APM microphysics (G. Luo)
15 May 2012 - R. Yantosca - Added ProTeX headers
07 Sep 2012 - R. Yantosca - Simplify coding, remove parallel loops
07 Sep 2012 - R. Yantosca - Now use 0e+0_fp instead of 0e0 to zero BC arrays
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Removed SEAC4RS C-preprocessor switch
```

3.3.6 read_window_tpcore_bc

Subroutine READ_WINDOW_TPCORE_BC reads tracer concentrations saved on the WINDOW REGION of a coarse-grid simulation (e.g. 4x5, 2x2.5). These concentrations will be used as boundary conditions for TPCORE transport.

INTERFACE:

```
      SUBROUTINE READ_WINDOW_TPCORE_BC( am_I_Root, Input_Opt,
     &                                  State_Chm, RC         )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TAU, TIMESTAMP_STRING
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry state object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
07 Mar 2003 - R. Yantosca - Initial version
(1 ) LINUX has a problem putting a function call w/in a WRITE statement.
     Now save output from TIMESTAMP_STRING to STAMP and print that.
     (bmy, 9/29/03)
```

```
(2 ) Now references N_TRACERS from "tracer_mod.f" (bmy, 7/20/04)
(3 ) Rewritten to be more generic (amv, bmy, 12/18/09)
15 May 2012 - R. Yantosca - Added ProTeX headers
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
```

3.3.7 get_4x5_bc_init

Function GET_4x5_BC_INIT initializes the MAP1x1 arrays.

INTERFACE:

```
SUBROUTINE GET_4x5_BC_INIT
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD,  ONLY : GET_XMID, GET_YMID
```

REMARKS:

```
NOTE: This routine was originally written for the 1 x 1 nested grid,
but this now works for the GEOS-5 0.5 x 0.666 nested grid data.  Keep
variable names I_1x1, J_1x1, etc. unchanged for the present.

For now we will assume that we have saved tracer concentrations from
a  4x5 window which overlays the corresponding 1x1 WINDOW REGION.
These 4x5 tracer concentrations are used as boundary conditions for
TPCORE.
```

REVISION HISTORY:

```
07 Mar 2003 - Y. Wang, R. Yantosca - Initial version
(1 ) Rename arguments to avoid conflict w/ I1x1, J1x1 parameters in
      CMN_SIZE. (bmy, 10/24/05)
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
15 May 2012 - R. Yantosca - Added ProTeX headers
10 Nov 2014 - C. Keller   - Split off from GET_4x5_BC
```

3.3.8 get_4x5_bc

Function GET_4x5_BC returns a value from the 4x5 BC boundary conditions array at the location of a nested grid box.

INTERFACE:

```
FUNCTION GET_4x5_BC( I_1x1, J_1x1, L_1x1, N_1x1 ) RESULT( VALUE )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I_1x1   ! Nested-grid lon    index
INTEGER, INTENT(IN) :: J_1x1   ! Nested-grid lat    index
INTEGER, INTENT(IN) :: L_1x1   ! Nested-grid level  index
INTEGER, INTENT(IN) :: N_1x1   ! Nested-grid tracer index
```

RETURN VALUE:

```
REAL(fp)              :: VALUE   ! 4 x 5 BC @ location of nested grid box
```

REMARKS:

```
NOTE: This routine was originally written for the 1 x 1 nested grid,
but this now works for the GEOS-5 0.5 x 0.666 nested grid data.  Keep
variable names I_1x1, J_1x1, etc. unchanged for the present.

                                                                      .
For now we will assume that we have saved tracer concentrations from
a  4x5 window which overlays the corresponding 1x1 WINDOW REGION.
These 4x5 tracer concentrations are used as boundary conditions for
TPCORE.
```

REVISION HISTORY:

```
07 Mar 2003 - Y. Wang, R. Yantosca - Initial version
(1 ) Rename arguments to avoid conflict w/ I1x1, J1x1 parameters in
      CMN_SIZE. (bmy, 10/24/05)
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
15 May 2012 - R. Yantosca - Added ProTeX headers
10 Nov 2014 - C. Keller   - Now initialize MAP1x1 array in separate routine
```

3.3.9 get_2x25_bc_init

Function GET_2x25_BC_INIT initializes the 2x25 mapping values.

INTERFACE:

```
SUBROUTINE GET_2x25_BC_INIT
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD, ONLY : GET_XMID, GET_YMID
```

RETURN VALUE:

REMARKS:

```
NOTE: This routine was originally written for the 1 x 1 nested grid,
but this now works for the GEOS-5 0.5 x 0.666 nested grid data.  Keep
variable names I_1x1, J_1x1, etc. unchanged for the present.

For now we will assume that we have saved tracer concentrations from
a 2 x 2.5 window which overlays the corresponding NESTED WINDOW REGION.
These 2 x 2.5 tracer concentrations are used as boundary conditions
for TPCORE.
```

REVISION HISTORY:

```
18 Dec 2009 - A. van Donkeelar - Initial version
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
15 May 2012 - R. Yantosca - Added ProTeX headers
10 Nov 2014 - C. Keller   - Split off from GET_2x25_BC. Now account
                            for high-res midpoints on edges.
```

3.3.10 get_2x25_bc

Function GET_2x25_BC returns a value from the 2 x 2.5 BC boundary conditions array at the location of a nested grid box.

INTERFACE:

```
FUNCTION GET_2x25_BC( I_1x1, J_1x1, L_1x1, N_1x1 ) RESULT( VALUE )
```

USES:

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I_1x1   ! Nested-grid lon    index
INTEGER, INTENT(IN) :: J_1x1   ! Nested-grid lat    index
INTEGER, INTENT(IN) :: L_1x1   ! Nested-grid level  index
INTEGER, INTENT(IN) :: N_1x1   ! Nested-grid tracer index
```

RETURN VALUE:

```
REAL(fp)              :: VALUE   ! 2 x 2.5 BC @ location of nested grid box
```

REMARKS:

```
NOTE: This routine was originally written for the 1 x 1 nested grid,
but this now works for the GEOS-5 0.5 x 0.666 nested grid data.  Keep
variable names I_1x1, J_1x1, etc. unchanged for the present.

For now we will assume that we have saved tracer concentrations from
a 2 x 2.5 window which overlays the corresponding NESTED WINDOW REGION.
These 2 x 2.5 tracer concentrations are used as boundary conditions
for TPCORE.
```

REVISION HISTORY:

```
18 Dec 2009 - A. van Donkeelar - Initial version
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
15 May 2012 - R. Yantosca - Added ProTeX headers
10 Nov 2014 - C. Keller   - Now initialize MAP1x1 array in separate routine
                            Also account for high-res midpoint on edges.
```

3.3.11 its_time_for_bc

Subroutine ITS_TIME_FOR_BC returns TRUE if it is time to read in the next set of boundary conditions for TPCORE, or FALSE otherwise.

INTERFACE:

```
FUNCTION ITS_TIME_FOR_BC() RESULT( FLAG )
```

USES:

```
USE TIME_MOD, ONLY : GET_ELAPSED_MIN
```

RETURN VALUE:

```
LOGICAL :: FLAG   ! =T if it's time to read BC's from disk
```

REVISION HISTORY:

```
05 Mar 2003 - R. Yantosca - Initial version
15 May 2012 - R. Yantosca - Added ProTeX headers
```

3.3.12 init_tpcore_bc

Subroutine INIT_TPCORE_BC initializes module variables and arrays.

INTERFACE:

```
SUBROUTINE INIT_TPCORE_BC( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE GC_GRID_MOD,        ONLY : GET_XOFFSET, GET_YOFFSET
USE GC_GRID_MOD,        ONLY : ITS_A_NESTED_GRID
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure
```

REVISION HISTORY:

```
10 Feb 2003 - R. Yantosca - Initial version
(1 ) Now references N_TRACERS from "tracer_mod.f".  Now references LWINDO
     from "logical_mod.f".  Now references TPBC_DIR from "directory_mod.f".
     Now references ITS_A_NESTED_GRID from "grid_mod.f".  Also added
     arguments to take values from "input_mod.f". (bmy, 7/20/04)
15 May 2012 - R. Yantosca - Added ProTeX headers
07 Sep 2012 - R. Yantosca - Now use 0e+0_fp instead of 0e0 to zero BC arrays
17 Oct 2012 - M. Payer    - Bug fix: Define extent of coarse grid BC region
                            even if LWINDO_CH = False to avoid out-of-bounds
                            errors in array BC
05 Jun 2013 - K. Yu       - Define BC boundaries for GEOS_57 0.25 NA grid
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Removed SEAC4RS C-preprocessor switch
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
01 Apr 2015 - L. Zhang    - IM_W, JM_W are no longer symmetric, but are
                            computed from I0_E and J0_E
```

3.3.13 cleanup_tpcore_bc

Subroutine CLEANUP_TPCORE_BC deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_TPCORE_BC
```

REVISION HISTORY:

```
04 Mar 2003 - R. Yantosca - Initial version
15 May 2012 - R. Yantosca - Added ProTeX headers
```

3.4 Fortran: Module Interface tpcore_fvdas_mod.F90

Overview

Module Tpcore_Fvdas_Mod contains routines for the TPCORE transport scheme, as implemented in the GMI model (cf. John Tannahill), based on Lin Rood 1995. The Harvard Atmospheric Chemistry Modeling Group has added modifications to implement the Philip-Cameron Smith pressure fixer for mass conservation. Mass flux diagnostics have also been added.

References

1. Lin, S.-J., and R. B. Rood, 1996: *Multidimensional flux form semi-Lagrangian transport schemes*, Mon. Wea. Rev., **124**, 2046-2070.

2. Lin, S.-J., W. C. Chao, Y. C. Sud, and G. K. Walker, 1994: *A class of the van Leer-type transport schemes and its applications to the moisture transport in a General Circulation Model*, Mon. Wea. Rev., **122**, 1575-1593.

Selecting E/W, N/S and vertical advection options

The flags IORD, JORD, KORD select which transport schemes are used in the E/W, N/S, and vertical directions, respectively. Here is a list of the possible values that IORD, JORD, KORD may be set to (original notes from S-J Lin):

1. 1st order upstream scheme (too diffusive, not a real option; it can be used for debugging purposes; this is THE only known "linear" monotonic advection scheme.).
2. 2nd order van Leer (full monotonicity constraint; see Lin et al 1994, MWR)
3. monotonic PPM* (Collela & Woodward 1984)
4. semi-monotonic PPM (same as 3, but overshoots are allowed)
5. positive-definite PPM (constraint on the subgrid distribution is only strong enough to prevent generation of negative values; both overshoots & undershoots are possible).
6. un-constrained PPM (nearly diffusion free; faster but positivity of the subgrid distribution is not quaranteed. Use this option only when the fields and winds are very smooth.
7. Huynh/Van Leer/Lin full monotonicity constraint. Only KORD can be set to 7 to enable the use of Huynh's 2nd monotonicity constraint for piece-wise parabolic distribution.

Recommended values:

- IORD=JORD=3 for high horizontal resolution.
- KORD=3 or 7

The implicit numerical diffusion decreases as _ORD increases. DO NOT use option 4 or 5 for non-positive definite scalars (such as Ertel Potential Vorticity).

In GEOS-Chem we have been using IORD=3, JORD=3, KORD=7. We have tested the OpenMP parallelization with these options. GEOS-Chem users who wish to use different (I,J,K)ORD options should consider doing single-procsessor vs. multi-processor tests to test the implementation of the parallelization.

GEOS-4 and GEOS-5 Hybrid Grid Definition

For GEOS-4 and GEOS-5 met fields, the pressure at the bottom edge of grid box (I,J,L) is defined as follows:

$$P_{edge}(I,J,L) = A_k(L) + [B_k(L) * P_{surface}(I,J)]$$

where

- $P_{surface}$(I,J) is the "true" surface pressure at lon,lat (I,J)
- A_k(L) has the same units as surface pressure [hPa]
- B_k(L) is a unitless constant given at level edges

$A_k(L)$ and $B_k(L)$ are supplied to us by GMAO.

REMARKS:

```
 Ak(L) and Bk(L) are defined at layer edges.
                 ////////////////////////////////
              / \ ------ Model top P=ak(1) --------- ak(1), bk(1)
               |
   delp(1)     |  ..........  q(i,j,1) ............
               |
              \ / ---------------------------------  ak(2), bk(2)
              / \ ---------------------------------  ak(k), bk(k)
               |
   delp(k)     |  ..........  q(i,j,k) ............
               |
              \ / ---------------------------------  ak(k+1), bk(k+1)
              / \ ---------------------------------  ak(km), bk(km)
               |
   delp(km)    |  ..........  q(i,j,km) .........
               |
              \ / -----Earth's surface P=Psfc ------ ak(km+1), bk(km+1)
                ////////////////////////////////
 Note: surface pressure can be of any unit (e.g., pascal or mb) as
 long as it is consistent with the definition of (ak, bk) defined above.
 Winds (u,v), ps, and q are assumed to be defined at the same points.

 The latitudes are given to the initialization routine: init_tpcore.
```

INTERFACE:

```
MODULE Tpcore_FvDas_Mod
```

USES:

```
 USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

 IMPLICIT NONE
 PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  ::  Init_Tpcore
PUBLIC  ::  Exit_Tpcore
PUBLIC  ::  Tpcore_FvDas
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE ::  Average_Const_Poles
PRIVATE ::  Set_Cross_Terms
PRIVATE ::  Calc_Vert_Mass_Flux
PRIVATE ::  Set_Jn_Js
PRIVATE ::  Calc_Advec_Cross_Terms
PRIVATE ::  Qckxyz
PRIVATE ::  Set_Lmts
PRIVATE ::  Set_Press_Terms
PRIVATE ::  Calc_Courant
PRIVATE ::  Calc_Divergence
PRIVATE ::  Do_Divergence_Pole_Sum
PRIVATE ::  Do_Cross_Terms_Pole_I2d2
PRIVATE ::  Xadv_Dao2
PRIVATE ::  Yadv_Dao2
PRIVATE ::  Do_Yadv_Pole_I2d2
PRIVATE ::  Do_Yadv_Pole_Sum
PRIVATE ::  Xtp
PRIVATE ::  Xmist
PRIVATE ::  Fxppm
PRIVATE ::  Lmtppm
PRIVATE ::  Ytp
PRIVATE ::  Ymist
PRIVATE ::  Do_Ymist_Pole1_I2d2
PRIVATE ::  Do_Ymist_Pole2_I2d2
PRIVATE ::  Fyppm
PRIVATE ::  Do_Fyppm_Pole_I2d2
PRIVATE ::  Do_Ytp_Pole_Sum
PRIVATE ::  Fzppm
PRIVATE ::  Average_Press_Poles
!PRIVATE DATA MEMBERS:

REAL(fp), ALLOCATABLE, SAVE :: dtdx5(:)
REAL(fp), ALLOCATABLE, SAVE :: dtdy5(:)
REAL(fp), ALLOCATABLE, SAVE :: cosp(:)
REAL(fp), ALLOCATABLE, SAVE :: cose(:)
REAL(fp), ALLOCATABLE, SAVE :: gw(:)
REAL(fp), ALLOCATABLE, SAVE :: DLAT(:)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, GMAO
Modified for GMI model by John Tannahill, LLNL (jrt@llnl.gov)
```

```
Implemented into GEOS-Chem by Claire Carouge (ccarouge@seas.harvard.edu)
ProTeX documentation added by Bob Yantosca (yantosca@seas.harvard.edu)
OpenMP parallelization added by Bob Yantosca (yantosca@seas.harvard.edu)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from the GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Added
                            OpenMP parallel loops in various routines (and
                            made some modifications to facilitate OpenMP).
01 Apr 2009 - C. Carouge  - Modified OpenMp parallelization and move the
                            loops over vertical levels outside the
                            horizontal transport routines for reducing
                            processing time.
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
21 Nov 2014 - M. Yannetti - Added PRECISION_MOD
19 Jan 2016 - E. Lundgren - Consolidated bpch and netcdf diagnostics code
```

3.4.1 Init_Tpcore

Subroutine Init_Tpcore allocates and initializes all module variables,

INTERFACE:

```
SUBROUTINE Init_Tpcore( IM, JM, KM, JFIRST, JLAST, NG, MG, dt, ae, clat )
```

USES:

```
USE PhysConstants
```

INPUT PARAMETERS:

```
INTEGER,   INTENT(IN)  :: IM        ! Global E-W dimension
INTEGER,   INTENT(IN)  :: JM        ! Global N-S dimension
INTEGER,   INTENT(IN)  :: KM        ! Vertical dimension
INTEGER,   INTENT(IN)  :: NG        ! large ghost width
INTEGER,   INTENT(IN)  :: MG        ! small ghost width
REAL(fp),  INTENT(IN)  :: dt        ! Time step in seconds
REAL(fp),  INTENT(IN)  :: ae        ! Earth's radius (m)
REAL(fp),  INTENT(IN)  :: clat(JM)  ! latitude in radian
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: JFIRST    ! Local first index for N-S direction
INTEGER, INTENT(OUT) :: JLAST     ! Local last  index for N-S direction
```

REVISION HISTORY:

```
     05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                                 Yeh with the TPCORE routines from GMI model.
                                 This eliminates the polar overshoot in the
                                 stratosphere.
     05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                                 Declare all REAL variables as REAL(fp).  Also
                                 make sure all numerical constants are declared
                                 with the "D" double-precision exponent.
```

3.4.2 Exit_Tpcore

Subroutine Exit_Tpcore deallocates all module variables.

INTERFACE:

```
   SUBROUTINE Exit_Tpcore
```

REVISION HISTORY:

```
     05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                                 Yeh with the TPCORE routines from GMI model.
                                 This eliminates the polar overshoot in the
                                 stratosphere.
     05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                                 Declare all REAL variables as REAL(fp).  Also
                                 make sure all numerical constants are declared
                                 with the "D" double-precision exponent.
     12 Feb 2015 - E. Lundgren - Add new diagnostic arrays for writing
                                 diagnostics ND24, ND25, and ND26 to netcdf.
```

3.4.3 Tpcore_FvDas

Subroutine Tpcore_FvDas takes horizontal winds on sigma (or hybrid sigma-p) surfaces and calculates mass fluxes, and then updates the 3D mixing ratio fields one time step (tdt). The basic scheme is a Multi-Dimensional Flux Form Semi-Lagrangian (FFSL) based on the van Leer or PPM (see Lin and Rood, 1995).

INTERFACE:

```
   SUBROUTINE Tpcore_FvDas( dt,       ae,       IM,       JM,      KM,       &
                            JFIRST,   JLAST,    ng,       mg,      nq,       &
                            ak,       bk,       u,        v,       ps1,      &
                            ps2,      ps,       q,        iord,    jord,     &
                            kord,     n_adj,    XMASS,    YMASS,   FILL,     &
 #if defined( BPCH_DIAG ) || defined( NC_DIAG )
  !%%% Adding DiagnArrays for writing diagnostics to netcdf (ewl, 2/12/15).
  !%%% MASSFLEW, MASSFLNS, and MASSFLUP are cumulative when BPCH=y.
```

```
  !%%% They are instantaneous when using NETCDF
                            MASSFLEW, MASSFLNS, MASSFLUP,                    &
 #endif
                            AREA_M2, ND24, ND25, ND26 )
```

USES:

```
    ! Include files w/ physical constants and met values
    USE PhysConstants
```

INPUT PARAMETERS:

```
    ! Transport time step [s]
    REAL(fp),  INTENT(IN)  :: dt

    ! Earth's radius [m]
    REAL(fp),  INTENT(IN)  :: ae

    ! Global E-W, N-S, and vertical dimensions
    INTEGER, INTENT(IN)    :: IM
    INTEGER, INTENT(IN)    :: JM
    INTEGER, INTENT(IN)    :: KM

    ! Latitude indices for local first box and local last box
    ! (NOTE: for global grids these are 1 and JM, respectively)
    INTEGER, INTENT(IN)    :: JFIRST
    INTEGER, INTENT(IN)    :: JLAST

    ! Primary ghost region
    ! (NOTE: only required for MPI parallelization; use 0 otherwise)
    INTEGER, INTENT(IN)    :: ng

    ! Secondary ghost region
    ! (NOTE: only required for MPI parallelization; use 0 otherwise)
    INTEGER, INTENT(IN)    :: mg

    ! Ghosted latitudes (3 required by PPM)
    ! (NOTE: only required for MPI parallelization; use 0 otherwise)
    INTEGER, INTENT(IN)    :: nq

    ! Flags to denote E-W, N-S, and vertical transport schemes
    INTEGER, INTENT(IN)    :: iord
    INTEGER, INTENT(IN)    :: jord
    INTEGER, INTENT(IN)    :: kord

    ! Number of adjustments to air_mass_flux (0 = no adjustment)
    INTEGER, INTENT(IN)    :: n_adj

    ! Ak and Bk coordinates to specify the hybrid grid
```

```
    ! (see the REMARKS section below)
    REAL(fp),  INTENT(IN)  :: ak(KM+1)
    REAL(fp),  INTENT(IN)  :: bk(KM+1)

    ! u-wind (m/s) at mid-time-level (t=t+dt/2)
    REAL(fp),  INTENT(IN)  :: u(:,:,:)

    ! E/W and N/S mass fluxes [kg/s]
    ! (These are computed by the pressure fixer, and passed into TPCORE)
    REAL(fp),  INTENT(IN)  :: XMASS(:,:,:)
    REAL(fp),  INTENT(IN)  :: YMASS(:,:,:)

    ! Grid box surface area for mass flux diag [m2]
    REAL(fp),  INTENT(IN)  :: AREA_M2(JM)

    ! Diagnostic flags
    INTEGER, INTENT(IN)    :: ND24    ! Turns on E/W     flux diagnostic
    INTEGER, INTENT(IN)    :: ND25    ! Turns on N/S     flux diagnostic
    INTEGER, INTENT(IN)    :: ND26    ! Turns on up/down flux diagnostic

    LOGICAL, INTENT(IN)    :: FILL    ! Fill negatives ?
```

INPUT/OUTPUT PARAMETERS:

```
    ! V-wind (m/s) at mid-time-level (t=t+dt/2)
    REAL(fp),  INTENT(INOUT) :: v(:,:,:)

    ! surface pressure at current time
    REAL(fp),  INTENT(INOUT) :: ps1(IM, JFIRST:JLAST)

    ! surface pressure at future time=t+dt
    REAL(fp),  INTENT(INOUT) :: ps2(IM, JFIRST:JLAST)

    ! Tracer "mixing ratios" [kg tracer/moist air kg]
    REAL(fp),  INTENT(INOUT), TARGET :: q(:,:,:,:)

#if defined( BPCH_DIAG ) || defined( NC_DIAG )
    ! E/W, N/S, and up/down diagnostic mass fluxes
    REAL(fp),  INTENT(INOUT) :: MASSFLEW(:,:,:,:)  ! for ND24 diagnostic
    REAL(fp),  INTENT(INOUT) :: MASSFLNS(:,:,:,:)  ! for ND25 diagnostic
    REAL(fp),  INTENT(INOUT) :: MASSFLUP(:,:,:,:)  ! for ND26 diagnostic
#endif
```

OUTPUT PARAMETERS:

```
    ! "Predicted" surface pressure [hPa]
    REAL(fp),  INTENT(OUT)   :: ps(IM,JFIRST:JLAST)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Modified OpenMp parallelization and move the
                            loops over vertical levels outside the
                            horizontal transport routines for reducing
                            processing time.
03 Dec 2009 - C. Carouge  - Modify declarations of MASSFLEW, MASSFLNS and
                            MASSFLUP to save memory space.
30 May 2013 - S. Farina   - For TOMAS, zero out UA and VA variables
04 Jun 2013 - R. Yantosca - Use assumed-shape declarations for XMASS, YMASS,
                            U, V, and Q arrays.  These arrays are used to
                            pass pointer references, so this may help to
                            reduce the creation of array temporaries,
                            which will reduce memory.
 5 Jun 2013 - R. Yantosca - Avoid array temporary in call to FZPPM
15 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                            (previously v/v)
01 Jul 2015 - E. Lundgren - Set tracer conc to small positive number if
                            negative at end of advection (occurs at poles)
```

3.4.4 Average_Const_Poles

Subroutine Average_Const_Poles averages the species concentrations at the Poles when the Polar cap is enlarged. It makes the last two latitudes equal.

INTERFACE:

```
SUBROUTINE Average_Const_Poles( dap ,   dbk,   rel_area, pctm1, const1, &
                                JU1_GL, J2_GL, I2_GL,    I1,    I2,     &
                                JU1,    J2,    ILO,    &
                                IHI,    JULO,  JHI )
```

INPUT PARAMETERS:

```
! Global latitude indices of the South Pole and North Pole
```

```
INTEGER, INTENT(IN)   :: JU1_GL, J2_GL

! Global max longitude index
INTEGER, INTENT(IN)   :: I2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)   :: I1,  I2
INTEGER, INTENT(IN)   :: JU1, J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: ILO,  IHI
INTEGER, INTENT(IN)   :: JULO, JHI

! Pressure difference across layer from (ai * pt) term [hPa]
REAL(fp),  INTENT(IN)   :: dap

! Difference in bi across layer - the dSigma term
REAL(fp),  INTENT(IN)   :: dbk

! Relative surface area of grid box [fraction]
REAL(fp),  INTENT(IN)   :: rel_area(JU1:J2)

! CTM surface pressure at t1 [hPa]
REAL(fp),  INTENT(IN)   :: pctm1( ILO:IHI, JULO:JHI )
```

INPUT/OUTPUT PARAMETERS:

```
! Species concentration, known at zone center [mixing ratio]
REAL(fp), INTENT(INOUT) :: const1( I1:I2, JU1:J2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

3.4.5 Set_Cross_Terms

Subroutine Set_Cross_Terms sets the cross terms for E-W horizontal advection.

INTERFACE:

```
SUBROUTINE Set_Cross_Terms( crx,   cry,   ua, va, J1P,   J2P,   &
                            I1_GL, I2_GL, JU1_GL, J2_GL, ILO,   &
                            IHI,   JULO,  JHI,    I1,    I2,    &
                            JU1,   J2,    CROSS )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)   :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: I1_GL,  I2_GL
INTEGER, INTENT(IN)   :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)   :: I1,     I2
INTEGER, INTENT(IN)   :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: ILO,    IHI
INTEGER, INTENT(IN)   :: JULO,   JHI

! Courant number in E-W direction
REAL(fp),  INTENT(IN) :: crx(ILO:IHI, JULO:JHI)

! Courant number in N-S direction
REAL(fp),  INTENT(IN) :: cry(ILO:IHI, JULO:JHI)

! Logical switch.  If CROSS=T then cross-terms will be computed.
LOGICAL, INTENT(IN) :: CROSS
```

OUTPUT PARAMETERS:

```
! Average of Courant numbers from il and il+1
REAL(fp), INTENT(OUT) :: ua(ILO:IHI, JULO:JHI)

! Average of Courant numbers from ij and ij+1
REAL(fp), INTENT(OUT) :: va(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
```

```
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.6 Calc_Vert_Mass_Flux

Subroutine Calc_Vert_Mass_Flux calculates the vertical mass flux.

INTERFACE:

```
SUBROUTINE Calc_Vert_Mass_Flux( dbk, dps_ctm, dpi, wz, I1,  &
                                I2,  JU1,     J2,  K1, K2 )
```

INPUT PARAMETERS:

```
! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)   :: I1,  I2
INTEGER, INTENT(IN)   :: JU1, J2
INTEGER, INTENT(IN)   :: K1,  K2

! Difference in bi across layer - the dSigma term
REAL(fp),  INTENT(IN)  :: dbk(K1:K2)

! CTM surface pressure tendency; sum over vertical of dpi
! calculated from original mass fluxes [hPa]
REAL(fp),  INTENT(IN)  :: dps_ctm(I1:I2, JU1:J2)

! Divergence at a grid point; used to calculate vertical motion [mb]
REAL(fp),  INTENT(IN)  :: dpi(I1:I2, JU1:J2, K1:K2)
```

OUTPUT PARAMETERS:

```
! Large scale mass flux (per time step tdt) in the vertical
! direction as diagnosed from the hydrostatic relationship [hPa]
REAL(fp), INTENT(OUT) :: wz(I1:I2, JU1:J2, K1:K2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops
```

3.4.7 Set_Jn_Js

Subroutine Set_Jn_Js determines Jn and Js, by looking where Courant number is ¿ 1.

INTERFACE:

```
SUBROUTINE Set_Jn_Js( jn,  js,     crx,   ILO, IHI, JULO, &
                      JHI, JU1_GL, J2_GL, J1P, J2P, I1,   &
                      I2,  JU1,    J2,    K1,  K2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)   :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)   :: I1,     I2
INTEGER, INTENT(IN)   :: JU1,    J2
INTEGER, INTENT(IN)   :: K1,     K2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: ILO,    IHI
INTEGER, INTENT(IN)   :: JULO,   JHI

! Courant number in E-W direction
REAL(fp),  INTENT(IN)  :: crx(ILO:IHI, JULO:JHI, K1:K2)
```

OUTPUT PARAMETERS:

```
! Northward of latitude index = jn; Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(OUT) :: jn(K1:K2)

! Southward of latitude index = js; Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(OUT) :: js(K1:K2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REMARKS:

```
We cannot parallelize this subroutine because there is a CYCLE statement
within the outer loop.
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

3.4.8 Calc_Advec_Cross_Terms

Subroutine Calc_Advec_Cross_Terms calculates the advective cross terms.

INTERFACE:

```
SUBROUTINE Calc_Advec_Cross_Terms( jn,     js,    qq1,  qqu,  qqv,   &
                                   ua,     va,    J1P,  J2P,  I2_GL, &
                                   JU1_GL, J2_GL, ILO,  IHI,  JULO,  &
                                   JHI,    I1,    I2,   JU1,  J2,    &
                                   CROSS )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
```

```
INTEGER, INTENT(IN)  ::         I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Northward of latitude index = jn, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)  :: Jn

! Southward of latitude index = js, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)  :: Js

! Species concentration (mixing ratio)
REAL(fp),  INTENT(IN)  :: qq1(ILO:IHI, JULO:JHI)

! Average of Courant numbers from il and il+1
REAL(fp),  INTENT(IN)  :: ua (ILO:IHI, JULO:JHI)

! Average of Courant numbers from ij and ij+1
REAL(fp),  INTENT(IN)  :: va (ILO:IHI, JULO:JHI)

! Logical switch: If CROSS=T then cross-terms are being computed
LOGICAL, INTENT(IN)  :: CROSS
```

OUTPUT PARAMETERS:

```
! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(OUT) :: qqu(ILO:IHI, JULO:JHI)

! concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(OUT) :: qqv(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
```

```
                              stratosphere.
     05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                              Declare all REAL variables as REAL(fp).  Also
                              make sure all numerical constants are declared
                              with the "D" double-precision exponent.  Added
                              OpenMP parallel do loops.
     01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.9 Qckxyz

Subroutine Qckxyz routine checks for "filling".

INTERFACE:

```
SUBROUTINE Qckxyz( dq1, J1P, J2P,  JU1_GL, J2_GL, &
                   ILO, IHI, JULO, JHI,    I1,    &
                   I2,  JU1, J2,   K1,     K2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max latitude (J) indices
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2
INTEGER, INTENT(IN)  :: K1,     K2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI
```

INPUT/OUTPUT PARAMETERS:

```
! Species density [hPa]
REAL(fp),  INTENT(INOUT) :: dq1(ILO:IHI, JULO:JHI, K1:K2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
```

3.4.10 Set_Lmts

Subroutine Set_Lmts sets ILMT, JLMT, KLMT.

INTERFACE:

```
SUBROUTINE Set_Lmts( ilmt, jlmt, klmt, I2_GL, J2_GL, iord, jord, kord )
```

INPUT PARAMETERS:

```
! Global maximum longitude (I) and longitude (J) indices
INTEGER, INTENT(IN)  :: I2_GL, J2_GL

! Flags to denote E-W, N-S, and vertical transport schemes
! (See REMARKS section of routine Tpcore_FvDas for more info)
INTEGER, INTENT(IN)  :: iord, jord, kord
```

OUTPUT PARAMETERS:

```
! Controls various options in E-W advection
INTEGER, INTENT(OUT) :: ilmt

! Controls various options in N-S advection
INTEGER, INTENT(OUT) :: jlmt

! Controls various options in vertical advection
INTEGER, INTENT(OUT) :: klmt
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
```

```
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

3.4.11 Set_Press_Terms

Subroutine Set_Press_Terms sets the pressure terms: DELP1, DELPM, PU.

INTERFACE:

```
SUBROUTINE Set_Press_Terms( dap,   dbk,  pres1,  pres2, delp1,   &
                           delpm, pu,   JU1_GL, J2_GL, ILO,     &
                           IHI,   JULO, JHI,    J1P,   J2P,     &
                           I1,    I2,   JU1,    J2)
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max latitude (J) indices
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Pressure difference across layer from (ai * pt) term [hPa]
REAL(fp),  INTENT(IN)  :: dap

! Difference in bi across layer - the dSigma term
REAL(fp),  INTENT(IN)  :: dbk

! Surface pressure at t1 [hPa]
REAL(fp),  INTENT(IN)  :: pres1(ILO:IHI, JULO:JHI)

! Surface pressure at t1+tdt [hPa]
REAL(fp),  INTENT(IN)  :: pres2(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Pressure thickness, the pseudo-density in a
! hydrostatic system at t1 [hPa]
REAL(fp), INTENT(OUT) :: delp1(ILO:IHI, JULO:JHI)

! Pressure thickness, the pseudo-density in a
! hydrostatic system at t1+tdt/2 (approximate) [hPa]
REAL(fp), INTENT(OUT) :: delpm(ILO:IHI, JULO:JHI)

! Pressure at edges in "u" [hPa]
REAL(fp), INTENT(OUT) :: pu(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.12 Calc_Courant

Subroutine Calc_Courant calculates courant numbers from the horizontal mass fluxes.

INTERFACE:

```
SUBROUTINE Calc_Courant( cose, delpm, pu,     xmass, ymass, crx, cry,  &
                         J1P,  J2P,   JU1_GL, J2_GL, ILO,   IHI, JULO, &
                         JHI,  I1,    I2,     JU1,   J2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max latitude (J) indices
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL
```

```
! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Cosine of grid box edges
REAL(fp),  INTENT(IN)  :: cose (JU1_GL:J2_GL)

! Pressure thickness, the pseudo-density in a hydrostatic system
! at t1+tdt/2 (approximate) (mb)
REAL(fp),  INTENT(IN)  :: delpm(ILO:IHI, JULO:JHI)

! pressure at edges in "u"  (mb)
REAL(fp),  INTENT(IN)  :: pu   (iLO:IHI, JULO:JHI)

! horizontal mass flux in E-W and N-S directions [hPa]
REAL(fp),  INTENT(IN)  :: xmass(ILO:IHI, JULO:JHI)
REAL(fp),  INTENT(IN)  :: ymass(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Courant numbers in E-W and N-S directions
REAL(fp),  INTENT(OUT) :: crx(ILO:IHI, JULO:JHI)
REAL(fp),  INTENT(OUT) :: cry(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO)
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.13 Calc_Divergence

Subroutine Calc_Divergence calculates the divergence.

INTERFACE:

```
SUBROUTINE Calc_Divergence( do_reduction, geofac_pc, geofac, dpi,   &
                            xmass,        ymass,     J1P,    J2P,   &
                            I1_GL,        I2_GL,     JU1_GL, J2_GL, &
                            ILO,          IHI,       JULO,   JHI,   &
                            I1,           I2,        JU1,    J2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Set to F if called on Master or T if called by Slaves
! (NOTE: This is only for MPI parallelization, for OPENMP it should be F)
LOGICAL, INTENT(IN)  :: do_reduction

! Special geometrical factor (geofac) for Polar cap
REAL(fp) , INTENT(IN)  :: geofac_pc

! Geometrical factor for meridional advection; geofac uses correct
! spherical geometry, and replaces acosp as the meridional geometrical
! factor in TPCORE
REAL(fp) , INTENT(IN)  :: geofac(JU1_GL:J2_GL)

! Horizontal mass flux in E/W and N/S directions [hPa]
REAL(fp) , INTENT(IN)  :: xmass(ILO:IHI, JULO:JHI)
REAL(fp) , INTENT(IN)  :: ymass(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Divergence at a grid point; used to calculate vertical motion [hPa]
```

```
REAL(fp),  INTENT(OUT) :: dpi(I1:I2, JU1:J2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.14 Do_Divergence_Pole_Sum

Subroutine Do_Divergence_Pole_Sum sets the divergence at the Poles.

INTERFACE:

```
SUBROUTINE Do_Divergence_Pole_Sum( do_reduction, geofac_pc, dpi, ymass, &
                                   I1_GL,        I2_GL,     J1P, J2P,   &
                                   JU1_GL,       J2_GL,     ILO, IHI,   &
                                   JULO,         JHI,       I1,  I2,    &
                                   JU1,          J2)
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2
```

```
! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Set to T if called on Master or F if called by slaves
! NOTE: This seems not to be used here....)
LOGICAL, INTENT(IN)   :: do_reduction

! Special geometrical factor (geofac) for Polar cap
REAL(fp),  INTENT(in)   :: geofac_pc

! Horizontal mass flux in N-S direction [hPa]
REAL(fp),  INTENT(IN)   :: ymass(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Divergence at a grid point; used to calculate vertical motion [hPa]
REAL(fp),  INTENT(OUT)  :: dpi(I1:I2, JU1:J2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent. Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.15 Do_Cross_Terms_Pole_I2d2

Subroutine Do_Cross_Terms_Pole_I2d2 sets "va" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Cross_Terms_Pole_I2d2( cry,   va,  I1_GL, I2_GL, JU1_GL, &
                                     J2_GL, J1P, ILO,   IHI,   JULO,   &
                                     JHI,   I1,  I2,    JU1,   J2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edge of the South polar cap
! J1P=JU1_GL+1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Courant number in N-S direction
REAL(fp),  INTENT(IN)  :: cry(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Average of Courant numbers from ij and ij+1
REAL(fp),  INTENT(OUT) :: va(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.16 Xadv_Dao2

Subroutine Xadv_Dao2 is the advective form E-W operator for computing the adx (E-W) cross term.

INTERFACE:

```
SUBROUTINE Xadv_Dao2( iad,    jn,    js,  adx,  qqv, &
                      ua,     ILO,   IHI, JULO, JHI, &
                      JU1_GL, J2_GL, J1P, J2P,  I1,  &
                      I2,     JU1,   J2)
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max latitude (J) indices
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! if iad = 1, use 1st order accurate scheme;
! if iad = 2, use 2nd order accurate scheme
INTEGER, INTENT(IN)  :: iad

! Northward of latitude index = jn, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)  :: jn

! southward of latitude index = js, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)  :: js

! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqv(ILO:IHI, JULO:JHI)

! Average of Courant numbers from il and il+1
REAL(fp),  INTENT(IN)  :: ua(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Cross term due to E-W advection [mixing ratio]
REAL(fp),  INTENT(OUT) :: adx(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.17 Yadv_Dao2

Subroutine Yadv_Dao2 is the advective form N-S operator for computing the ady (N-S) cross term.

INTERFACE:

```
SUBROUTINE Yadv_Dao2( iad,   ady,    qqu,   va,  I1_GL, &
                      I2_GL, JU1_GL, J2_GL, J1P, J2P,   &
                      ILO,   IHI,    JULO,  JHI, I1,    &
                      I2,    JU1,    J2)
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! If iad = 1, use 1st order accurate scheme;
! If iad = 2, use 2nd order accurate scheme
INTEGER, INTENT(IN)  :: iad
```

```
! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO:JHI)

! Average of Courant numbers from ij and ij+1
REAL(fp),  INTENT(IN)  :: va(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Cross term due to N-S advection (mixing ratio)
REAL(fp),  INTENT(OUT) :: ady(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.18 Do_Yadv_Pole_I2d2

Subroutine Do_Yadv_Pole_I2d2 sets "qquwk" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Yadv_Pole_I2d2 ( qqu, qquwk, I1_GL, I2_GL, JU1_GL, J2_GL, &
                               J1P, ILO,   IHI,   JULO,  JHI,    I1,    &
                               I2,  JU1,   J2  )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the South polar cap
! J1P=JU1_GL+1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL
```

```
! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! qqu working array [mixing ratio]
REAL(fp),  INTENT(OUT) :: qquwk(ILO:IHI, JULO-2:JHI+2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.19 Do_Yadv_Pole_Sum

Subroutine Do_Yadv_Pole_Sum sets the cross term due to N-S advection at the Poles.

INTERFACE:

```
SUBROUTINE Do_Yadv_Pole_Sum( ady, I1_GL, I2_GL, JU1_GL, J2_GL, J1P, &
                             ILO, IHI,   JULO,  JHI,    I1,    I2,  &
                             JU1, J2)
```

INPUT PARAMETERS:

```
! Global latitude index at the edge of the South polar cap
! J1P=JU1_GL+1; for a polar cap of 1 latitude band
```

```
! J1P=JU1_GL+2; for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)    :: J1P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: I1_GL,  I2_GL
INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2
INTEGER, INTENT(IN)    :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI
```

OUTPUT PARAMETERS:

```
! Cross term due to N-S advection (mixing ratio)
REAL(fp),  INTENT(INOUT) :: ady(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.  Also make a logical
                            to test if we are using an extended polar cap.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.20 Xtp

Subroutine Xtp does horizontal advection in the E-W direction.

INTERFACE:

```
SUBROUTINE Xtp( ilmt, jn,  js,    pu,     crx,   dq1, qqv, xmass, fx,  &
                J1P,  J2P, I2_GL, JU1_GL, J2_GL, ILO, IHI, JULO,  JHI, &
                I1,   I2,  JU1,   J2,  iord )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)    :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    ::         I2_GL
INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2
INTEGER, INTENT(IN)    :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI

! Controls various options in E-W advection
INTEGER, INTENT(IN)    :: ilmt

! Northward of latitude index = jn, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)    :: jn

! Southward of latitude index = js, Courant numbers could be > 1,
! so use the flux-form semi-Lagrangian scheme
INTEGER, INTENT(IN)    :: js

! Option for E-W transport scheme.  See module header for more info.
INTEGER, INTENT(IN)    :: iord

! pressure at edges in "u" [hPa]
REAL(fp),  INTENT(IN)    :: pu(ILO:IHI, JULO:JHI)

! Courant number in E-W direction
REAL(fp),  INTENT(IN)    :: crx(ILO:IHI, JULO:JHI)

! Horizontal mass flux in E-W direction [hPa]
REAL(fp),  INTENT(IN)    :: xmass(ILO:IHI, JULO:JHI)
```

INPUT/OUTPUT PARAMETERS:

```
! Species density [hPa]
REAL(fp),  INTENT(INOUT) :: dq1(ILO:IHI, JULO:JHI)

! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(INOUT) :: qqv(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! E-W flux [mixing ratio]
REAL(fp),  INTENT(OUT)   :: fx(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.21 Xmist

Subroutine Xmist computes the linear tracer slope in the E-W direction. It uses the Lin et. al. 1994 algorithm.

INTERFACE:

```
SUBROUTINE Xmist( dcx,  qqv, J1P, J2P, I2_GL, JU1_GL, J2_GL, ILO, IHI, &
                  JULO, JHI, I1,  I2,  JU1,   J2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  ::         I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
```

```
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqv(-I2/3:I2+I2/3, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Slope of concentration distribution in E-W direction [mixing ratio]
REAL(fp),  INTENT(OUT) :: dcx(-I2/3:I2+I2/3, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.22 Fxppm

Subroutine Fxppm is the 1D "outer" flux form operator based on the Piecewise Parabolic Method (PPM; see also Lin and Rood 1996) for computing the fluxes in the E-W direction.

INTERFACE:

```
SUBROUTINE Fxppm( ij,  ilmt, crx, dcx, fx, qqv,     &
                  ILO, IHI, JULO, JHI, I1,  I2 )
```

INPUT PARAMETERS:

```
! Local min & max longitude (I) and altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI

! Latitude (IJ) and altitude (IK) indices
```

```
INTEGER, INTENT(IN)    :: ij

! Controls various options in E-W advection
INTEGER, INTENT(IN)    :: ilmt

! Courant number in E-W direction
REAL(fp),  INTENT(IN)    :: crx(I1:I2, JULO:JHI)
```

INPUT/OUTPUT PARAMETERS:

```
  ! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(INOUT) :: qqv(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Slope of concentration distribution in E-W direction (mixing ratio)
REAL(fp),  INTENT(OUT)   :: dcx(ILO:IHI, JULO:JHI)

! E-W flux [mixing ratio]
REAL(fp),  INTENT(OUT)   :: fx(I1:I2, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REMARKS:

```
This routine is called from w/in a OpenMP parallel loop fro
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
                            Also remove the allocatable arrays, which
                            interfere w/ OpenMP parallelization.
01 Apr 2009 - C. Carouge  - The input arrays are now 2D only.
```

3.4.23 Lmtppm

Subroutine Lmtppm enforces the full monotonic, semi-monotonic, or the positive-definite constraint to the sub-grid parabolic distribution of the Piecewise Parabolic Method (PPM).

INTERFACE:

```
SUBROUTINE Lmtppm( lenx, lmt, a6, al, ar, dc, qa )
```

INPUT PARAMETERS:

```
! If 0 => full monotonicity;
! If 1 => semi-monotonic constraint (no undershoots);
! If 2 => positive-definite constraint
INTEGER, INTENT(IN)    :: lmt

! Vector length
INTEGER, INTENT(IN)    :: lenx
```

INPUT/OUTPUT PARAMETERS:

```
! Curvature of the test parabola
REAL(fp),  INTENT(INOUT) :: a6(lenx)

! Left edge value of the test parabola
REAL(fp),  INTENT(INOUT) :: al(lenx)

! Right edge value of the test parabola
REAL(fp),  INTENT(INOUT) :: ar(lenx)

! 0.5 * mismatch
REAL(fp),  INTENT(INOUT) :: dc(lenx)

! Cell-averaged value
REAL(fp),  INTENT(INOUT) :: qa(lenx)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

3.4.24 Ytp

Subroutine Ytp does horizontal advection in the N-S direction.

INTERFACE:

```
SUBROUTINE Ytp( jlmt,  geofac_pc, geofac, cry,  dq1,   qqu,    qqv,    &
                ymass, fy,        J1P,    J2P,  I1_GL, I2_GL,  JU1_GL, &
                J2_GL, ilong,     ILO,    IHI,  JULO,  JHI,    I1,     &
                I2,    JU1,       J2,    jord )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)    :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: I1_GL,  I2_GL
INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2
INTEGER, INTENT(IN)    :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI

! ???
INTEGER, INTENT(IN)    :: ilong

! Controls various options in N-S advection
INTEGER, INTENT(IN)    :: jlmt

! N-S transport scheme (see module header for more info)
INTEGER, INTENT(IN)    :: jord

! special geometrical factor (geofac) for Polar cap
REAL(fp),  INTENT(IN)    :: geofac_pc

! geometrical factor for meridional advection; geofac uses correct
! spherical geometry, and replaces acosp as the  meridional geometrical
! factor in tpcore
REAL(fp),  INTENT(IN)    :: geofac(JU1_GL:J2_GL)

! Courant number in N-S direction
REAL(fp),  INTENT(IN)    :: cry(ILO:IHI, JULO:JHI)

! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)    :: qqu(ILO:IHI, JULO:JHI)

! Horizontal mass flux in N-S direction [hPa]
REAL(fp),  INTENT(IN)    :: ymass(ILO:IHI, JULO:JHI)
```

INPUT/OUTPUT PARAMETERS:

```
! Species density [hPa]
REAL(fp),  INTENT(INOUT) :: dq1(ILO:IHI, JULO:JHI)

! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(INOUT) :: qqv(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! N-S flux [mixing ratio]
REAL(fp),  INTENT(OUT)   :: fy(ILO:IHI, JULO:JHI+1)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.25 Ymist

Subroutine Ymist computes the linear tracer slope in the N-S direction. It uses the Lin et. al. 1994 algorithm.

INTERFACE:

```
SUBROUTINE Ymist( id,    dcy, qqu, I1_GL, I2_GL, JU1_GL, &
                  J2_GL, J1P, ILO, IHI,   JULO,  JHI,    &
                  I1,    I2,  JU1, J2 )
```

INPUT PARAMETERS:

```
! Global latitude index at the edge of the South polar cap
! J1P=JU1_GL+1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P
```

```
! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! The "order" of the accuracy in the computed linear "slope"
! (or mismatch, Lin et al. 1994); it is either 2 or 4.
INTEGER, INTENT(IN)  :: id

! Concentration contribution from E-W advection (mixing ratio)
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Slope of concentration distribution in N-S direction [mixing ratio]
REAL(fp),  INTENT(OUT) :: dcy(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.26 Do_Ymist_Pole1_I2d2

Subroutine Do_Ymist_Pole1_I2d2 sets "dcy" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Ymist_Pole1_I2d2( dcy,   qqu, I1_GL, I2_GL, JU1_GL,   &
                                J2_GL, ILO, IHI,   JULO,  JHI,      &
                                I1,    I2,  JU1,   J2 )
```

INPUT PARAMETERS:

```
! Global min & max longitude (I) and latitude (J) indices
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO-2:JHI+2)
```

OUTPUT PARAMETERS:

```
! Slope of concentration distribution in N-S direction [mixing ratio]
REAL(fp), INTENT(OUT)  :: dcy(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.27 Do_Ymist_Pole2_I2d2

Subroutine Do_Ymist_Pole2_I2d2 sets "dcy" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Ymist_Pole2_I2d2( dcy,   qqu, I1_GL, I2_GL, JU1_GL, &
                                J2_GL, J1P, ILO,   IHI,   JULO,   &
                                JHI,   I1,  I2,    JU1,   J2 )
```

INPUT PARAMETERS:

```
! Global latitude index at the edge of the South polar cap
! J1P=JU1_GL+1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO-2:JHI+2)
```

OUTPUT PARAMETERS:

```
! Slope of concentration distribution in N-S direction [mixing ratio]
REAL(fp),  INTENT(OUT) :: dcy(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.28 Fyppm

Subroutine Fyppm is the 1D "outer" flux form operator based on the Piecewise Parabolic Method (PPM; see also Lin and Rood 1996) for computing the fluxes in the N-S direction.

INTERFACE:

```
SUBROUTINE Fyppm( jlmt,  cry,   dcy,    qqu,   qqv,   j1p, j2p,    &
                  i1_gl, i2_gl, ju1_gl, j2_gl, ilong, ilo, ihi,    &
                  julo,  jhi,   i1,     i2,    ju1,   j2 )
```

INPUT PARAMETERS:

```
! Global latitude indices at the edges of the S/N polar caps
! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)  :: J1P,    J2P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: I1_GL,  I2_GL
INTEGER, INTENT(IN)  :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)  :: I1,     I2
INTEGER, INTENT(IN)  :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)  :: ILO,    IHI
INTEGER, INTENT(IN)  :: JULO,   JHI

! ILONG ??
INTEGER, INTENT(IN)  :: ilong

! Controls various options in N-S advection
INTEGER, INTENT(IN)  :: jlmt

! Courant number in N-S direction
REAL(fp),  INTENT(IN)  :: cry(ILO:IHI, JULO:JHI)

! Slope of concentration distribution in N-S direction [mixing ratio]
REAL(fp),  INTENT(IN)  :: dcy(ILO:IHI, JULO:JHI)

! Concentration contribution from E-W advection [mixing ratio]
REAL(fp),  INTENT(IN)  :: qqu(ILO:IHI, JULO:JHI)
```

OUTPUT PARAMETERS:

```
! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(OUT) :: qqv(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.29 Do_Fyppm_Pole_I2d2

Subroutine Do_Fyppm_Pole_I2d2 sets "al" & "ar" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Fyppm_Pole_I2d2( al,  ar,  I1_GL, I2_GL, JU1_GL, J2_GL, &
                               ILO, IHI, JULO,  JHI,   I1,     I2,    &
                               JU1, J2 )
```

INPUT PARAMETERS:

```
! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: I1_GL,  I2_GL
INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2
INTEGER, INTENT(IN)    :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI
```

OUTPUT PARAMETERS:

```
! Left (al) and right (ar) edge values of the test parabola
REAL(fp),  INTENT(INOUT) :: al(ILO:IHI, JULO:JHI)
REAL(fp),  INTENT(INOUT) :: ar(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.30 Do_Ytp_Pole_Sum

Subroutine Do_Ytp_Pole_Sum sets "dq1" at the Poles.

INTERFACE:

```
SUBROUTINE Do_Ytp_Pole_Sum( geofac_pc, dq1,    qqv,   fy,  I1_GL,  &
                            I2_GL,     JU1_GL, J2_GL, J1P, J2P,    &
                            ILO,       IHI,    JULO,  JHI, I1,     &
                            I2,        JU1,    J2 )
!input PARAMETERS:
  ! Global latitude indices at the edges of the S/N polar caps
  ! J1P=JU1_GL+1; J2P=J2_GL-1 for a polar cap of 1 latitude band
  ! J1P=JU1_GL+2; J2P=J2_GL-2 for a polar cap of 2 latitude bands
  INTEGER, INTENT(IN)    :: J1P,    J2P

  ! Global min & max longitude (I) and latitude (J) indices
  INTEGER, INTENT(IN)    :: I1_GL,  I2_GL
  INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

  ! Local min & max longitude (I), latitude (J), altitude (K) indices
  INTEGER, INTENT(IN)    :: I1,     I2
  INTEGER, INTENT(IN)    :: JU1,    J2

  ! Local min & max longitude (I) and latitude (J) indices
  INTEGER, INTENT(IN)    :: ILO,    IHI
  INTEGER, INTENT(IN)    :: JULO,   JHI

  ! Special geometrical factor (geofac) for Polar cap
  REAL(fp),  INTENT(IN)    :: geofac_pc
```

```
! Concentration contribution from N-S advection [mixing ratio]
REAL(fp),  INTENT(IN)    :: qqv(ILO:IHI, JULO:JHI)
```

INPUT/OUTPUT PARAMETERS:

```
! Species density [hPa]
REAL(fp),  INTENT(INOUT) :: dq1(ILO:IHI, JULO:JHI)

! N-S mass flux [mixing ratio]
REAL(fp),  INTENT(INOUT) :: fy (ILO:IHI, JULO:JHI+1)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.  Added
                            OpenMP parallel DO loops.
01 Apr 2009 - C. Carouge  - Moved the IK loop outside the subroutine.
```

3.4.31 Fzppm

Subroutine Fzppm is the 1D "outer" flux form operator based on the Piecewise Parabolic Method (PPM; see also Lin and Rood 1996) for computing the fluxes in the vertical direction.

Fzppm was modified by S.-J. Lin, 12/14/98, to allow the use of the KORD=7 (klmt=4) option. KORD=7 enforces the 2nd monotonicity constraint of Huynh (1996). Note that in Huynh's original scheme, two constraints are necessary for the preservation of monotonicity. To use Huynh's algorithm, it was modified as follows. The original PPM is still used to obtain the first guesses for the cell edges, and as such Huynh's 1st constraint is no longer needed. Huynh's median function is also replaced by a simpler yet functionally equivalent in-line algorithm.

INTERFACE:

```
SUBROUTINE Fzppm( klmt,  delp1,  wz,  dq1, qq1,  fz,      &
                  J1P,   JU1_GL, J2_GL, ILO, IHI, JULO, JHI,     &
                  ILONG, IVERT,  I1,    I2,  JU1, J2,   K1,  K2 )
```

INPUT PARAMETERS:

```
! Global latitude index at the edges of the South polar cap
! J1P=JU1_GL+1 for a polar cap of 1 latitude band
! J1P=JU1_GL+2 for a polar cap of 2 latitude bands
INTEGER, INTENT(IN)    :: J1P

! Global min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: JU1_GL, J2_GL

! Local min & max longitude (I), latitude (J), altitude (K) indices
INTEGER, INTENT(IN)    :: I1,     I2
INTEGER, INTENT(IN)    :: JU1,    J2
INTEGER, INTENT(IN)    :: K1,     K2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)    :: ILO,    IHI
INTEGER, INTENT(IN)    :: JULO,   JHI

! Dimensions in longitude & altitude ???
INTEGER, INTENT(IN)    :: ilong,  ivert

! Controls various options in vertical advection
INTEGER, INTENT(IN)    :: klmt

! Pressure thickness, the pseudo-density in a
! hydrostatic system at t1 [hPa]
REAL(fp),  INTENT(IN)    :: delp1(ILO:IHI, JULO:JHI, K1:K2)

! Large scale mass flux (per time step tdt) in the vertical
! direction as diagnosed from the hydrostatic relationship [hPa]
REAL(fp),  INTENT(IN)    :: wz(I1:I2, JU1:J2, K1:K2)

! Species concentration [mixing ratio]
REAL(fp),  INTENT(IN)    :: qq1(:,:,:)
```

INPUT/OUTPUT PARAMETERS:

```
! Species density [hPa]
REAL(fp),  INTENT(INOUT) :: dq1(ILO:IHI, JULO:JHI, K1:K2)
```

OUTPUT PARAMETERS:

```
! Vertical flux [mixing ratio]
REAL(fp),  INTENT(OUT)   :: fz(ILO:IHI, JULO:JHI,  K1:K2)
```

AUTHOR:

```
Original code from Shian-Jiann Lin, DAO
John Tannahill, LLNL (jrt@llnl.gov)
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

3.4.32 Average_Press_Poles

Subroutine Average_Press_Poles averages pressure at the Poles when the Polar cap is enlarged. It makes the last two latitudes equal.

INTERFACE:

```
SUBROUTINE Average_Press_Poles( area_1D, press, I1,  I2,   JU1,  &
                                J2,      ILO,   IHI, JULO, JHI )
```

INPUT PARAMETERS:

```
! Local min & max longitude (I), latitude (J)
INTEGER, INTENT(IN)   :: I1,     I2
INTEGER, INTENT(IN)   :: JU1,    J2

! Local min & max longitude (I) and latitude (J) indices
INTEGER, INTENT(IN)   :: ILO,    IHI
INTEGER, INTENT(IN)   :: JULO,   JHI

! Surface area of grid box
REAL(fp),  INTENT(IN)   :: AREA_1D(JU1:J2)
```

INPUT/OUTPUT PARAMETERS:

```
! Surface pressure [hPa]
REAL(fp), INTENT(INOUT) :: press(ILO:IHI, JULO:JHI)
```

AUTHOR:

```
Philip Cameron-Smith and John Tannahill, GMI project @ LLNL (2003)
Implemented into GEOS-Chem by Claire Carouge (ccarouge@seas.harvard.edu)
```

REMARKS:

```
Subroutine from pjc_pfix.  Call this one once everything is working fine.
```

REVISION HISTORY:

```
05 Dec 2008 - C. Carouge  - Replaced TPCORE routines by S-J Lin and Kevin
                            Yeh with the TPCORE routines from GMI model.
                            This eliminates the polar overshoot in the
                            stratosphere.
05 Dec 2008 - R. Yantosca - Updated documentation and added ProTeX headers.
                            Declare all REAL variables as REAL(fp).  Also
                            make sure all numerical constants are declared
                            with the "D" double-precision exponent.
```

4 Convection and scavenging modules

These modules contain routines to perform the convective transport and to scavenge soluble species out of the atmosphere.

4.1 Fortran: Module Interface convection_mod.F90

Module CONVECTION_MOD contains routines which select the proper convection code for GEOS-3, GEOS-4, GEOS-5, MERRA, or GCAP met field data sets.

INTERFACE:

```
MODULE CONVECTION_MOD
```

USES:

```
USE ErrCode_Mod
USE PhysConstants    ! Physical constants
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: DO_CONVECTION
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: DO_GEOS4_CONVECT
PRIVATE :: DO_GCAP_CONVECT
PRIVATE :: NFCLDMX
PRIVATE :: DO_MERRA_CONVECTION
```

REVISION HISTORY:

```
27 Jan 2004 - R. Yantosca - Initial version
(1 ) Contains new updates for GEOS-4/fvDAS convection.  Also now references
     "error_mod.f".  Now make F in routine NFCLDMX a 4-D array to avoid
```

```
      memory problems on the Altix. (bmy, 1/27/04)
(2 ) Bug fix: Now pass NTRACE elements of TCVV to FVDAS_CONVECT in routine
      DO_CONVECTION (bmy, 2/23/04)
(3 ) Now references "logical_mod.f" and "tracer_mod.f" (bmy, 7/20/04)
(4 ) Now also references "ocean_mercury_mod.f" and "tracerid_mod.f"
      (sas, bmy, 1/19/05)
(5 ) Now added routines DO_GEOS4_CONVECT and DO_GCAP_CONVECT by breaking
      off code from DO_CONVECTION, in order to implement GCAP convection
      in a much cleaner way. (swu, bmy, 5/25/05)
(6 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(7 ) Shut off scavenging in shallow convection for GCAP (swu, bmy, 11/1/05)
(8 ) Modified for tagged Hg simulation (cdh, bmy, 1/6/06)
(9 ) Bug fix: now only call ADD_Hg2_WD if LDYNOCEAN=T (phs, 2/8/07)
(10) Fix for GEOS-5 met fields in routine NFCLDMX (swu, 8/15/07)
(11) Resize DTCSUM array in NFCLDMX to save memory (bmy, 1/31/08)
13 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2010 - R. Yantosca - Treat MERRA in the same way as for GEOS-5
29 Sep 2010 - R. Yantosca - Added modifications for MERRA
05 Oct 2010 - R. Yantosca - Added ND14 and ND38 diagnostics to
                            DO_MERRA_CONVECTION routine
16 Aug 2011 - J. Fisher   - Minor bug fixes in DO_MERRA_CONVECTION
15 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
02 Mar 2012 - R. Yantosca - Now reference the new grid_mod.F90
22 Oct 2012 - R. Yantosca - Now reference Headers/gigc_errcode_mod.F90
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
07 Nov 2014 - M. Yannetti - Added PRECISION_MOD
23 Jun 2015 - E. Lundgren - Convert tracer units from v/v dry air to
                            kg/kg total air for convection
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
06 Jul 2016 - E. Lundgren - Spc units are now kg/kg dry air in convection
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

4.1.1 do_convection

Subroutine DO_CONVECTION calls the appropriate convection driver program for different met field data sets.

INTERFACE:

```
      SUBROUTINE DO_CONVECTION( am_I_Root, Input_Opt,
     &                          State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
```

```
      USE DIAG_MOD,           ONLY : CONVFLUP
      USE ERROR_MOD,          ONLY : GC_Error
      USE UnitConv_Mod
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD38
#endif
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
      USE GC_GRID_MOD,        ONLY : GET_AREA_M2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE TIME_MOD,           ONLY : GET_TS_CONV
      USE WETSCAV_MOD,        ONLY : COMPUTE_F
      USE WETSCAV_MOD,        ONLY : H2O2s
      USE WETSCAV_MOD,        ONLY : SO2s
#if defined( NC_DIAG )
      USE HCO_ERROR_MOD
      USE HCO_INTERFACE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update

#endif
#if defined( USE_TEND )
      USE TENDENCIES_MOD
      USE State_Chm_Mod,      ONLY : Ind_
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
   25 May 2005 - S. Wu       - Initial version
   08 Feb 2007 - R. Yantosca - Now reference "CMN_SIZE".  Now references
                               CLDMAS, CMFMC, DTRAIN from "dao_mod.f" so that
                               we can pass either GEOS-5 or GEOS-3 meteorology
```

```
                           to NFCLDMX.
13 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2010 - R. Yantosca - Treat MERRA in the same way as for GEOS-5
29 Sep 2010 - R. Yantosca - Now call DO_MERRA_CONVECTION for MERRA met
05 Oct 2010 - R. Yantosca - Now attach diagnostics to MERRA conv routine
06 Oct 2010 - R. Yantosca - Parallelized call to DO_MERRA_CONVECTION
15 Oct 2010 - H. Amos     - Now get BXHEIGHT, T from dao_mod.f
15 Oct 2010 - R. Yantosca - Now get LDYNOCEAN from logical_mod.f
15 Oct 2010 - R. Yantosca - Now get ITS_A_MERCURY_SIM from tracer_mod.f
15 Oct 2010 - R. Yantosca - Now get IDTHg2, IDTHgP from tracerid_mod.f
15 Oct 2010 - R. Yantosca - Now get H2O2s, SO2s from wetscav_mod.f
15 Oct 2010 - H. Amos     - Now pass BXHEIGHT, T, to DO_MERRA_CONVECTION
15 Oct 2010 - R. Yantosca - Now pass H2O2s, SO2s to DO_MERRA_CONVECTION
15 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
29 Aug 2011 - R. Yantosca - Bug fix: reposition #if defined(APM) statement
09 Feb 2012 - R. Yantosca - For GEOS-5.7, PFICU and PFLCU fields are
                           defined on level edges.  Pass the top edge
                           of each level to DO_MERRA_CONVECTION
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
21 Jun 2012 - R. Yantosca - Now use poiners to pass array slices to routines
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                           derived type object
04 Feb 2013 - S. Kim      - Bug fix: H2O2s, SO2s, STT are not in State_Met
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
31 May 2013 - R. Yantosca - Now pass objects to NFCLDMX
03 Jun 2013 - R. Yantosca - Bug fix: pass State_Chm to DO_MERRA_CONVECTION
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
17 Apr 2014 - R. Yantosca - Speed up MERRA and GEOS-FP convection by
                           adding !$OMP+SCHEDULE( DYNAMIC )
17 Apr 2014 - R. Yantosca - Test if (ND14>0) and (ND38>0) outside OMP loop
18 Apr 2014 - R. Yantosca - Now use a pointer to pass a slice of the
                           F array to subroutine COMPUTE_F
18 Apr 2014 - R. Yantosca - Clean up call to DO_MERRA_CONVECTION, remove
                           stuff that was leftover from the column code
18 Apr 2014 - R. Yantosca - Now use proper # of tracers for APM in the
                           call to DO_MERRA_CONVECTION (MERRA & GEOS-FP)
25 Jun 2014 - R. Yantosca - Now pass Input_Opt to COMPUTE_F
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
                           Remove dependency on pressure_mod
28 Apr 2015 - E. Lundgren - Consolidate NFCLDMX arguments to remove
                           passing State_Met array slice
15 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                           (previously v/v)
10 Aug 2015 - E. Lundgren - Incoming tracer units are now kg/kg dry air
11 Aug 2015 - R. Yantosca - Added support for MERRA2 data
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
```

```
                           species ID from State_Chm%Map_Advect.
06 Jul 2016 - R. Yantosca - Use State_Chm%Map_WetDep to get species ID's
07 Jul 2016 - R. Yantosca - Now dimension DIAG14 and DIAG38 for the #
                           of soluble species (State_Chm%nWetDep)
07 Jul 2016 - E. Lundgren - Now use spc kg/kg dry instead of kg/kg total
 8 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

4.1.2 do_geos4_convect

Subroutine DO_GEOS4_CONVECT is a wrapper for the GEOS-4/fvDAS convection code. This was broken off from the old DO_CONVECTION routine above.

INTERFACE:

```
SUBROUTINE DO_GEOS4_CONVECT( am_I_Root, Input_Opt,
&                            State_Met, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG_MOD,           ONLY : AD37
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE FVDAS_CONVECT_MOD,  ONLY : INIT_FVDAS_CONVECT, FVDAS_CONVECT
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CONV
USE WETSCAV_MOD,        ONLY : COMPUTE_F
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
As of July 2016, we assume that all of the advected species are listed
first in the species database.  This is the easiest way to pass a slab
to the TPCORE routine.  This may change in the future. (bmy, 7/13/16)

%%%% GEOS-4 IS DEPRECATED AND MAY BE REMOVED SOON %%%%
```

REVISION HISTORY:

```
25 May 2005 - S. Wu       - Initial version
(1 ) Now use array masks to flip arrays vertically in call to FVDAS_CONVECT
     (bmy, 5/25/05)
(2 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(3 ) Add a check to set negative values in STT to TINY (ccc, 4/15/09)
13 Aug 2010 - R. Yantosca - Added ProTeX headers
15 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
14 Apr 2014 - R. Yantosca - Remove array temporary in call to FVDAS_CONVECT
18 Apr 2014 - R. Yantosca - Now use a pointer to pass a slice of the
                            F array to subroutine COMPUTE_F
23 Jun 2014 - R. Yantosca - Now pass Input_Opt to CONVTRAN
25 Jun 2014 - R. Yantosca - Now pass Input_Opt to COMPUTE_F
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE differences with
                            State_Met%DELP. Remove dependency on
                            pressure_mod
23 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                            (previously v/v)
22 Apr 2016 - R. Yantosca - Now pass State_Chm to FVDAS_CONVECT_MOD
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
06 Jul 2016 - E. Lundgren - Now use kg/kg dry air as spc units, requiring
                            use of DELP_DRY instead of DELP
```

4.1.3 do_gcap_convect

Subroutine DO_GCAP_CONVECT is a wrapper for the GCAP convection code. This was broken off from the old DO_CONVECTION routine above.

INTERFACE:

```
SUBROUTINE DO_GCAP_CONVECT( am_I_Root, Input_Opt,
&                           State_Met, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG_MOD,           ONLY : AD37
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE GCAP_CONVECT_MOD,   ONLY : GCAP_CONVECT
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
```

```
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CONV
      USE WETSCAV_MOD,        ONLY : COMPUTE_F
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    25 May 2005 - S. Wu       - Initial version
    (1 ) Now use array masks to flip arrays vertically in call to GCAP_CONVECT
         (bmy, 5/25/05)
    (2 ) Shut off scavenging in shallow convection for GCAP below 700 hPa
         (swu, bmy, 11/1/05)
    (3 ) Add a check to set negative values in STT to TINY (ccc, 4/15/09)
    13 Aug 2010 - R. Yantosca - Added ProTeX headers
    15 Feb 2011 - R. Yantosca - Add modifications for APM from G. Luo
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
    04 Nov 2013 - M. Sulprizio- Now use pointer variables to flip met fields in
                                the vertical
    15 Apr 2014 - R. Yantosca - Remove array temporaries in call to GCAP_CONVECT
    18 Apr 2014 - R. Yantosca - Now use a pointer to pass a slice of the
                                F array to subroutine COMPUTE_F
    25 Jun 2014 - R. Yantosca - Now pass Input_Opt to COMPUTE_F
    26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID.
                                Replace PEDGE difference with State_Met%DELP.
                                Remove dependency on pressure_mod.
    23 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                                (previously v/v)
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    06 Jul 2016 - E. Lundgren - Now use kg/kg dry air as spc units, requiring
                                use of DELP_DRY instead of DELP
```

4.1.4 nfcldmx

Subroutine NFCLDMX is S-J Lin's cumulus transport module for 3D GSFC-CTM, modified for the GEOS-Chem model. The "NF" stands for "no flipping", and denotes that you

don't have to flip the species array Q in the main program before passing it to NFCLDMX.

NOTE: NFCLDMX can be used with GEOS-1, GEOS-STRAT, and GEOS-3 met fields. For GEOS-4/fVDAS, you must use the routines in "fvdas_convect_mod.f"

INTERFACE:

```
      SUBROUTINE NFCLDMX( am_I_Root, Input_Opt, State_Met,
     &                    State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HgP_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_SNOWPACK
      USE DIAG_MOD,           ONLY : AD37
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD38
#endif
      USE DIAG_MOD,           ONLY : CONVFLUP
      USE ErrCode_Mod
      USE GC_GRID_MOD,        ONLY : GET_AREA_M2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PRESSURE_MOD,       ONLY : GET_BP
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CONV
      USE WETSCAV_MOD,        ONLY : COMPUTE_F
      USE ERROR_MOD,          ONLY : ALLOC_ERR

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      ! Are we on the root CPU
      LOGICAL,        INTENT(IN)    :: am_I_Root

      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
(1) The "NF" stands for "no flipping", and denotes that you don't have to
flip the species array Q in the main program before passing it to NFCLDMX.
(bmy, 2/12/97, 1/31/08)
(2) This version has been customized to work with GEOS-5 met fields.
Reference:
============================================================================
Lin, SJ.  "Description of the parameterization of cumulus transport
   in the 3D Goddard Chemistry Transport Model, NASA/GSFC, 1996.
Vertical indexing:
============================================================================
The indexing of the vertical sigma levels has been changed from
SJ-Lin's original code:
               Old Method          New Method
                (SJ Lin)
            ------------------------------------ Top of Atm.
               k = 1               k = NLAY
            ==================================== Max Extent
               k = 2               k = NLAY-1      of Clouds
            ------------------------------------


                ...                 ...
            ------------------------------------
               k = NLAY-3          k = 4
            ------------------------------------
               k = NLAY-2          k = 3
            ------------------------------------ Cloud base
               k = NLAY-1          k = 2
            -    -    -    -    -    -    -    -
               k = NLAY            k = 1
            ==================================== Ground
    which means that:
                Old Method                      New Method
                 (SJ Lin)
          k-1      ^                     k+1      ^
          ---------|---------             ---------|---------
                   |                               |
                 CMFMC(k)                        CMFMC(k)

                                 becomes
          k     DTRAIN(k),                k     DTRAIN(k),
                QC(k), Q(k)                     QC(k), Q(k)

                   ^                               ^
          ---------|---------             ---------|---------
                   |                               |
          k+1   CMFMC(k+1)                k-1   CMFMC(k-1)
```

```
    i.e., the lowest level    used to be  NLAY  but is now  1
          the level below k   used to be  k+1   but is now  k-1.
          the level above k   used to be  k-1   but is now  k+1
          the top of the atm. used to be  1     but is now  NLAY.
The old method required that the vertical dimensions of the CMFMC, DTRAIN,
and Q arrays had to be flipped before and after calling CLDMX.  Also,
diagnostic arrays generated within CLDMX also had to be flipped.  The new
indexing eliminates this requirement (and also saves on array operations).
Major Modifications:
=============================================================================
Original Author:   Shian-Jiann Lin, Code 910.3, NASA/GSFC
Original Release:  12 February 1997
                   Version 3, Detrainment and Entrainment are considered.
                   The algorithm reduces to that of version 2 if Dtrn = 0.
                                                                            .
Modified By:       Bob Yantosca, for Harvard Atmospheric Sciences
Modified Release:  27 January 1998
                   Version 3.11, contains features of V.3 but also
                   scavenges soluble tracer in wet convective updrafts.
                                                                            .
                   28 April 1998
                   Version 3.12, now includes mass flux diagnostic
                                                                            .
                   11 November 1999
                   Added mass-flux diagnostics
                                                                            .
                   04 January 2000
                   Updated scavenging constant AS2
                                                                            .
                   14 March 2000
                   Added new wet scavenging code and diagnostics
                   based on the GMI algorithm
                                                                            .
                   02 May 2000
                   Added parallel loop over species!
```

REVISION HISTORY:

```
12 Feb 1997 - M. Prather  - Initial version
(1 ) NFCLDMX is written in Fixed-Form Fortran 90.
(2 ) Added TCVV to the argument list.  Also cleaned up argument
      and local variable declarations. (bey, bmy, 11/10/99)
(3 ) AD38 and CONVFLUP are now declared allocatable in "diag_mod.f".
      (bmy, 11/29/99)
(4 ) Bug fix for tagged CO tracer run (bey, bmy, 1/4/00)
(5 ) Add new routines for computing scavenging coefficients,
      as well as adding the AD37 diagnostic array. (bmy, 3/14/00)
(6 ) Updated comments (bmy, 10/2/01)
```

```
(7 ) Now print a header to stdout on the first call, to confirm that
     NFCLDMX has been called (bmy, 4/15/02)
(8 ) Remove PZ from the arg list -- it isn't used! (bmy, 8/22/02)
(9 ) Fixed ND38 diagnostic so that it now reports correctly (must divide
     by DNS).  Updatec comments, cosmetic changes. (bmy, 1/27/03)
(10) Bug fix: remove duplicate K from PRIVATE declaration (bmy, 3/23/03)
(11) Now removed all arguments except NC, TCVV, Q from the arg list -- the
     other arguments can be supplied via F90 modules.  Now references
     "dao_mod.f", "grid_mod.f", "pressure_mod.f", and "time_mod.f".
     (bmy, 3/27/03)
(12) Bundled into "convection_mod.f" (bmy, 6/26/03)
(13) Make sure K does not go out of bounds in ND38 diagnostic.  Now make
     F a 4-D array in order to avoid memory problems on the Altix.
     (bmy, 1/27/04)
(14) Now references both "ocean_mercury_mod.f" and "tracerid_mod.f".
     Now call ADD_Hg2_WD from "ocean_mercury_mod.f" to pass the amt of Hg2
     lost by wet scavenging (sas, bmy, 1/19/05)
(15) Now references IS_Hg2 from "tracerid_mod.f".  Now pass tracer # IC
     to ADD_Hg2_WD. (cdh, bmy, 1/6/06)
(16) Bug fix: now only call ADD_Hg2_WD if LDYNOCEAN=T (phs, 2/8/07)
(17) Now make CLDMAS, DTRN as arguments, so that we can pass either
     GEOS-3 or GEOS-3 met data.  Redimension DTCSUM with NC instead of
     NNPAR.  In many cases, NC is less than NNPAR and this will help to
     save memory especially when running at 2x25 or greater resolution
     (bmy, 1/31/08)
(18) Add a check to set negative values in Q to TINY (ccc, 4/15/09)
(19) Updates for mercury simulation (ccc, 5/17/10)
13 Aug 2010 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
29 May 2013 - R. Yantosca - Now set TINY = 1d-60 only for TOMAS code
31 May 2013 - R. Yantosca - Now pass State_Chm and then have Q point to
                            State_Chm%Tracers.  This is for TOMAS.
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
04 Feb 2014 - R. Yantosca - Bug fix for TOMAS: call COMPUTE_F In its own
                            separate parallel loop.  Also save the values
                            of ISOL in the ISOL_SAVE array so that we can
                            pass them to the parallel tracer loop.
18 Apr 2014 - R. Yantosca - Now use a pointer to pass a slice of the
                            F array to subroutine COMPUTE_F
25 Jun 2014 - R. Yantosca - Now pass Input_Opt to COMPUTE_F
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE dinnerences with DELP and
                            remove dependency on pressure_mod
20 Apr 2015 - E. Lundgren - Use DELP*100/g instead of AD/area for BMASS
                            to keep definition as grid box moist mass/area
28 Apr 2015 - E. Lundgren - Remove CLDMAS and DTRM as arguments since
```

```
                            now included in State_Met
   09 Jun 2015 - R. Yantosca - Now deposit Hg2, HgP to snowpack regardless of
                               whether the dynamic ocean is used
   15 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units
                               (previously v/v)
   22 Apr 2016 - R. Yantosca - Now get Is_Hg2 and Is_HgP from species database
   22 Apr 2016 - R. Yantosca - Now pass ThisSpc to ADD_HG2_SNOWPACK
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                               species ID from State_Chm%Map_Advect.
   01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
   06 Jul 2016 - E. Lundgren - Now use kg/kg dry air as spc units, requiring
                               use of DELP_DRY instead of DELP
```

4.1.5 do_merra_convection

Subroutine DO_MERRA_CONVECTION (formerly called NFCLDMX) is S-J Lin's cumulus transport module for 3D GSFC-CTM, modified for the GEOS-Chem model.

INTERFACE:

```
      SUBROUTINE DO_MERRA_CONVECTION( am_I_Root,
     &                                Input_Opt,
     &                                State_Met,
     &                                State_Chm,
     &                                I,
     &                                J,
     &                                AREA_M2,
     &                                F,
     &                                TS_DYN,
     &                                USE_DIAG14,
     &                                DIAG14,
     &                                USE_DIAG38,
     &                                DIAG38,
     &                                RC          )
```

USES:

```
      USE CMN_SIZE_MOD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_SNOWPACK
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HgP_WD
      USE ERROR_MOD,          ONLY : IT_IS_NAN
      USE ERROR_MOD,          ONLY : IT_IS_FINITE
      USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP  ! hma Nov 3, debug
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

```
      USE Species_Mod,        ONLY : Species
      USE WETSCAV_MOD,        ONLY : H2O2s_3D => H2O2s ! [v/v]
      USE WETSCAV_MOD,        ONLY : SO2s_3D  => SO2s  ! [v/v]
      USE WETSCAV_MOD,        ONLY : WASHOUT
      USE WETSCAV_MOD,        ONLY : LS_K_RAIN
      USE WETSCAV_MOD,        ONLY : LS_F_PRIME
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root  ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met  ! Meteorology State object
      INTEGER,        INTENT(IN)    :: I, J       ! Lon & lat indices
      REAL(fp),       INTENT(IN)    :: AREA_M2    ! Surface area [m2]
      REAL(fp),       INTENT(IN)    :: F(:,:)     ! Fraction of soluble species
                                                  !  for updraft scavenging
                                                  !  [unitless].  Computed by
                                                  !  routine  COMPUTE_F.
      REAL(fp),       INTENT(IN)    :: TS_DYN     ! Dynamic timestep [min]
      LOGICAL,        INTENT(IN)    :: USE_DIAG14 ! Archive DIAG14?
      LOGICAL,        INTENT(IN)    :: USE_DIAG38 ! Archive DIAG38?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT)   :: DIAG14(:,:) ! Array for ND14 diagnostic
      REAL(fp),       INTENT(OUT)   :: DIAG38(:,:) ! Array for ND38 diagnostic
      INTEGER,        INTENT(OUT)   :: RC          ! Return code
```

REMARKS:

```
    Reference:
    ============================================================================
    Lin, SJ.  "Description of the parameterization of cumulus transport
       in the 3D Goddard Chemistry Transport Model, NASA/GSFC, 1996.

                                                                             .
    Unit conversion for BMASS:
        Ps - Pt (mb)| P2 - P1 | 100 Pa |  s^2  | 1  |  1 kg        kg
       -------------+---------+--------+-------+----+--------  =  -----
                    | Ps - Pt |   mb   | 9.8 m | Pa | m^2 s^2      m^2

                                                                             .
    NOTE: We are passing I & J down to this routine so that it can call the
    proper code from "mercury_mod.f".  Normally, we wouldn't pass I & J as
    arguments to columnized code.  This prevents rewriting the mercury_mod.f
    routines ADD_Hg2_
```

REVISION HISTORY:

```
15 Jul 2009 - R. Yantosca - Columnized and cleaned up.
                          - CLDMAS renamed to CMFMC and DTRN renamed
                            to DTRAIN for consistency w/ GEOS-5.
17 Jul 2009 - R. Yantosca - Now do unit conversion of Q array from
                            [kg] --> [v/v] and vice versa internally
14 Dec 2009 - R. Yantosca - Now remove internal unit conversion, since
                            Q now comes in as [mol/mol] (=[v/v]) from the
                            calling routine.
14 Dec 2009 - R. Yantosca - Remove COEF from the argument list
06 May 2010 - R. Yantosca - Now add IDENT via the argument list
29 Sep 2010 - R. Yantosca - Modified for MERRA met fields
05 Oct 2010 - R. Yantosca - Now pass COEF via the argument list
05 Oct 2010 - R. Yantosca - Attach ND14 and ND38 diagnostics
15 Oct 2010 - H. Amos     - Added BXHEIGHT and T as arguments
15 Oct 2010 - R. Yantosca - Added I, J, H2O2s and SO2s as arguments
15 Oct 2010 - H. Amos     - Added scavenging below cloud base
06 Apr 2011 - M.Fu, H.Amos- Bug fix: make sure washout adheres to the same
                            algorithm as in the wet deposition code.
27 Jul 2011 - R. Yantosca - Declare CLDBASE as INTEGER to avoid PGI errors
16 Aug 2011 - J. Fisher   - Bug fix: use IS_Hg2() and IS_HgP to test if
                            a tracer is Hg2 or HgP (for tagged species)
16 Aug 2011 - J. Fisher   - Now use WETLOSS instead of TO_SUM in the ND38
                            diagnostic below the cloud.  Using TO_SUM leads
                            us to over-count the tracer scavenged out of
                            the column.
22 Oct 2012 - R. Yantosca - Now reference Headers/gigc_errcode_mod.F90
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
31 May 2013 - R. Yantosca - Now pass State_Chm to WASHOUT
05 Sep 2013 - R. Yantosca - Bug fix: DT is apparently undefined, but still
                            passed to WASHOUT.  Use SDT instead.  This
                            avoids a floating-point error.
18 Apr 2014 - R. Yantosca - Now point to 3-D arrays internally
18 Apr 2014 - R. Yantosca - Now also pass N_TRACERS (to facilitate APM)
18 Apr 2014 - R. Yantosca - Remove code that we don't need anymore
04 Feb 2015 - M. Sulprizio- Fix calculation of WETLOSS for non-aerosol
                            tracers below the cloud base (C. Friedman)
20 Apr 2015 - E. Lundgren - Use DELP*100/g instead of AD/area as grid box
                            moist mass per area and remove AD from routine
20 May 2015 - M. Sulprizio- Apply bug fixes provided by Viral Shah:
                            -- Remove F(K,IC) > 0 condition that prevents
                               archiving of deposited mass in DIAG38
                            -- Add statement that subtracts the wet deposited
                               amount from the atmospheric mass
                            -- Fix inconsistency in units when TO_SUM is used
04 Jun 2015 - E. Lundgren - Adapt Viral Shah bug fixes to moist mixing ratio
09 Jun 2015 - R. Yantosca - Now deposit Hg2, HgP to snowpack regardless of
                            whether the dynamic ocean is used
```

```
15 Jun 2015 - E. Lundgren - Now use kg/kg total air as tracer units not v/v
22 Jun 2015 - E. Lundgren - Move QB_NUM calculation to within timestep loop
12 Aug 2015 - R. Yantosca - Treat MERRA2 in same way as we do for GEOS-FP
14 Sep 2015 - E. Lundgren - Apply bug fixes provided by Viral Shah:
                            -- Prevent ALPHA > 1 in washout of aerosols
                            -- Add tracer GAINED to Q before WETLOSS
                               calculation in aerosol washout
22 Apr 2016 - R. Yantosca - Now get Is_Hg2 & Is_HgP from species database
25 Apr 2016 - R. Yantosca - Now pass Hg category # to ADD_Hg2_* functions
28 Apr 2016 - R. Yantosca - Rewrite Is_Hg block to avoid unassociated
                            pointer seg faults
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
05 Jul 2016 - R. Yantosca - Now replace N_TRACERS argument with the
                            State_Chm%nAdvect field
06 Jul 2016 - E. Lundgren - Now use kg/kg dry air as spc units, requiring
                            use of DELP_DRY instead of DELP and PEDGE_DRY
                            for avg mixing ratio
07 Jul 2016 - R. Yantosca - Bug fix: F and ISOL need to be indexed with
                            the advected species index NA
07 Jul 2016 - R. Yantosca - DIAG14 and DIAG38 now are dimensioned with
                            of size State_Chm%nWetDep instead of N_TRACERS
20 Sep 2016 - R. Yantosca - Rewrote IF test to avoid Gfortran compiler error
```

4.2 Fortran: Module Interface wetscav_mod.F

Module WETSCAV_MOD contains routines and variables used in the wet scavenging of species in cloud updrafts, rainout, and washout.

INTERFACE:

```
MODULE WETSCAV_MOD
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC DATA MEMBERS:

```
! Save H2O2 and SO2 [v/v] for sulfate chemistry
REAL(fp), PUBLIC, ALLOCATABLE, TARGET :: H2O2s(:,:,:)
REAL(fp), PUBLIC, ALLOCATABLE, TARGET :: SO2s(:,:,:)
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CLEANUP_WETSCAV
PUBLIC  :: COMPUTE_F
PUBLIC  :: DO_WETDEP
PUBLIC  :: INIT_WETSCAV
PUBLIC  :: SETUP_WETSCAV
PUBLIC  :: WASHOUT
PUBLIC  :: LS_K_RAIN
PUBLIC  :: LS_F_PRIME
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: COMPUTE_L2G
PRIVATE :: CONV_F_PRIME
PRIVATE :: E_ICE
PRIVATE :: RAINOUT
PRIVATE :: GET_RAINFRAC
PRIVATE :: SAFETY
PRIVATE :: WASHFRAC_FINE_AEROSOL
PRIVATE :: WASHFRAC_COARSE_AEROSOL
PRIVATE :: WASHFRAC_LIQ_GAS
PRIVATE :: WASHFRAC_HNO3
PRIVATE :: GET_VUD
```

REMARKS:

```
References:
============================================================================
(1 ) Liu,H., D.J. Jacob, I. Bey and R.M. Yantosca, "Constraints from 210Pb
      and 7Be on wet deposition and transport in a global three-dimensional
      chemical tracer model driven by assimilated meteorological fields",
      JGR, Vol 106, pp 12109-12128, 2001.
(2 ) D.J. Jacob, H. Liu, C. Mari, and R. M. Yantosca, "Harvard wet
      deposition scheme for GMI", Harvard Atmospheric Chemistry Modeling
      Group, March 2000.
(3 ) Chin, M., D.J. Jacob, G.M. Gardner, M.S. Foreman-Fowler, and P.A.
      Spiro, "A global three-dimensional model of tropospheric sulfate",
      J. Geophys. Res., 101, 18667-18690, 1996.
(4 ) Balkanski, Y  D.J. Jacob, G.M. Gardner, W.C. Graustein, and K.K.
      Turekian, "Transport and Residence Times of Tropospheric Aerosols
      from a Global Three-Dimensional Simulation of 210Pb", JGR, Vol 98,
      (D11) pp 20573-20586, 1993.
(5 ) Giorgi, F, & W.L. Chaimedes, "Rainout Lifetimes of Highly Soluble
      Aerosols and Gases as Inferred from Simulations With a General
      Circulation Model", JGR, Vol 86 (D13) pp 14367-14376, 1986.
```

REVISION HISTORY:

```
(1 ) Now trap allocation errors with routine ALLOC_ERR. (bmy, 7/11/00)
(2 ) Moved routine MAKE_QQ here from "dao_mod.f" (bmy, 10/12/00)
(3 ) Reordered arguments in INIT_PRECIP (bmy, 10/12/00)
```

```
(4 ) Updated comments (bmy, 9/4/01)
(5 ) Bug fix in MAKE_QQ: BXHEIGHT is sized IIPAR,JJPAR,LLPAR (bmy, 10/4/01)
(6 ) Removed obsolete, commented-out code from 10/01 (bmy, 11/26/01)
(7 ) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
     MODULE ROUTINES sections.  Updated comments (bmy, 5/28/02)
(8 ) Now zero allocatable arrays (bmy, 8/5/02)
(9 ) Bug fix: ND39 diagnostic now closes the budget.  Also bundled several
     standalone routines into this module.  Now references F90 module
     "tracerid_mod.f".  Also set NSOLMAX=10 since we now have sulfate
     tracers for wetdep.   Now prevent out-of-bounds errors in routine
     WETDEP.  Added GET_WETDEP_NMAX function to return max # of soluble
     tracers for allocating diagnostic arrays.  Added functions
     GET_WETDEP_NSOL and GET_WETDEP_IDWETD.  Now init H2O2s and SO2s
     to the initial H2O2 and SO2 from STT.  Updated comments.
     (qli, bmy, 1/14/03)
(10) Improvements for SO2/SO4 scavenging (rjp, bmy, 3/23/03)
(11) Now references "time_mod.f".  Added driver routine DO_WETDEP to
     remove cumbersome calling sequence from MAIN program.  Also declared
     WETDEP and MAKE_QQ PRIVATE to this module. (bmy, 3/27/03)
(11) Add parallelization to routine WETDEP (bmy, 3/17/04)
(12) Added carbon and dust aerosol tracers (rjp, tdf, bmy, 4/5/04)
(13) Added seasalt aerosol tracers (rjp, bec, bmy, 4/20/04)
(14) Added secondary organic aerosol tracers (rjp, bmy, 7/13/04)
(15) Now references "logical_mod.f" and "tracer_mod.f".  Now move all
     internal routines to the module and pass arguments explicitly in
     order to facilitate parallelization on the Altix. (bmy, 7/20/04)
(16) Updated for mercury aerosol tracers (eck, bmy, 12/9/04)
(17) Updated for AS, AHS, LET, NH4aq, SO4aq.  Also now pass Hg2 wetdep loss
     to "ocean_mercury_mod.f". (cas, sas, bmy, 1/20/05)
(18) Bug fix to avoid numerical blowup in WETDEP.  Now use analytical
     function for E_ICE(T). (bmy, 3/7/05)
(19) Added SO4s, NITs.  Increased NSOLMAX to 31.  Also block out
     parallel loop in WETDEP for SGI MIPS compiler. (bec, bmy, 5/5/05)
(20) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(21) Bug fixes: do not over-deplete H2O2s.  Also include updates for
     tagged Hg simulation. (dkh, rjp, eck, cdh, bmy, 1/6/06)
(22) Now wet deposit SOG4, SOA4. Remove unnecessary variables in WETDEP.
     (dkh, bmy, 5/18/06)
(23) Bug fixes in COMPUTE_F (bmy, 7/26/06)
(24) Resize DSTT array in WETDEP to save memory.  Added fixes for GEOS-5
     wet deposition per Hongyu Liu's suggestions. (bmy, 3/5/08)
(25) Add wet scavenging of GLYX, MGLY, GLYC, SOAG, SOAM (tmf, 1/7/09)
(26) Effective Henry's law constant and coefficient from
     Sander, R, 1999, Compilation of Henry's Law Constants for
        Inorganic and Organic Species of Potential Importance in
        Environmental Chemistry.
        http://www.mpch-mainz.mpg.de/~sander/res/henry.html
     (tmf, 1/7/09)
```

```
(27) Remove support for SGI compiler.  Bug fix in RAINOUT. (bmy, 7/20/09)
(28) Update mercury simulation. (ccc, 5/17/10)
(29) Add LGTMM as condition to output AD39. (ccc, 11/18/09)
(30) Add snow scavenging, different washout/rainout ratio
     (wqq, ccc, 7/13/10)
13 Aug 2010 - R. Yantosca - Add modifications for MERRA (treat like GEOS-5)
16 Sep 2010 - R. Yantosca - Added ProteX headers
20 Sep 2010 - H. Amos, R. Yantosca - Implement new algorithms for MERRA
08 Oct 2010 - H. Amos     - WASHFRAC_LIQ_GAS is now a subroutine
08 Oct 2010 - H. Amos     - Various other modifications in WETDEP_MERRA
01 Aug 2011 - H. Amos     - Bug fix for function WASHFRAC_LIQ_GAS
01 Aug 2011 - H. Amos     - Updated comments
09 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x
21 Jun 2012 - R. Yantosca - Declare H2O2s, SO2s as TARGETs for pointers
23 Apr 2013 - R. Yantosca - Bug fix, eliminate white space from #if block
23 Apr 2013 - R. Yantosca - Remove LTOMAS logical, since we now invoke TOMAS
                            with either TOMAS=yes or TOMAS40=yes
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
24 Nov 2014 - M. Yannetti - Added PRECISION_MOD
12 Feb 2015 - C. Keller   - Added GET_F and GET_VUD. VUD is now stored in
                            State_Met. In an ESMF environment, it's values
                            are directly taken from the GEOS-5 model. In
                            the traditional GEOS-Chem, the updraft velocity
                            is still calculated in the old manner (5 m/s
                            over water, 10 m/s over land/ice).
23 Jun 2015 - M. Sulprizio- Add impaction scavenging for hydrophobic BC and
                            homogeneous IN removal from Qiaoqiao Wang
08 Jul 2015 - E. Lundgren - Add marine organic aerosols (B.Gantt, M.Johnson)
03 Sep 2015 - R. Yantosca - Remove NSOLMAX, we now get the # of wetdep
                            species from State_Chm%nWetDep
03 Sep 2015 - R. Yantosca - INIT_WETSCAV now just allocates arrays;
                            SETUP_WETSCAV now just sets up quantities
03 Sep 2015 - R. Yantosca - Remove WETDEPID routine, it's not needed
22 Sep 2015 - R. Yantosca - Re-introduce GET_WETDEP_NSOL routine
25 Sep 2015 - R. Yantosca - Use species database to collapse down routines
                            COMPUTE_F, RAINOUT, WASHOUT
16 Jun 2016 - L. Hu       - Replaced IDTXXX with Ind_('XXX')
20 Jun 2016 - R. Yantosca - Now define species ID's only in the INIT phase
20 Jun 2016 - R. Yantosca - Renamed species ID's IDTxxxx to id_XXXX
06 Jul 2016 - R. Yantosca - Removed GET_WETDEP_NSOL and GET_WETDEP_IDWETD,
                            these are now replaced by State_Chm fields
```

4.2.1 do_wetdep

Subroutine DO_WETDEP is a driver for the wet deposition code, called from the MAIN program.

INTERFACE:

```
      SUBROUTINE DO_WETDEP( am_I_Root, Input_Opt,
     &                      State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
#if defined( USE_TEND )
      USE TENDENCIES_MOD
#endif
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE UnitConv_Mod
#if defined( NC_DIAG )
      USE SPECIES_MOD
      USE HCO_ERROR_MOD
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    NOTE FROM HONGYU LIU (hyl@nianet.org) -- 3/5/08

    Rainout and washout from convective precipitation for previous GEOS
    archives were intended to represent precipitation from cloud anvils
```

```
[Liu et al., 2001]. For GEOS-5 (as archived at Harvard), the cloud anvil
precipitation was already included in the large-scale precipitation.

Therefore, we insert a #if block to ensure that call MAKE_QQ and WETDEP
are not called for convective precip in GEOS-5. (hyl, bmy, 3/5/08)
```

REVISION HISTORY:

```
27 Mar 2003 - R. Yantosca - Initial version
(1 ) Now references LPRT from "logical_mod.f" (bmy, 7/20/04)
(2 ) Don't do rainout/washout for conv precip for GEOS-5 (hyl, bmy, 3/5/08)
13 Aug 2010 - R. Yantosca - Treat GEOS-5 like MERRA
16 Sep 2010 - R. Yantosca - Added ProTeX headers
20 Sep 2010 - R. Yantosca - Rewrote #if block structure for clarity
09 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
02 Jul 2013 - R. Yantosca - Bug fix: add State_Chm to WETDEP calls for
                            met other than MERRA, GEOS-5.7 or GEOS-5
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
08 Aug 2015 - E. Lundgren - Tracer units are now input as [kg/kg]
12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
19 Jul 2016 - R. Yantosca - Now bracket tendency calls with #ifdef USE_TEND
```

4.2.2 make_qq

Subroutine MAKE_QQ computes the large-scale or convective precipitation fields for use with WETDEP

INTERFACE:

```
SUBROUTINE MAKE_QQ( State_Met, LS )
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN) :: LS         ! =T, denotes large scale precip
                                         ! =F, denotes convective precip
TYPE(MetState), INTENT(IN) :: State_Met  ! Meteorology State object
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%       FOR MERRA, MERRA2, and GEOS-FP MET FIELDS ONLY      %%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.
Construct QQ and PDOWN directly from GEOS-FP, MERRA, MERRA2  met fields.
.
This only applies to large-scale precip, as the #if defined
block in routine DO_WETDEP prevents the wet deposition
routines from being called if it is convective precip.
.
MERRA met fields:
=================
DQRLSAN   = 3-D precip production rate  (LS+anvil) [kg/kg/s]
PFILSAN   = Dwnwd flux of ice precip    (LS+anvil) [kg/m2/s]
PFLLSAN   = Dwnwd flux of liquid precip (LS+anvil) [kg/m2/s]
REEVAPLS  = Evap of precip'ing LS+anvil condensate [kg/kg/s]
.
Unit conversion for QQ:
=======================

    kg H2O   |   m^3 H2O   | AIRDEN kg air       m^3 H2O
 ------------+-------------+-------------- = -------------
  kg air * s | 1000 kg H2O |    m^3 air        m^3 air * s

and [m^3 H2O/m3 air] = [cm^3 H2O/cm3 air] because the same conversion
factor from m^3 -> cm^3 is in both the numerator and the denominator.
.
Unit conversion for PDOWN:
==========================
.
    kg H2O |   m^3 H2O   | 1e6 cm^3 |  m^2
 ----------+-------------+----------+--------- +
   m^2 * s | 1000 kg H2O |   m^3    | 1e4 cm2
.
    kg ice |   m^3 ice   | 1e6 cm^3 |  m^2
 ----------+-------------+----------+---------
   m^2 * s |  917 kg ice |   m^3    | 1e4 cm2
.
= [ (PFILSAN/1000) * 100 ] + [ (PFILSAN/1000) * 100]
.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%     FOR ALL OTHER MET FIELDS EXCEPT MERRA and GEOS-FP     %%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.
If there is total precipitation in the (I,J) column, then:
.
(1) Compute FRAC, the large scale fraction (if LS = .TRUE.) or
    convective fraction (if LS = .FALSE.) total precipitation.
    FRAC is computed from PREACC and PRECON.
.
```

```
(2) Compute QQ, the rate of formation of precipitation
    [cm3 H2O/cm3 air/s].  From MOISTQ [kg H2O/kg air/s],
    defined as the tendency in specific humidity, the unit conversion
    is:

                                                                             .
    kg H2O   |   m^3 H2O   | MAIRDEN kg air         m^3 H2O
 ------------+-------------+--------------- ==> -------------
  kg air * s | 1000 kg H2O |    m^3 air          m^3 air * s

                                                                             .
and

                                                                             .
        m^3 H2O                          cm^3 H2O
     -------------  is equivalent to  --------------
      m^3 air * s                     cm^3 air * s!

                                                                             .
since the same conversion factor (10^6 cm^3/m^3) is in both
the numerator and the denominator.

Therefore, the equation for QQ is:

  QQ(L,I,J) = FRAC * MOISTQ(I,J,L) * MAIRDEN(I,J,L) / 1000.0

(3) Compute PDOWN, the column precipitation
    [cm3 H2O/cm2 air/s], by multiplying QQ(L,I,J) by
    BXHEIGHT(I,J,L) * 100 cm.

(4) The reason why we do not force PTEMP to be positive is
    that PREACC is the integral of the MOISTQ field.  MOISTQ
    contains both negative (evap) and positive (precip)
    values.  If we forced PTEMP to be positive, then we would
    be adding extra precipitation to PDOWN (hyl, bmy, 3/6/99).
```

REVISION HISTORY:

```
29 Feb 2000 - H. Liu, R. Yantosca - Initial version
(1 ) Now we partition MOISTQ into large-scale and convective parts, using
      total precipitation PREACC and convective precipitation PRECON (both
      are vertical integral amounts). The precipitation field at altitudes
      (PDOWN) is also made (hyl, djj, 10/17/98).
(2 ) MAKE_QQ is written in Fixed-Form Fortran 90. (bmy, 4/2/99)!
(3 ) AIRDEN, MOISTQ, QQ, and PDOWN are dimensioned (LLPAR,IIPAR,JJPAR)
     in order to maximize loop efficiency when processing an (I,J)
     column layer by layer. (bmy, 3/14/00)
(4 ) MOISTQ is originally [g H2O/kg air/day], and is converted in
      READ_A6 to [kg H2O/kg air/s]. (bmy, 3/14/00)
(5 ) Now reference PREACC, PRECON from "dao_mod.f" instead of from
      common block header file "CMN_PRECIP" (bmy, 6/26/00)
(6 ) Now pass BXHEIGHT as an argument.  Also added to "dao_mod.f".
      (bmy, 6/26/00)
```

```
(7 ) Moved from "dao_mod.f" to "wetscav_mod.f".  Also made PREACC
      and PRECON into arguments. (bmy, 10/12/00)
(8 ) Updated comments (bmy, 9/4/01)
(9 ) BXHEIGHT is now sized (IIPAR,JJPAR,LLPAR) (bmy, 10/4/01)
(10) Removed obsolete, commented-out code from 10/01 (bmy, 11/26/01)
(11) Now reference met field arrays directly from "dao_mod.f" (bmy, 11/8/02)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
16 Sep 2010 - R. Yantosca - Compute QQ and PDOWN from MERRA met fields
09 Feb 2012 - R. Yantosca - Added modifications for GEOS-5.7.x met fields
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%MOISTQ(I,J,L)
29 Apr 2015 - E. Lundgren - Now use State_Met%MAIRDEN instead of AIRDEN
                            since AIRDEN is now dry air density and MAIRDEN
                            is moist air density, needed for use with MOISTQ
12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
```

4.2.3 e_ice

Subroutine E_ICE computes Eice(T), the saturation vapor pressure of ice at a given Celsius temperature.

INTERFACE:

```
FUNCTION E_ICE( TK ) RESULT( VALUE )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: TK      ! Temperature [K]
```

RETURN VALUE:

```
REAL(fp)             :: VALUE   ! Saturation vapor pressure [hPa]
```

REMARKS:

```
Marti & Mauersberber (GRL '93) formulation of saturation
vapor pressure of ice [Pa] is: log P = A/TK + B
```

REVISION HISTORY:

```
08 Feb 2005 - R. Yantosca - Initial version
(1 ) Now use the same analytic function as the Goddard CTM (bmy, 2/8/05)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
```

4.2.4 compute_l2g

Subroutine COMPUTE_L2G computes the ratio L2G = Cliq / Cgas, which is the mixing ratio of species in the liquid phase, divided by the mixing ratio of species in the gas phase.

INTERFACE:

```
SUBROUTINE COMPUTE_L2G( K0, CR, pKa, TK, H2OLIQ, L2G )
```

USES:

```
USE Henry_Mod, ONLY : Calc_KH
USE Henry_Mod, ONLY : Calc_Heff
```

INPUT PARAMETERS:

```
REAL(f8), INTENT(IN)  :: K0     ! Henry's solubility constant [M/atm]
REAL(f8), INTENT(IN)  :: CR     ! Henry's volatility constant [K]
REAL(f8), INTENT(IN)  :: pKa    ! Henry's pH correction factor [1]
REAL(fp), INTENT(IN)  :: TK     ! Temperature [K]
REAL(fp), INTENT(IN)  :: H2OLIQ ! Liquid water content [cm3 H2O/cm3 air]
```

OUTPUT PARAMETERS:

```
REAL(fp), INTENT(OUT) :: L2G    ! Cliq/Cgas ratio [1]
```

REMARKS:

```
The ratio Cliq / Cgas is obtained via Henry's law.  The appropriate
values of Kstar298 and H298_R must be supplied for each species.
(cf Jacob et al 2000, p. 3)
```

REVISION HISTORY:

```
23 Feb 2000 - R. Yantosca - Initial version
(1 ) Bundled into "wetscav_mod.f" (bmy, 11/8/02)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
10-Jan-2011 - H. Amos - Corrected the units on KStar298 from moles/atm
                        to M/atm
15-May-2013 - F. Paulot - Fix R constant
08 Dec 2015 - R. Yantosca - Now use functions from henry_mod.F
```

4.2.5 compute_f

Subroutine COMPUTE_F computes F, the fraction of soluble species lost by scavenging in convective cloud updrafts.

INTERFACE:

```
      SUBROUTINE COMPUTE_F( am_I_Root, N,         F,         ISOL,
     &                      Input_Opt, State_Met, State_Chm, RC    )
```

USES:

```
      USE CMN_Size_Mod
      USE ErrCode_Mod
      USE Error_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
#if defined( TOMAS )
      USE Tomas_Mod,          ONLY : GetFraction
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root  ! Are we on the root CPU?
      INTEGER,        INTENT(IN)    :: N          ! Species ID
      TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met  ! Met State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: ISOL       ! Index for ND38 diag
      REAL(fp),       INTENT(OUT)   :: F(:,:,:)   ! Soluble fraction of species
      INTEGER,        INTENT(OUT)   :: RC         ! Success or failure?
```

REVISION HISTORY:

```
   23 Feb 2000 - H. Liu, R. Yantosca - Initial version
   (1 ) Currently works computes scavenging fractions for either full
        chemistry simulation (NSRCX == 3) or Rn-Pb-Be chemistry simulation
        (NSRCX == 1).  Set the scavenging fraction to zero for other
        simulations which do not carry soluble tracers. (bmy, 3/2/00)
   (2 ) Need to call INIT_SCAV to initialize the Vud, C_H2O, CLDLIQ,
        and CLDICE fields once per timestep. (bmy, 2/23/00)
   (3 ) For aerosols only: now apply Eq. 2 for all temperatures.  Also
        use the distance between the grid box centers in Eq. 2.  Updated
        comments and made some cosmetic changes (hyl, bmy, 6/18/01)
   (4 ) Remove IREF, JREF -- these are obsolete.  T is now dimensioned
        (IIPAR,JJPAR,LLPAR).  T(IREF,JREF,L) is now T(I,J,L). (bmy, 9/27/01)
   (5 ) Removed obsolete code from 9/01 (bmy, 10/23/01)
   (6 ) Fix 2 bugs for aerosol scavenging in Rn-Pb-Be simulation:
        (a) set F(:,:,1) = 0 since we don't do any scavenging there.
        (b) DO L = 2, LLPAR to avoid any subscript range out of bounds
        errors (rjp, hyl, bmy, 1/10/02)
```

```
(7 ) Now set F=0 in the first level for all tracers.  Also now
     compute the distance between grid box centers and use that in
     in Eq. 10 from Jacob et al, 2000 to compute F. (hyl, bmy, 1/24/02)
(8 ) Eliminated obsolete code from 1/02 (bmy, 2/27/02)
(9 ) Now reference T from "dao_mod.f" instead of from "CMN".  Also reference
     BXHEIGHT from "dao_mod.f" instead of from "CMN_NOX".  Now bundled
     into "wetscav_mod.f".  Now references IDTHNO3, IDTH2O2, etc, from
     F90 module "tracerid_mod.f".  Added internal routines F_AEROSOL
     and GET_ISOL.  Rewritten so that we don't duplicate code for
     different chemistry simulations. (bmy, 1/17/03)
(10) Now compute F for SO2 in the same way for both fullchem and offline
     simulations (rjp, bmy, 3/23/03)
(11) Added slots for carbon aerosol & dust tracers.  Now modified internal
     routine GET_ISOL so it's not hardwired anymore. (rjp, bmy, 4/5/04)
(12) Added slots for sea salt aerosol tracers (rjp, bec, bmy, 4/20/04)
(13) Added slots for secondary organic aerosol tracers (rjp, bmy, 7/13/04)
(14) Remove reference to CMN, it's not needed.  Made internal routine
     F_AEROSOL a module procedure rather than an internal routine to
     COMPUTE_F in order to facilitate parallelization on the Altix.  Also
     now pass all arguments explicitly to F_AEROSOL. (bmy, 7/20/04)
(15) Now wet scavenge mercury aerosol tracers (eck, bmy, 12/9/04)
(16) Updated for AS, AHS, LET, NH4aq, SO4aq.  Also condensed the IF
     statement by combining branches for aerosols. (cas, bmy, 12/20/04)
(17) Updated for SO4s, NITs (bec, bmy, 4/25/05)
(18) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(19) Bug fix: Now do not over-deplete H2O2s.  Also change Henry's law
     constant for Hg2 to 1.0d+14. Now use functions IS_Hg2 and IS_HgP to
     determine if a tracer is an Hg2 or HgP tagged tracer.
     (dkh, rjp, eck, cdh, bmy, 1/6/06)
(20) Updated for SOG4 and SOA4 (dkh, bmy, 5/18/06)
(21) Bug fix: now use separate conversion factors for H2O2 and NH3.
     (havala, bmy, 7/26/06)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
10-Jan-2011 - H.Amos      - Changed Hg2 Henry's law constant from 1.0d14 (no
                            citation) to 1.4d6 M/atm (HgCl2, Lindqvist &
                            Rhode, 1985). Henry's law constant in
                            wetscav_mod.f is now consistent with what's used
                            in mercury_mod.f
27 Sep 2011 - H. Amos     - remove LHg_WETDasHNO3 logical, it's obsolete
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
06 Mar 2013 - H. Amos     - merge C. Friedman's POP code
31 May 2013 - R. Yantosca - Now accept State_Chm, and pass it to TOMAS code
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
18 Apr 2014 - R. Yantosca - Now make the F argument an assumed-shape array
```

```
                           so that we can pass a pointer array slice to it
25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
19 Dec 2014 - M. Sulprizio- Add bug fixes for CONV_H2O2 and CONV_NH3 from
                           Duncan Fairlie. The square root term should be
                           inverted to be consistent with Mari et al (2000).
04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
23 Jun 2015 - M. Sulprizio- Add impaction scavenging for hydrophobic BC and
                           homogeneous IN removal from Qiaoqiao Wang
04 Sep 2015 - R. Yantosca - Use species database to radically simplify
                           the structure of this routine.
24 Sep 2015 - E. Lundgren - Convert kg/kg total air <-> kg for TOMAS
25 Sep 2015 - R. Yantosca - Move the computation of the Ki rate (Eq. 1 from
                           Jacob et al 2000) into routine COMPUTE_Ki
25 Sep 2015 - R. Yantosca - Remove T pointer, it's not needed here
30 Sep 2015 - R. Yantosca - Now use ThisSpc%WD_Is_HNO3 and ThisSpc%WD_Is_SO2
                           to flag the special cases of HNO3 & SO2 wetdep
05 Oct 2015 - R. Yantosca - Need to make ThisSpc !$OMP THREADPRIVATE
06 Oct 2015 - R. Yantosca - Add missing variables for TOMAS
16 Oct 2015 - E. Lundgren - Consolidate remaining embedded ifelse blocks
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
07 Jul 2016 - R. Yantosca - Now set ISOL = -1 if not a wetdep species
07 Jul 2016 - R. Yantosca - Remove pointer nullification from declarations
```

4.2.6 compute_ki

Subroutine COMPUTE_Ki computes the loss of species by scavenging according to Jacob et al 2000, eq. 1.

INTERFACE:

```
SUBROUTINE COMPUTE_Ki( SpcInfo, C_H2O, CLDICE, CLDLIQ, Kc, T, Ki )
```

USES:

```
USE Species_Mod, ONLY : Species
```

INPUT PARAMETERS:

```
TYPE(Species), INTENT(IN)  :: SpcInfo  ! Species database object
REAL(fp),      INTENT(IN)  :: C_H2O    ! Mixing ratio of H2O [v/v]
REAL(fp),      INTENT(IN)  :: CLDICE   ! Cloud ice mixing ratio
                                       !  [cm3 ice/cm3 air]
REAL(fp),      INTENT(IN)  :: CLDLIQ   ! Cloud liquid water mix ratio
                                       !  [cm3 H2O/cm3 air]
REAL(fp),      INTENT(IN)  :: Kc       ! Rate for conversion of cloud
                                       !  condensate -> precip [1/s]
REAL(fp),      INTENT(IN)  :: T        ! Temperature [K]
```

OUTPUT PARAMETERS:

```
      REAL(fp),      INTENT(OUT) :: Ki       ! Loss of species from updraft
                                             !  (cf Eq. 1, Jacob et al, 2000)
```

REMARKS:

```
This routine centralizes computations that are used in routines
COMPUTE_F and RAINOUT.
```

REVISION HISTORY:

```
25 Sep 2015 - R. Yantosca - Initial version
08 Dec 2015 - R. Yantosca - Make K0, CR, pKa 8-byte variables for
                            compatibility w/ CALC_KH, CALC_HEFF routines
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
```

4.2.7 f_aerosol

Subroutine F_AEROSOL returns the fraction of aerosol scavenged in updrafts

INTERFACE:

```
      SUBROUTINE F_AEROSOL( KC, KcScale, State_Met, F )
```

USES:

```
      USE CMN_SIZE_MOD
      USE State_Met_Mod,      ONLY: MetState
```

INPUT PARAMETERS:

```
      REAL(fp),       INTENT(IN)  :: KC                  ! Cloud condensate to
                                                         !  precipitation rate
                                                         !  [1/s]
      REAL(fp),       INTENT(IN)  :: KcScale(3)          ! Scale factors for Kc
                                                         !  for 3 temperature
                                                         !  regimes
      TYPE(MetState), INTENT(IN)  :: State_Met           ! Meteorology State
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT) :: F(IIPAR,JJPAR,LLPAR) ! Fraction of aerosol
                                                          !  scavenged in
                                                          !  convective updrafts
```

REVISION HISTORY:

```
07 Nov 2002 - R. Yantosca - Initial version
16 Sep 2010 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
29 May 2013 - R. Yantosca - Segregate TOMAS-specific code with #ifdefs
```

```
10 Nov 2014 - C. Keller   - Now also apply TINY check in ESMF environment.
23 Jun 2015 - M. Sulprizio- Add impaction scavenging for hydrophobic BC and
                            homogeneous IN removal from Qiaoqiao Wang
25 Sep 2015 - R. Yantosca - Rewrite this routine to avoid testing on the
                            tracer number.  Remove the N argument.
```

4.2.8 rainout

Subroutine RAINOUT computes RAINFRAC, the fraction of soluble species lost to rainout events in precipitation.

INTERFACE:

```
      SUBROUTINE RAINOUT( I,         J,         L,        N,
     &                    K_RAIN,    DT,        F,        RAINFRAC,
     &                    Input_Opt, State_Met, State_Chm           )
```

USES:

```
      USE CMN_Size_Mod
      USE Error_Mod,          ONLY : Error_Stop
      USE Input_Opt_Mod,      ONLY : OptInput
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I          ! Longitude index
      INTEGER,        INTENT(IN)  :: J          ! Latitude index
      INTEGER,        INTENT(IN)  :: L          ! Level index
      INTEGER,        INTENT(IN)  :: N          ! Species number
      REAL(fp),       INTENT(IN)  :: K_RAIN     ! Rainout rate constant [1/s]
      REAL(fp),       INTENT(IN)  :: DT         ! Timestep for rainout event [s]
      REAL(fp),       INTENT(IN)  :: F          ! Fraction of grid box that is
                                                !  precipitating [unitless]
      TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input options
      TYPE(MetState), INTENT(IN)  :: State_Met  ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(IN)  :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT) :: RAINFRAC   ! Fraction of species lost
                                                !  to rainout [unitless]
```

REVISION HISTORY:

```
28 Feb 2000 - R. Yantosca - Initial version
(1 ) Currently works for either full chemistry simulation (NSRCX == 3)
     or Rn-Pb-Be chemistry simulation (NSRCX == 1).  Other simulations
     do not carry soluble tracer, so set RAINFRAC = 0. (bmy, 2/28/00)
(2 ) Need to call INIT_SCAV to initialize the Vud, C_H2O, CLDLIQ,
     and CLDICE fields once per dynamic timestep. (bmy, 2/28/00)
(3 ) K_RAIN, the rainout rate constant, and F, the areal fraction of the
     grid box undergoing precipitiation, are computed according to
     Giorgi & Chaimedes, as described in Jacob et al, 2000.
(4 ) Now no longer suppress scavenging of HNO3 and aerosol below 258K.
     Updated comments, cosmetic changes.  Now set TK = T(I,J,L) since
     T is now sized (IIPAR,JJPAR,LLPAR) in "CMN". (djj, hyl, bmy, 1/24/02)
(5 ) Eliminated obsolete code (bmy, 2/27/02)
(6 ) Now reference T from "dao_mod.f".  Updated comments.  Now bundled
     into "wetscav_mod.f". Now refererences "tracerid_mod.f".  Also
     removed reference to CMN since we don't need NSRCX. (bmy, 11/8/02)
(7 ) Now updated for carbon & dust aerosol tracers (rjp, bmy, 4/5/04)
(8 ) Now updated for seasalt aerosol tracers (rjp, bec, bmy, 4/20/04)
(9 ) Now updated for secondary aerosol tracers (rjp, bmy, 7/13/04)
(10) Now treat rainout of mercury aerosol tracers (eck, bmy, 12/9/04)
(11) Updated for AS, AHS, LET, NH4aq, SO4aq.  Also condensed the IF
     statement by grouping blocks together. (cas, bmy, 12/20/04)
(12) Updated for SO4s, NITs (bec, bmy, 4/25/05)
(13) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(14) Change Henry's law constant for Hg2 to 1.0d+14.  Now use functions
     IS_Hg2 and IS_HgP to determine if the tracer is a tagged Hg0 or
     HgP tracer. (eck, cdh, bmy, 1/6/06)
(15) Updated for SOG4 and SOA4 (dkh, bmy, 5/18/06)
(16) For GEOS-5, suppress rainout when T < 258K (hyl, bmy, 3/5/08)
(17) Bug fix: need to use separate conversion parameters for H2O2 and
     NH3.  This was the same fix as in COMPUTE_F but until now we had
     overlooked this. (havala, bmy, 7/20/09)
25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
16 Sep 2010 - R. Yantosca - Added ProTeX headers
27 Sep 2011 - H. Amos     - remove LHg_WETDasHNO3 logical, it's obsolete
09 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
19 Dec 2014 - M. Sulprizio- Add bug fixes for CONV_H2O2 and CONV_NH3 from
                            Duncan Fairlie. The square root term should be
                            inverted to be consistent with Mari et al (2000).
23 Jun 2015 - M. Sulprizio- Add impaction scavenging for hydrophobic BC and
```

```
                            homogeneous IN removal from Qiaoqiao Wang
08 Jul 2015 - E. Lundgren - Add marine organic aerosols (B.Gantt, M.Johnson)
23 Sep 2015 - R. Yantosca - Use the species database to eliminate many
                            IF blocks to simplify the code logic
25 Sep 2015 - R. Yantosca - Now call routine COMPUTE_Ki to compute the
                            rate of scavenging (Eq. 1, Jacob et al 2000)
25 Sep 2015 - R. Yantosca - Now define THREADPRIVATE pointers
28 Sep 2015 - R. Yantosca - Needed to add special case for HNO3
30 Sep 2015 - R. Yantosca - Now use ThisSpc%WD_Is_HNO3 and ThisSpc%WD_Is_SO2
                            to flag the special cases of HNO3 & SO2 wetdep
16 Oct 2015 - E. Lundgren - Use ThisSpc%WD_Is_H2SO4 to treat H2SO4 as
                            aerosol for wetdep (for microphysics)
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
 7 Jul 2016 - R. Yantosca - Now remove pointer threadprivate declarations
```

4.2.9 apply_rainout_eff

Subroutine APPLY_RAINOUT_EFF multiplies the rainout fraction computed by RAINOUT with the rainout efficiency for one of 3 temperature ranges: (1) T ¡ 237 K; (2) 237 K ¡= T ¡ 258 K; (3) T ¿ 258 K. The rainout efficiencies for each aerosol species are defined in the species database object (i.e. State_Chm

This allows us to apply the impaction scavenging of certain aerosol species (BC, dust, HNO3) as implemented by Qiaoqiao Wang, while also suppressing rainout for other aerosol species. The prior code achieved this by using a large and confusing IF statement, whose logic was hard to understand.

INTERFACE:

```
SUBROUTINE APPLY_RAINOUT_EFF( TK, SpcInfo, RainFrac )
```

USES:

```
USE Species_Mod, ONLY : Species
```

INPUT PARAMETERS:

```
REAL(fp),      INTENT(IN)    :: TK         ! Temperature [K]
TYPE(Species), INTENT(IN)    :: SpcInfo    ! Species Database object
```

INPUT/OUTPUT PARAMETERS:

```
REAL(fp),      INTENT(INOUT) :: RainFrac   ! Rainout fraction
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
```

4.2.10 get_rainfrac

Function GET_RAINFRAC computes the fraction of species lost to rainout according to Jacob et al 2000.

INTERFACE:

```
FUNCTION GET_RAINFRAC( K, F, DT ) RESULT( RAINFRAC )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: K          ! Rainout rate constant [1/s]
REAL(fp), INTENT(IN) :: F          ! Timestep for rainout event [s]
REAL(fp), INTENT(IN) :: DT         ! Fraction of grid box that is
                                   !  undergoing precipitation [unitless]
```

RETURN VALUE:

```
REAL(fp)             :: RAINFRAC   ! Fraction of species lost to rainout
```

REVISION HISTORY:

```
08 Nov 2002 - R. Yantosca - Initial version
(1 ) Now move internal routines GET_RAINFRAC to the module and pass all
     arguments explicitly.  This facilitates parallelization on the
     Altix platform (bmy, 7/20/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
```

4.2.11 washout

Subroutine WASHOUT computes WASHFRAC, the fraction of soluble species lost to washout events in precipitation.

INTERFACE:

```
SUBROUTINE WASHOUT( am_I_Root, I, J, L,  N,  BXHEIGHT, TK,   PP,
&                   DT, F, H2O2s, SO2s, WASHFRAC, KIN,
&                   Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
#if defined( TOMAS )
USE ERROR_MOD
USE TOMAS_MOD,          ONLY : IBINS,    ICOMP
USE UnitConv_Mod
#endif
```

INPUT PARAMETERS:

```
LOGICAL,         INTENT(IN)    :: am_I_Root  ! Are we on the root CPU?
INTEGER,         INTENT(IN)    :: I          ! Longitude index
INTEGER,         INTENT(IN)    :: J          ! Latitude index
INTEGER,         INTENT(IN)    :: L          ! Level index
INTEGER,         INTENT(IN)    :: N          ! Species number
REAL(fp),        INTENT(IN)    :: BXHEIGHT   ! Grid box height [m]
REAL(fp),        INTENT(IN)    :: TK         ! Temperature [K]
REAL(fp),        INTENT(IN)    :: PP         ! Precip rate thru bottom
                                             !  of grid (I,J,L)
                                             !  [cm3 H2O/cm2 air/s]
REAL(fp),        INTENT(IN)    :: DT         ! Timestep [s]
REAL(fp),        INTENT(IN)    :: F          ! Fraction of grid box that
                                             !  is precipitating [1]

TYPE(OptInput), INTENT(IN)     :: Input_Opt  ! Input Options
TYPE(MetState), INTENT(IN)     :: State_Met  ! Meteorology State
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
REAL(fp),       INTENT(INOUT) :: H2O2s      ! H2O2 [v/v] and SO2 [v/v]
REAL(fp),       INTENT(INOUT) :: SO2s       ! conc's after aqueous rxns
                                            ! are applied.  These are
                                            ! computed in the sulfate
                                            ! chemistry module and
                                            ! passed here as arguments.
```

OUTPUT PARAMETERS:

```
REAL(fp),        INTENT(OUT)   :: WASHFRAC   ! Fraction of species lost
                                             !  to washout [1]
LOGICAL,         INTENT(OUT)   :: KIN        ! =T washout is a
                                             !    kinetic process
                                             ! =F washout is an
                                             !    equilibrium process
INTEGER,         INTENT(OUT)   :: RC         ! Success or failure?
```

REVISION HISTORY:

```
28 Feb 2000 - R. Yantosca - Initial version
(1 ) Currently works for either full chemistry simulation (NSRCX == 3)
     or Rn-Pb-Be chemistry simulation (NSRCX == 1).  Other simulations
     do not carry soluble tracers, so set WASHFRAC = 0.
(2 ) K_WASH, the rainout rate constant, and F, the areal fraction of the
     grid box undergoing precipitiation, are computed according to
     Giorgi & Chaimedes, as described in Jacob et al, 2000.
(3 ) Washout is only done for T >= 268 K, when the cloud condensate is
     in the liquid phase.
```

```
(4 ) T(I+I0,J+J0,L) is now T(I,J,L).  Removed IREF, JREF -- these are
     obsolete.  Updated comments. (bmy, 9/27/01)
(5 ) Removed obsolete commented out code from 9/01 (bmy, 10/24/01)
(6 ) Now reference BXHEIGHT, T from "dao_mod.f".  Also remove reference
     to "CMN_NOX".  Updated comments.  Now bundled into "wetscav_mod.f".
     Now also references "tracerid_mod.f".  Added internal routines
     WASHFRAC_AEROSOL and WASHFRAC_LIQ_GAS.  Also removed reference to
     CMN since we don't need to use NSRCX here. (bmy, 11/6/02)
(7 ) Updated for carbon aerosol and dust tracers (rjp, bmy, 4/5/04)
(8 ) Updated for seasalt aerosol tracers (rjp, bec, bmy, 4/20/04)
(9 ) Updated for secondary organic aerosol tracers (rjp, bmy, 7/13/04)
(10) Now move internal routines WASHFRAC_AEROSOL and WASHFRAC_LIQ_GAS
     to the module and pass all arguments explicitly.  This facilitates
     parallelization on the Altix platform (bmy, 7/20/04)
(11) Now handle washout of mercury aerosol tracers (eck, bmy, 12/9/04)
(13) Updated for AS, AHS, LET, NH4aq, SO4aq.  Also condensed the IF
     statement by grouping blocks together (cas, bmy, 12/20/04)
(14) Updated for SO4s, NITs (bec, bmy, 4/25/05)
(15) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(16) Bug fix: Deplete H2O2s the same as SO2s.  Also change Henry's law
     constant for Hg2 to 1.0d+14. Now use functions IS_Hg2 and IS_HgP to
     determine if a tracer is a tagged Hg0 or HgP tracer.
     (dkh, rjp, eck, cdh, bmy, 1/6/06)
(17) Updated for SOG4 and SOA4 (bmy, 5/18/06)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
30 Sep 2010 - H. Amos     - WASHFRAC_LIQ_GAS now a subroutine (was an
                            external function)
14 Oct 2010 - H. Amos     - Remove dependence on I, J. That means removing
                            I, J as input arguments and adding T, BXHEIGHT,
                            H2O2s, and SO4s and input arguments.
16 Aug 2011 - H. Amos     - move K_WASH to WASHFRAC_AEROSOL, WASHFRAC_HNO3,
                            and WASHFRAC_LIQ_GAS
16 Aug 2011 - H. Amos     - Replace logical AER with KIN. Serves the same
                            purpose in the code, but emphasizes to the user
                            that the difference in washout isn't whether or
                            not the tracer is an aerosol, it's whether or not
                            washout is modeled as a kinetic vs equilibrium
                            process.
27 Sep 2011 - H. Amos     - remove LHg2_WETDasHNO3 logical, it's obsolete
20 Jan 2012 - H. Amos     - WASHFRAC for aerosol is now either computed by
                            WASHFRAC_FINE_AEROSOL or WASHFRAC_COARSE_AEROSOL
31 May 2013 - R. Yantosca - Now accept State_Chm, and pass it to TOMAS code
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
27 Sep 2013 - M. Sulprizio- DST2-DST4 are now considered coarse mode aerosol
                            following the recommendation of T.D. Fairlie.
```

```
                              NITd, SO4d, and DALK are similarly updated.
25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
12 May 2015 - E. Lundgren - Change tracer units from v/v -> kg for TOMAS if
                              not already in kg (ie. called from convection)
04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
23 Jun 2015 - E. Lundgren - Adjust 5/12/15 TOMAS bug fix to convert
                              kg/kg total air <-> kg for new convection units
08 Jul 2015 - E. Lundgren - Add marine organic aerosols (B.Gantt, M.Johnson)
22 Sep 2015 - E. Lundgren - Add kg/m2 <-> kg conversion for TOMAS
30 Sep 2015 - R. Yantosca - Now use ThisSpc%WD_Is_HNO3 and ThisSpc%WD_Is_SO2
                              to flag the special cases of HNO3 & SO2 wetdep
16 Oct 2015 - E. Lundgren - Use ThisSpc%WD_Is_H2SO4 to treat H2SO4 as aerosol
                              for wetdep, and consolidate ifelse blocks
27 Jul 2016 - E. Lundgren - Now expect dry mixing ratio not total
```

4.2.12 washfrac_fine_aerosol

Function WASHFRAC_FINE_AEROSOL returns the fraction of soluble aerosol species lost to washout.

INTERFACE:

```
      FUNCTION WASHFRAC_FINE_AEROSOL( DT, F, PP, TK )
     &         RESULT( WASHFRAC )
```

USES:

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN) :: DT        ! Timestep of washout event [s]
      REAL(fp), INTENT(IN) :: F         ! Fraction of grid box that is
                                        !  precipitating [unitless]
      REAL(fp), INTENT(IN) :: PP        ! Precip rate thru bottom of grid
                                        !  box (I,J,L)  [cm3 H2O/cm2 air/s]
      REAL(fp), INTENT(IN) :: TK        ! Temperature in grid box [K]
```

RETURN VALUE:

```
      REAL(fp)             :: WASHFRAC  ! Fraction of soluble species
                                        !  lost to washout [1]
```

REVISION HISTORY:

```
    08 Nov 2002 - R. Yantosca - Initial version
    (1 ) WASHFRAC_AEROSOL used to be an internal function to subroutine WASHOUT.
         This caused NaN's in the parallel loop on Altix, so we moved it to
         the module and now pass Iall arguments explicitly (bmy, 7/20/04)
```

```
16 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Jan 2011 - J. Fisher & Q. Wang - Update to account for time-dependent
      shift in aerosol size distribution that slows washout as a rain
      event proceeds (see e.g. Feng et al., 2007, 2009).
16 Aug 2011 - H Amos      - Remove K_WASH from input list, make a defined
                            parameter.
20 Jan 2012 - H Amos      - rename WASHFRAC_FINE_AEROSOL to distinguish
                            this function from WASHFRAC_COARSE_AEROSOL
04 Sep 2013 - R. Yantosca - Bug fix: Prevent div-by-zero if F=0.  Because F
                            multiplies the whole expression for WASHFRAC,
                            WASHFRAC=0 whenever F=0 anyway.
```

4.2.13 washfrac_coarse_aerosol

Function WASHFRAC_COARSE_AEROSOL returns the fraction of soluble aerosol species lost to washout.

INTERFACE:

```
      FUNCTION WASHFRAC_COARSE_AEROSOL( DT, F, PP, TK )
     &         RESULT( WASHFRAC )
```

USES:

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN) :: DT         ! Timestep of washout event [s]
      REAL(fp), INTENT(IN) :: F          ! Fraction of grid box that is
                                         !  precipitating [unitless]
      REAL(fp), INTENT(IN) :: PP         ! Precip rate thru bottom of grid
                                         !  box (I,J,L)  [cm3 H2O/cm2 air/s]
      REAL(fp), INTENT(IN) :: TK         ! Temperature in grid box [K]
```

RETURN VALUE:

```
      REAL(fp)             :: WASHFRAC   ! Fraction of soluble species
                                         !  lost to washout
```

REVISION HISTORY:

```
08 Nov 2002 - R. Yantosca - Initial version
(1 ) WASHFRAC_AEROSOL used to be an internal function to subroutine WASHOUT.
      This caused NaN's in the parallel loop on Altix, so we moved it to
      the module and now pass Iall arguments explicitly (bmy, 7/20/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
16 Aug 2011 - H Amos      - Remove K_WASH from input list, make a defined
                            parameter.
```

```
20 Jan 2012 - H Amos      - WASHFRAC_COARSE_AEROSOL created to handle
                            SALC and DST4
04 Sep 2013 - R. Yantosca - Bug fix: Prevent div-by-zero if F=0.  Because F
                            multiplies the whole expression for WASHFRAC,
                            WASHFRAC=0 whenever F=0 anyway.
```

4.2.14 washfrac_size_aerosol

Subroutine WASHFRAC_SIZE_AEROSOL retrieves fraction of soluble aerosol species lost to washout. Size resolved version for TOMAS.

INTERFACE:

```
 SUBROUTINE WASHFRAC_SIZE_AEROSOL( DT, F, PP, TK, N, I, J, L,
&                                  State_Met, State_Chm, WASHFRAC,
&                                  RC )
```

USES:

```
 USE ErrCode_Mod
 USE ERROR_MOD
 USE State_Chm_Mod,      ONLY : ChmState
 USE State_Met_Mod,      ONLY : MetState
 USE TOMAS_MOD,          ONLY : IBINS, GETDP, STRATSCAV
```

INPUT PARAMETERS:

```
 REAL(fp),       INTENT(IN)    :: DT         ! Dynamic timestep [s]
 REAL(fp),       INTENT(IN)    :: F          ! Fraction of grid box
                                             !  that is precipitating
 REAL(fp),       INTENT(IN)    :: PP         ! Precip rate thru bottom
                                             !  of grid box (I,J,L)
                                             !  [cm3 H2O/cm2 air/s]
 REAL(fp),       INTENT(IN)    :: TK         ! Temperature [K]
 INTEGER,        INTENT(IN)    :: I          ! Longitude index
 INTEGER,        INTENT(IN)    :: J          ! Latitude index
 INTEGER,        INTENT(IN)    :: L          ! Level index
 INTEGER,        INTENT(IN)    :: N          ! Species index

 TYPE(MetState), INTENT(IN)    :: State_Met  ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
 TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
 REAL(fp),       INTENT(OUT)   :: WASHFRAC   ! Fraction of species
                                             !  lost to washout [1]
 INTEGER,        INTENT(OUT)   :: RC         ! Success or failure?
```

REVISION HISTORY:

```
31 May 2013 - R. Yantosca - Now accept State_Met, State_Chm as arguments
04 Sep 2013 - R. Yantosca - Bug fix: Prevent div-by-zero if F=0.  Because F
                            multiplies the whole expression for WASHFRAC,
                            WASHFRAC=0 whenever F=0 anyway.
24 Sep 2015 - E. Lundgren - Function is now a subroutine and outputs RC
```

4.2.15 washfrac_hno3

Function WASHFRAC_HNO3 returns the fraction of HNO3 species lost to washout.

INTERFACE:

```
FUNCTION WASHFRAC_HNO3( DT, F, PP, TK ) RESULT( WASHFRAC )
```

USES:

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: DT        ! Timestep of washout event [s]
REAL(fp), INTENT(IN) :: F         ! Fraction of grid box that is
                                  !  precipitating [unitless]
REAL(fp), INTENT(IN) :: PP        ! Precip rate thru bottom of grid
                                  !  box (I,J,L)  [cm3 H2O/cm2 air/s]
REAL(fp), INTENT(IN) :: TK        ! Temperature in grid box [K]
```

RETURN VALUE:

```
REAL(fp)             :: WASHFRAC  ! Fraction of soluble species
```

REVISION HISTORY:

```
13 Aug 2011, H Amos: Initial version, modeled after WASHFRAC_AEROSOL.
                     Seperate function created to emphasize that the new,
                     updated washout coefficients from Feng et al (2007;
                     2009) should only be applied to aerosol species. It
                     was a coincidence before that the original washout
                     coefficients for aerosols and HNO3 were the same.
16 Aug 2011, H Amos: Remove K_WASH from input list, now a defined parameter
04 Sep 2013 - R. Yantosca - Bug fix: Prevent div-by-zero if F=0.  Because F
                            multiplies the whole expression for WASHFRAC,
                            WASHFRAC=0 whenever F=0 anyway.
```

4.2.16 washfrac_liq_gas

!Subroutine WASHFRAC_LIQ_GAS returns the fraction of soluble liquid/gas phase species lost to washout.

INTERFACE:

```
 SUBROUTINE WASHFRAC_LIQ_GAS( K0, CR, pKa, PP,       DT,
&                             F,  DZ, TK,  WASHFRAC, KIN )
```

INPUT PARAMETERS:

```
 REAL(f8), INTENT(IN)  :: K0        ! Henry's solubility constant [M/atm]
 REAL(f8), INTENT(IN)  :: CR        ! Henry's volatility constant [K]
 REAL(f8), INTENT(IN)  :: pKa       ! Henry's pH correction [1]
 REAL(fp), INTENT(IN)  :: PP        ! Precip rate thru bottom of the
                                    !  grid box [cm3 H2O/cm2 air/s]
 REAL(fp), INTENT(IN)  :: DT        ! Timestep for washout event [s]
 REAL(fp), INTENT(IN)  :: F         ! Fraction of grid box that is
                                    !  precipitating [unitless]
 REAL(fp), INTENT(IN)  :: DZ        ! Height of grid box [cm]
 REAL(fp), INTENT(IN)  :: TK        ! Temperature in grid box [K]
```

OUTPUT PARAMETERS:

```
 REAL(fp), INTENT(OUT) :: WASHFRAC  ! Fraction of species lost to washout
 LOGICAL,  INTENT(OUT) :: KIN       ! T = washout is a kinetic process
                                    ! F = washout is an equilibrium process
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
(1 ) WASHFRAC_LIQ_GAS used to be an internal function to subroutine WASHOUT.
      This caused NaN's in the parallel loop on Altix, so we moved it to
      the module and now pass all arguments explicitly (bmy, 7/20/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
10 Jan 2011 - H. Amos     - Remove AER from the argument list
03 Jun 2011 - H. Amos     - convert from a function to a subroutine and
                            add AER to the argument list
16 Aug 2011 - H. Amos     - remove K_WASH from input list, now a defined
                            parameter
16 Aug 2911 - H. Amos     - rename AER logical KIN to emphasize that washout
                            is either a kinetic or equilibrium process
```

4.2.17 wetdep

Subroutine WETDEP computes the downward mass flux of species due to washout and rainout of aerosols and soluble species in a column. The timestep is the dynamic timestep.

INTERFACE:

```
      SUBROUTINE WETDEP( am_I_Root, Input_Opt, State_Met, State_Chm,
     &                   RC,        LS                              )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HgP_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_SNOWPACK
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GET_NDEP_MOD,       ONLY : SOIL_WETDEP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      LOGICAL,        INTENT(IN)    :: LS         ! =T for large-scale precip
                                                  ! =F for convective precip
      TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input options
      TYPE(MetState), INTENT(IN)    :: State_Met  ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

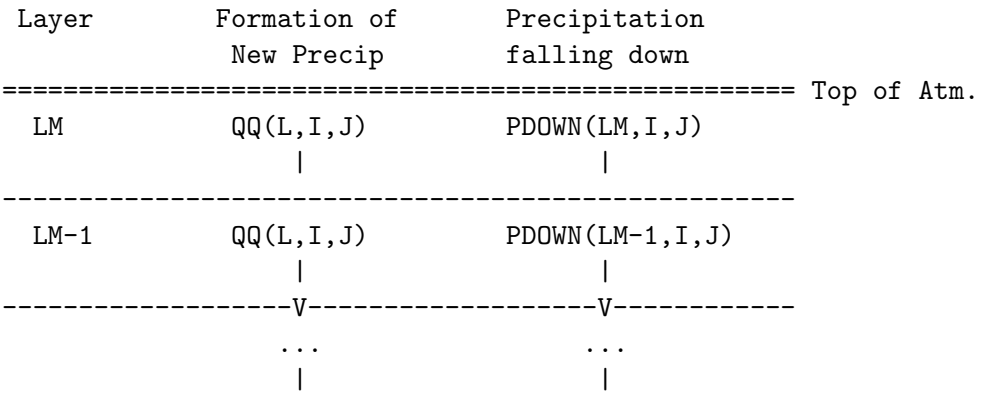
```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Precipitation fields:
    =====================
```



```
    ------------------V------------------V------------
      3           QQ(L,I,J)         PDOWN(3,I,J)
                      |                   |
    ------------------V-------------------------------
      2           QQ(L,I,J)         PDOWN(2,I,J)
                      |                   |
    ------------------------------------------------
      1           QQ(L,I,J)         PDOWN(1,I,J)
                      |                   |
    ==================V==================V============ Ground
```

Where:
  (a) New formation forming in grid box (I,J,L) = QQ(L,I,J)
  (b) Precip coming in thru top   of layer L = PDOWN(L+1,I,J)
  (c) Precip going out thru bottom of layer L = PDOWN(L, I,J)

Rainout:
========
Rainout occurs when there is more precipitation in grid box (I,J,L) than in grid box (I,J,L+1). In other words, rainout occurs when the amount of rain falling through the bottom of grid box (I,J,L) is more than the amount of rain coming in through the top of grid box (I,J,L).

Soluble gases/aerosols are incorporated into the raindrops and are completely removed from grid box (I,J,LLPAR). There is no evaporation and "resuspension" of aerosols during a rainout event.

For large-scale (a.k.a. stratiform) precipitation, the first order rate constant for rainout in the grid box (I,J,L=LLPAR) (cf. Eq. 12, Jacob et al, 2000) is given by:

$$K\_RAIN = K\_MIN + \frac{Q}{L + W} \quad \text{[units: s\^-1]}$$

and the areal fraction of grid box (I,J,L=LLPAR) that is actually experiencing large-scale precipitation (cf. Eq. 11, Jacob et al, 2000) is given by:

$$F' = \frac{Q}{K\_RAIN * (L + W)} \quad \text{[unitless]}$$

Where:

K_MIN = minimum value for K_RAIN
       = 1.0e-4 [s^-1]

```
     L + W  = condensed water content in cloud
            = 1.5e-6 [cm3 H2O/cm3 air]

     Q = QQ = rate of precipitation formation
              [ cm3 H2O / cm3 air / s ]

For convective precipitation, K_RAIN = 5.0e-3 [s^-1], and the expression
for F' (cf. Eq. 13, Jacob et al, 2000) becomes:

                                      { DT        }
                        FMAX * Q * MIN{ --- , 1.0 }
                                      { TAU       }
     F' = ---------------------------------------------------
                  { DT        }
           Q * MIN{ --- , 1.0 }  +  FMAX * K_RAIN * ( L + W )
                  { TAU       }

Where:

     Q = QQ = rate of precipitation formation
              [cm3 H2O/cm3 air/s]

     FMAX   = maximum value for F'
            = 0.3

     DT     = dynamic time step from the CTM [s]

     TAU    = duration of rainout event
            = 1800 s (30 min)

     L + W  = condensed water content in cloud
            = 2.0e-6 [cm3 H2O/cm3 air]

K_RAIN and F' are needed to compute the fraction of species in grid box
(I,J,L=LLPAR) lost to rainout.  This is done in module routine RAINOUT.

Washout:
========
Washout occurs when we have evaporation (or no precipitation at all) at
grid box (I,J,L), but have rain coming down from grid box (I,J,L+1).
```

REVISION HISTORY:

```
02 Apr 1999 - H. Liu, I. Bey, R. Yantosca - Initial version
(1 ) WETDEP should be called twice, once with LS = .TRUE. and once
      with LS = .FALSE.  This will handle both large-scale and
      convective precipitation. (bmy, 2/28/00)
(2 ) Call subroutine MAKE_QQ to construct the QQ and PDOWN precipitation
```

```
      fields before calling WETDEP. (bmy, 2/28/00)
(3 ) Since we are working with an (I,J) column, the ordering of the
      loops goes J - I - L - N.  Dimension arrays DSTT, PDOWN, QQ
      to take advantage of this optimal configuration (bmy, 2/28/00)
(4 ) Use double-precision exponents to force REAL(fp) accuracy
      (e.g. 1e+0_fp, bmy, 2/28/00)
(5 ) Diagnostics ND16, ND17, ND18, and ND39 use allocatable arrays
      from "diag_mod.f"  (bmy, bey, 3/14/00)
(6 ) WETDEP only processes soluble tracers and/or aerosols, as are
      defined in the NSOL and IDWETD arrays (bmy, 3/14/00)
(7 ) Add kludge to prevent wet deposition in the stratosphere (bmy, 6/21/00)
(8 ) Removed obsolete code from 10/27/00 (bmy, 12/21/00)
(9 ) Remove IREF, JREF -- they are obsolete (bmy, 9/27/01)
(10) Removed obsolete commented out code from 9/01 (bmy, 10/24/01)
(11) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
      to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(12) Now reference BXHEIGHT from "dao_mod.f".  Also references routine
      GEOS_CHEM_STOP from "error_mod.f".  Also fix ND39 diagnostic so that
      the budget of tracer lost to wetdep is closed.  Now bundled into
      "wetscav_mod.f".  Now only save to AD16, AD17, AD18, AD39 if L<=LD16,
      L<=LD17, L<=LD18, and L<=LD39 respectively; this avoids out-of-bounds
      array errors. Updated comments, cosmetic changes. (qli, bmy, 11/26/02)
(13) References IDTSO2, IDTSO4 from "tracerid_mod.f". SO2 in sulfate
      chemistry is wet-scavenged on the raindrop and converted to SO4 by
      aqueous chem. If evaporation occurs then SO2 comes back as SO4.
      (rjp, bmy, 3/23/03)
(14) Now use function GET_TS_DYN() from "time_mod.f" (bmy, 3/27/03)
(15) Now parallelize over outermost J-loop.  Also move internal routines
      LS_K_RAIN, LS_F_PRIME, CONV_F_PRIME, and SAFETY to the module, since
      we cannot call internal routines from w/in a parallel loop.
      (bmy, 3/18/04)
(16) Now references STT & N_TRACERS from "tracer_mod.f".  Also now make
      DSTT a 4-d internal array so as to facilitate -C checking on the
      SGI platform. (bmy, 7/20/04)
(17) Now references IDTHg2 from "tracerid_mod.f".  Now pass the amt of
      Hg2 wet scavenged out of the column to "ocean_mercury_mod.f" via
      routine ADD_Hg2_WD. (sas, bmy, 1/19/05)
(18) Bug fix: replace line that can cause numerical blowup with a safer
      analytical expression. (bmy, 2/23/05)
(19) Block out parallel loop with #ifdef statements for SGI_MIPS compiler.
      For some reason this causes an error. (bmy, 5/5/05)
(20) Now use function IS_Hg2 to determine if a tracer is a tagged Hg2
      tracer.  Now also pass N to ADD_Hg2_WD.  Now references LDYNOCEAN
      from "logical_mod.f".  Now do not call ADD_Hg2_WD if we are not
      using the dynamic ocean model. (eck, sas, cdh, bmy, 2/27/06)
(21) Eliminate unnecessary variables XDSTT, L_PLUS_W.  Also zero all
      unused variables for each grid box. (bmy, 5/24/06)
(22) Redimension DSTT with NSOL instead of NSOLMAX. In many cases, NSOL is
```

```
      less than NSOLMAX and this will help to save memory especially when
      running at 2x25 or greater resolution. (bmy, 1/31/08)
(23) Remove reference to SGI_MIPS (bmy, 7/8/09)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
27 May 2011 - R. Yantosca - Now pass F_RAINOUT to DO_WASHOUT_ONLY
25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
02 Apr 2015 - E. Lundgren - Move tracer unit conversion from kg/kg to kg
                            to within this routine
04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
09 Jun 2015 - R. Yantosca - Now deposit Hg2, HgP to snowpack regardless of
                            whether the dynamic ocean is used
22 Sep 2015 - E. Lundgren - Tracer units now converted to kg/m2 from kg/kg
22 Apr 2016 - R. Yantosca - Now get Is_Hg2, Is_HgP from species database
25 Apr 2016 - R. Yantosca - Now get the Hg category # from species database
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
05 Jul 2016 - R. Yantosca - Now replace IDWETD with State_Chm%Map_Wetdep
05 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
05 Aug 2016 - R. Yantosca - Remove reference to Spc, it's not needed
```

4.2.18 wetdep_merra

Subroutine WETDEP_MERRA computes the downward mass flux of species due to washout and rainout of aerosols and soluble species in a column. This subroutine implements a new algorithm in which the precipitation fields come directly from the MERRA archive.

INTERFACE:

```
      SUBROUTINE WETDEP_MERRA( am_I_Root, Input_Opt, State_Met,
     &                         State_Chm, RC, LS )
```

USES:

```
      USE CMN_SIZE_MOD
      USE CMN_DIAG_MOD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HgP_WD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_Hg2_SNOWPACK
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_DYN
      USE Species_Mod,        ONLY : Species
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,         INTENT(IN)    :: am_I_Root  ! Are we on the root CPU?
LOGICAL,         INTENT(IN)    :: LS         ! =T for large-scale precip
                                             ! =F for convective precip
TYPE(OptInput), INTENT(IN)     :: Input_Opt  ! Input options
TYPE(MetState), INTENT(IN)     :: State_Met  ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,         INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Precipitation fields:
=====================

 Layer        Formation of       Precipitation
               New Precip        falling down
=================================================== Top of Atm.
  LM           QQ(L,I,J)         PDOWN(LM,I,J)
                   |                   |
---------------------------------------------------
  LM-1         QQ(L,I,J)         PDOWN(LM-1,I,J)
                   |                   |
------------------V------------------V------------
                ...                 ...
                   |                   |
------------------V------------------V------------
  3            QQ(L,I,J)         PDOWN(3,I,J)
                   |                   |
------------------V-------------------------------
  2            QQ(L,I,J)         PDOWN(2,I,J)
                   |                   |
---------------------------------------------------
  1            QQ(L,I,J)         PDOWN(1,I,J)
                   |                   |
==================V==================V============ Ground

Where:
  (a) New formation forming in grid box (I,J,L) = QQ(L,I,J)
  (b) Precip coming in  thru top    of layer L  = PDOWN(L+1,I,J)
  (c) Precip going  out thru bottom of layer L  = PDOWN(L,  I,J)

Rainout:
========
Rainout occurs when there is more precipitation in grid box (I,J,L) than
```

in grid box (I,J,L+1). In other words, rainout occurs when the amount of rain falling through the bottom of grid box (I,J,L) is more than the amount of rain coming in through the top of grid box (I,J,L).

.

Soluble gases/aerosols are incorporated into the raindrops and are completely removed from grid box (I,J,LLPAR). There is no evaporation and "resuspension" of aerosols during a rainout event.

.

For large-scale (a.k.a. stratiform) precipitation, the first order rate constant for rainout in the grid box (I,J,L=LLPAR) (cf. Eq. 12, Jacob et al, 2000) is given by:

.

$$K\_RAIN = K\_MIN + \frac{Q}{L + W} \quad [\text{units: s}^{-1}]$$

.

and the areal fraction of grid box (I,J,L=LLPAR) that is actually experiencing large-scale precipitation (cf. Eq. 11, Jacob et al, 2000) is given by:

.

$$F' = \frac{Q}{K\_RAIN * (L + W)} \quad [\text{unitless}]$$

.

Where:

.

K_MIN = minimum value for K_RAIN
= 1.0e-4 [s^-1]

.

L + W = condensed water content in cloud
= 1.5e-6 [cm3 H2O/cm3 air]

.

Q = QQ = rate of precipitation formation
[cm3 H2O / cm3 air / s]

.

For convective precipitation, K_RAIN = 5.0e-3 [s^-1], and the expression for F' (cf. Eq. 13, Jacob et al, 2000) becomes:

.

$$F' = \frac{FMAX * Q * MIN\{ DT / TAU , 1.0 \}}{Q * MIN\{ DT / TAU , 1.0 \} + FMAX * K\_RAIN * (L + W)}$$

.

Where:

.

```
      Q = QQ = rate of precipitation formation
             [cm3 H2O/cm3 air/s]

      FMAX   = maximum value for F'
             = 0.3

      DT     = dynamic time step from the CTM [s]

      TAU    = duration of rainout event
             = 1800 s (30 min)

      L + W  = condensed water content in cloud
             = 2.0e-6 [cm3 H2O/cm3 air]

    K_RAIN and F' are needed to compute the fraction of species in grid box
    (I,J,L=LLPAR) lost to rainout.  This is done in module routine RAINOUT.

    Washout:
    ========
    Washout occurs when we have evaporation (or no precipitation at all) at
    grid box (I,J,L), but have rain coming down from grid box (I,J,L+1).
```

REVISION HISTORY:

```
    20 Sep 2010 - R. Yantosca - Initial version, based on WETDEP
    28 Sep 2010 - H. Amos     - Now define Q, QDOWN directly from MERRA met
    08 Oct 2010 - R. Yantosca - Adjusted OpenMP do loop
    09-Dec-2010 - H. Amos     - Added PDOWN(L+1) > 0 to criterion for IS_WASHOUT
    09-Dec-2010 - H. Amos     - SAFETY now prints PDOWN(L+1) instead of PDOWN(L)
    31-Dec-2010 - H. Amos     - Clean up code, remove obsolete code
    31-Dec-2010 - H. Amos     - Added comments
    27 May 2011 - R. Yantosca - Now pass F_RAINOUT to DO_WASHOUT_ONLY
    25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
    01 Apr 2015 - L. Zhang    - Don't do wetdep in nested-grid buffer zone
    02 Apr 2015 - E. Lundgren - Move tracer unit conversion from kg/kg to kg
                                to within this routine
    04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
    09 Jun 2015 - R. Yantosca - Now deposit Hg2, HgP to snowpack regardless of
                                whether the dynamic ocean is used
    04 Mar 2016 - C. Keller   - Added option to scale convective fraction of
                                large-scale precip.
    22 Apr 2016 - R. Yantosca - Now get Is_Hg2, Is_HgP from species database
    25 Apr 2016 - R. Yantosca - Now get the Hg category # from species database
    29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
    01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
    05 Jul 2016 - R. Yantosca - Now replace IDWETD with State_Chm%Map_Wetdep
```

```
05 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
05 Aug 2016 - R. Yantosca - Remove reference to Spc, it's not needed
```

4.2.19 ls_k_rain

Function LS_K_RAIN computes K_RAIN, the first order rainout rate constant for large-scale (a.k.a. stratiform) precipitation.

INTERFACE:

```
FUNCTION LS_K_RAIN( Q ) RESULT( K_RAIN )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: Q        ! Rate of precipitation formation
                                 !  [cm3 H2O/cm3 air/s]
```

RETURN VALUE:

```
REAL(fp)             :: K_RAIN   ! 1st order rainout rate constant [1/s]
```

REVISION HISTORY:

```
18 Mar 2004 - R. Yantosca - Initial version
(1 ) Now made into a MODULE routine since we cannot call internal routines
     from w/in a parallel loop.  Updated comments. (bmy, 3/18/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
23 Oct 2015 - R. Yantosca - Now use parameter COND_WATER_CONTENT
```

4.2.20 ls_f_prime

Function LS_F_PRIME computes F', the fraction of the grid box that is precipitating during large scale (a.k.a. stratiform) precipitation.

INTERFACE:

```
FUNCTION LS_F_PRIME( Q, K_RAIN ) RESULT( F_PRIME )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: Q        ! Rate of precipitation formation
                                 !  [cm3 H2O/cm3 air/s]
REAL(fp), INTENT(IN) :: K_RAIN   ! 1st order rainout rate constant [1/s]
```

REMARKS:

```
REAL(fp)             :: F_PRIME  ! Fraction of grid box undergoing
                                 !  large-scale precipitation [unitless]
```

REVISION HISTORY:

```
18 Mar 2004 - R. Yantosca - Initial version
(1 ) Now made into a MODULE routine since we cannot call internal routines
      from w/in a parallel loop.  Updated comments. (bmy, 3/18/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
23 Oct 2015 - R. Yantosca - Now use COND_WATER_CONTENT parameter
```

4.2.21 conv_f_prime

Function CONV_F_PRIME computes F', the fraction of the grid box that is precipitating during convective precipitation.

INTERFACE:

```
FUNCTION CONV_F_PRIME( Q, K_RAIN, DT ) RESULT( F_PRIME )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: Q         ! Rate of precipitation formation
                                  !  [cm3 H2O/cm3 air/s]
REAL(fp), INTENT(IN) :: K_RAIN    ! 1st order rainout rate constant [1/s]
REAL(fp), INTENT(IN) :: DT        ! Wet deposition timestep [s]
```

RETURN VALUE:

```
REAL(fp)             :: F_PRIME   ! Frac. of grid box undergoing
                                  !  convective precipitation [unitless]
```

REVISION HISTORY:

```
18 Mar 2004 - R. Yantosca - Initial version
(1 ) Now made into a MODULE routine since we cannot call internal routines
      from w/in a parallel loop.  Updated comments. (bmy, 3/18/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
```

4.2.22 do_rainout_only

Subroutine DO_RAINOUT_ONLY removes species by rainout.

INTERFACE:

```
 SUBROUTINE DO_RAINOUT_ONLY( am_I_Root, LS,        I, J, L,
&                            IDX,       ERRMSG,    F_RAINOUT,
&                            K_RAIN,    DT,        DSpc,
&                            Input_Opt, State_Met, State_Chm,
&                            RC                               )
```

USES:

```
      USE CMN_DIAG_MOD                                ! Diagnostic flags
      USE CMN_SIZE_MOD                                ! Size parameters
      USE DIAG_MOD,           ONLY : AD16             ! ND16 diag array
      USE DIAG_MOD,           ONLY : AD17             ! ND17 diag array
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD39             ! ND39 diag array
#endif
      USE DIAG_MOD,           ONLY : CT16             ! ND16 diag counter
      USE DIAG_MOD,           ONLY : CT17             ! ND17 diag counter
      USE ERROR_MOD,          ONLY : IT_IS_NAN        ! Test for NaN
      USE GET_NDEP_MOD,       ONLY : SOIL_WETDEP      ! Wet deposited species
      USE Input_Opt_Mod,      ONLY : OptInput         ! Input options type
      USE State_Chm_Mod,      ONLY : ChmState         ! Chemistry State type
      USE State_Met_Mod,      ONLY : MetState         ! Met State type
#if defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS, ICOMP, AQOXID
      USE TOMAS_MOD,          ONLY : GETFRACTION
      USE DIAG_MOD,           ONLY : AD05
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN)    :: am_I_Root     ! Are we on root CPU?
      LOGICAL,          INTENT(IN)    :: LS            ! =T denotes LS precip
      INTEGER,          INTENT(IN)    :: I             ! Longitude index
      INTEGER,          INTENT(IN)    :: J             ! Latitude index
      INTEGER,          INTENT(IN)    :: L             ! Level index
      INTEGER,          INTENT(IN)    :: IDX           ! ND38 index
      REAL(fp),         INTENT(IN)    :: F_RAINOUT     ! Fraction of grid box
                                                       !  undergoing rainout
      REAL(fp),         INTENT(IN)    :: K_RAIN        ! Rainout constant
      REAL(fp),         INTENT(IN)    :: DT            ! Rainout timestep [s]
      CHARACTER(LEN=*), INTENT(IN)    :: ERRMSG        ! Error message
      TYPE(OptInput),   INTENT(IN)    :: Input_Opt     ! Input options
      TYPE(MetState),   INTENT(IN)    :: State_Met     ! Met State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),         INTENT(INOUT) :: DSpc(:,:,:,:) ! Accumulator array [kg]
      TYPE(ChmState),   INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,          INTENT(OUT)   :: RC            ! Success or failure?
```

REMARKS:

```
    The modifications for the MERRA met fields require calling this same
```

```
sequence of code more than once.  The expedient solution was to just move
the relevant code into this subroutine.
                                                                             .
An IF statement in WETDEP decides if this rainout is to be done (and thus
if this routine will be called.  The criteria for rainout is:
                                                                             .
FOR MERRA MET FIELDS:
   There is rainout if there is new precip formation in the grid box
   (i.e. DQRLSAN(I,J,L) > 0) and the fraction of the grid box experiencing
   rainout (i.e. F_RAINOUT) is greater than or equal to the fraction of
   the grid box directly overhead experiencing precip (i.e. FTOP).
      -- Helen Amos (9/10/10)
                                                                             .
FOR ALL OTHER MET FIELDS:
   We use a simple test: if the rainout fraction in this grid box
   (i.e. F_RAINOUT) is nonzero, do rainout.  Don't compare to the grid
   box immediately above us (i.e. FTOP).
```

REVISION HISTORY:

```
16 Sep 2010 - R. Yantosca - Initial version
25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
22 Sep 2015 - E. Lundgren - Input STT is now in kg/m2 (prev kg)
24 Sep 2015 - E. Lundgren - Now pass am_I_Root and RC as arguments
29 Sep 2015 - E. Lundgren - Now pass State_Chm as argument and use
                            local pointer for STT array [kg/m2]
30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
05 Jul 2016 - R. Yantosca - Now replace IDWETD with State_Chm%Map_WetDep
```

4.2.23 do_washout_only

Subroutine DO_WASHOUT_ONLY removes species by washout.

The modifications for the MERRA met fields require calling this same sequence of code more than once. The expedient solution was to just move the relevant code into this this subroutine.

INTERFACE:

```
      SUBROUTINE DO_WASHOUT_ONLY( am_I_Root, LS,        I, J, L,
     &                            IDX,       ERRMSG,    QDOWN,
     &                            Q,         F_WASHOUT, F_RAINOUT,
     &                            DT,        PDOWN,     DSpc,
     &                            Input_Opt, State_Met, State_Chm,
     &                            RC,        REEVAP               )
```

USES:

```
      USE CMN_DIAG_MOD                                ! Diagnostic flags
      USE CMN_SIZE_MOD                                ! Size parameters
      USE DIAG_MOD,           ONLY : AD16             ! ND16 diag array
      USE DIAG_MOD,           ONLY : AD17             ! ND17 diag array
      USE DIAG_MOD,           ONLY : AD18             ! ND18 diag array
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD39             ! ND39 diag array
#endif
      USE DIAG_MOD,           ONLY : CT16             ! ND16 diag counter
      USE DIAG_MOD,           ONLY : CT17             ! ND17 diag counter
      USE DIAG_MOD,           ONLY : CT18             ! ND18 diag counter
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GET_NDEP_MOD,       ONLY : SOIL_WETDEP      ! Wet deposited species
      USE Input_Opt_Mod,      ONLY : OptInput         ! Input options
      USE State_Chm_Mod,      ONLY : ChmState         ! Chemistry State object
      USE State_Met_Mod,      ONLY : MetState         ! Met State object
#if defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS, ICOMP, AQOXID
      USE DIAG_MOD,           ONLY : AD05
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN)    :: am_I_Root    ! Are we on the root CPU?
      LOGICAL,OPTIONAL, INTENT(IN)    :: REEVAP       ! Do re-evaporation?
      LOGICAL,          INTENT(IN)    :: LS           ! =T denotes LS precip
      INTEGER,          INTENT(IN)    :: I            ! Longitude index
      INTEGER,          INTENT(IN)    :: J            ! Latitude index
      INTEGER,          INTENT(IN)    :: L            ! Level index
      INTEGER,          INTENT(IN)    :: IDX          ! ND38 index
      CHARACTER(LEN=*), INTENT(IN)    :: ERRMSG       ! Error message
      REAL(fp),         INTENT(IN)    :: QDOWN        ! Precip leaving thru
                                                      !  bottom of box (I,J,L)
      REAL(fp),         INTENT(IN)    :: Q            ! Precip forming or
                                                      ! evaporating
                                                      ! in box (I,J,L)
      REAL(fp),         INTENT(IN)    :: F_WASHOUT    ! Fraction of grid box
                                                      !  undergoing washout
      REAL(fp),         INTENT(IN)    :: F_RAINOUT    ! Fraction of grid box
                                                      !  undergoing rainout
      REAL(fp),         INTENT(IN)    :: DT           ! Rainout timestep [s]
      REAL(fp),         INTENT(IN)    :: PDOWN(:,:,:) ! Precip
      TYPE(OptInput),   INTENT(IN)    :: Input_Opt    ! Input options
      TYPE(MetState),   INTENT(IN)    :: State_Met    ! Met State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),         INTENT(INOUT) :: DSpc(:,:,:,:) ! Accumulator array
```

```
                                                        ! [kg/m2]
   TYPE(ChmState),   INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
   INTEGER,          INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

A fraction ALPHA of the raindrops falling down from grid box (I,J,L+1) to grid box (I,J,L) will evaporate along the way. ALPHA is given by:

$$\text{ALPHA} = \frac{\text{precip leaving (I,J,L+1)} - \text{precip leaving (I,J,L)}}{\text{precip leaving (I,J,L+1)}}$$

$$= \frac{-QQ(L,I,J) * DZ(I,J,L)}{PDOWN(L+1,I,J)}$$

We assume that a fraction ALPHA2 = 0.5 * ALPHA of the previously rained-out aerosols and HNO3 coming down from level (I,J,L+1) will evaporate and re-enter the atmosphere in the gas phase in grid box (I,J,L). This process is called "resuspension".

For non-aerosol species, the amount of previously rained out mass coming down from grid box (I,J,L+1) to grid box (I,J,L) is figured into the total mass available for washout in grid box (I,J,L). We therefore do not have to use the fraction ALPHA2 to compute the resuspension.

NOTE from Hongyu Liu about ALPHA (hyl, 2/29/00)
==========
If our QQ field was perfect, the evaporated amount in grid box (I,J,L) would be at most the total rain amount coming from above (i.e. PDOWN(I,J,L+1)). But this is not true for the MOISTQ field we are using. Sometimes the evaporation in grid box (I,J,L) can be more than the rain amount from above. The reason is our "evaporation" also includes the effect of cloud detrainment. For now we cannot find a way to distinguish betweeen the two. We then decided to release aerosols in both the detrained air and the evaporated air.

Therefore, we should use this term in the numerator:

```
                -QQ(I,J,L) * BXHEIGHT(I,J,L)

   instead of the term:

                PDOWN(L+1)-PDOWN(L)

   Recall that in make_qq.f we have restricted PDOWN to
   positive values, otherwise, QQ would be equal to
   PDOWN(L+1)-PDOWN(L).
   ============================================================
   Update (V. Shah 6/29/16)
   For GEOS-FP, MERRA and MERRA2 met fields we use the
   following term in the numerator instead:
  REEVAP(L,I,J) * BXHEIGHT(I,J,L)
   ============================================================
```

REVISION HISTORY:

```
   16 Sep 2010 - R. Yantosca - Initial version
   20 Sep 2010 - R. Yantosca - Update definition of ALPHA if we are doing
                               partial re-evaporation.
   28 Sep 2010 - H. Amos     - Now check for NaN's with function IT_IS_NAN
   31 Dec 2010 - H. Amos     - new variable, TK, for temperature
   26 May 2011 - R. Yantosca - Bug fix: Only apply the error trap for the
                               condition WASHFRAC < 1d-3 for MERRA met
   25 May 2011 - Q. Wang     - new variable, TF, for total precip fraction
   25 May 2011 - Q. Wang     - Also pass F_RAINOUT via the arg list
   25 May 2011 - Q. Wang     - Correct the washfrac to make sure that washout
                               is applied the area of F_washout instead of
                               total area of (F_washout+F_rainout)
   27 May 2011 - R. Yantosca - Added comments, readjusted IF statements to
                               avoid floating-point problems
   16 Aug 2011 - H. Amos     - Replace logical AER with KIN to emphasize that
                               washout is either modeled as a kinetic process
                               or an equilibrium process
   09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                               derived type object
   26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
   25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
   04 Feb 2015 - M. Sulprizio- Fix calculation of WETLOSS for non-aerosol
                               tracers (C. Friedman)
   20 May 2015 - M. Sulprizio- Remove WASHFRAC < 1D-3 error trap for MERRA
                               following recommendation by Viral Shah
   04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
   22 Sep 2015 - E. Lundgren - Incoming tracer units are now [kg/m2]
   29 Sep 2015 - E. Lundgren - Now use local pointer for STT array [kg/m2]
   30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
   05 Jul 2016 - R. Yantosca - Replace IDWETD with State_Chm%Map_WetDep
```

4.2.24 do_complete_reevap

Subroutine DO_COMPLETE_REEVAP re-evaporates all of the soluble species back into the atmosphere.

INTERFACE:

```
      SUBROUTINE DO_COMPLETE_REEVAP( am_I_Root, LS,        I, J, L,
     &                               IDX,       ERRMSG,    DT,
     &                               DSpc,      Input_Opt, State_Met,
     &                               State_Chm, RC                   )
```

USES:

```
      USE CMN_DIAG_MOD                                ! Diagnostic flags
      USE CMN_SIZE_MOD                                ! Size parameters
      USE DIAG_MOD,           ONLY : AD16             ! ND16 diag array
      USE DIAG_MOD,           ONLY : AD17             ! ND17 diag array
      USE DIAG_MOD,           ONLY : AD18             ! ND18 diag array
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD39             ! ND39 diag array
#endif
      USE DIAG_MOD,           ONLY : CT16             ! ND16 diag counter
      USE DIAG_MOD,           ONLY : CT17             ! ND17 diag counter
      USE DIAG_MOD,           ONLY : CT18             ! ND18 diag counter
      USE ERROR_MOD
      USE GET_NDEP_MOD,       ONLY : SOIL_WETDEP      ! Wet deposited species
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
#if defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS, ICOMP, AQOXID
      USE DIAG_MOD,           ONLY : AD05
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN)    :: am_I_Root     ! Are we on the root CPU?
      LOGICAL,          INTENT(IN)    :: LS            ! =T denotes LS precip
      INTEGER,          INTENT(IN)    :: I             ! Longitude index
      INTEGER,          INTENT(IN)    :: J             ! Latitude index
      INTEGER,          INTENT(IN)    :: L             ! Level index
      INTEGER,          INTENT(IN)    :: IDX           ! ND38 index
      CHARACTER(LEN=*), INTENT(IN)    :: ERRMSG        ! Error message
      REAL(fp),         INTENT(IN)    :: DT            ! Rainout timestep [s]
      TYPE(OptInput),   INTENT(IN)    :: Input_Opt     ! Input options
      TYPE(MetState),   INTENT(IN)    :: State_Met     ! Meteorology State obj
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState),   INTENT(INOUT) :: State_Chm     ! Chemistry State object
      REAL(fp),         INTENT(INOUT) :: DSpc(:,:,:,:) ! Accumulator array
                                                       ! [kg/m2]
```

OUTPUT PARAMETERS:

```
      INTEGER,          INTENT(OUT)   :: RC            ! Success or failure?
```

REMARKS:

```
    The modifications for the MERRA met fields require calling this same
    sequence of code more than once.  The expedient solution was to just move
    the relevant code into this this subroutine.
```

REVISION HISTORY:

```
    16 Sep 2010 - R. Yantosca - Initial version
    22 Sep 2015 - E. Lundgren - Incoming tracer units are now kg/m2 (prev kg)
    24 Sep 2015 - E. Lundgren - Now pass am_I_Root and RC as arguments and
                                local pointer for STT array [kg/m2]
    30 Sep 2015 - E. Lundgren - Now pass Input_Opt for use in TOMAS AQOXID
    30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
    05 Jul 2016 - R. Yantosca - Replace IDWETD with State_Chm%Map_WetDep
```

4.2.25 do_washout_at_sfc

Subroutine DO_WASHOUT_AT_SFC washes out the species at the surface.

INTERFACE:

```
      SUBROUTINE DO_WASHOUT_AT_SFC( am_I_Root, LS,        I, J, L,
     &                              IDX,       ERRMSG,    QDOWN,
     &                              F,         DT,        DSpc,
     &                              Input_Opt, State_Met, State_Chm,
     &                              RC                              )
```

USES:

```
      USE CMN_DIAG_MOD                              ! Diagnostic flags
      USE CMN_SIZE_MOD                              ! Size parameters
      USE DIAG_MOD,           ONLY : AD16           ! ND16 diag array
      USE DIAG_MOD,           ONLY : AD17           ! ND17 diag array
      USE DIAG_MOD,           ONLY : AD18           ! ND18 diag array
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD39           ! ND39 diag array
#endif
      USE DIAG_MOD,           ONLY : CT16           ! ND16 diag counter
      USE DIAG_MOD,           ONLY : CT17           ! ND17 diag counter
      USE DIAG_MOD,           ONLY : CT18           ! ND18 diag counter
```

```
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : IT_IS_NAN         ! Test for NaN
      USE GET_NDEP_MOD,       ONLY : SOIL_WETDEP       ! Wet deposited species
      USE Input_Opt_Mod,      ONLY : OptInput          ! Input options
      USE State_Chm_Mod,      ONLY : ChmState          ! Chm State object
      USE State_Met_Mod,      ONLY : MetState          ! Met State object
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN)    :: am_I_Root     ! Are we on the root CPU?
      LOGICAL,          INTENT(IN)    :: LS            ! =T denotes LS precip
      INTEGER,          INTENT(IN)    :: I             ! Longitude index
      INTEGER,          INTENT(IN)    :: J             ! Latitude index
      INTEGER,          INTENT(IN)    :: L             ! Level index
      INTEGER,          INTENT(IN)    :: IDX           ! ND38 index
      CHARACTER(LEN=*), INTENT(IN)    :: ERRMSG        ! Error message
      REAL(fp),         INTENT(IN)    :: QDOWN         ! Precip leaving thru
                                                       !  bottom of box (I,J,L)
      REAL(fp),         INTENT(IN)    :: F             ! Fraction of grid box
                                                       !  undergoing precip
      REAL(fp),         INTENT(IN)    :: DT            ! Rainout timestep [s]
      TYPE(OptInput),   INTENT(IN)    :: Input_Opt     ! Input options
      TYPE(MetState),   INTENT(IN)    :: State_Met     ! Met State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),         INTENT(INOUT) :: DSpc(:,:,:,:) ! Accumulator array
                                                       ! [kg/m2]
      TYPE(ChmState),   INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,          INTENT(OUT)   :: RC            ! Success or failure?
```

REMARKS:

```
    Assume all of the species precipitating down from grid box (I,J,L=2) to
    grid box (I,J,L=1) gets washed out in grid box (I,J,L=1).

                                                                             .
    The modifications for the MERRA met fields require calling this same
    sequence of code more than once.  The expedient solution was to just move
    the relevant code into this this subroutine.
```

REVISION HISTORY:

```
    16 Sep 2010 - R. Yantosca - Initial version
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    25 Aug 2014 - M. Sulprizio- Now accept Input_Opt as an argument
    04 Jun 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
    22 Sep 2015 - E. Lundgren - Tracer units are now kg/m2 (prev kg)
```

```
29 Sep 2015 - E. Lundgren - Now use local pointer for STT array [kg/m2]
30 Jun 2016 - R. Yantosca - Replace STT with Spc and DSTT with DSpc
05 Jul 2016 - R. Yantosca - Now replace IDWETD with State_Chm%Map_Wetdep
```

4.2.26 safety

Subroutine SAFETY stops the run with debug output and an error message if negative species are found.

INTERFACE:

```
 SUBROUTINE SAFETY( I,         J,           L,        N,
&                   A,         LS,          PDOWN,    QQ,
&                   ALPHA,     ALPHA2,      RAINFRAC, WASHFRAC,
&                   MASS_WASH, MASS_NOWASH, WETLOSS,  GAINED,
&                   LOST,      DSpc,        Spc )
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD,    ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
! Arguments
LOGICAL,          INTENT(IN) :: LS           !
INTEGER,          INTENT(IN) :: I            !
INTEGER,          INTENT(IN) :: J            !
INTEGER,          INTENT(IN) :: L            !
INTEGER,          INTENT(IN) :: N            !
CHARACTER(LEN=*), INTENT(IN) :: A            !
REAL(fp),         INTENT(IN) :: PDOWN        !
REAL(fp),         INTENT(IN) :: QQ           !
REAL(fp),         INTENT(IN) :: ALPHA        !
REAL(fp),         INTENT(IN) :: ALPHA2       !
REAL(fp),         INTENT(IN) :: RAINFRAC     !
REAL(fp),         INTENT(IN) :: WASHFRAC     !
REAL(fp),         INTENT(IN) :: MASS_WASH    !
REAL(fp),         INTENT(IN) :: MASS_NOWASH  !
REAL(fp),         INTENT(IN) :: WETLOSS      !
REAL(fp),         INTENT(IN) :: GAINED       !
REAL(fp),         INTENT(IN) :: LOST         !
REAL(fp),         INTENT(IN) :: DSpc(LLPAR)  !
REAL(fp),         INTENT(IN) :: Spc(LLPAR)   !
```

REVISION HISTORY:

```
18 Mar 2004 - R. Yantosca - Initial version
(1 ) Now made into a MODULE routine since we cannot call internal routines
      from w/in a parallel loop.  Updated comments. (bmy, 3/18/04)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
```

4.2.27 get_vud

Function GET_VUD returns the vertical updraft velocity in m/s at location I, J, L.

INTERFACE:

```
FUNCTION GET_VUD( State_Met, I, J, L ) RESULT( VUD )
```

USES:

```
USE DAO_MOD,            ONLY : IS_WATER
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
INTEGER,        INTENT(IN)    :: I, J, L     ! Location
```

RETURN VALUE:

```
REAL(fp)                      :: VUD     ! Vertical updraft velocity in m/s.
```

REVISION HISTORY:

```
12 Feb 2015 - C. Keller   - Initial version
26 Feb 2015 - E. Lundgren - Remove dependency on pressure_mod since not used.
27 Jun 2016 - C. Keller   - Use VUD_DEFINED instead of ESMF_ compiler switch.
```

4.2.28 get_f

Function GET_F returns the scavenged fraction at location I, J, L and for the given rate constant K.

INTERFACE:

```
FUNCTION GET_F( State_Met, I, J, L, K ) RESULT( F )
```

USES:

```
USE DAO_MOD,            ONLY : IS_WATER
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN) :: State_Met  ! Meteorology State object
INTEGER,        INTENT(IN) :: I, J, L    ! Lon, lat, level indices
REAL(fp),       INTENT(IN) :: K          ! Rate constant
```

RETURN VALUE:

```
REAL(fp)                   :: F          ! Fraction of species scavenged
                                         !  out of the updraft [1]
```

REVISION HISTORY:

```
12 Feb 2015 - C. Keller   - Initial version
26 Feb 2015 - E. Lundgren - Remove dependency on pressure_mod since not used.
25 Jun 2015 - M. Sulprizio- Now pass FF as an optional argument for aerosols
25 Sep 2015 - R. Yantosca - Remove FF; we scale Kc in F_AEROSOL now.
```

4.2.29 init_wetscav

Subroutine INIT_WETSCAV initializes updraft velocity, cloud liquid water content, cloud ice content, and mixing ratio of water fields, which are used in the wet scavenging routines.

INTERFACE:

```
SUBROUTINE INIT_WETSCAV( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_Size_Mod
USE ErrCode_Mod
USE Error_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
03 Sep 2015 - R. Yantosca - Split off from the old INIT_WETSCAV.  We now
                            just allocate arrays here.  Arrays are assigned
                            values from State_Met in SETUP_WETSCAV.
```

```
03 Sep 2015 - R. Yantosca - Also initialize IDWETD here; this makes routine
                            WETDEPID obsolete, so we can remove it.
22 Sep 2015 - R. Yantosca - Bug fix: only define the IDWETD array if
                            wetdep or drydep is turned on.  Also only
                            print info if wetdep is turned on.
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
20 Jun 2016 - R. Yantosca - Now define species IDs in the init phase
```

4.2.30 setup_wetscav

Subroutine SETUP_WETSCAV initializes updraft velocity, cloud liquid water content, cloud ice content, and mixing ratio of water fields, which are used in the wet scavenging routines.

INTERFACE:

```
SUBROUTINE SETUP_WETSCAV( am_I_Root, Input_Opt,
&                         State_Met, State_Chm, RC )
```

USES:

```
USE CMN_Size_Mod
USE ErrCode_Mod
USE Error_Mod,          ONLY : Alloc_Err
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AIRMW
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
23 Feb 2000 - R. Yantosca - Initial version
(1 ) References "e_ice.f" -- routine to compute Eice(T).
(2 ) Vud, CLDLIQ, CLDICE, C_H2O are all independent of tracer, so we
      can compute them once per timestep, before calling the cloud
```

```
      convection and wet deposition routines.
(3 ) Set C_H2O = 0 below -120 Celsius.  E_ICE(T) has a lower limit of
      -120 Celsius, so temperatures lower than this will cause a stop
      with an error message. (bmy, 6/15/00)
(4 ) Replace {IJL}GLOB with IIPAR,JJPAR,LLPAR.  Also rename PW to P.
      Remove IREF, JREF, these are obsolete.  Now reference IS_WATER
      from "dao_mod.f" to determine water boxes.
(5 ) Removed obsolete code from 9/01.  Updated comments and made
      cosmetic changes. (bmy, 10/24/01)
(6 ) Now use routine GET_PCENTER from "pressure_mod.f" to compute the
      pressure at the midpoint of grid box (I,J,L).  Also removed P and
      SIG from the argument list (dsa, bdf, bmy, 8/20/02)
(7 ) Now reference T from "dao_mod.f".  Updated comments.  Now allocate
      Vud, C_H2O, CLDLIQ and CLDICE here on the first call.  Now references
      ALLOC_ERR from "error_mod.f".  Now set H2O2s and SO2s to the initial
      values from for the first call to COMPUTE_F .  Now call WETDEPID
      on the first call to initialize the wetdep index array. (bmy, 1/27/03)
(8 ) Now references STT from "tracer_mod.f".  Also now we call WETDEPID
      from "input_mod.f" (bmy, 7/20/04)
(9 ) Now references new function E_ICE, which is an analytic function of
      Kelvin temperature instead of Celsius. (bmy, 3/7/05)
16 Sep 2010 - R. Yantosca - Added ProTeX headers
18 Oct 2012 - R. Yantosca - Removed DEVEL from #ifdef statement, now use
                            EXTERNAL_GRID || EXTERNAL_FORCING
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID_DRY.
                            Remove dependency on pressure_mod.
28 Apr 2015 - E. Lundgren - Change PMID_DRY to PMID for Dalton's Law.
13 Aug 2015 - E. Lundgren - Incoming tracer units are now kg/kg dry air
03 Sep 2015 - R. Yantosca - Now allocate IDWETD
03 Sep 2015 - R. Yantosca - Now move array allocation into INIT_WETSCAV
22 Sep 2015 - R. Yantosca - Bug fix: now initialize H2O2s and SO2s on
                            the first call.  This was done in INIT_WETSCAV,
                            but that is now called before the restart file
                            is read from disk.
23 Sep 2015 - R. Yantosca - Now accept State_Chm as an argument
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
23 Jun 2016 - R. Yantosca - Remove reference to tracerid_mod.F
30 Jun 2016 - R. Yantosca - Remove instances of STT and State_Chm%TRACERS
04 Jul 2016 - M. Yannetti - Replace TCVV with species db MW and phys constant
05 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

4.2.31 cleanup_wetscav

Subroutine CLEANUP_WETSCAV deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_WETSCAV
```

REVISION HISTORY:

```
23 Feb 2000 - R. Yantosca - Initial version
16 Sep 2010 - R. Yantosca - Added ProTeX headers
03 Sep 2015 - R. Yantosca - Now deallocate IDWETD
```

5 Boundary layer mixing modules

These modules contain routines to perform the boundary layer mixing.

5.1 Fortran: Module Interface mixing_mod.F90

Module mixing_mod.F90 is a wrapper module for the PBL mixing in GEOS-Chem.

INTERFACE:

```
MODULE MIXING_MOD
```

USES:

```
USE PRECISION_MOD

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: INIT_MIXING
PUBLIC :: DO_MIXING
PUBLIC :: DO_TEND
```

PRIVATE MEMBER FUNCTIONS:

REVISION HISTORY:

```
04 Mar 2015 - C. Keller   - Initial version.
```

5.1.1 init_mixing

Subroutine INIT_MIXING initialized the pbl mixing wrapper module.

INTERFACE:

```
SUBROUTINE INIT_MIXING ( am_I_Root, Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : COMPUTE_PBL_HEIGHT
USE PBL_MIX_MOD,        ONLY : DO_PBL_MIX
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
USE VDIFF_MOD,          ONLY : DO_PBL_MIX_2
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
TYPE(OptInput),   INTENT(IN   )  :: Input_Opt  ! Input opts
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState),   INTENT(INOUT)  :: State_Met  ! Met state
TYPE(ChmState),   INTENT(INOUT)  :: State_Chm  ! Chemistry state
INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
!REMARKS
 (A) While all dry deposition rates are calculated either in
     DO_PBL_MIX2 or DO_TEND, settling of aerosols is still
     computed in the dust/seasalt modules.
```

REVISION HISTORY:

```
04 Mar 2015 - C. Keller   - Initial version
26 Oct 2016 - R. Yantosca - Now also call COMPUTE_PBL_HEIGHT so that we
                            populate PBL quantities w/ the initial met
```

5.1.2 do_mixing

Subroutine DO_MIXING performs the PBL mixing.

INTERFACE:

```
SUBROUTINE DO_MIXING ( am_I_Root, Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GC_Error
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : DO_PBL_MIX
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
USE UnitConv_Mod
USE VDIFF_MOD,          ONLY : DO_PBL_MIX_2
```

INPUT PARAMETERS:

```
    LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
    TYPE(OptInput),   INTENT(IN   )  :: Input_Opt  ! Input opts
```

INPUT/OUTPUT PARAMETERS:

```
    TYPE(MetState),   INTENT(INOUT)  :: State_Met  ! Met state
    TYPE(ChmState),   INTENT(INOUT)  :: State_Chm  ! Chemistry state
    INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
  !REMARKS
   (A) While all dry deposition rates are calculated either in
       DO_PBL_MIX2 or DO_TEND, settling of aerosols is still
       computed in the dust/seasalt modules.
```

REVISION HISTORY:

```
   04 Mar 2015 - C. Keller   - Initial version
   12 Aug 2015 - E. Lundgren - Input tracer units are now [kg/kg] and
                               are converted to [v/v] for mixing
   30 Sep 2014 - E. Lundgren - Move unit conversion for DO_TEND to DO_TEND
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                               species ID from State_Chm%Map_Advect.
   08 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

5.1.3 do_tend

Subroutine DO_TEND adds the species tendencies (dry deposition and emissions) to the species array.

INTERFACE:

```
  SUBROUTINE DO_TEND ( am_I_Root, Input_Opt,    State_Met, &
                       State_Chm, OnlyAbovePBL, RC,    DT   )
```

USES:

```
    USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
    USE CMN_DIAG_MOD,       ONLY : ND44
    USE CMN_SIZE_MOD,       ONLY : IIPAR,   JJPAR,   LLPAR
    USE DRYDEP_MOD,         ONLY : DEPSAV
    USE ErrCode_Mod
    USE ERROR_MOD,          ONLY : ERROR_STOP, SAFE_DIV
    USE GET_NDEP_MOD,       ONLY : SOIL_DRYDEP
    USE HCO_INTERFACE_MOD,  ONLY : GetHcoVal, GetHcoDiagn
    USE Input_Opt_Mod,      ONLY : OptInput
    USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
    USE PhysConstants,      ONLY : AVO
    USE Species_Mod,        ONLY : Species
    USE State_Met_Mod,      ONLY : MetState
```

```
    USE State_Chm_Mod,      ONLY : ChmState
    USE TIME_MOD,           ONLY : GET_TS_DYN, GET_TS_CONV, GET_TS_CHEM
    USE State_Chm_Mod,      ONLY : Ind_
    USE UnitConv_Mod
#if defined( BPCH_DIAG )
    USE DIAG_MOD,           ONLY : AD44
#endif
#if defined( NC_DIAG )
    USE HCO_ERROR_MOD
    USE HCO_INTERFACE_MOD,  ONLY : HcoState, GetHcoID
    USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif
#if defined( USE_TEND )
    USE TENDENCIES_MOD
#endif
```

INPUT PARAMETERS:

```
    LOGICAL,          INTENT(IN   )           :: am_I_Root    ! root CPU?
    TYPE(OptInput),   INTENT(IN   )           :: Input_Opt    ! Input opts
    TYPE(MetState),   INTENT(IN   )           :: State_Met    ! Met state
    LOGICAL,          INTENT(IN   )           :: OnlyAbovePBL ! Only above PBL?
    REAL(fp),         INTENT(IN   ), OPTIONAL :: DT           ! Time step [s]
```

INPUT/OUTPUT PARAMETERS:

```
    TYPE(ChmState),   INTENT(INOUT)           :: State_Chm    ! Chemistry state
    INTEGER,          INTENT(INOUT)           :: RC           ! Failure or success
```

REVISION HISTORY:

```
   04 Mar 2015 - C. Keller   - Initial version
   09 Mar 2015 - R. Yantosca - Bug fix: Use the drydep ID number instead of the
                               tracer number to index the AD44 drydep array
   09 Mar 2015 - R. Yantosca - Bug fix: Remove an IF ( L1 == 1 ) block where
                               we define DRYDEPID.  This isn't needed here.
   10 Apr 2015 - C. Keller   - Now exchange PARANOX loss fluxes via HEMCO
                               diagnostics.
   12 Jun 2015 - R. Yantosca - Bug fix in SAFE_DIV: the denominator was
                               arranged wrongly.  Now corrected.
   18 Jun 2015 - C. Keller   - Now restrict all emissions to chemistry grid
                               if UCX=false.
   30 Sep 2015 - E. Lundgren - Now convert locally to kg/m2 for area-independent
                               compatibility between tracer units and flux
   22 Mar 2016 - C. Keller   - Bug fix: make sure drydep velocities are written
                               to diagnostics if emissions are zero.
   16 Mar 2016 - E. Lundgren - Exclude specialty simulations in restriction of
                               all emissions to chemistry grid if UCX=false
   29 Feb 2016 - C. Keller   - Make sure PARANOx fluxes are applied to tracers.
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

```
    25 May 2016 - E. Lundgren - Replace input_opt%TRACER_MW_KG with species
                                database field emMW_g (emitted species g/mol)
    16 Jun 2016 - C. Miller   - Now define species ID's with the Ind_ function
    17 Jun 2016 - R. Yantosca - Only define species ID's on the first call
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
    19 Jul 2016 - R. Yantosca - Now bracket tendency calls with #ifdef USE_TEND
```

5.2 Fortran: Module Interface pbl_mix_mod.F

Module PBL_MIX_MOD contains routines and variables used to compute the planetary boundary layer (PBL) height and to mix tracers underneath the PBL top.

INTERFACE:

```
      MODULE PBL_MIX_MOD
```

USES:

```
      USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CLEANUP_PBL_MIX
      PUBLIC  :: DO_PBL_MIX
      PUBLIC  :: GET_FRAC_OF_PBL
      PUBLIC  :: GET_FRAC_UNDER_PBLTOP
      PUBLIC  :: GET_PBL_MAX_L
      PUBLIC  :: GET_PBL_TOP_hPa
      PUBLIC  :: GET_PBL_TOP_L
      PUBLIC  :: GET_PBL_TOP_m
      PUBLIC  :: GET_PBL_THICK
      PUBLIC  :: INIT_PBL_MIX
      PUBLIC  :: COMPUTE_PBL_HEIGHT

#if defined ( DEVEL )
      PUBLIC :: PBL_TOP_L, PBL_TOP_m
#endif
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: TURBDAY
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
(1 ) Now modified for GCAP and GEOS-5 met fields (bmy, 5/24/05)
(2 ) Remove reference to "CMN" and XTRA2. (bmy, 8/30/05)
(3 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(4 ) Add INIT_PBL_MIX and COMPUTE_PBL_HEIGHT as PUBLIC routines
      (lin, 5/29/09)
(5 ) Extend tracers for APM simulation (GanLuo, 2010)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
28 Feb 2012 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
19 Nov 2014 - M. Yannetti - Added PRECISION_MOD
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
```

5.2.1 do_pbl_mix

Subroutine DO_PBL_MIX is the driver routine for planetary boundary layer mixing. The PBL layer height and related quantities are always computed. Complete mixing of tracers underneath the PBL top is toggled by the DO_TURBDAY switch.

INTERFACE:

```
      SUBROUTINE DO_PBL_MIX( am_I_Root,  DO_TURBDAY, Input_Opt,
     &                       State_Met,  State_Chm,  RC )
```

USES:

```
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TS_CONV
#if defined( USE_TEND )
      USE TENDENCIES_MOD
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Root CPU?
      LOGICAL,        INTENT(IN)    :: DO_TURBDAY  ! =T means call TURBDAY
                                                   !    for full PBL mixing
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      INTEGER,        INTENT(INOUT) :: RC          ! Return code
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
07 Sep 2011 - G. Luo      - Add modifications for APM
28 Feb 2012 - R. Yantosca - Added ProTeX headers
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
22 Aug 2014 - R. Yantosca - Now declare State_Met INTENT(INOUT)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
06 Jul 2016 - R. Yantosca - Now pass State_Chm and am_I_Root to TURBDAY
19 Jul 2016 - R. Yantosca - Now bracket tendency calls with #ifdef USE_TEND
08 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

5.2.2 compute_pbl_height

Subroutine COMPUTE_PBL_HEIGHT computes the PBL height and other related quantities.

INTERFACE:

```
SUBROUTINE COMPUTE_PBL_HEIGHT( State_Met )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE ERROR_MOD,          ONLY : ERROR_STOP
USE PhysConstants            ! Scale height
USE State_Met_Mod,      ONLY : MetState
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
(1 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(2 ) Remove reference to "CMN" and XTRA2 -- they're obsolete.  Also do not
     force BLTOP, BLTHIK to minimum values for GEOS-STRAT met fields.
     (bmy, 8/30/05)
(3 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
28 Feb 2012 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
22 Aug 2014 - R. Yantosca - Now declare State_Met INTENT(INOUT)
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
                            Remove dependency on pressure_mod.
```

5.2.3 turbday

! Subroutine TURBDAY executes the GEOS-Chem boundary layer mixing algorithm (full PBL mixing).

INTERFACE:

```
      SUBROUTINE TURBDAY( am_I_root, Input_Opt,
     &                    State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : TURBFLUP
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : AIRMW
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CONV
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root
      TYPE(OptInput), INTENT(IN)    :: Input_Opt
      TYPE(MetState), INTENT(IN)    :: State_Met
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC
```

REMARKS:

```
    Original subroutine by Dale Allen, Univ of MD.
```

REVISION HISTORY:

```
    30 Jan 1998 - I. Bey, R. Yantosca - Initial version
    (1 ) TURBDAY is written in Fixed-Form Fortran 90.  Also use F90
         syntax for declarations (bmy, 4/1/99).
    (2 ) New tracer concentrations are returned in TC.
    (3 ) PS(I,J) is ACTUAL surface pressure and not Psurface - PTOP
    (4 ) Change in tracer in kg is now stored in DTC(I,J,L,N).  This makes
         it easier to compute diagnostic quantities.  The new mixing ratio
         is computed as TC(I,J,L,N) = TC(I,J,L,N) + DTC(I,J,L,N) / AD(I,J,L).
    (5 ) XTRA2(*,*,5) is the height of the PBL in # of layers.  So if the
         PBL top is located in the middle of the 3rd sigma layer at (I,J)
```

```
      the value of XTRA2(I,J,5) would be 2.5.  The XTRA2 variable is
      used by the HCTM drydep subroutines...it really is a historical
      holdover.
(6 ) Restore the following NDxx diagnostics: (a) ND63 : Mass balance
      (CNVUPP) (b) ND15 : Mass change due to mixing in the boundary layer
(7 ) Now pass TCVV and NCONV for the mass flux diagnostics.  Also
      updated comments and cleaned up a few things. (bey, bmy, 11/10/99)
(8 ) Remove PTOP and XNUMOL from the arg list.  PTOP is now a parameter
      in "CMN_SIZE".  XNUMOL is no longer used in TURBDAY. (bmy, 2/10/00)
(9 ) Also removed obsolete ND63 diagnostics and updated comments.
      (bmy, 4/12/00)
(10) Now use NTRC instead of NNPAR to dimension variables TC, TCVV, DTC,
      and DTCSUM (bmy, 10/17/00).
(11) Removed obsolete code from 10/17/00 (bmy, 12/21/00)
(12) If the PBL depth is very small (or zero), then assume a PBL depth
      of 2 mb -- this prevents NaN's from propagating throughout the
      code.  Also updated comments & made cosmetic changes. (bmy, 3/9/01)
(13) DTCSUM was declared twice but wasn't used.  Elminate declarations
      to DTCSUM. (bmy, 7/16/01)
(14) XTRA2(IREF,JREF,5) is now XTRA2(I,J).  Also updated comments.
      Also remove IREF, JREF and some debug output. (bmy, 9/25/01)
(15) Removed obsolete commented out code from 9/01 (bmy, 10/24/01)
(16) Now takes in P=PS-PTOP instead of PS.  Redimension SIGE to
      (1:LLPAR+1).
(17) Renamed PS to PZ so as not to conflict w/ the existing P variable.
      Now pass P-PTOP thru PZ, in order to ensure that P and AD are
      consistent w/ each other.  Added parallel DO-loops. Updated comments,
      cosmetic changes.  Now print a header to stdout on the first call,
      to confirm that TURBDAY has been called. (bmy, 4/11/02)
(18) Now use GET_PEDGE from "pressure_mod.f" to compute the pressure
      at the bottom edge of grid box (I,J,L).  Deleted obsolete code from
      4/02.  Removed PZ, SIGE from the argument list, since we now compute
      pressure from GET_PEDGE. (dsa, bdf, bmy, 8/22/02)
(19) Now reference AD, PBL from "dao_mod.f".  Now removed DXYP from the
      arg list, use GET_AREA_M2 from "grid_mod.f" instead.  Now removed
      NCONV, ALPHA_d, ALPHA_n from the arg list.  Now no longer reference
      SUNCOS.  Now set A(:,:)=1 day & nite; we assume full mixing all the
      time regardless of SUNCOS.  Updated comments, cosmetic changes.
      (bmy, 2/11/03)
(20) Now can handle PBL field in meters for GEOS-4/fvDAS.  Also the
      atmospheric scale height from CMN_GCTM. (bmy, 6/23/03)
(21) Now bundled into "pbl_mix_mod.f".  Broke off the part which computes
      PBL height and related quantities into COMPUTE_PBL_HEIGHT.
      (bmy, 2/15/05)
28 Feb 2012 - R. Yantosca - Added ProTeX headers
 2 Mar 2012 - R. Yantosca - Remove reference to GET_AREA_M2
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

```
15 Jul 2015 - C. Keller   - Added tendencies module
06 Jul 2016 - R. Yantosca - Now pass State_Chm and am_I_Root as args
                            so that we can loop over advected species
25 Jul 2016 - M. Yannetti - Now takes in State_Chm to access spec db
```

5.2.4 get_frac_of_pbl

Function GET_FRAC_OF_PBL returns the fraction of grid box (I,J,L) that lies within the planetary boundary layer.

INTERFACE:

```
FUNCTION GET_FRAC_OF_PBL( I, J, L ) RESULT( FRAC )
```

USES:

```
USE CMN_SIZE_MOD   ! Size parameters
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J, L    ! Lon, lat, lev indices
```

RETURN VALUE:

```
REAL(fp)              :: FRAC       ! Fraction of box (I,J,L) in the PBL
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.5 get_frac_under_pbltop

Function GET_FRAC_UNDER_PBLTOP returns the fraction of grid box (I,J,L) that lies underneath the planetary boundary layer top.

INTERFACE:

```
FUNCTION GET_FRAC_UNDER_PBLTOP( I, J, L ) RESULT( FRAC )
```

USES:

```
USE CMN_SIZE_MOD                ! Size parameters
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J, L   ! Lon, lat, level indices
```

RETURN VALUE:

```
REAL(fp)              :: FRAC      ! Fraction of box (I,J,L) below PBL top
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.6 get_pbl_max_l

Function GET_PBL_MAX_L returns the model level at the highest part of the planetary boundary layer.

INTERFACE:

```
FUNCTION GET_PBL_MAX_L() RESULT( TOP )
```

RETURN VALUE:

```
INTEGER  :: TOP   ! Highest extent of PBL [model levels]
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.7 get_pbl_top_hpa

Function GET_PBL_TOP_hPa returns the planetary boundary layer top [hPa] at a given GEOS-Chem surface location (I,J).

INTERFACE:

```
FUNCTION GET_PBL_TOP_hPa( I, J ) RESULT( TOP )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J   ! Lon and lat indices
```

RETURN VALUE:

```
REAL(fp)              :: TOP    ! PBL top [hPa]
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.8 get_pbl_top_l

Function GET_PBL_TOP_L returns the planetary boundary layer top [model levels] at a given GEOS-Chem surface location (I,J).

INTERFACE:

```
FUNCTION GET_PBL_TOP_L( I, J ) RESULT( TOP )
```

USES:

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J   ! Lon and lat indices
```

RETURN VALUE:

```
REAL(fp)              :: TOP    ! PBL top [model levels]
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.9 get_pbl_top_m

Function GET_PBL_TOP_m returns the planetary boundary layer top [m] at a given GEOS-CHEM surface location (I,J).

INTERFACE:

```
FUNCTION GET_PBL_TOP_m( I, J ) RESULT( TOP )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J   ! Lon and lat indices
```

RETURN VALUE:

```
REAL(fp)              :: TOP    ! PBL top [m]
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.10

Function GET_PBL_THICK returns the thickness of the PBL at a given surface location (I,J).

INTERFACE:

```
FUNCTION GET_PBL_THICK( I, J ) RESULT( THICK )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I, J    ! Lon and lat indices
```

RETURN VALUE:

```
REAL(fp)              :: THICK   ! PBL thickness [hPa]
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.2.11 init_pbl_mix

Subroutine INIT_PBL_MIX allocates and zeroes module arrays

INTERFACE:

```
SUBROUTINE INIT_PBL_MIX
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD, ONLY : ALLOC_ERR
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
14 Nov 2014 - C. Keller   - Added error trap to prevent second allocation
                            attempt in ESMF environment.
```

5.2.12 cleanup_pbl_mix

Subroutine CLEANUP_PBL_MIX allocates and zeroes module arrays.

INTERFACE:

```
      SUBROUTINE CLEANUP_PBL_MIX
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
28 Feb 2012 - R. Yantosca - Added ProTeX headers
```

5.3 Fortran: Module Interface vdiff_mod.F90

Module VDIFF_MOD includes all routines for the non-local PBL mixing scheme.

INTERFACE:

```
MODULE VDIFF_MOD
```

USES:

```
  USE CMN_DIAG_MOD,  ONLY : ND15,  ND44           ! Diagnostics
  USE CMN_SIZE_MOD,  ONLY : IIPAR, JJPAR, LLPAR   ! Grid dimensions
  USE CMN_SIZE_MOD,  ONLY : plev  => LLPAR        ! # of levels
  USE ERROR_MOD,     ONLY : DEBUG_MSG             ! Routine for debug output
  USE PhysConstants                               ! Physical constants
  USE PRECISION_MOD                               ! For GEOS-Chem Precision(fp)
  USE VDIFF_PRE_MOD, ONLY : PCNST                 ! N_TRACERS
  USE VDIFF_PRE_MOD, ONLY : LPRT                  ! Debug print?
  USE VDIFF_PRE_MOD, ONLY : LTURB                 ! Do PBL mixing?

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  public :: DO_PBL_MIX_2
  !PRIVATE DATA MEMBERS:

  save

  integer :: plevp

  real(fp), parameter ::            &
       cpair  = 1004.64e+0_fp,      &
       latvap = 2.5104e+06_fp,      &
       rhoh2o = 1.e+3_fp,           &
       tfh2o  = 273.16e+0_fp,       &
       rair   = Rd,                 &
       rh2o   = Rv,                 &
       gravit = g0,                 &
```

```
      zvir   = rh2o/rair - 1.,     &
      cappa  = Rd/cpair,           &
      r_g    = Rd / g0

 ! Obsolete variables and variables that are now defined with global params
 ! (ewl, 1/7/16)
  real(fp), parameter ::          &
       rearth = 6.37122e+6_fp,      & ! not used
       cpwv   = 1.81e+3_fp,         & ! not used
       ra     = 1.e+0_fp/rearth,    & ! not used
       epsilo = 0.622e+0_fp,        & ! not used
       latice = 3.336e+5_fp,        & ! not used
       rair   = 287.04e+0_fp,       & ! now use global Rd
       rh2o   = 461.e+0_fp,         & ! now use global Rv
       gravit = 9.80616e+0_fp,      & ! now use global g0
       cappa  = rair/cpair,     &     ! now use global Rd
       r_g    = rair / gravit,  &     ! now use global Rd and g0

!-----------------------------------------------------------------------
  ... pbl constants
!-----------------------------------------------------------------------

 ! These are constants, so use PARAMETER tag
 real(fp), parameter ::   &
      betam  = 15.e+0_fp,   & ! constant in wind gradient expression
      betas  =  5.e+0_fp,   & ! constant in surface layer gradient expression
      betah  = 15.e+0_fp,   & ! constant in temperature gradient expression
      fak    =  8.5e+0_fp,  & ! constant in surface temperature excess
      fakn   =  7.2e+0_fp,  & ! constant in turbulent prandtl number
      ricr   =   .3e+0_fp,  & ! critical richardson number
      sffrac =   .1e+0_fp,  & ! surface layer fraction of boundary layer
      vk     =   .4e+0_fp     ! von karmans constant

 ! These are assigned later, so we can't use the PARAMETER tag
 real(fp) ::              &
      g,                & ! gravitational acceleration
      onet,             & ! 1/3 power in wind gradient expression
      ccon,             & ! fak * sffrac * vk
      binm,             & ! betam * sffrac
      binh                ! betah * sffrac

!-----------------------------------------------------------------------
  ... constants used in vertical diffusion and pbl
!-----------------------------------------------------------------------
 real(fp) :: &
      zkmin            ! minimum kneutral*f(ri)
 real(fp), allocatable :: ml2(:)   ! mixing lengths squaredB
 real(fp), allocatable :: qmincg(:)   ! min. constituent concentration
```

```
                                    !  counter-gradient term

   integer :: &
        ntopfl, &        ! top level to which vertical diffusion is applied.
        npbl             ! maximum number of levels in pbl from surface

   logical, parameter :: divdiff = .true. , arvdiff = .false.

   logical, parameter :: pblh_ar = .true.

   logical, parameter :: pbl_mean_drydep = .false.  ! use mean concentration
                                                    !  within the  PBL for
                                                    ! calculating drydep fluxes
   logical, parameter :: drydep_back_cons = .false. ! backward consistency
                                                    !  with previous GEOS-Chem
                                                    !  drydep budgets
                                                    !-- useless when
                                                    !   pbl_mean_drydep=.false.
```

REMARKS:

```
The non-local PBL mixing routine VDIFF modifies the specific humidity,
(State_Met%SPHU) field.  Therefore, we must pass State_Met as an argument
to DO_PBL_MIX_2 and VDIFFDR with INTENT(INOUT).

                                                                             .
Because logical_mod.F and tracer_mod.F have been superseded by Input_Opt,
we now use VDIFF_PRE_MOD to supply values
```

REVISION HISTORY:

```
(1 ) This code is modified from mo_vdiff.F90 in MOZART-2.4. (lin, 5/14/09)
07 Oct 2009 - R. Yantosca - Added CVS Id Tag
24 Sep 2010 - J. Lin      - Modified ND15 to account for all mixing
                            processes but not dry deposition and emissions.
17 Dec 2010 - R. Yantosca - Declare constants w/ the PARAMETER attribute
20 Dec 2010 - R. Yantosca - Bug fixes for the parallelization
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
25 Mar 2011 - R. Yantosca - Corrected bug fixes noted by Jintai Lin
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.2 met
22 Jun 2012 - R. Yantosca - Now use pointers to flip arrays in vertical
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
24 Jun 2014 - R. Yantosca - Now get PCNST from vdiff_pre_mod.F90
24 Nov 2014 - M. Yannetti - Added PRECISION_MOD
07 Jan 2016 - E. Lundgren - Replace hard-coded physical params w/ global and
                            remove unused parameters
22 Jun 2016 - M. Yannetti - Replace TCVV with species db MW and phys constant
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

5.3.1 pbinti

Subroutine PBINTI initializes time independent variables of pbl package

INTERFACE:

```
subroutine pbinti( gravx )
```

USES:

```
implicit none
```

INPUT PARAMETERS:

```
real(fp), intent(in) :: gravx     !  acceleration of gravity
```

REVISION HISTORY:

```
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
```

5.3.2 vdiff

Subroutine vdiff is the driver routine to compute vertical diffusion of momentum, moisture, trace constituents and potential temperature.

INTERFACE:

```
subroutine vdiff( lat,        ip,        uwnd,       vwnd,       &
                  tadv,       pmid,      pint,       rpdel_arg,  &
                  rpdeli_arg, ztodt,     zm_arg,     shflx_arg,  &
                  sflx,       thp_arg,   as2,        pblh_arg,   &
                  kvh_arg,    kvm_arg,   tpert_arg,  qpert_arg,  &
                  cgs_arg,    shp,       wvflx_arg,  plonl,      &
                  Input_Opt,  State_Met, State_Chm,  taux_arg,   &
                  tauy_arg,   ustar_arg )
```

USES:

```
USE DIAG_MOD,           ONLY : TURBFLUP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState

implicit none
```

INPUT PARAMETERS:

```
integer, intent(in) :: lat, ip ! latitude index, long tile index
integer, intent(in) :: plonl   ! number of local longitudes
real(fp),  intent(in) ::   &
```

```
     ztodt                    ! 2 delta-t
real(fp),  intent(in) ::   &
     uwnd(:,:,:),        &     ! u wind input
     vwnd(:,:,:),        &     ! v wind input
     tadv(:,:,:),        &     ! temperature input
     pmid(:,:,:),        &     ! midpoint pressures
     pint(:,:,:),        &     ! interface pressures
     rpdel_arg(:,:,:),   &     ! 1./pdel  (thickness bet interfaces)
     rpdeli_arg(:,:,:),  &     ! 1./pdeli (thickness bet midpoints)
     zm_arg(:,:,:),      &     ! midpoint geoptl height above sfc
     shflx_arg(:,:),     &     ! surface sensible heat flux (w/m2)
     sflx(:,:,:),        &     ! surface constituent flux (kg/m2/s)
     wvflx_arg(:,:)            ! water vapor flux (kg/m2/s)
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
real(fp), intent(inout) :: &
     as2(:,:,:,:),       &     ! moist, tracers after vert. diff
     shp(:,:,:),         &     ! specific humidity (kg/kg)
     thp_arg(:,:,:)            ! pot temp after vert. diffusion
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
real(fp), intent(out) ::   &
     kvh_arg(:,:,:),     &     ! coefficient for heat and tracers
     kvm_arg(:,:,:),     &     ! coefficient for momentum
     tpert_arg(:,:),     &     ! convective temperature excess
     qpert_arg(:,:),     &     ! convective humidity excess
     cgs_arg(:,:,:)            ! counter-grad star (cg/flux)

real(fp), optional, intent(inout) :: &
     taux_arg(:,:),      &     ! x surface stress (n)
     tauy_arg(:,:),      &     ! y surface stress (n)
     ustar_arg(:,:)            ! surface friction velocity

real(fp), intent(inout) :: pblh_arg(:,:) ! boundary-layer height [m]
```

REMARKS:

```
Free atmosphere diffusivities are computed first; then modified by the
boundary layer scheme; then passed to individual parameterizations mvdiff,
qvdiff.
The free atmosphere diffusivities are based on standard mixing length forms
for the neutral diffusivity multiplied by functions of Richardson number.
k = l^2 * |dv/dz| * f(ri). The same functions are used for momentum,
potential temperature, and constitutents.
```

```
The stable Richardson num function (ri>0) is taken from Holtslag and
Beljaars (1989), ECMWF proceedings. f = 1 / (1 + 10*ri*(1 + 8*ri)).
The unstable richardson number function (ri<0) is taken from ccm1.
f = sqrt(1 - 18*ri)
```

REVISION HISTORY:

```
(1 ) All arguments are full arrays now. Latitude slices are copied in local
     variables. (ccc, 11/19/09)
 24 Sep 2010 - J. Lin      - Moved call to ND15 at the end of vdiff.
                             Modified to account for all mixing processes.
 02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                             involve explicitly using "D" exponents
 09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                             derived type object
 25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
 25 Jun 2014 - R. Yantosca - Remove references to tracer_mod.F
 04 Aug 2016 - M. Yannetti - Now pass State_Chm as argument; replace TCVV
                             with species db MW and phys constant
```

5.3.3 pbldif

Subroutine PBLDIF computes the atmospheric boundary layer. The nonlocal scheme determines eddy diffusivities based on a diagnosed boundary layer height and a turbulent velocity scale. Also, countergradient effects for heat and moisture, and constituents are included, along with temperature and humidity perturbations which measure the strength of convective thermals in the lower part of the atmospheric boundary layer.

References:

1. Holtslag, A. A. M., and B. A. Boville, 1993: *Local versus nonlocal boundary-layer diffusion in a global climate model*, J. Clim., **6**, 1825-1842.

INTERFACE:

```
subroutine pbldif( th      ,q       ,z       ,u       ,v, &
                   t       ,pmid    ,kvf     ,cflx    ,shflx, &
                   kvm     ,kvh, &
                   cgh     ,cgq     ,cgs     ,pblh    ,tpert, &
                   qpert   ,wvflx   ,cgsh    ,plonl, &
                   taux    ,tauy    ,ustar )
```

USES:

```
  implicit none
```

INPUT PARAMETERS:

```
    integer, intent(in) :: &
  plonl
    real(fp), intent(in) :: &
         th(plonl,plev), &          ! potential temperature [k]
         q(plonl,plev), &           ! specific humidity [kg/kg]
         z(plonl,plev), &           ! height above surface [m]
         u(plonl,plev), &           ! windspeed x-direction [m/s]
         v(plonl,plev), &           ! windspeed y-direction [m/s]
         t(plonl,plev), &           ! temperature (used for density)
         pmid(plonl,plev), &        ! midpoint pressures
         kvf(plonl,plevp), &        ! free atmospheric eddy diffsvty [m2/s]
         cflx(plonl,pcnst), &       ! surface constituent flux (kg/m2/s)
         wvflx(plonl), &            ! water vapor flux (kg/m2/s)
         shflx(plonl)               ! surface heat flux (w/m2)
```

INPUT/OUTPUT PARAMETERS:

```
    real(fp), optional, intent(inout) :: &
         taux(plonl), &            ! x surface stress (n)
         tauy(plonl), &            ! y surface stress (n)
         ustar(plonl)              ! surface friction velocity

    real(fp), intent(inout) :: pblh(plonl)       ! boundary-layer height [m]
```

OUTPUT PARAMETERS:

```
    real(fp), intent(out) :: &
         kvm(plonl,plevp), &        ! eddy diffusivity for momentum [m2/s]
         kvh(plonl,plevp), &        ! eddy diffusivity for heat [m2/s]
         cgh(plonl,plevp), &        ! counter-gradient term for heat [k/m]
         cgq(plonl,plevp,pcnst), &  ! counter-gradient term for constituents
         cgsh(plonl,plevp), &       ! counter-gradient term for sh
         cgs(plonl,plevp), &        ! counter-gradient star (cg/flux)
         tpert(plonl), &            ! convective temperature excess
         qpert(plonl)               ! convective humidity excess
```

REVISION HISTORY:

```
   02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                               involve explicitly using "D" exponents
```

5.3.4 qvdiff

Subroutine QVDIFF solve vertical diffusion eqtn for constituent with explicit srfc flux.

INTERFACE:

```
  subroutine qvdiff( ncnst, qm1, qflx, cc, ze, &
              term, qp1, plonl )
```

USES:

```
implicit none
```

INPUT PARAMETERS:

```
integer, intent(in) :: &
     plonl
integer, intent(in) :: &
     ncnst                    ! num of constituents being diffused
real(fp), intent(in) :: &
     qm1(plonl,plev,ncnst), & ! initial constituent
     qflx(plonl,ncnst), &     ! sfc q flux into lowest model level
     cc(plonl,plev), &        ! -lower diag coeff.of tri-diag matrix
     term(plonl,plev)         ! 1./(1. + ca(k) + cc(k) - cc(k)*ze(k-1))
```

INPUT/OUTPUT PARAMETERS:

```
real(fp), intent(inout) :: &
     ze(plonl,plev)           ! term in tri-diag. matrix system
```

OUTPUT PARAMETERS:

```
real(fp), intent(out) :: &
     qp1(plonl,plev,ncnst)    ! final constituent
```

REMARKS:

```
Procedure for solution of the implicit equation follows :
Richtmyer and Morton (1967,pp 198-199)
```

REVISION HISTORY:

```
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
```

5.3.5 vdiffar

Subroutine VDIFFAR is the driver routine to compute vertical diffusion of trace constituents using archived coefficients for cgs and kvh. This is a gutted version of vdiff.

INTERFACE:

```
SUBROUTINE VDIFFAR( lat   ,tadv , &
                    pmid  ,pint ,rpdel_arg ,rpdeli_arg  ,ztodt, &
                    sflx  ,as2  ,kvh_arg   ,cgs_arg     ,plonl )
```

USES:

```
implicit none
```

INPUT PARAMETERS:

```
integer, intent(in) :: lat     ! latitude index
integer, intent(in) :: plonl   ! lon tile dim
real(fp), intent(in) :: &
     ztodt , &                 ! 2 delta-t
     tadv(:,:,:), &        ! temperature input
     pmid(:,:,:), &     ! midpoint pressures
     pint(:,:,:), &    ! interface pressures
     rpdel_arg(:,:,:), &      ! 1./pdel  (thickness bet interfaces)
     rpdeli_arg(:,:,:), &     ! 1./pdeli (thickness bet midpoints)
     sflx(:,:,:), &      ! surface constituent flux (kg/m2/s)
     kvh_arg(:,:,:), &       ! coefficient for heat and tracers
     cgs_arg(:,:,:)          ! counter-grad star (cg/flux)
```

INPUT/OUTPUT PARAMETERS:

```
real(fp), intent(inout) :: &
     as2(:,:,:,:)     ! moist, tracers after vert. diff
```

REVISION HISTORY:

```
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
```

5.3.6 pbldifar

Subroutine PBLDIFAR is a modified version of pbldif which only calculates cgq given cgs.

INTERFACE:

```
SUBROUTINE PBLDIFAR( t, pmid, cflx, cgs, cgq, plonl )
```

USES:

```
implicit none
```

INPUT PARAMETERS:

```
integer, intent(in) :: &
     plonl
real(fp), intent(in) :: &
     t(plonl,plev), &        ! temperature (used for density)
     pmid(plonl,plev), &     ! midpoint pressures
     cflx(plonl,pcnst), &     ! surface constituent flux (kg/m2/s)
     cgs(plonl,plevp)        ! counter-gradient star (cg/flux)
```

OUTPUT PARAMETERS:

```
real(fp), intent(out) :: &
     cgq(plonl,plevp,pcnst)  ! counter-gradient term for constituents
```

REVISION HISTORY:

```
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
```

5.3.7 vdinti

Subroutine VDINTI initializes time independent fields for vertical diffusion. Calls initialization routine for boundary layer scheme.

INTERFACE:

```
SUBROUTINE VDINTI
```

USES:

```
USE ERROR_MOD,    ONLY : ALLOC_ERR
USE PRESSURE_MOD, ONLY : GET_AP, GET_BP

implicit none
```

REVISION HISTORY:

```
02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                            involve explicitly using "D" exponents
```

5.3.8 vdiffdr

Subroutine VDIFFDR calculates the vertical diffusion on a latitude slice of data.

1. The dummy argument as2 is in vv. (lin, 06/04/08)
2. TCVV and TRACER_MW_KG assume 12 g/mol for all HCs. Thus, when using them to convert units of HCs to be the inputs for vdiffdr, the converted units are NOT kg/kg for concentrations and kg/m2/s for surface flux. However, since the units for both inputs are consistent, there should not be any problem. (lin, 06/04/08)

INTERFACE:

```
SUBROUTINE VDIFFDR( am_I_Root, Input_Opt, State_Met, State_Chm )
```

USES:

```
    USE DAO_MOD,             ONLY : IS_ICE, IS_LAND
    USE DEPO_MERCURY_MOD,    ONLY : ADD_Hg2_DD, ADD_HgP_DD
    USE DEPO_MERCURY_MOD,    ONLY : ADD_Hg2_SNOWPACK
#if defined( BPCH_DIAG )
    USE DIAG_MOD,            ONLY : AD44
#endif
    USE DRYDEP_MOD,          ONLY : DEPSAV
    USE GET_NDEP_MOD,        ONLY : SOIL_DRYDEP
    USE GLOBAL_CH4_MOD,      ONLY : CH4_EMIS
    USE GC_GRID_MOD,         ONLY : GET_AREA_M2
    USE Input_Opt_Mod,       ONLY : OptInput
    USE MERCURY_MOD,         ONLY : HG_EMIS
    USE OCEAN_MERCURY_MOD,   ONLY : Fg !hma
```

```
    USE OCEAN_MERCURY_MOD,  ONLY : OMMFP => Fp
    USE OCEAN_MERCURY_MOD,  ONLY : LHg2HalfAerosol !cdh
    USE PBL_MIX_MOD,        ONLY : GET_PBL_TOP_m, COMPUTE_PBL_HEIGHT, &
                                   GET_PBL_MAX_L, GET_FRAC_UNDER_PBLTOP
    USE Species_Mod,        ONLY : Species
    USE State_Chm_Mod,      ONLY : ChmState
    USE State_Chm_Mod,      ONLY : Ind_
    USE State_Met_Mod,      ONLY : MetState
    USE TIME_MOD,           ONLY : GET_TS_CONV, GET_TS_EMIS, GET_TS_CHEM
#if defined( USE_TEND )
    USE TENDENCIES_MOD
#endif

    ! HEMCO update
    USE HCO_INTERFACE_MOD,  ONLY : GetHcoID, GetHcoVal, GetHcoDiagn
#if defined( NC_DIAG )
    USE ERROR_MOD,          ONLY : ERROR_STOP
    USE HCO_INTERFACE_MOD,  ONLY : HcoState
    USE HCO_ERROR_MOD,      ONLY : HCO_SUCCESS
    USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif

    implicit none
```

INPUT/OUTPUT PARAMETERS:

```
    ! is this the root CPU?
    LOGICAL,        INTENT(IN)            :: am_I_Root

    ! Input options object
    TYPE(OptInput), INTENT(IN)            :: Input_Opt

    ! Meteorology State object
    TYPE(MetState), INTENT(INOUT)         :: State_Met

    ! Chemistry State object
    TYPE(ChmState), INTENT(INOUT)         :: State_Chm
```

REMARKS:

(1) Need to declare the Meteorology State object (State_MET) with INTENT(INOUT). This is because VDIFF will modify the specific humidity field. (bmy, 11/21/12)

.

(2) VDIFF also archives drydep fluxes to the soil NOx emissions module (by calling routine SOIL_DRYDEP) and to the ND44 diagnostic.

.

(3) As of July 2016, we assume that all of the advected species are listed first in the species database. This is the easiest way to pass a slab

```
      to the TPCORE routine.  This may change in the future. (bmy, 7/13/16)
```

REVISION HISTORY:

```
  (1 ) Calls to vdiff and vdiffar are now done with full arrays as arguments.
       (ccc, 11/19/09)
  04 Jun 2010 - C. Carouge  - Updates for mercury simulations with GTMM
  25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
  24 Sep 2010 - J. Lin      - Move ND15 to vdiff.
  21 Dec 2010 - R. Yantosca - Add logical flags for different sim types
  21 Dec 2010 - R. Yantosca - Now call ITS_A_FULLCHEM_SIM instead of
                              relying on NCS == 0
  22 Dec 2010 - C. Carouge  - Combine array flipping w/ unit conversion
                              to save on operations
  02 Mar 2011 - R. Yantosca - Bug fixes for PGI compiler: these mostly
                              involve explicitly using "D" exponents
  26 Apr 2011 - J. Fisher   - Use MERRA land fraction information
  25 Oct 2011 - H. Amos     - bring Hg2 gas-particle partitioning code into
                              v9-01-02
  08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.2 in the same way as MERRA
  01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
  22 Jun 2012 - R. Yantosca - Now use pointers to flip arrays in vertical
  09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                              derived type object
  18 Jun 2013 - M. Payer    - Add emissions for offline aerosol simulation
  01 Aug 2013 - R. Yantosca - Now pass Input_Opt via the arg list
  01 Aug 2013 - J. Lin      - Modified for Rn-Pb-Be simulation
  20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
  26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
  06 Jun 2014 - R. Yantosca - Fix parallelization error in the HEMCO
                              modifications: Hold TOPMIX, TEMPBL private
  06 Jun 2014 - R. Yantosca - Wrap some debug printout in #if defined(DEBUG)
  25 Jun 2014 - R. Yantosca - Now get N_MEMBERS from input_mod.F
  16 Oct 2014 - C. Keller   - Bug fix: now add deposition rates instead of
                              overwriting them.
  26 Feb 2015 - E. Lundgren - Replace GET_PEDGE and GET_PCENTER with
                              State_Met%PEDGE and State_Met%PMID.
                              Remove dependency on pressure_mod.
                              Use virtual temperature in hypsometric eqn.
  10 Apr 2015 - C. Keller   - Now exchange PARANOX loss fluxes via HEMCO
                              diagnostics.
  25 Jan 2016 - E. Lundgren - Update netcdf drydep flux diagnostic
  22 Apr 2016 - R. Yantosca - Now get Hg info from species database
  29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
  26 May 2016 - E. Lundgren - Replace input_opt TRACER_MW_KG with species
                              database field emMW_g (emitted species molec wt)
  16 Jun 2016 - K. Yu       - Now define species ID's with the Ind_ function
  17 Jun 2016 - R. Yantosca - Only define species ID's on the first call
```

```
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
13 Jul 2016 - R. Yantosca - Now use NA as loop index for advected species
                            and ND as loop index for drydep species
19 Jul 2016 - R. Yantosca - Now bracket tendency calls with #ifdef USE_TEND
27 Jul 2016 - R. Yantosca - Bug fix: set nDrydep=0 if drydep is turned off
04 Aug 2016 - M. Yannetti - Replace TCVV with species db MW and phys constant
08 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

5.3.9 do_pbl_mix_2

Subroutine DO_PBL_MIX_2 is the driver routine for planetary boundary layer mixing. The PBL layer height and related quantities are always computed. Mixing of tracers underneath the PBL top is toggled by the DO_TURBDAY switch.

INTERFACE:

```
SUBROUTINE DO_PBL_MIX_2( am_I_Root, DO_VDIFF,  Input_Opt,  &
                         State_Met, State_Chm, RC         )
```

USES:

```
USE DAO_MOD,            ONLY : AIRQNT
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : INIT_PBL_MIX
USE PBL_MIX_MOD,        ONLY : COMPUTE_PBL_HEIGHT
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : ITS_TIME_FOR_EMIS

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root    ! Are we on the root CPU?
LOGICAL,        INTENT(IN)    :: DO_VDIFF     ! Switch which turns on PBL
                                              !  mixing of tracers
TYPE(OptInput), INTENT(IN)    :: Input_Opt    ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met    ! Meteorology State object
TYPE(ChmState), INTENT(INOUT) :: State_Chm    ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC           ! Success or failure?
```

REVISION HISTORY:

```
11 Feb 2005 - R. Yantosca - Initial version
21 Dec 2010 - R. Yantosca - Now only call SETEMIS for fullchem simulations
22 Dec 2010 - R. Yantosca - Bug fix: print debug output only if LPRT=T
05 Mar 2013 - R. Yantosca - Add am_I_root, Input_Opt, RC arguments
05 Mar 2013 - R. Yantosca - Now call SETEMIS with am_I_Root, Input_Opt, RC
05 Mar 2013 - R. Yantosca - Now use Input_Opt%ITS_A_FULLCHEM_SIM
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
01 Aug 2013 - R. Yantosca - Now pass the Input_Opt object to VDIFFDR
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
22 Aug 2014 - R. Yantosca - Renamed DO_TURBDAY to DO_VDIFF for clarity
16 Nov 2015 - E. Lundgren - Update air quantities after VDIFFDR call
                            since specific humidity is updated
13 Jul 2016 - R. Yantosca - Remove STT, we can point to State_Chm%Species
                            in the VDIFFDR routine directly
```

5.4 Fortran: Module Interface vdiff_pre_mod.F90

Module VDIFF_PRE_MOD contains variables used in VDIFF_MOD.

INTERFACE:

```
MODULE VDIFF_PRE_MOD
```

USES:

```
  IMPLICIT NONE

  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC :: Init_VDIFF_PRE
  PUBLIC :: Cleanup_VDIFF_PRE
  PUBLIC :: Set_VDIFF_VALUES
```

PUBLIC DATA MEMBERS:

```
  LOGICAL, PUBLIC      :: LPRT              ! Passes LPRT to vdiff_mod
  LOGICAL, PUBLIC      :: LTURB             ! Passes LTURB to vdiff_mod
  INTEGER, PUBLIC      :: PCNST             ! Passes N_TRACERS to vdiff_mod
```

REVISION HISTORY:

```
01 Jun 2009 - C. Carouge & J. Lin - Initial version
07 Oct 2009 - R. Yantosca         - Added CVS Id tag
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
24 Jun 2014 - R. Yantosca - Now add PCNST as a module variable
```

```
24 Jun 2014 - R. Yantosca - Add routine SET_VDIFF_VALUES, since we need to
                            pass N_TRACERS, LPRT, LTURB to vdiff_mod.F90
                            now that logical_mod.F, tracer_mod.F are gone.
24 Jun 2014 - R. Yantosca - Renamed to vdiff_pre_mod.F90
24 Nov 2014 - M. Yannetti - Added PRECISION_MOD
30 Jun 2016 - M. Sulprizio- Remove NCS, NDRYDEP, ND15, ND44, IIPAR, JJPAR
                            since they are not used anymore
```

5.4.1 init_vdiff_pre

Subroutine INIT_VDIFF_PRE allocates all module arrays.

INTERFACE:

```
SUBROUTINE Init_VDIFF_PRE( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
Need to add error-checking on the allocation statements, so that we
exit the code upon error.
```

REVISION HISTORY:

```
19 Nov 2012 - R. Yantosca - Added ProTeX headers
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
24 Jun 2014 - R. Yantosca - Now allocate EMIS_SAVE to the # of tracers
                            in the simulation (i.e. INIT_OPT)
22 May 2015 - R. Yantosca - Remove variables made obsolete by HEMCO
```

5.4.2 cleanup_vdiff_pre

Subroutine CLEANUP_VDIFF_PRE deallocates all module arrays.

INTERFACE:

```
SUBROUTINE Cleanup_VDIFF_PRE( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

REVISION HISTORY:

```
19 Nov 2012 - R. Yantosca - Initial version
```

5.4.3 set_vdiff_values

Subroutine SET_VDIFF_VALUES initializes the PCNST value, which is the number of advected species. This is needed in vdiff_mod.F90.

INTERFACE:

```
SUBROUTINE Set_VDIFF_VALUES( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
This routine has to be called after routine READ_INPUT_FILE.
```

REVISION HISTORY:

```
24 Jun 2014 - R. Yantosca - Initial version
```

6 Dry deposition modules

These modules contain routines to remove species from the atmosphere by dry deposition. Related modules compute the land cover that is used by the dry depostion routines.

6.1 Fortran: Module Interface drydep_mod.F

Module DRYDEP_MOD contains variables and routines for the GEOS-Chem dry deposition scheme.

INTERFACE:

```
      MODULE DRYDEP_MOD
```

USES:

```
      USE CMN_SIZE_MOD                          ! Size parameters
      USE CMN_DIAG_MOD                          ! Diag counters & flags
      USE DAO_MOD                               ! Met field subroutines
#if defined( BPCH_DIAG )
      USE DIAG_MOD,       ONLY : AD44           ! Diagnostic arrays
#endif
      USE ERROR_MOD                             ! Error handling routines
      USE GC_GRID_MOD,    ONLY : GET_AREA_CM2   ! Grid box surface areas [cm2]
      USE PBL_MIX_MOD                           ! Boundary layer quantities
      USE TIME_MOD,       ONLY : GET_TS_CHEM    ! Chemistry timestep
#if   defined( TOMAS )
      USE TOMAS_MOD                             ! For TOMAS microphysics
#endif
      USE PhysConstants                         ! Physical constants
      USE PRECISION_MOD                         ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC :: CLEANUP_DRYDEP
      PUBLIC :: DO_DRYDEP
      PUBLIC :: INIT_DRYDEP
      PUBLIC :: INIT_WEIGHTSS
```

PUBLIC DATA MEMBERS:

```
      PUBLIC :: DEPNAME
      PUBLIC :: DEPSAV
      PUBLIC :: NUMDEP
      PUBLIC :: NTRAIND
      PUBLIC :: IDEP,   IRGSS,  IRAC, IRCLS
      PUBLIC :: IRGSO,  IRLU,   IRI,  IRCLO, DRYCOEFF
       PUBLIC :: NDVZIND ! MSL -> For MPI broadcasting in GCHP
```

REMARKS:

References:

(1) Baldocchi, D.D., B.B. Hicks, and P. Camara, "A canopy stomatal resistance model for gaseous deposition to vegetated surfaces", Atmos. Environ. 21, 91-101, 1987.
(2) Brutsaert, W., "Evaporation into the Atmosphere", Reidel, 1982.
(3) Businger, J.A., et al., "Flux-profile relationships in the atmospheric surface layer", J. Atmos. Sci., 28, 181-189, 1971.
(4) Dwight, H.B., "Tables of integrals and other mathematical data", MacMillan, 1957.
(5) Guenther, A., and 15 others, A global model of natural volatile organic compound emissions, J. Geophys. Res., 100, 8873-8892, 1995.
(6) Hicks, B.B., and P.S. Liss, "Transfer of SO2 and other reactive gases across the air-sea interface", Tellus, 28, 348-354, 1976.
(7) Jacob, D.J., and S.C. Wofsy, "Budgets of reactive nitrogen, hydrocarbons, and ozone over the Amazon forest during the wet season", J. Geophys. Res., 95, 16737-16754, 1990.
(8) Jacob, D.J., et al, "Deposition of ozone to tundra", J. Geophys. Res., 97, 16473-16479, 1992.
(9) Levine, I.N., "Physical Chemistry, 3rd ed.", McGraw-Hill, New York, 1988.
(10) Munger, J.W., et al, "Atmospheric deposition of reactive nitrogen oxides and ozone in a temperate deciduous forest and a sub-arctic woodland", J. Geophys. Res., in press, 1996.
(11) Walcek, C.J., R.A. Brost, J.S. Chang, and M.L. Wesely, "SO2, sulfate, and HNO3 deposition velocities computed using regional landuse and meteorological data", Atmos. Environ., 20, 949-964, 1986.
(12) Wang, Y.H., paper in preparation, 1996.
(13) Wesely, M.L, "Improved parameterizations for surface resistance to gaseous dry deposition in regional-scale numerical models", Environmental Protection Agency Report EPA/600/3-88/025, Research Triangle Park (NC), 1988.
(14) Wesely, M. L., Parameterization of surface resistance to gaseous dry deposition in regional-scale numerical models. Atmos. Environ., 23 1293-1304, 1989.
(15) Price, H., L. Jaegl, A. Rice, P. Quay, P.C. Novelli, R. Gammon, Global Budget of Molecular Hydrogen and its Deuterium Content: Constraints from Ground Station, Cruise, and Aircraft Observations, submitted to J. Geophys. Res., 2007.
(16) Karl, T., Harley, P., Emmons, L., Thornton, B., Guenther, A., Basu, C., Turnipseed, A., and Jardine, K.: Efficient Atmospheric Cleansing of Oxidized Organic Trace Gases by Vegetation, Science, 330, 816-819, 10.1126/science.1192534, 2010.

REVISION HISTORY:

27 Jan 2003 - R. Yantosca - Moved standalone routines into this module

(1) Bug fix: Do not assume NO2 is the 2nd drydep species. This causes a mis-indexing for CANOPYNOX. Now archive ND44 diagnostic in kg for Radon runs in routine DRYFLXRnPbBe; convert to kg/s in diag3.f (bmy, 1/27/03)
(2) Now references "grid_mod.f" and the new "time_mod.f". Renamed DRYDEP routine to DO_DRYDEP for consistency w/ other drivers called from the MAIN program. (bmy, 2/11/03)
(3) Added error check in DRYFLX for SMVGEAR II (bmy, 4/28/03)
(4) Added drydep of N2O5. Now added PBLFRAC array, which is the fraction of each level below the PBL top. Also now compute drydep throughout the entire PBL, in order to prevent short-lived species such as HNO3 from being depleted in the shallow GEOS-3 surface layer. (rjp, bmy, 7/21/03)
(5) Bug fix for GEOS-4 in DRYFLXRnPbBe (bmy, 12/2/03)
(6) Now made CFRAC, RADIAT local variables in DO_DRYDEP (bmy, 12/9/03)
(7) Now enclose AD44 in !$OMP CRITICAL block for drydep flux (bmy, 3/24/04)
(8) Now handle extra carbon & dust tracers (rjp, tdf, bmy, 4/1/04)
(9) Added routines AERO_SFCRS1, AERO_SFCRSII. Increased MAXDEP to 25. Now handles extra carbon & dust tracers. (rjp, tdf, bmy, 4/1/04)
(10) Increased MAXDEP to 26. Added A_RADI and A_DEN module variables. Other modifications for size-resolved drydep. (rjp, bec, bmy, 4/20/04)
(11) Increased MAXDEP to 35 and handle extra SOA tracers (rjp, bmy, 7/13/04)
(12) Now references "logical_mod.f", "directory_mod.f", and "tracer_mod.f" (bmy, 7/20/04)
(13) Add Hg2, HgP as drydep tracers (eck, bmy, 12/8/04)
(14) Updated for AS, AHS, LET, NH4aq, SO4aq (cas, bmy, 1/6/05)
(15) Now references "pbl_mix_mod.f". Removed PBLFRAC array. (bmy, 2/22/05)
(16) Now include SO4s, NITs tracers. Now accounts for hygroscopic growth of seasalt aerosols when computing aerodynamic resistances. (bec, bmy, 4/13/05)
(17) Now modified for GEOS-5 and GCAP met fields (bmy, 5/25/05)
(18) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(19) Now change Reynold's # criterion from 1 to 0.1 in DEPVEL. Also change Henry's law constant for Hg2. Also increase MAXDEP from 35 to 37. (eck, djj, bmy, 2/1/06)
(20) Bug fix in INIT_DRYDEP (bmy, 4/17/06)
(21) Now bundle function DIFFG into "drydep_mod.f". Also updated for SOG4 and SOA4 tracers. Bug fix in INIT_DRYDEP. (dkh, bmy, 5/24/06)
(22) Fix typo in INIT_DRYDEP (dkh, bmy, 6/23/06)
(23) Add H2 and HD as drydep tracers. Added subroutine DRYFLXH2HD for H2HD offline sim (phs, 9/18/07)
(24) Extra error check for small RH in AERO_SFCRII (phs, 6/11/08)
(25) Added 15 more dry deposition species (tmf, 7/31/08)
(26) Modify dry depostion to follow the non-local PBL scheme. (lin, ccc, 5/29/09)
(27) Minor bug fix in mol wts for ALPH, LIMO (bmy, 10/19/09)
(28) Change MAXDEP from 50 to 81 (win, 7/14/09)
(28a) modified to use Zhang 2001 for all non-size resolved aerosols (hotp)

```
(29) Add aromatics SOA (dkh)
(30) Add new species. Some tracers give 2 deposition species: ISOPN-> ISOPNB
     and ISOPND. (fp)
(31) Updates for mercury simulation (ccc, 5/17/10)
(32) Add POPs (eck, 9/20/10)
(33) Increase MAXDEP to 51 for dicarbonyls simulation. (ccc, 10/8/10)
01 Aug 2011 - J. Fisher - Set aerosol dry deposition velocity to 0.03 cm/s
                          over snow and ice based on Nilsson & Rannik, 2001
21 Dec 2011 - M. Payer  - Updates for sea salt (jaegle 5/11/11)
22 Dec 2011 - M. Payer  - Added ProTeX headers
10 Jan 2012 - M. Payer  - Update to use local surface pressure
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
26 Mar 2012 - R. Yantosca - Now reference CMN_SIZE_MOD at the top of module
26 Mar 2012 - R. Yantosca - Replace NNTYPE, NNPOLY, NNVEGTYPE w/ the
                            values NTYPE, NPOLY, NVEGTYPE from CMN_SIZE
26 Mar 2012 - R. Yantosca - Now retire MODIN and RDDRYCF; read drydep inputs
                            from a netCDF file w/ routine READ_DRYDEP_INPUTS
26 Mar 2012 - R. Yantosca - Reorganize module USE statements for clarity
09 Apr 2012 - R. Yantosca - Now replace IJREG, IJLAND, IJUSE, XYLAI arrays
                            with IREG, ILAND, IUSE, XLAI.
31 Jul 2012 - R. Yantosca - Modifications for grid-independence
11 Dec 2012 - M. Long     - Now call READ_DRYDEP_INPUTS from INIT_DRYDEP
11 Dec 2012 - R. Yantosca - Now call INIT_WEIGHTSS from INIT_DRYDEP
13 Dec 2012 - R. Yantosca - Remove reference to obsolete CMN_DEP_mod.F
26 Feb 2013 - R. Yantosca - Now use Input_Opt fields where possible
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
29 Jan 2014 - R. Yantosca - Now set MAXDEP=105 for all simulations.  For
                            TOMAS we had MAXDEP=100; this is close enough.
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
25 Jul 2014 - R. Yantosca - Removed reference to commsoil_mod.F
12 Nov 2014 - M. Yannetti - Added PRECISION_MOD, changed REAL*8 to REAL(fp)
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE
03 Mar 2015 - C. Keller   - Disabled DRYFLX. Now done in mixing_mod.F90
15 Jun 2015 - R. Yantosca - Disabled DRYFLXRnPbBe, also done in mixing_mod
01 Oct 2015 - R. Yantosca - Remove DVZ_MINVAL function
01 Oct 2015 - R. Yantosca - Added PRIVATE flag ID_ACET
06 Jan 2016 - E. Lundgren - Use global physical parameters
13 Jul 2016 - R. Yantosca - Remove DRYHg0, DRYHg2, DRYHgP ID flags
13 Jul 2016 - R. Yantosca - Also make NDVZIND a local variable for now
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

6.1.1 do_drydep

Subroutine DO_DRYDEP is the driver for the GEOS-CHEM dry deposition scheme. DO_DRYDEP calls DEPVEL to compute deposition velocities [m/s], which are then converted to [cm/s]. Drydep frequencies are also computed. (lwh, gmg, djj, 1989, 1994; bmy, 2/11/03, 5/25/05)

INTERFACE:

```
      SUBROUTINE DO_DRYDEP( am_I_Root, Input_Opt,
     &                      State_Met, State_Chm, RC )
```

USES:

```
      USE ErrCode_Mod
      USE HCO_ERROR_MOD
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
      USE Input_Opt_Mod,      ONLY : OptInput
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    NOTE: Modeled aerosol dry deposition velocities over snow and ice surfaces
    in the Arctic are much higher than estimated from measured values (e.g.,
    Ibrahim et al. [1983]; Duan et al. [1988]; Nilsson and Rannik [2001]).
    We will impose a dry deposition velocity of 0.03 cm/s for all aerosols
    over snow and ice surfaces. (Jenny Fisher, 01 Aug 2011)
    References (see full citations above):
    ============================================================================
    (1 ) Wesely, M. L., 1989
    (2 ) Jacob, D.J., and S.C. Wofsy, 1990
```

REVISION HISTORY:

```
    (1 ) Remove SUNCOS, USTAR, AZO, OBK from the arg list; now reference these
         as well as AD and T from "dao_mod.f".  Cleaned up code and updated
```

```
      comments.  Now only order tracer numbers into NTRAIND on the first
      call.  Now force double-precision with "D" exponents.  Now also
      reference IDTNOX, IDTOX, etc. from "tracerid_mod.f".  Bundled into
      "drydep_mod.f" (bmy, 11/19/02)
(2 ) Now make sure that the PBL depth (THIK) is greater than or equal to
      the thickness of the first layer.  Now initialize PBLFRAC array on
      each call. (rjp, bmy, 7/21/03)
(3 ) Now declare CFRAC, RADIAT, AZO, USTAR as local variables, which are
      returned by METERO.  CFRAC and RADIAT have also been deleted from
      "CMN_DEP". (bmy, 12/9/03)
(4 ) Now use explicit formula for IJLOOP to allow parallelization.
      Also reference LPRT from "logical_mod.f" (bmy, 7/20/04)
(5 ) Now use routines from "pbl_mix_mod.f" to get PBL quantities, instead
      of re-computing them here.  Removed PBLFRAC array.  Removed reference
      to "pressure_mod.f".  Removed reference to header file CMN.
      Parallelize DO-loops. (bmy, 2/22/05)
(6 ) Now define RHB as a local array, which is defined in METERO and then
      passed to DEPVEL. (bec, bmy, 4/13/05)
(7 ) Now dimension AZO for GEOS or GCAP met fields.  Remove obsolete
      variables. (swu, bmy, 5/25/05)
(8 ) Remove reference to TRACERID_MOD, it's not needed (bmy, 10/3/05)
01 Aug 2011 - J. Fisher - Set aerosol dry deposition velocity to 0.03 cm/s
                          over snow and ice based on Nilsson & Rannik, 2001
15 Aug 2011 - R. Yantosca - Now reference IDTxxx flags from tracerid_mod.f
07 Oct 2011 - R. Yantosca - Rename SUNCOS30 to SUNCOS_MID, which is the
                            cos(SZA) at the midpt of the chemistry timestep
22 Dec 2011 - M. Payer    - Added ProTeX headers
10 Jan 2012 - M. Payer    - Added local surface pressure
26 Mar 2012 - R. Yantosca - Now read drydep inputs from a netCDF file
                            via routine READ_DRYDEP_INPUTS
26 Mar 2012 - R. Yantosca - Remove calls to obsolete MODIN, RDDRYCF routines
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Now make SUNCOS_MID a local array of size
                            MAXIJ, populated from State_Met%SUNCOSmid
11 Dec 2012 - R. Yantosca - Now do not call READ_DRYDEP_INPUTS and
                            INIT_WEIGHTSS when using the ESMF environment
11 Dec 2012 - R. Yantosca - Remove FIRST variable, as we now read inputs
                            from disk in routine INIT_DRYDEP
12 Dec 2012 - R. Yantosca - Now pass State_Met to DEPVEL
26 Feb 2013 - R. Yantosca - Now use Input_Opt fields where possible.  This
                            facilitates connection to the GEOS-5 GCM.
31 May 2013 - R. Yantosca - Now pass Input_Opt & State_Chm to DEPVEL
15 Jan 2015 - R. Yantosca - Add new netCDF diagnostics structure
12 Aug 2015 - E. Lundgren - Tracer units are now [kg/kg]
01 Oct 2015 - R. Yantosca - Remove DVZ_MINVAL; now use species database
```

```
                            to set the minimum drydep velocity for aerosols
   01 Oct 2015 - R. Yantosca - Now use species database to set Vd for aerosols
                            over snow/ice; combine with the prior update to
                            enforce a minimum Vd for aerosol species
   01 Oct 2015 - R. Yantosca - Remove references to tracerid_mod.F (except
                            for TOMAS for now)
   21 Jan 2016 - E. Lundgren - Update netcdf diagnostics for drydep trcr names
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   17 May 2016 - M. Sulprizio- Remove IJLOOP and change dimension of arrays
                            from (MAXIJ) to (IIPAR,JJPAR)
   18 Jul 2016 - M. Sulprizio- Remove special handling for ISOPN and MVKN for
                            ND44 netCDF diagnostic. Family tracers have been
                            eliminated.
```

6.1.2 metero

Subroutine METERO calculates meteorological constants needed for the dry deposition velocity module. (lwh, gmg, djj, 1989, 1994; bmy, 10/3/05)

INTERFACE:

```
      SUBROUTINE METERO( State_Met, CZ1,    TCO,  OBK,       CFRAC,
     &                   RADIAT,    AZO,    USTR, ZH,        LSNOW,
     &                   RHB,       PRESSU, W10,  SUNCOS_MID        )
```

USES:

```
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      LOGICAL,  INTENT(OUT) :: LSNOW (IIPAR,JJPAR)  ! Flag for denoting snow/ice
      REAL(f8), INTENT(OUT) :: CZ1   (IIPAR,JJPAR)  ! Midpt ht of 1st model lev
                                                    !  [m]
      REAL(f8), INTENT(OUT) :: TCO   (IIPAR,JJPAR)  ! Grid box sfc temp [K]
      REAL(f8), INTENT(OUT) :: OBK   (IIPAR,JJPAR)  ! Monin-Obhukov length [m]
      REAL(f8), INTENT(OUT) :: CFRAC (IIPAR,JJPAR)  ! Column cloud fraction
                                                    !  [unitless]
      REAL(f8), INTENT(OUT) :: RADIAT(IIPAR,JJPAR)  ! Solar radiation @ ground
                                                    !  [W/m2]
      REAL(f8), INTENT(OUT) :: RHB   (IIPAR,JJPAR)  ! Rel humidity at sfc
                                                    !  [unitless]
      REAL(f8), INTENT(OUT) :: USTR  (IIPAR,JJPAR)  ! Friction velocity [m/s]
      REAL(f8), INTENT(OUT) :: ZH    (IIPAR,JJPAR)  ! PBL height [m]
      REAL(f8), INTENT(OUT) :: PRESSU(IIPAR,JJPAR)  ! Local surface press [Pa]
```

```
      REAL(f8), INTENT(OUT) :: W10   (IIPAR,JJPAR)  ! 10 meter windspeed [m/s]
      REAL(f8), INTENT(OUT) :: SUNCOS_MID(IIPAR,JJPAR) ! COS(SZA) @ midpt of
                                                       !  current chem timestep

      ! Dimension AZO for GCAP or GEOS met fields (swu, bmy, 5/25/05)
#if   defined( GCAP )
      REAL(f8), INTENT(OUT) :: AZO(NTYPE)       ! Roughness heights, by landtype
#else
      REAL(f8), INTENT(OUT) :: AZO(IIPAR,JJPAR) ! Roughness heights, by grid box
#endif
```

REMARKS:

.

```
References (see full citations above):
=============================================================================
(1 ) Wesely, M. L., 1989.
(2 ) Jacob, D.J., and S.C. Wofsy, 1990
```

REVISION HISTORY:

```
(1 ) Now reference GET_PEDGE from "pressure_mod.f".  Now reference T from
      "dao_mod.f".  Removed obsolete code & comments, and added new
       documentation header.  Now force double precision with "D"
       exponents.  Now compute OBK here as well.  Bundled into F90 module
       "drydep_mod.f" (bmy, 11/20/02)
(2 ) Now reference CLDFRC, RADSWG, ZO, USTAR from "dao_mod.f".  Also now
       pass CFRAC, RADIAT, AZO, USTR back to the calling routine
       via the arg list. (bmy, 12/9/03)
(3 ) Now use explicit formula for IJLOOP to allow parallelization
      (bmy, 7/20/04)
(4 ) Now compute ZH and LSNOW here instead of w/in DO_DRYDEP.  Parallelize
      DO-loops.  Now use BXHEIGHT from "dao_mod.f" instead of computing
      the thickness of the 1st level here.  Remove reference to
      "pressure_mod.f".  Remove reference to T from "dao_mod.f".  Now
      reference ALBD from "dao_mod.f" (bmy, 2/22/05)
(5 ) Now references RH from "dao_mod.f".  Now passes relative humidity
      from the surface layer back via RHB argument. (bec, bmy, 4/13/05)
(6 ) Now call GET_OBK from "dao_mod.f" to get the M-O length for both
      GEOS or GCAP met fields.  Remove local computation of M-O length
      here.  Also now dimension AZO appropriately for GCAP or GEOS met
      fields.  Remove obsolete variables. (swu, bmy, 5/25/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Move XLTMMP function to module MEGANUT_MOD. (ccc, 11/20/09)
(9 ) Add sea level pressure and 10m windspeed as arguments (jaegle 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
10 Jan 2012 - M. Payer    - Added local surface pressure
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

```
28 Nov 2012 - R. Yantosca - Add SUNCOS_MID to the argument list and
                            populate that with State_Met%SUNCOSmid
21 Oct 2013 - R. Yantosca - Bug fix: need to hold SP private in OMP loop
25 Jul 2014 - R. Yantosca - Now remove reference to function SFCWINDSQR
17 May 2016 - M. Sulprizio- Remove IJLOOP and change dimension of output
                            arrays from (MAXIJ) to (IIPAR,JJPAR)
```

6.1.3 depvel

Subroutine DEPVEL computes the dry deposition velocities using a resistance-in-series model.

INTERFACE:

```
 SUBROUTINE DEPVEL( am_I_Root, Input_Opt, State_Met, State_Chm,
&                   RADIAT,    TEMP,      SUNCOS,
&                   F0,        HSTAR,     XMW,       AIROSOL,
&                   USTAR,     CZ1,       OBK,       CFRAC,
&                   ZH,        LSNOW,     DVEL,      ZO,
&                   RHB,       PRESSU,    W10,       RC          )
```

USES:

```
USE Drydep_Toolbox_Mod, ONLY : BioFit
USE ErrCode_Mod
USE ERROR_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN) :: am_I_Root      ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN) :: Input_Opt      ! Input Options object
TYPE(MetState), INTENT(IN) :: State_Met      ! Meteorology state object

REAL(f8), INTENT(IN) :: RADIAT (IIPAR,JJPAR) ! Solar radiation [W/m2]
REAL(f8), INTENT(IN) :: TEMP   (IIPAR,JJPAR) ! Temperature [K]
REAL(f8), INTENT(IN) :: SUNCOS (IIPAR,JJPAR) ! Cosine of solar zenith angle
LOGICAL,  INTENT(IN) :: AIROSOL(NUMDEP)      ! =T denotes aerosol species
REAL(f8), INTENT(IN) :: F0     (NUMDEP)      ! React. factor for oxidation
                                             !  of biological substances
REAL(f8), INTENT(IN) :: HSTAR  (NUMDEP)      ! Henry's law constant
REAL(f8), INTENT(IN) :: XMW    (NUMDEP)      ! Molecular weight [kg/mol]
REAL(f8), INTENT(IN) :: USTAR  (IIPAR,JJPAR) ! Friction velocity [m/s]
REAL(f8), INTENT(IN) :: CZ1    (IIPAR,JJPAR) ! Alt @ which Vd is computed
                                             !  [m]
```

```
      REAL(f8), INTENT(IN) :: OBK    (IIPAR,JJPAR) ! Monin-Obhukov length [m]
      REAL(f8), INTENT(IN) :: CFRAC  (IIPAR,JJPAR) ! Surface cloud fraction
      REAL(f8), INTENT(IN) :: ZH     (IIPAR,JJPAR) ! Roughness height [m]
      REAL(f8), INTENT(IN) :: RHB    (IIPAR,JJPAR) ! Relative humidity [%]
      REAL(f8), INTENT(IN) :: PRESSU (IIPAR,JJPAR) ! Surface pressure [hPa]
      REAL(f8), INTENT(IN) :: W10    (IIPAR,JJPAR) ! Wind speed @ 10m altitude
                                                   !  [m/s]
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,  INTENT(OUT) :: RC                  ! Success or failure?
      REAL(f8), INTENT(OUT) :: DVEL(IIPAR,JJPAR,NUMDEP) ! Drydep velocity [m/s]
```

REMARKS:

```
    Need as landtype input for each grid square (I,J); see CMN_DEP_mod.F
       IREG(I,J)       - # of landtypes in grid square
       ILAND(I,J,LDT)  - Land type ID for element LDT =1, IREG(I,J)
                         (could be from any source - mapped to deposition
                         surface ID in input unit 65)
       IJUSE(I,J,LDT) - Fraction ((per mil) of gridbox area occupied by
                        land type element LDT
                                                                             .
    Need as leaf area index; see CMN_DEP_mod.F
       XLAI(I,J,LDT)  - Leaf Area Index of land type element LDT
                                                                             .
    Need as meteorological input for each grid square(I,J) (passed):
       RADIAT(I,J)    - Solar radiation in W m-2
       TEMP(I,J)      - Surface air temperature in K
       SUNCOS(I,J)    - Cosine of solar zenith angle
       LSNOW(I,J)     - Logical for snow and sea ice
       RHB(I,J)       - Relative humidity at the surface
       PRESSU(I,J)    - Local surface pressure
       W10(I,J)       - 10m wind speed
                                                                             .
    Need as input for each species K (passed):
       F0(K)          - reactivity factor for oxidation of biological substances
       HSTAR(K)       - Henry's Law constant
       XMW(K)         - Molecular weight (kg/mole) of species K
                        (used to calculate molecular diffusivities)
       AIROSOL(K)     - LOGICAL flag (T = aerosol species;
                                      F = gas-phase species)
                                                                             .
    Also need to call the following subroutines to read drydep input data:
       READ_DRYDEP_INPUTS    - (in this module) Reads in Olson land type
                               indices, dry deposition land type indices,
```

```
                           default roughness heights, and polynomial
                           coefficients.  (This supersedes MODIN, RDDRYCF)
   COMPUTE_OLSON_LANDMAP - (in olson_landmap_mod.F90).  Reads in the
                           Olson land types at native resolution and re-bins
                           them on-the-fly to the GEOS-Chem grid resolution.
                           (This supersedes RDLAND)
   "rdlai.f"             - reads Leaf Area Indices from files "lai**.global"
                                                                             .
Some variables used in the subroutine (passed):
   LRGERA(I,J)    T -> stable atmosphere; a high aerodynamic resistance
                       (RA=1.E4 m s-1) is imposed; else RA is calculated
   USTAR(I,J)     - Friction velocity (m s-1)
   CZ1(I,J)       - Altitude (m) at which deposition velocity is computed
   OBK(I,J)       - Monin-Obukhov length (m): set to 1.E5 m under neutral
                    conditions
   CFRAC(I,J)     - Fractional cloud cover
   ZH(I,J)        - Mixing depth (m)
                                                                             .
Some variables used in the subroutine:
   MAXDEP         - the maximum number of species for which the dry
                    deposition calculation is done
   ZO(LDT)        - Roughness height (m) for specific surface type indexed
                    by LDT
   RSURFC(K,LDT)  - Bulk surface resistance (s m-1) for species K to
                    surface LDT
   C1X(K)         - Total resistance to deposition (s m-1) for species K
                                                                             .
Returned:
   DVEL(I,J,K) - Deposition velocity (m s-1) of species K
                                                                             .
References:
=============================================================================
   Baldocchi, D.D., B.B. Hicks, and P. Camara, A canopy stomatal
     resistance model for gaseous deposition to vegetated surfaces,
     Atmos. Environ. 21, 91-101, 1987.
   Brutsaert, W., Evaporation into the Atmosphere, Reidel, 1982.
   Businger, J.A., et al., Flux-profile relationships in the atmospheric
     surface layer, J. Atmos. Sci., 28, 181-189, 1971.
   Dwight, H.B., Tables of integrals and other mathematical data,
     MacMillan, 1957.
   Guenther, A., and 15 others, A global model of natural volatile
     organic compound emissions, J. Geophys. Res., 100, 8873-8892, 1995.
   Hicks, B.B., and P.S. Liss, Transfer of SO2 and other reactive
     gases across the air-sea interface, Tellus, 28, 348-354, 1976.
   Jacob, D.J., and S.C. Wofsy, Budgets of reactive nitrogen,
     hydrocarbons, and ozone over the Amazon forest during the wet season,
     J.  Geophys. Res., 95, 16737-16754, 1990.
   Jacob, D.J., and 9 others, Deposition of ozone to tundra,
```

J. Geophys. Res., 97, 16473-16479, 1992.
Levine, I.N., Physical Chemistry, 3rd ed., McGraw-Hill, New York, 1988.
Munger, J.W., and 8 others, Atmospheric deposition of reactive nitrogen oxides and ozone in a temperate deciduous forest and a sub-arctic woodland, J. Geophys. Res., in press, 1996.
Walcek, C.J., R.A. Brost, J.S. Chang, and M.L. Wesely, SO2, sulfate, and HNO3 deposition velocities computed using regional landuse and meteorological data, Atmos. Environ., 20, 949-964, 1986.
Wang, Y.H., paper in preparation, 1996.
Wesely, M.L, Improved parameterizations for surface resistance to gaseous dry deposition in regional-scale numerical models, Environmental Protection Agency Report EPA/600/3-88/025, Research Triangle Park (NC), 1988.
Wesely, M.L., same title, Atmos. Environ., 23, 1293-1304, 1989.

REVISION HISTORY:

```
** Contact: D.J. Jacob, Harvard U. (djj@io.harvard.edu)
** Modularized by G.M. Gardner, Harvard U.
** Version 3.2:   5/27/97
** Version 3.2.1: 3/4/99   -- bug fix in expression for RT
** Version 3.2.2: 3/26/99  -- bug fix: specify a large Ra for aerosols
** Version 3.2.3: 11/12/99 -- change Reynolds # criterion from 10 to 1
                           -- force double precision w/ "D" exponents
** Version 3.3:   5/8/00   -- bug fixes, cleanup, updated comments.
** Version 3.4:   1/22/03  -- remove hardwire for CANOPYNOX
** Version 3.5    7/21/03  -- Remove cap of surface resistance in RLUXX
** Version 3.6    4/01/04  -- Now do drydep of DUST aerosol tracers
** Version 3.7    4/20/04  -- Now also do drydep of SEASALT aerosol tracers
** Version 3.8    4/13/05  -- Accounts for hygroscopic growth of SEASALT
**                            aerosol tracers.  DUST aerosol tracers do
**                            not grow hygroscopically.  Added RHB as
**                            an input argument.
** Version 3.9    5/25/05  -- Now restore GISS-specific code for GCAP model
** Version 3.9.1  11/17/05 -- change Reynolds # criterion from 1 to 0.1
  11 May 2011 - L. Jaegle   - Updated to use actual Sea level pressure instead
                              of 1000 hPa
                            - Modified to used Slinn & Slinn (1980) over Ocean
                              surfaces
  22 Dec 2011 - M. Payer    - Added ProTeX headers
  10 Jan 2012 - M. Payer    - Updated to use local surface pressure
  09 Apr 2012 - R. Yantosca - Remove IJREG, IJLAND, IJUSE, XYLAI arrays and
                              replace w/ IREG, ILAND, IUSE, XLAI
  09 Apr 2012 - R. Yantosca - Remove reference to CMN_VEL_mod.F
  09 Apr 2012 - R. Yantosca - Now use INTENT(IN), INTENT(OUT) for arguments
  30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                              running with the traditional driver main.F
  12 Dec 2012 - R. Yantosca - Now get ILAND, IUSE, IREG from State_Met
  13 Dec 2012 - R. Yantosca - Now get XLAI from State_Met
```

```
  06 Mar 2013 - H. Amos     - Merge C. Friedman's PAH code
  31 May 2013 - R. Yantosca - Now pass State_Chm, for TOMAS
  14 Jun 2013 - R. Yantosca - Now use Input_Opt%ITS_A_POPS_SIM
  29 Aug 2013 - R. Yantosca - Bug fix: Skip to the next species if unless
                              HSTAR>0 and XMW>0, or AIROSOL=t.  This avoids
                              a floating-point invalid condition.
  12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                              aerosols (T.D. Fairlie)
  28 Jan 2014 - R. Yantosca - For TOMAS, don't hold A_RADI and A_DEN PRIVATE
  19 May 2014 - C. Keller   - Now call BIOFIT from drydep_toolbox_mod.F\
  12 Aug 2015 - E. Lundgren - Now accept am_I_Root and RC as input args
  12 Aug 2015 - E. Lundgren - Now pass am_I_Root and RC to AERO_DIADEN
                              to enable unit conversion in that routine
  22 Sep 2015 - R. Yantosca - Now use NUMDEP instead of MAXDEP for arrays
  15 Mar 2016 - C. Keller   - Prevent very small numbers of CORR1 and ZOOBK
  29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
  17 May 2016 - M. Sulprizio- Remove IJLOOP and change dimension of arrays
                              from (MAXIJ) to (IIPAR,JJPAR); Also remove NPTS
                              input argument
*****************************************************************************
   Changes from Version 3.2 to Version 3.3:                                ***
   * We now suppress dry deposition over aerodynamically smooth            ***
     surfaces.  The previous algorithm yielded negative numbers            ***
     when u* was very small (due to the logarithm going negative).         ***
     See the comments below for more information.                          ***
   * Now eliminate obsolete variables ZLMO and SIH from the code.          ***
   * Obsolete comments have been updated or removed.                       ***
*****************************************************************************
   Changes from version 3.1 to version 3.2:                                ***
   * In unstable atmospheres with |ZLMO| < ZO, as can happen               ***
    occasionally under very low wind conditions with tall canopies,        ***
    application of Monin-Obukhov similarity yields negative values         ***
    for RA.  This was a problem in version 3.1.  In fact,                  ***
    Monin-Obukhov similarity does not apply under such conditions,         ***
    so we now set RA to zero and let the boundary                          ***
    resistance RB define the overall aerodynamic resistance.  Since        ***
    RB varies inversely with U* it will impose a large aerodynamic         ***
    resistance under very low wind conditions.                             ***
   * The range of applicability of stability correction functions          ***
    to Monin-Obukhov similarity has been extended to                       ***
    -2.5 < z/zMO < 1.5, based on Figure 2 of Businger et al. [1971].       ***
    The range used to be -1 < z/zMO < 1 in version 3.1.                    ***
*****************************************************************************
```

6.1.4 diffg

Subroutine DIFFG calculates the molecular diffusivity [m2/s] in air for a gas X of molecular weight XM [kg] at temperature TK [K] and pressure PRESS [Pa]. (bmy, 5/16/06)

INTERFACE:

```
FUNCTION DIFFG( TK, PRESS, XM ) RESULT( DIFF_G )
```

INPUT PARAMETERS:

```
REAL(f8), INTENT(IN) :: TK     ! Temperature [K]
REAL(f8), INTENT(IN) :: PRESS  ! Pressure [Pa]
REAL(f8), INTENT(IN) :: XM     ! Molecular weight of gas [kg]
```

REMARKS:

```
We specify the molecular weight of air (XMAIR) and the hard-sphere molecular
radii of air (RADAIR) and of the diffusing gas (RADX).  The molecular
radius of air is given in a Table on p. 479 of Levine [1988].  The Table
also gives radii for some other molecules.  Rather than requesting the user
to supply a molecular radius we specify here a generic value of 2.E-10 m for
all molecules, which is good enough in terms of calculating the diffusivity
as long as molecule is not too big.
```

REVISION HISTORY:

```
(1 ) Originally was a standalone function; now bundled into drydep_mod.f.
     Also now force REAL(f8) precision with D exponents.  Now use F90
     style syntax and updated comments. (bmy, 5/16/06)
22 Dec 2011 - M. Payer    - Added ProTeX headers
06 Jan 2016 - E. Lundgren - Now use global physical parameters
```

6.1.5 read_drydep_inputs

Subroutine READ_DRYDEP_INPUTS reads inputs for the dry deposition module corresponding to either the Olson 1992 (GEOS-Chem default) or Olson 2001 (planned replacement for Olson 1992) land map.

INTERFACE:

```
SUBROUTINE READ_DRYDEP_INPUTS( am_I_Root, Input_Opt,
&                              DRYCOEFF,  IOLSON,   IDEP,
&                              IWATER,    NWATER,   IZO,
&                              IDRYDEP,   IRI,      IRLU,
&                              IRAC,      IRGSS,    IRGSO,
&                              IRCLS,     IRCLO,    IVSMAX,
&                              RC )
```

USES:

```
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput

      ! Modules for netCDF read
      USE m_netcdf_io_open
      USE m_netcdf_io_get_dimlen
      USE m_netcdf_io_read
      USE m_netcdf_io_readattr
      USE m_netcdf_io_close

#     include "netcdf.inc"
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN) :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      !-----------------------------------------------------------------------
      ! DRYCOEFF : Baldocchi polynomial coeffs
      ! IOLSON   : Olson land type indices (+1)
      ! IDEP     : Mapping: Olson ==> drydep ID
      ! IWATER   : Olson types that represent water
      ! NWATER   : Number of Olson types that are water
      ! IZO      : Default Z0 (routgness height) for each Olson land type
      ! IDRYDEP  : Dry deposition land type indices
      ! IRI      : RI   resistance for drydep
      ! IRLU     : RLU  resistance for drydep
      ! IRAC     : RAC  resistance for drydep
      ! IRGSS    : RGSS resistance for drydep
      ! IRGSO    : RGSO resistance for drydep
      ! IRCLS    : RCLS resistance for drydep
      ! IRCLO    : RCLO resistance for drydep
      ! IVSMAX   : Max drydep velocity (for aerosol) perr drydep land type
      !-----------------------------------------------------------------------
      REAL(fp), INTENT(OUT) :: DRYCOEFF(NPOLY    )
      INTEGER,  INTENT(OUT) :: IOLSON  (NVEGTYPE )
      INTEGER,  INTENT(OUT) :: IDEP    (NVEGTYPE )
      INTEGER,  INTENT(OUT) :: IWATER  (NVEGTYPE )
      INTEGER,  INTENT(OUT) :: NWATER
      INTEGER,  INTENT(OUT) :: IZO     (NVEGTYPE )
      INTEGER,  INTENT(OUT) :: IDRYDEP (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRI     (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRLU    (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRAC    (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRGSS   (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRGSO   (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IRCLS   (NDRYDTYPE)
```

```
      INTEGER,  INTENT(OUT) :: IRCLO   (NDRYDTYPE)
      INTEGER,  INTENT(OUT) :: IVSMAX  (NDRYDTYPE)

      ! Success or failure flag
      INTEGER,  INTENT(OUT) :: RC
```

REMARKS:

```
    Routine READ_DRYDEP_INPUTS replaces routines MODIN (which read the ASCII
    file "drydep.table") and RDDRYCF (which read the ASCII file "drydep.coef").
                                                                             .
    READ_DRYDEP_INPUTS was generated from the Perl script "ncCodeRead", which
    is part of the NcdfUtilities package (with subsequent hand-editing).
                                                                             .
    Assumes that you have:
    (1) A netCDF library (either v3 or v4) installed on your system
    (2) The NcdfUtilities package (from Bob Yantosca) source code
```

REVISION HISTORY:

```
    26 Mar 2012 - R. Yantosca - Initial version
    03 Feb 2014 - M. Sulprizio- Change the internal resistance for coniferous
                                forests to match the internal resistance for
                                deciduous forests when using the Olson 2001
                                land map (skim, 1/27/14)
    18 Dec 2014 - R. Yantosca - Now read DRYCOEFF at REAL*8 precision and
                                then cast to flexible precision
    13 Mar 2015 - R. Yantosca - Replace DATA_DIR_1x1 w/ CHEM_INPUTS_DIR
```

6.1.6 aero_sfcrsii

Function AERO_SFCRSII computes the aerodynamic resistance of seasalt aerosol species according to Zhang et al 2001. We account for hygroscopic growth of the seasalt aerosol particles. (rjp, tdf, bec, bmy, 4/1/04, 6/11/08)

INTERFACE:

```
      FUNCTION AERO_SFCRSII( K, II, PRESS, TEMP, USTAR, RHB,
     &                       W10, Input_Opt ) RESULT(RS)
```

USES:

```
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: K     ! Drydep species index (range: 1-NUMDEP)
      INTEGER,        INTENT(IN) :: II    ! Surface type index of GEOS-CHEM
      REAL(f8),       INTENT(IN) :: PRESS ! Pressure [kPa] (1 mb=100 Pa=0.1 kPa)
      REAL(f8),       INTENT(IN) :: TEMP  ! Temperature [K]
```

```
REAL(f8),       INTENT(IN) :: USTAR ! Friction velocity [m/s]
REAL(f8),       INTENT(IN) :: RHB   ! Relative humidity (fraction)
REAL(f8),       INTENT(IN) :: W10   ! 10 m windspeed [m/s]
TYPE(OptInput), INTENT(IN) :: Input_Opt  ! Input Options object
```

RETURN VALUE:

```
REAL(f8)                   :: RS    ! Surface resistance for particles [s/m]
```

REMARKS:

```
Do computations internally with REAL*8 (8-byte) floating-point precision,
in order to avoid a loss of precision.
```

REVISION HISTORY:

```
(1 ) Updated comments.  Also now force double precision w/ "D" exponents.
     (bmy, 4/1/04)
(2 ) Now limit relative humidity to [tiny(real(f8)),0.99] range for DLOG
      argument (phs, 6/11/08)
(3 ) Bug fixes to the Gerber (1985) growth function (jaegle 5/11/11)
(4)  Update growth function to Lewis and Schwartz (2006) and density
     calculation based on Tang et al. (1997) (bec, jaegle 5/11/11)
(5 ) Updates of sea salt deposition over water to follow the Slinn & Slinn
     (1980) formulation over water surface. Described in Jaegle et al. (ACP,
     11, 2011) (jaegle 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
14 Jun 2013 - R. Yantosca - Now pass Input_Opt via the arg list
06 Jan 2015 - E. Lundgren - Use global physical parameters
```

6.1.7 init_weightss

Subroutine INIT_WEIGHTSS calculates the volume size distribution of sea-salt. This only has to be done once. We assume that sea-salt is the combination of a coarse mode and accumulation model log-normal distribution functions. The resulting arrays are: DMID = diameter of bin and SALT_V = dV/dln(D) [in um3]. (jaegle 5/11/11)

INTERFACE:

```
SUBROUTINE INIT_WEIGHTSS( Input_Opt )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN) :: Input_Opt
```

REVISION HISTORY:

```
11 May 2011 - L. Jaegle   - Initial version
22 Dec 2011 - M. Payer    - Added ProTeX headers
14 Jun 2013 - R. Yantosca - Now accept Input_Opt via tha argument list
06 Jan 2016 - E. Lundgren - Use global physical parameters
```

6.1.8 dust_sfcrsi

Function DUST_SFCRSI computes the aerodynamic resistance of dust aerosol species according to Seinfeld et al 96. We do not consider hygroscopic growth of the dust aerosol particles. (rjp, tdf, bmy, bec, 4/1/04, 4/15/05)

INTERFACE:

```
FUNCTION DUST_SFCRSI( K, II, PRESS, TEMP, USTAR ) RESULT( RS )
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: K       ! Drydep species (range: 1-NUMDEP)
INTEGER,  INTENT(IN) :: II      ! Surface type index of GEOS-CHEM
REAL(f8), INTENT(IN) :: PRESS   ! Pressure [kPa]
REAL(f8), INTENT(IN) :: TEMP    ! Temperature [K]
REAL(f8), INTENT(IN) :: USTAR   ! Friction velocity [m/s]
```

RETURN VALUE:

```
REAL(f8)             :: RS      ! Surface resistance for particles [s/m]
```

REVISION HISTORY:

```
(1 ) Updated comments.  Also now force double precision w/ "D" exponents.
     (bmy, 4/1/04)
(2 ) Renamed to DUST_SFCRSII, since this will only be used to compute
     aerodynamic resistance of dust aerosols.  (bec, bmy, 4/15/05)
22 Dec 2011 - M. Payer    - Added ProTeX headers
06 Jan 2016 - E. Lundgren - Use global physical paramters
```

6.1.9 adust_sfcrsii

Function ADUST_SFCRSII computes the aerodynamic resistance of non-size resolved aerosol according to Zhang et al 2001. We do not consider the hygroscopic growth of the aerosol particles. (rjp, tdf, bec, bmy, 4/1/04, 4/15/05)

This routine is used for all aerosols except dust, sulfate, and seasalt (hotp 7/31/09)

INTERFACE:

```
FUNCTION ADUST_SFCRSII( K, II, PRESS, TEMP, USTAR ) RESULT( RS )
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: K     ! Drydep species index (range: 1-NUMDEP)
INTEGER,  INTENT(IN) :: II    ! Surface type index of GEOS-CHEM
REAL(f8), INTENT(IN) :: PRESS ! Pressure [kPa] (1 mb = 100 Pa = 0.1 kPa)
REAL(f8), INTENT(IN) :: TEMP  ! Temperature [K]
REAL(f8), INTENT(IN) :: USTAR ! Friction velocity [m/s]
```

RETURN VALUE:

```
REAL(f8)             :: RS    ! Surface resistance for particles [s/m]
```

REVISION HISTORY:

```
(1 ) Updated comments.  Also now force double precision w/ "D" exponents.
     (bmy, 4/1/04)
(2 ) Renamed to DUST_SFCRSII, since this will only be used to compute
     aerodynamic resistance of dust aerosols.  (bec, bmy, 4/15/05)
(3 ) Modified hotp for non size resolved aerosols. This is just DUST_SFCRSII
     renamed and the diameter and density fixed. (hotp 7/12/07)
22 Dec 2011 - M. Payer    - Added ProTeX headers
06 Jan 2016 - E. Lundgren - Use global physical parameters
```

6.1.10 dust_sfcrsii

Function DUST_SFCRSII computes the aerodynamic resistance of dust aerosol species according to Zhang et al 2001. We do not consider the hygroscopic growth of the aerosol particles. (rjp, tdf, bec, bmy, 4/1/04, 4/15/05)

INTERFACE:

```
FUNCTION DUST_SFCRSII( K, II, PRESS, TEMP, USTAR, DIAM, DEN )
& RESULT( RS )
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: K       ! Drydep species index (range: 1-NUMDEP)
INTEGER,  INTENT(IN) :: II      ! Surface type index of GEOS-CHEM
REAL(f8), INTENT(IN) :: PRESS   ! Pressure [kPa]
REAL(f8), INTENT(IN) :: TEMP    ! Temperature [K]
REAL(f8), INTENT(IN) :: USTAR   ! Friction velocity [m/s]
REAL(f8), INTENT(IN) :: DIAM    ! Particle diameter [m]
REAL(f8), INTENT(IN) :: DEN     ! Particle density [kg/m3]
```

RETURN VALUE:

```
REAL(f8)             :: RS      ! Surface resistance for particles [s/m]
```

REVISION HISTORY:

```
(1 ) Updated comments.  Also now force double precision w/ "D" exponents.
     (bmy, 4/1/04)
(2 ) Renamed to DUST_SFCRSII, since this will only be used to compute
     aerodynamic resistance of dust aerosols.  (bec, bmy, 4/15/05)
22 Dec 2011 - M. Payer    - Added ProTeX headers
31 Jan 2014 - R. Yantosca - Now pass DIAM and DEN as arguments so as to
                            avoid parallelization errors when using
                            the TOMAS microphysics package.
06 Jan 2016 - E. Lundgren - Use global physical parameters
```

6.1.11 init_drydep

Subroutine INIT_DRYDEP initializes certain variables for the GEOS-CHEM dry deposition subroutines. (bmy, 11/19/02, 10/19/09)

INTERFACE:

```
SUBROUTINE INIT_DRYDEP( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?!
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry_State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
We now know how many drydep species there are before INIT_DRYDEP is
called.  This allows us to get rid of MAXDEP.  NUMDEP should be
equal to State_Chm%nDryDep, otherwise there is an error.
Also note: we need to use the actual molecular weights instead of
the emitted molecular weights.  These are necessary for the Schmidt #
computation.
```

REVISION HISTORY:

```
(1 ) Added N2O5 as a drydep tracer, w/ the same drydep velocity as
     HNO3.  Now initialize PBLFRAC array. (rjp, bmy, 7/21/03)
(2 ) Added extra carbon & dust aerosol tracers (rjp, tdf, bmy, 4/1/04)
(3 ) Added seasalt aerosol tracers.  Now use A_RADI and A_DEN to store
     radius & density of size-resolved tracers.  Also added fancy
     output. (bec, rjp, bmy, 4/26/04)
(3 ) Now handles extra SOA tracers (rjp, bmy, 7/13/04)
(4 ) Now references LDRYD from "logical_mod.f" and N_TRACERS,
     SALA_REDGE_um, and SALC_REDGE_um from "tracer_mod.f" (bmy, 7/20/04)
(5 ) Included Hg2, HgP tracers (eck, bmy, 12/14/04)
(6 ) Included AS, AHS, LET, NH4aq, SO4aq tracers (cas, bmy, 1/6/05)
(7 ) Remove reference to PBLFRAC array -- it's obsolete (bmy, 2/22/05)
(8 ) Included SO4s, NITs tracers (bec, bmy, 4/13/05)
(9 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(10) Now set Henry's law constant to 1.0d+14 for Hg2.  Now use ID_Hg2,
     ID_HgP, and ID_Hg_tot from "tracerid_mod.f".  Bug fix: split up
     compound IF statements into separate 2 IF statements for ID_Hg2,
     ID_HgP to avoid seg faults. (eck, cdh, bmy, 4/17/06)
(11) Now also initialize SOG4, SOA4 drydep species.  Bug fix: Remove 2nd
     "IF ( IS_Hg ) THEN" statement. (dkh, bmy, 5/24/06)
(12) Bug fix: fix TYPO in IF block for IDTSOA4 (dkh, bmy, 6/23/06)
(13) Included H2/HD tracers for offline H2-HD sim (phs, 9/18/07)
(14) Add dicarbonyl chemistry species (tmf, ccc, 3/6/09)
(15) Minor bug fix: ALPH, LIMO should have molwt = 136.23, not 136 even
     (bmy, 10/19/09)
(16) Add TOMAS aerosol NK1-NK30 and H2SO4 to drydep list (win, 7/14/09)
15 Dec 2011 - M. Payer    - Update OVOC drydep according to Karl et al. 2010
                            and add drydep for MVK and MACR. (J. Mao)
21 Dec 2011 - M. Payer    - Add allocation for size distribution of sea salt
                            SALT_V and DMID (jaegle, 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
14 Mar 2013 - M. Payer    - Replace NOx and Ox with NO2 and O3 as part
                            of removal of NOx-Ox partitioning
12 Jun 2013 - R. Yantosca - Bug fix: now only copy NUMDEP values to
                            Input_Opt%NDVZIND and Input_Opt%DEPNAME
14 Jun 2013 - R. Yantosca - Now replace fields from tracer_mod.F
                            with fields from Input_Opt
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
29 Aug 2013 - R. Yantosca - Assign XMW=118d-3 to RIP and IEPOX.  This now
                            prevents XMW=0e+0_f8 from being passed to function
                            DIFFG, where it is in the denominator.
04 Sep 2013 - R. Yantosca - Improve printout of drydep species
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
```

```
                            aerosols (T.D. Fairlie)
15 Jan 2015 - R. Yantosca - Now save NTRAIND to Input_Opt%NTRAIND
08 Jul 2015 - E. Lundgren - Add marine organic aerosols (B.Gantt, M.Johnson)
22 Sep 2015 - R. Yantosca - Now allocate internal variables that used
                            to be of size MAXDEP.
30 Sep 2015 - R. Yantosca - DD_A_Density is renamed to Density
30 Sep 2015 - R. Yantosca - DD_A_Radius is renamed to Radius
14 Dec 2015 - R. Yantosca - Now use actual MW (MW_g) instead of emitted MW
                            (EmMW_g) to define the XMW array
20 Jun 2016 - R. Yantosca - Now define a couple of species ID flags here
                            as module variables on the first call
18 Jul 2016 - M. Sulprizio- Remove special handling for ISOPN and MVKN.
                            Family tracers have been eliminated.
```

6.1.12 cleanup_drydep

Subroutine CLEANUP_DRYDEP deallocates all module arrays. (bmy, 2/27/03, 2/22/05)

INTERFACE:

```
SUBROUTINE CLEANUP_DRYDEP
```

REVISION HISTORY:

```
(1 ) Remove reference to PBLFRAC array; it's obsolete (bmy, 2/22/05)
(2 ) Added SALT_V and DMID (jaegle, 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
22 Sep 2015 - R. Yantosca - Now deallocate arrays that were formerly
                            sized to MAXDEP.
```

6.2 Fortran: Module Interface modis_lai_mod.F90

Module MODIS_LAI_MOD reads the MODIS LAI and CHLR data at native resolution (either 0.25 x 0.25 or 0.5 x 0.5, in netCDF format) and rebins them to the proper GEOS-Chem LAI and CHLR arrays. CHLR data is only read if marine organic aerosol tracers are enabled. This module eliminates the need for the following GEOS-Chem modules, routines, and data files:

- lai_mod.F
- readlai.F
- rdlai.F
- findmon.F
- The `lai*.global` input files

- CMN_VEL_mod.F

INTERFACE:

```
MODULE Modis_Lai_Mod
```

USES:

```
  USE CMN_SIZE_Mod                              ! Size parameters
  USE Error_Mod                                 ! Error checking routines
  USE PRECISION_MOD                             ! For GEOS-Chem Precision (fp)
  USE Mapping_Mod                               ! Mapping weights & areas
  USE Time_Mod                                  ! EXPAND_DATE

  IMPLICIT NONE
  PRIVATE
```

PUBLIC DATA MEMBERS:

```
   REAL(fp),  PUBLIC, POINTER            :: GC_LAI(:,:)  ! DailyLAI, G-C grid
   REAL(fp),  PUBLIC, POINTER            :: GC_CHLR(:,:) ! DailyCHLR, G-C grid
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: Read_Modis_Lai
  PUBLIC  :: Compute_Modis_Lai
  PUBLIC  :: Find_Lai_Month
  PUBLIC  :: Init_Modis_Lai
  PUBLIC  :: Cleanup_Modis_Lai
```

PRIVATE MEMBER FUNCTIONS:

```
  PUBLIC  :: Read_Modis
  PUBLIC  :: Compute_Modis
  PRIVATE :: RoundOff
```

REMARKS:

```
   Functionality of this module:
   ============================================================================
   If you are using the Olson 1992 land map, then this module will pick the
   MODIS LAI data at 0.5 x 0.5 native resolution.  This is because the legacy
   code assumed a direct correspondence between the Olson 1992 land map and
   the MODIS LAI data.  Similarly, if you are using the Olson 2001 land map,
   then this module will pick the MODIS LAI data at 0.25 x 0.25 resolution.
                                                                             .
   Follows the same algorithm as in the IDL codes used to regrid MODIS LAI
   data (regridmodis_lai_v5.pro; contact GEOS-Chem Support team).
                                                                             .
                                                                             .
   Historical background of how LAI data have been used in GEOS-Chem:
   ============================================================================
```

```
Note that GEOS-Chem (as of April 2012) uses LAI data from two separate
sources.  The dry deposition and soil NOx modules rely on the data from
"lai*.global" ASCII files.  These files (which are pre-processed offline
by IDL codes) are generated for each specific GEOS-Chem grid configuration
(e.g. 4x5, 2x25, 0.5x0.666 nested grids).  These files are read from disk
by routine RDLAI, which saves the LAI data into the XLAI and XYLAI arrays.
XLAI and XYLAI store the leaf area index as a function of Olson land type
(cf Olson 1992 land map).

.

However, the MEGAN biogenic emissions code relies on LAI data stored at
1x1 resolution stored in bpch format.  These binary files are read by
routine RDISOLAI (and other underlying routines in lai_mod.F), and are
regridded on-the-fly to the current GEOS-Chem grid resolution.

.

Therefore, these two sources of LAI data present an inconsistency that
should be resolved.  Also, for the Grid-Indpendent GEOS-Chem project,
we must move away from ASCII files (which prevent interfacing with
external GCMs).  We also cannot assume any particular horizontal grid,
since that is now to be specified at the start of the simulation.

.

Also, to facilitate simulations at ultra-fine horizontal resolution, we
will eventually adopt the Olson 2001 land map, which has a native
resolution of 0.25 x 0.25 degrees, and likewise use an updated version
of the MODIS LAI data at 0.25 x 0.25 resolution.

.

To resolve these issues, we have created a new module (modis_lai_mod.F90)
which reads from the MODIS LAI data in netCDF format at the native
resolution and then regrids the LAI data to GEOS-Chem resolution on-the-
fly.  The XLAI array is populated for backwards compatibility with the
existing legacy codes.  The LAI arrays used for MEGAN (ISOLAI, PMISOLAI,
MISOLAI, and NMISOLAI) are now replaced by arrays GC_LAI, GC_LAI_PM,
GC_LAI_CM, and GC_LAI_NM) from modis_lai_mod.F.

.

We have validated that the new scheme generates identical XLAI arrays
w/r/t the old scheme.  The arrays GC_LAI etc. differ from the ISOLAI etc.
arrays slightly (but generally agree to within 0.001).  This is due to
the fact that the ISOLAI arrays were regridded from 1 x 1 native
resolution, but now we are regridding from much finer resolution
(either 0.5 x 0.5 or 0.25 x 0.25).

.

NOTES:
(1) At the present time, we have removed all references to the obsolete
    XYLAI array and its parent module CMN_VEL_mod.F.
(2) At the present time, we have not yet disabled the RDISOLAI function.
    We will do so in the future, and will validate this with a separate
    benchmark.
(3) As of December 2012, XLAI and XLAI2 have been moved out of obsolete
    module Headers/CMN_DEP_mod.F and are now carried as part of the
```

```
    Meteorology State object (State_Met).  This modification was made
    to facilitate the Grid-Independent GEOS-Chem (GIGC) project.

    -- Bob Yantosca (geos-chem-support@as.harvard.edu), 13 Dec 2012
(4) The previous, current, and next month LAI values (GC_LAI_PM,
    GC_LAI_CM, GC_LAI_NM) were only used for MEGAN. In the HEMCO
    implementation, MEGAN only needs GC_LAI as input, so all the
    other GC_LAI arrays were removed. This also makes MODIS_LAI_PM
    obsolete (ckeller, 10/9/2014).
                                                                             .
                                                                             .
LAI arrays and where they are (or will be) used in GEOS-Chem:
==============================================================================
(1) State_Met%XLAI  --> Used in dry deposition routine DEPVEL
(2) State_Met%XLAI2 --> Used to compute XLAI
(3) XYLAI           --> %%% OBSOLETE: REMOVED, NOW REPLACED BY XLAI %%%
(4) GC_LAI          --> Intended replacement for ISOLAI   (from lai_mod.F)
(5) GC_LAI_PM       --> Intended replacement for PMISOLAI (from lai_mod.F)
(6) GC_LAI_CM       --> Intended replacement for MISOLAI  (from lai_mod.F)
(7) GC_LAI_NM       --> Intended replacement for NMISOLAI (from lai_mod.F)
```

REVISION HISTORY:

```
03 Apr 2012 - R. Yantosca - Initial version
05 Apr 2012 - R. Yantosca - Added descriptive comments
09 Apr 2012 - R. Yantosca - Fixed error in ROUNDOFF function that caused
                            numbers to be rounded up incorrectly.
09 Apr 2012 - R. Yantosca - Changed variables to REAL(fp)
09 Apr 2012 - R. Yantosca - Now set MODIS_START and MODIS_END depending
                            on which version of MODIS LAI we are using
13 Dec 2012 - R. Yantosca - Remove reference to obsolete CMN_DEP_mod.F;
                            XLAI, XLAI2 now are carried in State_Met
23 Jun 2014 - R. Yantosca - Removed references to logical_mod.F
09 Oct 2014 - C. Keller   - Removed GC_LAI_PM, GC_LAI_CM, GC_LAI_NM and
                            MODIS_LAI_PM.
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
07 Jul 2015 - E. Lundgren - Now also read and compute MODIS chlorophyll-a
                            (B. Gantt, M. Johnson). Use separate end years.
```

6.2.1 read_modis_lai

Subroutine READ_MODIS_LAI is the wrapper routine to read the MODIS LAI from disk in netCDF format for the current month, and for next month. If enabled, MODIS CHLR is also read in the same way as LAI.

INTERFACE:

```
SUBROUTINE Read_Modis_Lai( am_I_Root, Input_Opt, yyyy, mm, wasModisRead, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root     ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt     ! Input Options object
INTEGER,        INTENT(IN)  :: yyyy          ! Year for LAI data
INTEGER,        INTENT(IN)  :: mm            ! Month for LAI data
```

OUTPUT PARAMETERS:

```
LOGICAL,        INTENT(OUT) :: wasModisRead  ! Was LAI data just read in?
INTEGER,        INTENT(OUT) :: RC            ! Success or failure?
```

REVISION HISTORY:

```
03 Apr 2012 - R. Yantosca - Initial version
05 Apr 2012 - R. Yantosca - Renamed arg "doMonthly" to "wasModisRead"
05 Jun 2013 - R. Yantosca - Bug fix, use "mm" for current month index
20 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
09 Oct 2014 - C. Keller   - MODIS_LAI_PM not needed anymore.
05 Mar 2015 - R. Yantosca - Now read data w/r/t ExtData/CHEM_INPUTS
07 Jul 2015 - E. Lundgren - Generalized to read either LAI or CHLR
08 Jul 2015 - E. Lundgren - Now read LAI and CHLR data. Abstracted
                            read code to new routine Read_Modis.
```

6.2.2 read_modis

Subroutine READ_MODIS reads the MODIS LAI or CHLR from disk (in netCDF format) for the current month, and for next month.

INTERFACE:

```
SUBROUTINE Read_Modis( am_I_Root, ReadLAI, nc_tmpl,      Input_Opt,  &
                       yyyy,      mm,      wasModisRead, RC         )
```

USES:

```
USE m_netcdf_io_open                         ! netCDF file open
USE m_netcdf_io_read                         ! netCDF read
USE m_netcdf_io_readattr                     ! netCDF attribute reads
USE m_netcdf_io_close                        ! netCDF file close
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput

#   include "netcdf.inc"                     ! netCDF settings & parameters
```

INPUT PARAMETERS:

```
LOGICAL,            INTENT(IN)  :: am_I_Root ! Are we on the root CPU?
LOGICAL,            INTENT(IN)  :: ReadLAI   ! T for LAI, F to read CHLR
TYPE(OptInput),     INTENT(IN)  :: Input_Opt ! Input Options object
CHARACTER(LEN=255), INTENT(IN)  :: nc_tmpl
INTEGER,            INTENT(IN)  :: yyyy      ! Year for LAI data
INTEGER,            INTENT(IN)  :: mm        ! Month for LAI data
```

OUTPUT PARAMETERS:

```
LOGICAL,        INTENT(OUT) :: wasModisRead  ! Was data just read in?
INTEGER,        INTENT(OUT) :: RC            ! Success or failure?
```

REVISION HISTORY:

```
07 Jul 2015 - E. Lundgren - Initial version, containing legacy Read_Modis_Lai
                            code plus modifications to read CHLR
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

6.2.3 compute_modis_lai

Subroutine COMPUTE_MODIS_LAI is the wrapper routine to compute the daily MODIS leaf area indices for GEOS-Chem directly from the native grid resolution (0.25 x 0.25 or 0.5 x 0.5). If marine organic aerosol tracers are used, then daily MODIS chlorophyll is also computed.

INTERFACE:

```
SUBROUTINE Compute_Modis_Lai( am_I_Root,    Input_Opt, State_Met,  &
                              doy,          mm,        mapping,    &
                              wasModisRead, RC                    )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,         INTENT(IN)  :: am_I_Root     ! Are we on the root CPU?
TYPE(OptInput),  INTENT(IN)  :: Input_Opt     ! Input Options object
INTEGER,         INTENT(IN)  :: doy           ! Day of year
INTEGER,         INTENT(IN)  :: mm            ! Month for LAI data
TYPE(MapWeight), POINTER     :: mapping(:,:)  ! "fine" -> "coarse" grid map
LOGICAL,         INTENT(IN)  :: wasModisRead  ! Was LAI data just read in?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState),  INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
    INTEGER,         INTENT(OUT) :: RC           ! Success or failure?
```

REVISION HISTORY:

```
    03 Apr 2012 - R. Yantosca - Initial version
    05 Apr 2012 - R. Yantosca - Renamed arg "doMonthly" to "wasModisRead"
    09 Apr 2012 - R. Yantosca - Changed variables to REAL(fp)
    09 Apr 2012 - R. Yantosca - Now follows same algorithm as rdlai.F for
                                populating XLAI array
    09 Apr 2012 - R. Yantosca - Remove refs to CMN_VEL_mod.F and XYLAI array;
                                these are now obsolete
    17 Apr 2012 - R. Yantosca - Now rename "map" object to "mapping" to avoid
                                name confusion w/ an F90 intrinsic function
    13 Dec 2012 - R. Yantosca - Add am_I_Root, State_Met, RC arguments
    13 Dec 2012 - R. Yantosca - XLAI, XLAI2 are now carried in State_Met
                                instead of in obsolete Headers/CMN_DEP_mod.F
    23 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
    09 Oct 2014 - C. Keller   - Removed GC_LAI_PM, GC_LAI_CM, GC_LAI_NM and
                                MODIS_LAI_PM.
    08 Jul 2015 - E. Lundgren - Now compute LAI and CHLR data. Abstracted
                                compute code to new routine Compute_MODIS
```

6.2.4 compute_modis

Subroutine COMPUTE_MODIS computes either the daily MODIS leaf area indices or the daily chlorophyll for GEOS-Chem directly from the native grid resolution (0.25 x 0.25 or 0.5 x 0.5). The XLAI array (used in the legacy soil NOx and dry deposition routines) are populated accordingly. The XYLAI array is now obsolete and has been replaced by XLAI.

INTERFACE:

```
   SUBROUTINE Compute_Modis( am_I_Root,  ComputeLAI,                    &
                             Input_Opt,  State_Met,    doy,             &
                             mm,         mapping,      wasModisRead,  RC )
```

USES:

```
    USE ErrCode_Mod
    USE Input_Opt_Mod,      ONLY : OptInput
    USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
    LOGICAL,         INTENT(IN)  :: am_I_Root     ! Are we on the root CPU?
    LOGICAL,         INTENT(IN)  :: ComputeLAI
    TYPE(OptInput),  INTENT(IN)  :: Input_Opt     ! Input Options object
    INTEGER,         INTENT(IN)  :: doy           ! Day of year
    INTEGER,         INTENT(IN)  :: mm            ! Month for LAI data
    TYPE(MapWeight), POINTER     :: mapping(:,:)  ! "fine" -> "coarse" grid map
    LOGICAL,         INTENT(IN)  :: wasModisRead  ! Was LAI data just read in?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState),  INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
INTEGER,         INTENT(OUT) :: RC            ! Success or failure?
```

REMARKS:

```
Uses same algorithm as RDISOLAI in the existing lai_mod.F.
```

REVISION HISTORY:

```
07 Jul 2015 - E. Lundgren - Initial version, contains old Compute_Modis_Lai
                            code plus modifications to compute CHLR
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

6.2.5 find_lai_month

Function FIND_LAI_MONTH returns the corresponding LAI month and year for the current calendar date. Note that the LAI data starts at mid-month.

INTERFACE:

```
SUBROUTINE Find_Lai_Month( doy, month, year, mm, yyyy )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)  :: doy       ! Current day of year
INTEGER, INTENT(IN)  :: month     ! Current month
INTEGER, INTENT(IN)  :: year      ! Current year
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: mm        ! Output month for LAI data
INTEGER, INTENT(OUT) :: yyyy      ! Output year  for LAI data
```

REVISION HISTORY:

```
05 Jan 1994 - Y. H. Wang, G.M. Gardner, D. Jacob - Initial version
(1 ) Updated comments, cosmetic changes (bmy, 4/4/03)
(2 ) Add the current simulation year as input & the current LAI as output.
     This is necessary for reading in MODIS LAI (mpb,2009).
08 Dec 2009 - R. Yantosca - Added ProTeX headers
03 Apr 2012 - R. Yantosca - Renamed to FIND_LAI_MONTH; made PUBLIC
```

6.2.6 RoundOff

Rounds a number X to N decimal places of precision.

INTERFACE:

```
FUNCTION RoundOff( X, N ) RESULT( Y )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: X   ! Number to be rounded
INTEGER, INTENT(IN)   :: N   ! Number of decimal places to keep
```

RETURN VALUE:

```
REAL(fp)              :: Y   ! Number rounded to N decimal places
```

REMARKS:

```
The algorithm to round X to N decimal places is as follows:
(1) Multiply X by 10**(N+1)
(2) If X < 0, then add -5 to X; otherwise add 5 to X
(3) Take the integer part of X
(4) Divide X by 10**(N+1)
(5) Truncate X to N decimal places: INT( X * 10**N ) / 10**N

Rounding algorithm from: Hultquist, P.F, "Numerical Methods for Engineers
 and Computer Scientists", Benjamin/Cummings, Menlo Park CA, 1988, p. 20.

Truncation algorithm from: http://en.wikipedia.org/wiki/Truncation

The two algorithms have been merged together for efficiency.
```

REVISION HISTORY:

```
06 Apr 2012 - R. Yantosca - Initial version
09 Apr 2012 - R. Yantosca - Changed all variables & arguments to REAL(fp)
```

6.2.7 init_modis

Subroutine INIT_MODIS_LAI initializes and allocates all module variables.

INTERFACE:

```
SUBROUTINE Init_Modis_Lai( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    03 Apr 2012 - R. Yantosca - Initial version
    03 Feb 2014 - M. Sulprizio- Force last year of MODIS data to 2008. There is
                                a large difference in the 2009 file that still
                                needs to be investigated (skim, 1/29/14)
    23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
    08 Jul 2015 - E. Lundgren - New end years to match files from M. Johnson
```

6.2.8 cleanup_modis_lai

Subroutine CLEANUP_MODIS_LAI deallocates all previously-allocated module variables.

INTERFACE:

```
  SUBROUTINE Cleanup_Modis_Lai
```

REVISION HISTORY:

```
    03 Apr 2012 - R. Yantosca - Initial version
```

6.3 Fortran: Module Interface olson_landmap_mod.F90

Module OLSON_LANDMAP_MOD reads the Olson land map and computes the IREG, ILAND, and IUSE arrays. This module was written to facilitate Grid-Independent GEOS-Chem development while still keeping backwards compatibility with existing legacy code. It replaces the old routine rdland.F.

INTERFACE:

```
 MODULE Olson_LandMap_Mod
```

USES:

```
  USE CMN_SIZE_MOD                    ! Size parameters
  USE ERROR_MOD                       ! Error checking routines
  USE GC_GRID_MOD                     ! Horizontal grid definition
  USE MAPPING_MOD                     ! Mapping weights & areas
  USE PhysConstants                   ! Physical constants
  USE PRECISION_MOD                   ! For GEOS-Chem Precision (fp)

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: Init_Olson_Landmap
PUBLIC  :: Compute_Olson_Landmap
PUBLIC  :: Cleanup_Olson_LandMap
```

REMARKS:

```
The Olson land types are as follows:
=============================================================================
 0 Water              25 Deciduous          50 Desert
 1 Urban              26 Deciduous          51 Desert
 2 Shrub              27 Conifer            52 Steppe
 3 ---                28 Dwarf forest       53 Tundra
 4 ---                29 Trop. broadleaf    54 rainforest
 5 ---                30 Agricultural       55 mixed wood/open
 6 Trop. evergreen    31 Agricultural       56 mixed wood/open
 7 ---                32 Dec. woodland      57 mixed wood/open
 8 Desert             33 Trop. rainforest   58 mixed wood/open
 9 ---                34 ---                59 mixed wood/open
10 ---                35 ---                60 conifers
11 ---                36 Rice paddies       61 conifers
12 ---                37 agric              62 conifers
13 ---                38 agric              63 Wooded tundra
14 ---                39 agric.             64 Moor
15 ---                40 shrub/grass        65 coastal
16 Scrub              41 shrub/grass        66 coastal
17 Ice                42 shrub/grass        67 coastal
18 ---                43 shrub/grass        68 coastal
19 ---                44 shrub/grass        69 desert
20 Conifer            45 wetland            70 ice
21 Conifer            46 scrub              71 salt flats
22 Conifer            47 scrub              72 wetland
23 Conifer/Deciduous  48 scrub              73 water
24 Deciduous/Conifer  49 scrub
                                                                            .
                                                                            .
Arrays computed by olson_landmap_mod.F90
=============================================================================
(1) IREG   (in CMN_DEP_mod.F): # of Olson land types per G-C grid box
(2) ILAND  (in CMN_DEP_mod.F): List of all Olson land types in G-C grid box
(3) IUSE   (in CMN_DEP_mod.F): Coverage of each Olson type in G-C grid box
(4) IJREG  (in CMN_VEL_mod.F): %%%%% OBSOLETE: NOW REPLACED BY IREG  %%%%%
(5) IJLAND (in CMN_VEL_mod.F): %%%%% OBSOLETE: NOW REPLACED BY ILAND %%%%%
(6) IJUSE  (in CMN_VEL_mod.F): %%%%% OBSOLETE: NOW REPLACED BY IUSE  %%%%%
(7) FRCLND (in CMN_DEP_mod.F): Fraction of G-C grid box that is not water
                                                                            .
NOTES:
(1) IREG,  ILAND,  IUSE  are used by the soil NOx emissions routines
```

```
(2) IJREG, IJLAND, IJUSE are used by the drydep routines (legacy code)
(3) FRCLND               is  used by various GEOS-Chem routines
                                                                             .
                                                                             .
BUG IN THE OLD "rdland.F" FOR 2 X 2.5 DEGREE RESOLUTION
=============================================================================
This module ("olson_landmap_mod.F") replaces the old routine "rdland.F",
which previously read in the Olson landtype data from the ASCII format
file named "vegtype.global".  There used to be a different "vegtype.global"
file for each different horizontal grid resolution.
                                                                             .
The "vegtype.global" stored the following quantities, such that values
for a single grid box were saved on a single line:
                                                                             .
  I, J, IREG(I,J), ILAND(I,J,K), IUSE(I,J,K)  (where K=1,IREG(I,J))
                                                                             .
Routine "rdland.F" reads these quantities from "vegtype.global" assuming
there were 20 integer characters on a single line (i.e. using Fortran
FORMAT '(20i4)').   However, ~ 12 lines of the 2 x 2.5 "vegtype.global"
file contained more than 20 integer values.  This caused "rdland.F",
to read in the values from these lines improperly, which in turn caused
the IREG, ILAND, IUSE, IJREG, IJLAND, IJUSE, and FRCLND arrays to be
improperly initialized for the grid boxes corresponding to these
lines in the "vegtype.global" file.
                                                                             .
Bob Yantosca has validated that "olson_landmap_mod.F" returns results
100% identical to the "vegtype.global" file.  Therefore, if you want
to compare the output of model simulations using "olson_landmap_mod.F"
the output of simulations using "rdland.F", you will see a slight
difference in the MCL lifetime and tracer concentrations.
                                                                             .
If you need to run a GEOS-Chem simulation with an older version of the
code using "rdland.F", then this bug may be corrected by changing the
line of code:
                                                                             .
    101  FORMAT(20I4)
                                                                             .
to:
                                                                             .
   #if   defined( GRID2x25 )
    101  FORMAT(25I4)
   #else
    100  FORMAT(20I4)
   #endif
                                                                             .
This is more or less a moot point, as "olson_landmap_mod.F" will be
installed into GEOS-Chem v9-01-03 and higher versions.
                                                                             .
```

```
NOTE FOR 0.5 x 0.666 grids
=============================================================================
As of 21 Mar 2012, the IUSE values computed by "olson_landmap_mod.F90"
may slightly differ from those specified in the "vegtype.global" files
for 0.5 x 0.666 nested grids.  We attribute this to roundoff error caused
by the the longitude spacing being an irrational number (0.6666666...).
We are still investigating.
```

REVISION HISTORY:

```
13 Mar 2012 - R. Yantosca - Initial version
19 Mar 2012 - R. Yantosca - Minor last-minute bug fixes
21 Mar 2012 - R. Yantosca - Now use REAL*4 for computations
22 Mar 2012 - R. Yantosca - Now read surface area from the file
22 Mar 2012 - R. Yantosca - Now make lon, lat, OLSON, A_CM2 allocatable
22 Mar 2012 - R. Yantosca - Now define I_OLSON, J_OLSON, N_OLSON, D_LON,
                            and D_LAT in routine Init_Olson_LandMap
27 Mar 2012 - R. Yantosca - Now reference USE_OLSON_2001 from logical_mod.F
02 Apr 2012 - R. Yantosca - Now reference mapping_mod.F90
02 Apr 2012 - R. Yantosca - Moved routine GET_MAP_WT to mapping_mod.F90
02 Apr 2012 - R. Yantosca - Now Save mapping info for later use
09 Apr 2012 - R. Yantosca - Removed IJREG, IJUSE, IJLAND; these are now
                            replaced by IREG, IUSE, ILAND arrays
09 Apr 2012 - R. Yantosca - Removed reference to CMN_VEL_mod.F
20 Mar 2014 - R. Yantosca - Speed up Olson computation by skipping boxes
24 Jun 2014 - R. Yantosca - Remove references to logical_mod.F
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

6.3.1 compute_olson_landmap

Subroutine COMPUTE_OLSON_LANDMAP computes the GEOS-Chem arrays IREG, ILAND, IUSE (and corresponding 1-D arrays IJREG, IJLAND, IJUSE) on-the-fly from the Olson Land map file. This routine, which is intended to facilitate the Grid-Independent GEOS-Chem, replaces the old rdland.F, which read from pre-computed "vegtype.global" files.

INTERFACE:

```
SUBROUTINE Compute_Olson_LandMap( am_I_Root, mapping, State_Met )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,         INTENT(IN)    :: am_I_Root    ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MapWeight), POINTER       :: mapping(:,:) ! "fine" -> "coarse" mapping
TYPE(MetState),  INTENT(INOUT) :: State_Met    ! Meteorology State object
```

REMARKS:

```
This routine supplies arrays that are required for legacy code routines:
(1) IREG,  ILAND,  IUSE are used by the Soil NOx routines
(2) IJREG, IJLAND, IJUSE are used by the dry deposition routines
```

REVISION HISTORY:

```
13 Mar 2012 - R. Yantosca - Initial version
19 Mar 2012 - R. Yantosca - Reorder ILAND, IUSE, IJLAND, IJUSE to be
                            consistent w/ the leaf area indices
19 Mar 2012 - R. Yantosca - Compute the FRCLND array (from CMN_DEP_mod.F)
21 Mar 2012 - R. Yantosca - Now use REAL*4 for computation, to reduce
                            roundoff errors at high-resolution
22 Mar 2012 - R. Yantosca - Now get surface area directly from variable
                            A_CM2 (read from disk) instead of computing it
02 Apr 2012 - R. Yantosca - Now pass MAP (mapping weight object) via the
                            arg list, to save the mapping info for later
09 Apr 2012 - R. Yantosca - Remove IJLOOP variable
09 Apr 2012 - R. Yantosca - Now do not compute IJREG, IJLAND, IJUSE; these
                            are replaced by IREG, ILAND, IUSE arrays
17 Apr 2012 - R. Yantosca - Rename "map" object to "mapping" to avoid name
                            confusion with an F90 intrinsic function
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
29 Nov 2012 - R. Yantosca - Added am_I_Root argument
12 Dec 2012 - R. Yantosca - Now get IREG, ILAND, IUSE from State_Met
20 Mar 2014 - R. Yantosca - Add shunts in lat & lon to reduce wall time
```

6.3.2 init_olson_landmap

Subroutine INIT_OLSON_LANDMAP reads Olson land map information from disk (in netCDF format).

INTERFACE:

```
SUBROUTINE Init_Olson_LandMap( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE m_netcdf_io_open
USE m_netcdf_io_read
USE m_netcdf_io_readattr
```

```
      USE m_netcdf_io_close

      IMPLICIT NONE

#     include "netcdf.inc"
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
    Assumes that you have:
    (1) A netCDF library (either v3 or v4) installed on your system
    (2) The NcdfUtilities package (from Bob Yantosca) source code
```

REVISION HISTORY:

```
    13 Mar 2012 - R. Yantosca - Initial version
    22 Mar 2012 - R. Yantosca - Also read in surface areas [m2] from file
    27 Mar 2012 - R. Yantosca - Now read the "units" attribute of each variable
    27 Mar 2012 - R. Yantosca - Now echo file I/O status info to stdout
    27 Mar 2012 - R. Yantosca - Now can read Olson 1992 or Olson 2001 land map
    29 Nov 2012 - R. Yantosca - Add am_I_Root to the argument list
    26 Feb 2013 - M. Long     - Now pass DATA_DIR_1x1 via the argument list
    24 Jun 2014 - R. Yantosca - Now accept Input_Opt, RC via the arg list
    05 Mar 2015 - R. Yantosca - Now read data w/r/t ExtData/CHEM_INPUTS
```

6.3.3 cleanup_olson_landmap

Subroutine CLEANUP_OLSON_LANDMAP deallocates all allocated global module variables.

INTERFACE:

```
   SUBROUTINE Cleanup_Olson_LandMap( am_I_Root )
```

INPUT PARAMETERS:

```
      LOGICAL, INTENT(IN) :: am_I_Root   ! Are we on the root CPU?
```

REVISION HISTORY:

```
    22 Mar 2012 - R. Yantosca - Initial version
    29 Nov 2012 - R. Yantosca - Add am_I_Root as an argument
```

6.4 Fortran: Module Interface mapping_mod.F90

Module MAPPING_MOD contains a derived-type object to compute and save the mapping weight (i.e. fraction of each "fine" grid box that fits into the "coarse" grid box") and areal mapping (i.e. the area of each "fine" grid box contained within a "coarse" grid box).

INTERFACE:

```
MODULE Mapping_Mod
```

USES:

```
  USE CMN_SIZE_MOD                    ! Size parameters
  USE ERROR_MOD                       ! Error handling routines
  USE PRECISION_MOD                   ! For GEOS-Chem Precision (fp)

  IMPLICIT NONE
  PRIVATE
```

PUBLIC DATA MEMBERS:

```
  PUBLIC :: MapWeight
  TYPE MapWeight
     INTEGER          :: count        ! # of "fine" boxes per "coarse" box
     INTEGER, POINTER :: II(:)        ! Longitude indices,  "fine"   grid
     INTEGER, POINTER :: JJ(:)        ! Latitude  indices,  "fine"   grid
     INTEGER, POINTER :: olson(:)     ! Olson land type,    "fine"   grid
     INTEGER, POINTER :: ordOlson(:)  ! Ordering of Olson land types
     REAL*4,  POINTER :: area(:)      ! Surface areas,      "fine"   grid
     REAL*4           :: sumarea      ! Total surface area, "coarse" grid
  END TYPE MapWeight
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: Init_Mapping
  PUBLIC  :: Get_Map_Wt
  PUBLIC  :: Cleanup_Mapping
```

REMARKS:

```
   The mapping weights and areal mapping are initialized when the Olson
   land map is read from disk (in olson_landmap_mod.F90).  They are used
   again when the MODIS leaf area index data is prepared for input into
   GEOS-Chem's (legacy) dry deposition module.

   Also, we do not define the mapping weight object within this module.
   This allows you to create more than one mapping weight object for
   different native grids (e.g. 0.5 x 0.5 and 0.25 x 0.25, etc.)
```

REVISION HISTORY:

```
03 Apr 2012 - R. Yantosca - Initial version
05 Apr 2012 - R. Yantosca - Comment out mapwt field of MapWeight type,
                            leave this for future expansion
17 Apr 2012 - R. Yantosca - Rename pointer object "map" to "mapping,
                            to remove confusion w/ F90 intrinsic
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

6.4.1 init_mapping

Subroutine INIT_MAPPING allocates and initializes a derived-type object containing grid mapping information.

INTERFACE:

```
SUBROUTINE Init_Mapping( am_I_Root, Input_Opt, I_FINE,  J_FINE,  &
                         I_COARSE,  J_COARSE,  mapping, RC      )
```

USES:

```
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN) :: am_I_Root ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN) :: Input_Opt ! Input Options object
INTEGER,        INTENT(IN) :: I_FINE    ! # of lons on the "fine" grid
INTEGER,        INTENT(IN) :: J_FINE    ! # of lats on the,"fine" grid
INTEGER,        INTENT(IN) :: I_COARSE  ! # of lons on the "coarse" grid
INTEGER,        INTENT(IN) :: J_COARSE  ! # of lats on the "coarse" grid
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MapWeight), POINTER, INTENT(INOUT) :: mapping(:,:) !"fine" -> "coarse"
```

OUTPUT PARAMETERS:

```
  INTEGER,       INTENT(OUT) :: RC      ! Success or failure?
```

REVISION HISTORY:

```
03 Apr 2012 - R. Yantosca - Initial version
10 Apr 2012 - R. Yantosca - Now add a different # to FINE_PER_COARSE
                            depending on which Olson map we are using
17 Apr 2012 - R. Yantosca - Rename to "map" to "mapping" to avoid confusion
                            with a F90 intrinsic function
17 Apr 2012 - R. Yantosca - Add error check for mapping object
18 Apr 2012 - R. Yantosca - Improve error check for sub-fields of mapping
                            object so as not to interfere w/ parallel loop
23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
```

6.4.2 get_map_wt

Subroutine GET_MAP_Wt returns the "mapping weight", that is, the fraction that each "fine" grid box fits into each "coarse" grid box.

INTERFACE:

```
SUBROUTINE Get_Map_Wt( xedge_w, xedge_e, xedgeC_w, xedgeC_e,   &
                       yedge_s, yedge_n, yedgeC_s, yedgeC_n,   &
                       mapWt                                  )
```

INPUT PARAMETERS:

```
REAL*4, INTENT(IN)  :: xedge_w,  xedge_e    ! Lon edges, fine grid
REAL*4, INTENT(IN)  :: xedgeC_w, xedgeC_e   ! Lon edges, coarse grid
REAL*4, INTENT(IN)  :: yedge_s,  yedge_n    ! Lat edges, fine grid
REAL*4, INTENT(IN)  :: yedgeC_s, yedgeC_n   ! Lat edges, coarse grid
REAL*4, INTENT(OUT) :: mapWt                ! Mapping weight
```

REMARKS:

```
Follows the algorithm from GAMAP routine ctm_getweight.pro
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
21 Mar 2012 - R. Yantosca - Typo: set xOverLap to zero if it is out of the
                            range of 0-1.  (We had set yOverLap=0 before)
21 Mar 2012 - R. Yantosca - Now use REAL*4 for computations to avoid
                            roundoff errors at hi-res grids
03 Apr 2012 - R. Yantosca - Moved from "olson_landmap_mod.F90" to here;
                            renamed "Get_Mapping"
```

6.4.3 cleanup_mapping

Subroutine CLEANUP_MAPPING deallocates memory from a derived-type object containing mapping information.

INTERFACE:

```
SUBROUTINE Cleanup_Mapping( mapping )
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MapWeight), POINTER, INTENT(INOUT) :: mapping(:,:)
```

REVISION HISTORY:

```
03 Mar 2012 - R. Yantosca - Initial version
17 Apr 2012 - R. Yantosca - Rename to "map" to "mapping to avoid name
                            confusion with a F90 intrinsic function
```

6.5 Fortran: Module Interface get_ndep_mod.F

Module GET_NDEP_MOD contains routines for computing the accumulated nitrogen dry and wet deposition between emission time steps. These variables are needed for soil NOx emission calculations.

This module is basically a simple wrapper module to save out the nitrogen dry and wet deposition rates and pass them to HEMCO for soil NOx emission calculation (via hcoi_gc_main_mod.F90).

IMPORTANT: Routine RESET_DEP_N resets the deposition arrays to zero. It is called in hcoi_gc_main_mod.F90 after the emission calculations.

INTERFACE:

```
MODULE GET_NDEP_MOD
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC DATA MEMBERS:

```
! Soil NOx deposited N arrays
REAL(fp), PUBLIC, POINTER   :: DRY_TOTN (:,:) => NULL() ! Drydep'd N
REAL(fp), PUBLIC, POINTER   :: WET_TOTN (:,:) => NULL() ! Wetdep'd N
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: SOIL_DRYDEP
PUBLIC  :: SOIL_WETDEP
PUBLIC  :: RESET_DEP_N
PUBLIC  :: Init_Get_Ndep
PUBLIC  :: Cleanup_Get_Ndep
```

REVISION HISTORY:

```
23 Oct 2012 - M. Payer    - Added ProTeX headers
25 Jul 2014 - R. Yantosca - Moved module variables DEP_RESERVOIR, DRY_TOTN,
                            and WET_TOTN here from Headers/commsoil_mod.F90
25 Jul 2014 - R. Yantosca - Add routine INIT_GET_NDEP
25 Jul 2014 - R. Yantosca - Add routine CLEANUP_GET_NDEP
09 Oct 2014 - C. Keller   - Removed obsolete routines DEP_RESERVOIR,
                            GET_DEP_N, SOURCE_DRYN, and SOURCE_WETN. These
                            are now handled in hcox_soilnox_mod.F90.
13 Nov 2014 - M. Yannetti - Added PRECISION_MOD
16 Jun 2016 - C. Miller   - Now define species ID flags with Ind_
17 Jun 2016 - R. Yantosca - Add species ID flags as module variables
```

6.5.1 soil_drydep

Subroutine SOIL_DRYDEP holds dry deposited species [molec/cm2/s]. This is called from dry_dep_mod.F.

INTERFACE:

```
SUBROUTINE SOIL_DRYDEP( I, J, L, NN, TDRYFX )
```

USES:

```
USE State_Chm_Mod,      only : Ind_
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)   :: I          ! I
INTEGER, INTENT(IN)   :: J          ! J
INTEGER, INTENT(IN)   :: L          ! Level
INTEGER, INTENT(IN)   :: NN         ! Dry Dep Tracer #
REAL(fp), INTENT(IN)  :: TDRYFX     ! Dry dep flux [molec/cm2/s]
```

REVISION HISTORY:

```
23 Oct 2012 - M. Payer    - Added ProTeX headers
14 Mar 2013 - M. Payer    - Replace NOx with NO2 as part of removal of
                            NOx-Ox partitioning
16 Jun 2016 - C. Miller   - Now use
```

6.5.2 soil_wetdep

Subroutine SOIL_WETDEP holds wet deposited species [molec/cm2/s]. This is called from wetscav_mod.F.

INTERFACE:

```
SUBROUTINE SOIL_WETDEP( I, J, L, NN, TWETFX )
```

USES:

```
USE State_Chm_Mod,      Only : Ind_
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: I          ! I
INTEGER,  INTENT(IN) :: J          ! J
INTEGER,  INTENT(IN) :: L          ! Level
INTEGER,  INTENT(IN) :: NN         ! Wet Dep Tracer #
REAL(fp), INTENT(IN) :: TWETFX     ! Wet dep flux [kg/s]
```

REVISION HISTORY:

```
23 Oct 2012 - M. Payer    - Added ProTeX headers
```

6.5.3 reset_dep_N

Subroutine RESET_DEP_N resets the dry and wet deposition arrays and variables so that they can be refilled.

INTERFACE:

```
SUBROUTINE RESET_DEP_N()
```

REVISION HISTORY:

```
03 Apr 2014 - C. Keller   - Initial version
```

6.5.4 Init_Get_Ndep

Routine INIT_GET_NDEP allocates all module arrays.

INTERFACE:

```
SUBROUTINE Init_Get_Ndep( am_I_Root, RC )
```

USES:

```
USE CMN_SIZE_Mod
USE ErrCode_Mod
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Success or failure
```

REMARKS:

```
We now allocate the DEP_RESERVOIR, DRY_TOTN, and WET_TOTN arrays within
get_ndep_mod.F.  These were formerly contained in Headers/commsoil_mod.F90,
which was rendered mostly obsolete by HEMCO.
```

REVISION HISTORY:

```
25 Jul 2014 - R. Yantosca - Initial version
09 Oct 2014 - C. Keller   - Removed obsolete variable DEP_RESERVOIR
```

6.5.5 cleanup_commsoil

Subroutine CLEANUP_COMMSOIL deallocates all module arrays.

INTERFACE:

```
SUBROUTINE Cleanup_Get_NDep( am_I_Root, RC )
```

USES:

```
USE ErrCode_Mod
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT) :: RC          ! Return code
```

REVISION HISTORY:

```
25 Jul 2014 - R. Yantosca - Initial version
09 Oct 2014 - C. Keller   - Removed obsolete variable DEP_RESERVOIR
```

7 Emisions and chemistry modules

These modules contain routines to (1) call HEMCO to compute emissions rates and (2) feed them into the FlexChem/KPP chemstry solver.

7.1 Fortran: Module Interface emissions_mod.F90

Module emissions_mod.F90 is a wrapper module to interface GEOS-Chem and HEMCO. It basically just calls the GEOS-Chem - HEMCO interface routines. For some specialty sims, a few additional steps are required that are also executed here.

INTERFACE:

```
MODULE EMISSIONS_MOD
```

USES:

```
IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: EMISSIONS_INIT
PUBLIC :: EMISSIONS_RUN
PUBLIC :: EMISSIONS_FINAL
```

REVISION HISTORY:

```
27 Aug 2014 - C. Keller   - Initial version.
20 Jun 2016 - R. Yantosca - Declare species ID flags as module variables
```

7.1.1 emissions_init

Subroutine EMISSIONS_INIT calls the HEMCO - GEOS-Chem interface initialization routines.

INTERFACE:

```
SUBROUTINE EMISSIONS_INIT( am_I_Root, Input_Opt, State_Met, State_Chm, &
                           RC,        HcoConfig )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCOI_GC_MAIN_MOD,   ONLY : HCOI_GC_INIT
USE HCO_TYPES_MOD,      ONLY : ConfigObj
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )          :: am_I_Root  ! root CPU?
TYPE(MetState),   INTENT(IN   )          :: State_Met  ! Met state
TYPE(ChmState),   INTENT(IN   )          :: State_Chm  ! Chemistry state
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput),   INTENT(INOUT)          :: Input_Opt  ! Input opts
TYPE(ConfigObj),  POINTER,      OPTIONAL :: HcoConfig  ! HEMCO config object
INTEGER,          INTENT(INOUT)          :: RC         ! Failure or success
```

REVISION HISTORY:

```
27 Aug 2014 - C. Keller   - Initial version
16 Jun 2016 - J. Sheng    - Added tracer index retriever
20 Jun 2016 - R. Yantosca - Now define species IDs only in the INIT phase
```

7.1.2 emissions_run

Subroutine EMISSIONS_RUN calls the HEMCO - GEOS-Chem interface run routines.

INTERFACE:

```
SUBROUTINE EMISSIONS_RUN( am_I_Root, Input_Opt, State_Met, &
                          State_Chm, EmisTime,  Phase,     RC )
```

USES:

```
    USE BROMOCARB_MOD,      ONLY : SET_BRO
    USE BROMOCARB_MOD,      ONLY : SET_CH3BR
    USE CARBON_MOD,         ONLY : EMISSCARBON
    USE CO2_MOD,            ONLY : EMISSCO2
    USE ErrCode_Mod
    USE ERROR_MOD,          ONLY : GC_Error
    USE GLOBAL_CH4_MOD,     ONLY : EMISSCH4
    USE HCOI_GC_MAIN_MOD,   ONLY : HCOI_GC_RUN
    USE Input_Opt_Mod,      ONLY : OptInput
    USE State_Met_Mod,      ONLY : MetState
    USE State_Chm_Mod,      ONLY : ChmState
#if defined ( TOMAS )
    USE CARBON_MOD,         ONLY : EMISSCARBONTOMAS !jkodros
    USE SULFATE_MOD,        ONLY : EMISSSULFATETOMAS !jkodros
#endif

    ! Use old mercury code for now (ckeller, 09/23/2014)
    USE MERCURY_MOD,        ONLY : EMISSMERCURY

    ! For UCX, use Seb's routines for now
#if defined( UCX )
    USE UCX_MOD,            ONLY : EMISS_BASIC
#endif
```

INPUT PARAMETERS:

```
    LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
    LOGICAL,          INTENT(IN   )  :: EmisTime   ! Emissions in this time step
    INTEGER,          INTENT(IN   )  :: Phase      ! Run phase
```

INPUT/OUTPUT PARAMETERS:

```
    TYPE(MetState),   INTENT(INOUT)  :: State_Met  ! Met state
    TYPE(ChmState),   INTENT(INOUT)  :: State_Chm  ! Chemistry state
    TYPE(OptInput),   INTENT(INOUT)  :: Input_Opt  ! Input opts
    INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
```

REVISION HISTORY:

```
   27 Aug 2014 - C. Keller    - Initial version
   13 Nov 2014 - C. Keller    - Added EMISSCARBON (for SESQ and POA)
   21 Nov 2014 - C. Keller    - Added EMISSVOC to prevent VOC build-up
                                above tropopause
   22 Sep 2016 - R. Yantosca  - Don't call EMISSCARBON unless we are doing
                                a fullchem or aerosol simulation
```

7.1.3 emissions_final

Subroutine EMISSIONS_FINAL calls the HEMCO - GEOS-Chem interface finalization routines.

INTERFACE:

```
SUBROUTINE EMISSIONS_FINAL( am_I_Root, ERROR )
```

USES:

```
USE HCOI_GC_MAIN_MOD, ONLY : HCOI_GC_FINAL
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
LOGICAL,          INTENT(IN   )  :: ERROR      ! Cleanup after crash?
```

REVISION HISTORY:

```
27 Aug 2014 - C. Keller    - Initial version
```

7.2 Fortran: Module Interface chemgrid_mod.F

Module CHEMGRID_MOD contains routines and variables for reading and returning vertical layer limits.

INTERFACE:

```
MODULE CHEMGRID_MOD
```

USES:

```
USE CMN_SIZE_MOD, ONLY : LLSTRAT

USE PRECISION_MOD   ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CLEANUP_CHEMGRID
PUBLIC  :: CHECK_VAR_TROP
PUBLIC  :: DIAG_TROPOPAUSE
PUBLIC  :: GET_MIN_CHEMGRID_LEVEL
PUBLIC  :: GET_MAX_CHEMGRID_LEVEL
PUBLIC  :: GET_MIN_TPAUSE_LEVEL
PUBLIC  :: GET_MAX_TPAUSE_LEVEL
PUBLIC  :: GET_TPAUSE_LEVEL
PUBLIC  :: GET_CHEMGRID_LEVEL
PUBLIC  :: INIT_CHEMGRID
PUBLIC  :: ITS_IN_THE_TROP
PUBLIC  :: ITS_IN_THE_STRAT
PUBLIC  :: ITS_IN_THE_MESO
```

```
PUBLIC  :: ITS_IN_THE_STRATMESO
PUBLIC  :: ITS_IN_THE_CHEMGRID
PUBLIC  :: ITS_IN_THE_NOCHEMGRID
PUBLIC  :: READ_TROPOPAUSE
```

PUBLIC DATA MEMBERS:

```
! Scalars
INTEGER, PUBLIC :: LMIN   ! Minimum level where chemistry happens
INTEGER, PUBLIC :: LMAX   ! Maximum levle where chemistry happens
```

REVISION HISTORY:

```
22 Aug 2005 - R. Yantosca - Initial version
(1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(2 ) Simplify counting of tropospheric boxes (bmy, 11/1/05)
(3 ) Added case of variable tropopause.
     The definition of the tropopause boxes is different in the two cases.
     They are part of the troposphere in the case of a variable
     troposphere. LMAX, LMIN are the min and max extent of the troposphere
     in that case.  (bdf, phs, 1/19/07)
(4 ) Bug fix: set NCS=NCSURBAN for safety's sake (bmy, 4/25/07)
(5 ) Updated comments (bmy, 9/18/07)
(6 ) Bug fix: make ITS_IN_THE_STRAT more robust. (phs, 11/14/08)
09 Sep 2010 - R. Yantosca   - Added ProTeX headers
24 Mar 2013 - S. D. Eastham - Adapted from tropopause_mod.F. Can now
                              identify atmospheric layers, chemistry grids
                              and aerosol grids independently of one another
20 Feb 2014 - M. Sulprizio  - Removed "define.h", this is now obsolete
21 Feb 2014 - M. Sulprizio  - Now make INIT_CHEMGRID a public function
06 Nov 2014 - M. Yannetti   - Added PRECISION_MOD
```

7.2.1 check_var_trop

Subroutine CHECK_VAR_TROP checks that the entire variable troposphere is included in the 1..LLTROP range, and set the LMIN and LMAX to current min and max tropopause.

INTERFACE:

```
SUBROUTINE CHECK_VAR_TROP( State_Met )
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
24 Aug 2006 - P. Le Sager - Initial version
(1 ) LLTROP is set at the first level entirely above 20 km (phs, 9/29/06)
(2 ) Fix LPAUSE for CH4 chemistry (phs, 1/19/07)
09 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Feb 2014 - M. Sulprizio- Now pass State_Met object via the arg list
```

7.2.2 read_tropopause

Subroutine READ_TROPOPAUSE reads in the annual mean tropopause.

INTERFACE:

```
SUBROUTINE READ_TROPOPAUSE( am_I_Root, Input_Opt, RC )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_NAME_EXT, GET_RES_EXT
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE m_netcdf_io_open
USE m_netcdf_io_read
USE m_netcdf_io_readattr
USE m_netcdf_io_close
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root  ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC         ! Success or failure?
```

REMARKS:

```
#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (05 Mar 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
13 Dec 1999 - Q. Li, R. Yantosca - Initial version
(1 ) Call READ_BPCH2 to read in the annual mean tropopause data
      which is stored in binary punch file format. (bmy, 12/13/99)
```

```
(2 ) Now also read integer flags for ND27 diagnostic -- these determine
     how to sum fluxes from boxes adjacent to the annual mean tropoause.
     (qli, bmy, 1/7/00)
(3 ) Cosmetic changes (bmy, 3/17/00)
(4 ) Reference F90 module "bpch2_mod" which contains routine "read_bpch2"
     for reading data from binary punch files (bmy, 6/28/00)
(5 ) Call TRANSFER_2D from "transfer_mod.f" to cast data from REAL*4 to
     INTEGER and also to resize to (IIPAR,JJPAR).  ARRAY needs to be of
     size (IIPAR,JJPAR).  Also updated comments and made cosmetic changes.
     Removed obsolete variables.(bmy, 9/26/01)
(6 ) Removed obsolete code from 9/01 (bmy, 10/26/01)
(7 ) Now read annual mean tropopause files from the ann_mean_trop_200202/
     subdirectory of DATA_DIR (bmy, 1/24/02)
(8 ) Eliminated obsolete code from 1/02 (bmy, 2/27/02)
(9 ) Now write file name to stdout (bmy, 4/3/02)
(10) Now reference GEOS_CHEM_STOP from "error_mod.f", which frees all
     allocated memory before stopping the run. (bmy, 10/15/02)
(11) Now call READ_BPCH2 with QUIET=.TRUE. to suppress printing of extra
     info to stdout.  Also updated FORMAT strings. (bmy, 3/14/03)
(12) Now references DATA_DIR from "directory_mod.f" (bmy, 7/20/04)
(13) Now bundled into "tropopause_mod.f' (bmy, 2/10/05)
(14) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(15) Simplify counting of # of tropospheric boxes (bmy, 11/1/05)
09 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Feb 2014 - M. Sulprizio- Remove call to INIT_TROPOPAUSE, this is now
                            done in the init stage
20 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
05 Mar 2015 - R. Yantosca - Add Input_Opt%RES_DIR to data path
06 Mar 2015 - R. Yantosca - Now read ann mean trop from netCDF
```

7.2.3 get_max_tpause_level

Function GET_MAX_TPAUSE_LEVEL returns GEOS-Chem level at the highest extent of the annual mean tropopause.

INTERFACE:

```
FUNCTION GET_MAX_TPAUSE_LEVEL() RESULT( L_MAX )
```

RETURN VALUE:

```
INTEGER :: L_MAX    ! Maximum tropopause level
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca - Initial version
09 Sep 2010 - R. Yantosca - Added ProTeX headers
```

7.2.4 get_min_tpause_level

Function GET_MIN_TPAUSE_LEVEL returns GEOS-Chem level at the lowest extent of the annual mean tropopause.

INTERFACE:

```
FUNCTION GET_MIN_TPAUSE_LEVEL() RESULT( L_MIN )
```

RETURN VALUE:

```
INTEGER :: L_MIN   ! Minimum tropopause level
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca - Initial version
09 Sep 2010 - R. Yantosca - Added ProTeX headers
```

7.2.5 get_min_chemgrid_level

Function GET_MIN_CHEMGRID_LEVEL returns GEOS-Chem level at the lowest extent of the chemistry grid

INTERFACE:

```
FUNCTION GET_MIN_CHEMGRID_LEVEL() RESULT( L_MIN )
```

USES:

RETURN VALUE:

```
INTEGER :: L_MIN   ! Minimum chemistry grid level
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca   - Initial version
09 Sep 2010 - R. Yantosca   - Added ProTeX headers
25 Mar 2013 - S. D. Eastham - Adapted from GET\_MIN\_TPAUSE\_LEVEL
```

7.2.6 get_max_chemgrid_level

Function GET_MAX_CHEMGRID_LEVEL returns GEOS-Chem level at the highest extent of the chemistry grid.

INTERFACE:

```
FUNCTION GET_MAX_CHEMGRID_LEVEL() RESULT( L_MAX )
```

USES:

RETURN VALUE:

```
INTEGER :: L_MAX    ! Maximum chemistry grid level
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca   - Initial version
09 Sep 2010 - R. Yantosca   - Added ProTeX headers
28 Aug 2013 - S. D. Eastham - Adapted from GET\_MAX\_TPAUSE\_LEVEL
```

7.2.7 get_chemgrid_level

Function GET_CHEMGRID_LEVEL returns the chemistry grid limit L_CHEM at surface location (I,J). Therefore, grid box (I,J,L_CHEM) is partially within the chemistry grid and partially outside of it. The grid box below this, (I,J,L_CHEM-1), is the last fully legitimate chemistry grid box in the column.

INTERFACE:

```
FUNCTION GET_CHEMGRID_LEVEL( I, J, State_Met ) RESULT( L_CHEM )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! Longitude index
INTEGER,        INTENT(IN) :: J           ! Latitude index
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
INTEGER             :: L_CHEM ! Chemgrid limit at (I,J)
```

REVISION HISTORY:

```
25 Mar 2013 - S. D. Eastham - Initial version
21 Feb 2014 - M. Sulprizio  - Now pass State_Met object via the arg list
```

7.2.8 get_tpause_level

Function GET_TPAUSE_LEVEL returns the tropopause level L_TP at surface location (I,J). Therefore, grid box (I,J,L_TP) is partially in the troposphere and partially in the stratosphere. The grid box below this, (I,J,L_TP-1), is the last totally tropospheric box in the column.

INTERFACE:

```
FUNCTION GET_TPAUSE_LEVEL( I, J, State_Met ) RESULT( L_TP )
```

USES:

```
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE State_Met_Mod,      ONLY : MetState

USE CMN_SIZE_MOD             ! Size parameters
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! Longitude index
INTEGER,        INTENT(IN) :: J           ! Latitude index
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
INTEGER                    :: L_TP   ! Tropopause level at (I,J)
```

REVISION HISTORY:

```
22 Aug 2005 - R. Yantosca - Initial version
09 Sep 2010 - R. Yantosca - Added ProTeX headers
10 Sep 2010 - R. Yantosca - Update comments, remove obsolete documentation
21 Feb 2014 - M. Sulprizio- Now pass State_Met object via the arg list
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
                            Remove dependency on pressure_mod.
```

7.2.9 its_in_the_trop

Function ITS_IN_THE_TROP returns TRUE if grid box (I,J,L) lies within the troposphere, or FALSE otherwise.

INTERFACE:

```
FUNCTION ITS_IN_THE_TROP( I, J, L, State_Met ) RESULT ( IS_TROP )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! Longitude index
INTEGER,        INTENT(IN) :: J           ! Latitude index
INTEGER,        INTENT(IN) :: L           ! Level index
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
LOGICAL                    :: IS_TROP   ! =T if we are in the troposphere
```

REMARKS:

REVISION HISTORY:

```
10 Feb 2005 - P. Le Sager - Initial version
(1 ) Modified for variable tropopause (phs, 9/14/06)
09 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Feb 2014 - M. Sulprizio- Now pass State_Met object via the arg list
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
                            Remove dependency on pressure_mod.
```

7.2.10 its_in_the_stratmeso

Function ITS_IN_THE_STRATMESO returns TRUE if grid box (I,J,L) lies without the troposphere, or FALSE otherwise.

INTERFACE:

```
      FUNCTION ITS_IN_THE_STRATMESO( I, J, L, State_Met )
     &                               RESULT( IS_SMESO )
```

USES:

```
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I           ! Longitude index
      INTEGER,        INTENT(IN) :: J           ! Latitude index
      INTEGER,        INTENT(IN) :: L           ! Level index
      TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
      LOGICAL                    :: IS_SMESO    ! =F if we are in the trop
```

REVISION HISTORY:

```
10 Feb 2005 - P. Le Sager - Initial version
(1 ) Modified for variable tropopause (phs, 9/14/06)
(2 ) Now return the opposite value of ITS_IN_THE_TROP.  This should help
      to avoid numerical issues. (phs, 11/14/08)
09 Sep 2010 - R. Yantosca   - Added ProTeX headers
25 Mar 2013 - S. D. Eastham - Adapted from ITS_IN_THE_STRAT
21 Feb 2014 - M. Sulprizio  - Now pass State_Met object via the arg list
```

7.2.11 its_in_the_strat

Function ITS_IN_THE_STRAT returns TRUE if grid box (I,J,L) lies within the stratosphere, or FALSE otherwise.

INTERFACE:

```
FUNCTION ITS_IN_THE_STRAT( I, J, L, State_Met ) RESULT( IS_STRAT )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! Longitude index
INTEGER,        INTENT(IN) :: J           ! Latitude index
INTEGER,        INTENT(IN) :: L           ! Level index
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
LOGICAL                    :: IS_STRAT  ! =T if we are in the stratosphere
```

REVISION HISTORY:

```
10 Feb 2005 - P. Le Sager - Initial version
(1 ) Modified for variable tropopause (phs, 9/14/06)
(2 ) Now return the opposite value of ITS_IN_THE_TROP.  This should help
      to avoid numerical issues. (phs, 11/14/08)
09 Sep 2010 - R. Yantosca - Added ProTeX headers
24 Mar 2013 - S. D. Eastham - Now distinguish between strat and mesosphere
21 Feb 2014 - M. Sulprizio  - Now pass State_Met object via the arg list
```

7.2.12 its_in_the_meso

Function ITS_IN_THE_MESO returns TRUE if grid box (I,J,L) lies within the mesosphere, or FALSE otherwise.

INTERFACE:

```
FUNCTION ITS_IN_THE_MESO( I, J, L ) RESULT( IS_MESO )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I          ! Longitude index
INTEGER, INTENT(IN) :: J          ! Latitude index
INTEGER, INTENT(IN) :: L          ! Level index
```

RETURN VALUE:

```
LOGICAL             :: IS_MESO    ! =T if we are in the mesosphere
```

REVISION HISTORY:

```
10 Feb 2005 - P. Le Sager - Initial version
(1 ) Modified for variable tropopause (phs, 9/14/06)
(2 ) Now return the opposite value of ITS_IN_THE_TROP.  This should help
      to avoid numerical issues. (phs, 11/14/08)
09 Sep 2010 - R. Yantosca   - Added ProTeX headers
24 Mar 2013 - S. D. Eastham - Now distinguish between strat and mesosphere
```

7.2.13 its_in_the_chemgrid

Function ITS_IN_THE_CHEMGRID returns TRUE if grid box (I,J,L) lies within the chemistry grid, or FALSE otherwise.

INTERFACE:

```
 FUNCTION ITS_IN_THE_CHEMGRID( I, J, L, State_Met )
&                              RESULT( IS_CHEM )
```

USES:

```
 USE State_Met_Mod,      ONLY : MetState
 USE CMN_SIZE_MOD,       Only : LLCHEM
```

INPUT PARAMETERS:

```
 INTEGER,        INTENT(IN) :: I           ! Longitude index
 INTEGER,        INTENT(IN) :: J           ! Latitude index
 INTEGER,        INTENT(IN) :: L           ! Level index
 TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
 LOGICAL                    :: IS_CHEM     ! =T if we are in the chem grid
```

REVISION HISTORY:

```
24 Mar 2013 - S. D. Eastham - Initial version
21 Feb 2014 - M. Sulprizio  - Now pass State_Met object via the arg list
```

7.2.14 its_in_the_nochemgrid

Function ITS_IN_THE_NOCHEMGRID returns TRUE if grid box (I,J,L) lies outside the chemistry grid, or FALSE otherwise.

INTERFACE:

```
 FUNCTION ITS_IN_THE_NOCHEMGRID( I, J, L, State_Met )
&                              RESULT( IS_NOCHEM )
```

USES:

```
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I           ! Longitude index
      INTEGER,        INTENT(IN) :: J           ! Latitude index
      INTEGER,        INTENT(IN) :: L           ! Level index
      TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
      LOGICAL                    :: IS_NOCHEM    ! =F if we are in the chem grid
```

REVISION HISTORY:

```
   24 Mar 2013 - S. D. Eastham - Initial version
   21 Feb 2014 - M. Sulprizio  - Now pass State_Met object via the arg list
```

7.2.15 diag_tropopause

Subroutine DIAG_TROPOPAUSE archives the ND55 tropopause diagnostic.

INTERFACE:

```
      SUBROUTINE DIAG_TROPOPAUSE( am_I_Root, Input_Opt, State_Met, RC )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE CMN_DIAG_MOD             ! Diagnostic switches
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD55
#endif
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
#if defined( NC_DIAG )
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE Error_Mod,          ONLY : Error_Stop
      USE HCO_Diagn_Mod,      ONLY : Diagn_Update
      USE HCO_Error_Mod
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root    ! Is this the root CPU?
      TYPE(MetState), INTENT(IN)    :: State_Met    ! Meteorology State object
      TYPE(OptInput), INTENT(IN)    :: Input_Opt    ! Input options object
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(INOUT) :: RC           ! Success or failure
```

REMARKS:

For GEOS-4, GEOS-5, 'MERRA', we use the tropopause pressure from the met field archive to determine if we are in the tropopause or not. Therefore, the 3rd slot of AD55 should be archived with the tropopause pressure from the met fields.

.

For other met fields, we have to estimate the tropopause pressure from the tropopause level. Archive the pressure at the midpoint of the level in which the tropopause occurs. NOTE: this may result in lower minimum tropopause pressure than reality.

REVISION HISTORY:

30 Nov 1999 - H. Liu, R. Yantosca - Initial version
(1) Make sure the DO-loops go in the order L-J-I, wherever possible.
(2) Now archive ND55 diagnostic here rather than in DIAG1.F. Also, use an allocatable array (AD55) to archive tropopause heights.
(3) HTPAUSE is now a local variable, since it is only used here.
(4) Make LTPAUSE a local variable, since LPAUSE is used to store the annual mean tropopause. (bmy, 4/17/00)
(5) Replace PW(I,J) with P(I,J). Also updated comments. (bmy, 10/3/01)
(6) Removed obsolete code from 9/01 and 10/01 (bmy, 10/24/01)
(7) Added polar tropopause for GEOS-3 in #if defined(GEOS_3) block (bmy, 5/20/02)
(8) Replaced all instances of IM with IIPAR and JM with JJPAR, in order to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(9) Now use GET_PCENTER from "pressure_mod.f" to compute the pressure at the midpoint of box (I,J,L). Also deleted obsolete, commented-out code. (dsa, bdf, bmy, 8/21/02)
(10) Now reference BXHEIGHT and T from "dao_mod.f". Also reference routine ERROR_STOP from "error_mod.f" (bmy, 10/15/02)
(11) Now uses routine GET_YMID from "grid_mod.f" to compute grid box latitude. (bmy, 2/3/03)
(12) Add proper polar tropopause level for GEOS-4 (bmy, 6/18/03)
(13) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(14) Get tropopause level from TROPOPAUSE_MOD.F routines (phs, 10/17/06)
10 Sep 2010 - R. Yantosca - Added ProTeX headers
10 Sep 2010 - R. Yantosca - For GEOS-4, GEOS-5, MERRA met fields, take the the tropopause pressure directly from the met fields rather than computing it here.
10 Sep 2010 - R. Yantosca - Remove reference to LPAUSE, it's obsolete
10 Sep 2010 - R. Yantosca - Reorganize #if blocks for clarity
10 Sep 2010 - R. Yantosca - Renamed to DIAG_TROPOPAUSE and bundled into tropopause_mod.f
21 Feb 2014 - M. Sulprizio- Now pass State_Met object via the arg list

```
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE and GET_PCENTER with
                            State_Met%PEDGE and State_Met%PMID.
                            Remove dependency on pressure_mod.
21 Jan 2016 - E. Lundgren - Update diagnostic for netcdf output using HEMCO

29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

7.2.16 init_chemgrid

Subroutine INIT_CHEMGRID allocates and zeroes module arrays.

INTERFACE:

```
SUBROUTINE INIT_CHEMGRID( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca - Initial version
09 Sep 2010 - R. Yantosca - Added ProTeX headers
29 Mar 2013 - R. Yantosca - Now made public so we can shadow LVARTROP
```

7.2.17 cleanup_chemgrid

Subroutine CLEANUP_CHEMGRID deallocates module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_CHEMGRID
```

REVISION HISTORY:

```
10 Feb 2005 - R. Yantosca - Initial version
09 Sep 2010 - R. Yantosca - Added ProTeX headers
```

7.3 Fortran: Module Interface chemistry_mod.F

Module CHEMISTRY_MOD is used to call the proper chemistry subroutine for the various GEOS-Chem simulations.

INTERFACE:

```
MODULE CHEMISTRY_MOD
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)
USE GEOS_TIMERS_MOD  ! For GEOS-Chem timers (optional)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: INIT_CHEMISTRY
PUBLIC  :: DO_CHEMISTRY
PUBLIC  :: RECOMPUTE_OD
PRIVATE :: CHEM_PASSIVE_TRACER
```

REVISION HISTORY:

```
(1 ) Bug fix in DO_CHEMISTRY (bnd, bmy, 4/14/03)
(2 ) Now references DEBUG_MSG from "error_mod.f" (bmy, 8/7/03)
(3 ) Now references "tagged_ox_mod.f"(bmy, 8/18/03)
(4 ) Now references "Kr85_mod.f" (jsw, bmy, 8/20/03)
(5 ) Bug fix: Now also call OPTDEPTH for GEOS-4 (bmy, 1/27/04)
(6 ) Now references "carbon_mod.f" and "dust_mod.f" (rjp, tdf, bmy, 4/5/04)
(7 ) Now references "seasalt_mod.f" (rjp, bec, bmy, 4/20/04)
(8 ) Now references "logical_mod.f", "tracer_mod.f", "diag20_mod.f", and
      "diag65_mod.f", and "aerosol_mod." (bmy, 7/20/04)
(9 ) Now references "mercury_mod.f" (bmy, 12/7/04)
(10) Updated for SO4s, NITs chemistry (bec, bmy, 4/13/05)
(11) Now call CHEM_HCN_CH3CN from "hcn_ch3cn_mod.f".  Also remove all
      references to the obsolete CO-OH param simulation. (xyp, bmy, 6/24/05)
(12) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(13) Now call MAKE_RH from "main.f" (bmy, 3/16/06)
(14) Updated for SOA from isoprene (dkh, bmy, 6/1/06)
(15) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(16) For now, replace use RPMARES instead of ISORROPIA. (bmy, 4/2/08)
(17) Added KPP chemistry driver subroutine (phs,ks,dhk, 09/15/09)
(18) Added public member function recompute_OD (skim, 02/03/11)
17 Dec 2009 - R. Yantosca - Added ProTeX headers
28 Jan 2010 - C. Carouge, R. Yantosca - Modified for ISORROPIA II
08 Aug 2012 - R. Yantosca - Now align IF statements better
10 Aug 2012 - R. Yantosca - Cosmetic changes
25 Mar 2013 - M. Payer    - Now pass State_Chm to several routines
```

```
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
19 May 2014 - C. Keller   - Added INIT_CHEMISTRY
15 Dec 2014 - M. Yannetti - KPP code is commented out unless compiling KPP
08 Jan 2015 - M. Sulprizio- Now restrict KPP to REAL*8 to allow for KPP code
                            to compile properly
13 Aug 2015 - E. Lundgren - Tracer units are now kg/kg and converted to
                            kg within DO_CHEMISTRY
03 Nov 2016 - C. Keller   - Added wrapper routine for passive tracers.
```

7.3.1 do_chemistry

Subroutine DO_CHEMISTRY is the driver routine which calls the appropriate chemistry subroutine for the various GEOS-Chem simulations.

INTERFACE:

```
      SUBROUTINE DO_CHEMISTRY( am_I_Root, Input_Opt,
     &                         State_Chm, State_Met, RC )
```

USES:

```
      USE AEROSOL_MOD,        ONLY : AEROSOL_CONC
      USE AEROSOL_MOD,        ONLY : RDAER
      USE AEROSOL_MOD,        ONLY : SOILDUST
      USE C2H6_MOD,           ONLY : CHEMC2H6
      USE CARBON_MOD,         ONLY : CHEMCARBON
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DUST_MOD,           ONLY : CHEMDUST
      USE DUST_MOD,           ONLY : RDUST_ONLINE
      USE ErrCode_Mod
      USE ERROR_MOD
      USE FlexChem_Mod,       ONLY : Do_FlexChem
      USE GLOBAL_CH4_MOD,     ONLY : CHEMCH4
      USE Input_Opt_Mod,      ONLY : OptInput
      USE ISOROPIAII_MOD,     ONLY : DO_ISOROPIAII
      USE MERCURY_MOD,        ONLY : CHEMMERCURY
      USE POPS_MOD,           ONLY : CHEMPOPS
      USE RnPbBe_MOD,         ONLY : CHEMRnPbBe
      USE RPMARES_MOD,        ONLY : DO_RPMARES
      USE SEASALT_MOD,        ONLY : CHEMSEASALT
      USE SULFATE_MOD,        ONLY : CHEMSULFATE
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Chm_Mod,      ONLY : Ind_
      USE State_Met_Mod,      ONLY : MetState
      USE STRAT_CHEM_MOD,     ONLY : DO_STRAT_CHEM
      USE TAGGED_CO_MOD,      ONLY : CHEM_TAGGED_CO
      USE TAGGED_O3_MOD,      ONLY : CHEM_TAGGED_O3
```

```
      USE TIME_MOD,           ONLY : GET_ELAPSED_MIN
      USE TIME_MOD,           ONLY : GET_TS_CHEM
#if defined( USE_TEND )
      USE TENDENCIES_MOD
#endif
      USE UnitConv_Mod

#if defined (UCX )
      USE UCX_MOD,            ONLY : CALC_STRAT_AER ! (SDE 04/20/13)
      USE UCX_MOD,            ONLY : READ_PSC_FILE
      USE UCX_MOD,            ONLY : WRITE_STATE_PSC
#endif
#if defined( TOMAS )
      USE TOMAS_MOD,          ONLY : DO_TOMAS  !(win, 7/14/09)
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

REVISION HISTORY:

```
    (1 ) Now reference DELP, T from "dao_mod.f" since we need to pass this
         to OPTDEPTH for GEOS-1 or GEOS-STRAT met fields (bnd, bmy, 4/14/03)
    (2 ) Now references DEBUG_MSG from "error_mod.f" (bmy, 8/7/03)
    (3 ) Removed call to CHEMO3, it's obsolete.  Now calls CHEM_TAGGED_OX !
         from "tagged_ox_mod.f" when NSRCX==6.  Now calls Kr85 chemistry if
         NSRCX == 12 (jsw, bmy, 8/20/03)
    (4 ) Bug fix: added GEOS-4 to the #if block in the call to OPTDEPTH.
         (bmy, 1/27/04)
    (5 ) Now calls CHEMCARBON and CHEMDUST to do carbon aerosol & dust
         aerosol chemistry (rjp, tdf, bmy, 4/2/04)
    (6 ) Now calls CHEMSEASALT to do seasalt aerosol chemistry
         (rjp, bec, bmy, 4/20/04)
    (7 ) Now references "logical_mod.f" & "tracer_mod.f".  Now references
         AEROSOL_CONC, AEROSOL_RURALBOX, and RDAER from "aerosol_mod.f".
         Now includes "CMN_DIAG" and "comode.h".  Also call READER, READCHEM,
         and INPHOT to initialize the FAST-J arrays so that we can save out !
```

```
      AOD's to the ND21 diagnostic for offline runs. (bmy, 7/20/04)
(8 ) Now call routine CHEMMERCURY from "mercury_mod.f" for an offline
      Hg0/Hg2/HgP simulation. (eck, bmy, 12/7/04)
(9 ) Now do not call DO_RPMARES if we are doing an offline aerosol run
      with crystalline sulfur & aqueous tracers (cas, bmy, 1/7/05)
(10) Now use ISOROPIA for aer thermodyn equilibrium if we have seasalt
      tracers defined, or RPMARES if not.  Now call CHEMSEASALT before
      CHEMSULFATE.  Now do aerosol thermodynamic equilibrium before
      aerosol chemistry for offline aerosol runs.  Now also reference
      CLDF from "dao_mod.f" (bec, bmy, 4/20/05)
(11) Now modified for GCAP met fields.  Now call CHEM_HCN_CH3CN from
      "hcn_ch3cn_mod.f".  Also remove allreferences to the obsolete
       CO-OH param simulation. (xyp, bmy, 6/23/05)
(12) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(13) Now call MAKE_RH from "main.f" (bmy, 3/16/06)
(14) Removed ISOP_PRIOR as a local variable (dkh, bmy, 6/1/06)
(15) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(16) Now use DRYFLXH2HD and CHEM_H2_HD for H2/HD sim (lyj, phs, 9/18/07)
(17) Bug fix: now hardwired to use RPMARES since ISORROPIA can return very
      unphysical values at low RH.  Wait for ISORROPIA II. (bmy, 4/2/08)
(18) The dry deposition diagnostic (ND44) is done in vdiff_mod if using non-
      local PBL (lin, ccc, 5/29/09)
(19) Now calls CHEMPOPS from "pops_mod.f" for an offline POPs simulation
     (eck, 9/20/10)
17 Dec 2009 - R. Yantosca - Added ProTeX headers
25 Jan 2010 - R. Yantosca - Now call DO_TOMAS for TOMAS microphysics
28 Jan 2010 - C. Carouge, R. Yantosca - Modified for ISORROPIA II
19 Mar 2012 - R. Yantosca - Add C-preprocessor switch to shut off
                            ISORROPIA to facilitate debugging
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument, and pass
                            this down to lower-level chem routines for GIGC
08 Aug 2012 - R. Yantosca - Now align IF statements better
10 Aug 2012 - R. Yantosca - Cosmetic changes
18 Oct 2012 - R. Yantosca - Rename GC_MET argument to State_Met
18 Oct 2012 - R. Yantosca - Rename CHEM_STATE argument to State_Chem
19 Oct 2012 - R. Yantosca - Now reference gigc_state_chm_mod.F90
19 Oct 2012 - R. Yantosca - Now reference gigc_state_met_mod.F90
25 Oct 2012 - R. Yantosca - Add comments for GIGC #ifdefs
25 Oct 2012 - R. Yantosca - Add the RC output argument for the GIGC
08 Nov 2012 - R. Yantosca - Now pass Input_Opt argument for the GIGC and
                            use fields of Input_Opt to replace logicals
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Nov 2012 - R. Yantosca - Now pass Input_Opt, State_Chm, RC to routine
                            DO_STRAT_CHEM (in GeosCore/strat_chem_mod.F90)
11 Dec 2012 - R. Yantosca - Remove NI, NJ, NL, NCNST arguments; these are
                            now obtained either from CMN_SIZE_mod.F or
                            from the Input_Opt object
```

```
05 Mar 2013 - R. Yantosca - Now pass am_I_Root, Input_Opt, RC to DRYFLX
25 Mar 2013 - H. Amos     - merged C. Friedman's PAH code into v9-01-03
28 Mar 2013 - S.D. Eastham- Updated to use FAST_JX_MOD
31 May 2013 - R. Yantosca - Now pass Input_Opt, State_Chm to DO_TOMAS
19 May 2014 - C. Keller   - Removed call for acetone ocean sink - now done
                            in HEMCO.
06 Nov 2014 - M. Yannetti - Added PRECISION_MOD
08 May 2015 - C. Keller   - Added WRITE_STATE_PSC.
18 May 2015 - R. Yantosca - Remove DIAG_STATE_PSC, that is not used anymore
15 Jun 2015 - R. Yantosca - Removed calls to DRYFLXRnPbBe, that's obsolete
04 Sep 2015 - C. Keller   - Added passive tracer call.
17 Mar 2016 - M. Sulprizio- Remove call to OPTDEPTH. The optical depth fields
                            are now saved into State_Met%OPTD in the routines
                            that read the met fields from disk.
16 May 2016 - M. Sulprizio- Remove call to AEROSOL_RURALBOX. The FlexChem
                            implementation has rendered the routine obsolete.
16 Jun 2016 - C. Miller   - Now use Ind_ function to define species ID's
17 Jun 2016 - R. Yantosca - Now define species ID's only on first call
17 Jun 2016 - R. Yantosca - Now reset first-time flag at end of routine
30 Jun 2016 - R. Yantosca - Remove instances of STT.
19 Jul 2016 - R. Yantosca - Now bracket DO_TEND calls with #ifdef USE_TEND
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
11 Aug 2016 - R. Yantosca - Clean up calls to error subroutines
```

7.3.2 recompute_od

Subroutine RECOMPUTE_OD will update the optical depth values before accumulating or writing the diagnostics.

INTERFACE:

```
      SUBROUTINE RECOMPUTE_OD( am_I_Root, Input_Opt,
     &                         State_Met, State_Chm, RC )
```

USES:

```
      ! References to F90 modules
      USE AEROSOL_MOD,        ONLY : AEROSOL_CONC
      USE AEROSOL_MOD,        ONLY : RDAER
      USE AEROSOL_MOD,        ONLY : SOILDUST
      USE DUST_MOD,           ONLY : RDUST_ONLINE
      USE DUST_MOD,           ONLY : RDUST_OFFLINE
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH
```

```
      USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    03 Fev 2011 - Adapted from chemdr.f by skim
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    13 Nov 2012 - R. Yantosca - Now pass Input_Opt and RC arguments for GIGC
    15 Nov 2012 - M. Payer    - Now pass all met fields via State_Met
    25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
    12 Aug 2015 - E. Lundgren  - Input tracer units are now [kg/kg] and
                                 are converted to [kg] for recomputing OD
```

7.3.3 chem_passive_tracer

Subroutine RUN_PASSIVE_TRACER performs loss chemistry on all passive tracers.

INTERFACE:

```
      SUBROUTINE CHEM_PASSIVE_TRACER ( am_I_Root, Input_Opt,
     &                                 State_Met, State_Chm, RC )
```

USES:

```
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : GC_Error
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ind_
      USE PASSIVE_TRACER_MOD, ONLY : PASSIVE_TRACER_GETRATE
      USE PASSIVE_TRACER_MOD, ONLY : NPASSIVE, PASSIVE_NAME
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN   )  :: am_I_Root  ! root CPU?
      TYPE(OptInput),   INTENT(IN   )  :: Input_Opt  ! Input options object
      TYPE(MetState),   INTENT(IN   )  :: State_Met  ! Meteorology state object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState),   INTENT(IN   )  :: State_Chm  ! Chemistry state object
      INTEGER,          INTENT(INOUT)  :: RC         ! Failure or success
  !REMARKS
```

REVISION HISTORY:

```
    04 Sep 2015 - C. Keller    - Initial version
    03 Nov 2016 - C. Keller    - Moved to chemistry_mod
```

7.3.4 init_chemistry

Subroutine INIT_CHEMISTRY initializes chemistry variables.

INTERFACE:

```
      SUBROUTINE INIT_CHEMISTRY( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD,       ONLY : LLTROP
      USE ErrCode_Mod
      USE FAST_JX_MOD,        ONLY : INIT_FJX
      USE FlexChem_Mod,       ONLY : Init_FlexChem
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)     :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT)  :: Input_Opt   ! Input Options object
      TYPE(ChmState), INTENT(INOUT)  :: State_Chm   ! Chemistry State object
      INTEGER,        INTENT(INOUT)  :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    19 May 2014 - C. Keller   - Initial version (stripped from do_chemistry
                                and chemdr.F)
    20 Jun 2014 - R. Yantosca - Now pass Input_Opt to INIT_FJX
    23 Jun 2016 - R. Yantosca - Remove call to SETTRACE, it's obsolete
```

7.4 Fortran: Module Interface fast_jx_mod.F

Module FAST_JX_MOD contains routines and variables for calculating photolysis rates using the Fast-JX scheme (Prather et al). Current implementation is version 7.0a.

INTERFACE:

```
MODULE FAST_JX_MOD
```

USES:

```
USE CMN_FJX_MOD
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE

PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: EXITC
PUBLIC  :: PHOTO_JX
PUBLIC  :: INIT_FJX
PUBLIC  :: FAST_JX
PUBLIC  :: PHOTRATE_ADJ
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: SOLAR_JX
PRIVATE :: OPMIE
PRIVATE :: MIESCT
PRIVATE :: LEGND0
PRIVATE :: BLKSLV
PRIVATE :: GEN_ID
PRIVATE :: JRATET
PRIVATE :: X_INTERP
PRIVATE :: SPHERE2
PRIVATE :: EXTRAL
PRIVATE :: RD_PROF_NC
PRIVATE :: RD_XXX
PRIVATE :: RD_AOD
PRIVATE :: RD_MIE
PRIVATE :: RD_JS_JX
PRIVATE :: SET_AER
```

REVISION HISTORY:

```
27 Mar 2013 - S. D. Eastham - Initial version (based on original GEOS-Chem
                              files and instructions from J. Mao)
28 Mar 2013 - S. D. Eastham - Upgraded to Fast-JX v7.0
20 Feb 2014 - M. Sulprizio  - Removed "define.h", this is now obsolete
13 Nov 2014 - M. Yannetti   - Added PRECISION_MOD
29 Mar 2016 - R. Yantosca   - Add flags for rxns adjusted by PHOTRATE_ADJ
27 Jun 2016 - M. Sulprizio  - Remove FJXFUNC and JV_INDEX routines. We now
                              obtain the photolysis rates directly from the
                              ZPJ array.
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

7.4.1 fast_jx

Subroutine FAST_JX loops over longitude and latitude, and calls PHOTO_JX to compute J-Values for each column at every chemistry time-step.

INTERFACE:

```
      SUBROUTINE FAST_JX( WLAOD, am_I_Root, Input_Opt, State_Met,
     &                    State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
      USE CMN_SIZE_MOD,       ONLY : IIPAR, JJPAR, LLPAR
      USE CMN_SIZE_MOD,       ONLY : NDUST
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP, ALLOC_ERR
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE GC_GRID_MOD,        ONLY : GET_YMID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Chm_Mod,      ONLY : Ind_
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH, GET_DAY, GET_DAY_OF_YEAR
      USE TIME_MOD,           ONLY : GET_TAU,   GET_YEAR
      USE TOMS_MOD,           ONLY : GET_OVERHEAD_O3

      IMPLICIT NONE

  ======================================================================
   Uncomment the appropriate #define statement to denote which of the
   available cloud overlap options that you wish to use.

  ! Linear overlap
  #define USE_LINEAR_OVERLAP 1

   Approximate random overlap (balance between accuracy & speed)
 #define USE_APPROX_RANDOM_OVERLAP 1

  ! Maximum random cloud overlap (most computationally intensive)
  #define USE_MAXIMUM_RANDOM_OVERLAP 1
  ======================================================================
```

INPUT PARAMETERS:

```
      ! How was AOD calculated? (1: 550 nm, 0: 999 nm)
      INTEGER,        INTENT(IN)  :: WLAOD

      ! Is this the root CPU?
      LOGICAL,        INTENT(IN)  :: am_I_Root
```

```
! Input options
TYPE(OptInput), INTENT(IN)  :: Input_Opt

! Meteorology State object
TYPE(MetState), INTENT(IN)  :: State_Met

! Chemistry State object
TYPE(ChmState), INTENT(IN)  :: State_Chm
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC
```

REMARKS:

```
Parameter to choose cloud overlap algorithm:
=============================================================================
(1 ) OVERLAP (INTEGER) : 1 - Linear Approximation (used up to v7-04-12)
                         2 - Approximate Random Overlap (default)
                         3 - Maximum Random Overlap (computation intensive)
```

REVISION HISTORY:

```
01 Apr 1998 - P. Murti, R. Martin, R. Yantosca - Initial version
(1 ) Call this routine EACH chemistry time-step, before solver.
(2 ) This routine must know IMAX, JMAX, LMAX.
(3 ) Now use new !$OMP compiler directives for parallelization (bmy, 5/2/00)
(4 ) Now reference "cmn_fj.h" and "jv_cmn.h" for the aerosol
     optical depths (bmy, 10/2/00)
(5 ) Add OPTDUST as a local variable -- make OPTDUST private for
     the parallel DO-loop, since it stores 1 column of aerosol optical
     depth for each dust type (bmy, rvm, 10/2/00)
(6 ) For now, LPAR in "cmn_fj.h" = LGLOB in "CMN_SIZE".  Therefore we
     assume that we are always doing global runs. (bmy, 10/2/00)
(7 ) Removed obsolete code from 10/2/00 (bmy, 12/21/00)
(8 ) Replace {IJL}GLOB w/ IIPAR,JJPAR,LLPAR everywhere.  Also YLMID(NLAT)
     needs to be referenced by YLMID(NLAT+J0). (bmy, 9/26/01)
(9 ) Remove obsolete code from 9/01.  Updated comments. (bmy, 10/24/01)
(10) Add OPTAER as a local variable, make it private for the parallel
     DO loop, since it stores 1 column of aerosol optical depths for each
     aerosol type.  Pass OPTAER to PHOTOJ via the argument list.  Declare
     OPTAER as PRIVATE for the parallel DO-loop. (rvm, bmy, 2/27/02)
(11) Now reference GET_PEDGE from "pressure_mod.f", which returns the
     correct "floating" pressure. (dsa, bdf, bmy, 8/20/02)
(12) Now reference T from "dao_mod.f" (bmy, 9/23/02)
(13) Now uses routine GET_YMID from "grid_mod.f" to compute grid box
     latitude.  Now make IDAY, MONTH local variables.  Now use function
     GET_DAY_OF_YEAR from "time_mod.f".  Bug fix: now IDAY (as passed to
     photoj.f) is day of year rather than cumulative days since Jan 1,
```

```
      1985. (bmy, 2/11/03)
(14) Now reference routine GET_YEAR from "time_mod.f".  Added LASTMONTH
      as a SAVEd variable.  Now call READ_TOMSO3 from "toms_mod.f" at the
      beginning of a new month (or the first timestep) to read TOMS O3
      columns which will be used by "set_prof.f".  Now also reference
      routine GET_DAY from "time_mod.f".  Rename IDAY to DAY_OF_YR. Pass
      day of month to PHOTOJ.  Updated comments, cosmetic changes.
      (bmy, 7/17/03)
(15) Bug fix: PRES needs to be the true surface pressure for GEOS-4, but
      PS-PTOP for all prior GEOS models.  (bmy, 2/6/04)
(16) Now account for cloud overlap (Maximum-Random Overlap and Random
      Overlap) in each column (hyl, phs, bmy, 9/18/07)
(17) Now initialize the PJ array here, instead of two layers below in
      "set_prof.f".  Now no longer pass PRES to "photoj.f". (bmy, 11/29/07)
(18) Now switch to approx. random overlap option (hyl, phs, bmy, 10/7/08)
(19) Now can handle GEOS-5 reprocessed met data with OPTDEPTH being
      in-cloud optical depths. (bmy, hyl, 10/24/08)
(10) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
13 Aug 2010 - R. Yantosca - Added ProTeX headers
13 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
06 Mar 2012 - R. Yantosca - Now call GET_OVERHEAD_O3 to get the total
                            overhead O3 column for FAST-J
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
10 Aug 2012 - R. Yantosca - Replace IPAR, JPAR, LPAR w/ IIPAR, JJPAR, LLPAR
27 Mar 2013 - S.D. Eastham- Rolled in FAST_JX_MOD
21 Feb 2014 - M. Sulprizio- Replaced all met field arrays with State_Met
                            derived type object
28 Feb 2014 - M. Sulprizio- Now obtain O3_CTM directly from CSPEC
05 Mar 2014 - R. Yantosca - Cosmetic changes
06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%OPTD(I,J,L)
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE with State_Met%PEDGE.
                            Remove dependency on pressure_mod and
                            redundant PEDGE pre-preprocessor block if
                            EXTERNAL_GRID.
09 Apr 2015 - R. Yantosca - Bug fixes: Add missing vars to !$OMP+PRIVATE
                            clause and error check for JLOOP > 0
11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as for GEOS-FP
21 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
17 Jun 2016 - R. Yantosca - Now define id_O3 with the Ind_ function
```

7.4.2 blkslv

Subroutine BLKSLV solves the block tri-diagonal system

INTERFACE:

```
      SUBROUTINE BLKSLV
     &     (FJ,POMEGA,FZ,ZTAU,ZFLUX,RFL,PM,PM0,FJTOP,FJBOT,ND)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)   ::  ND
      REAL(fp), INTENT(IN)  ::  POMEGA(M2_,N_,W_),FZ(N_,W_),ZTAU(N_,W_),
     &                          PM(M_,M2_),PM0(M2_),
     &                          RFL(W_),ZFLUX(W_)
```

OUTPUT PARAMETERS:

```
      REAL(fp), INTENT(OUT) ::  FJ(N_,W_),FJTOP(W_),FJBOT(W_)
```

REMARKS:

```
  The block tri-diagonal system:
        A(I)*X(I-1) + B(I)*X(I) + C(I)*X(I+1) = H(I)
```

REVISION HISTORY:

```
   27 Mar 2013 - S. D. Eastham - Copied from GEOS-Chem v9-01-03
```

7.4.3 gen_id

Subroutine GEN generates coefficient matrices for the block tri-diagonal system described in BLKSLV.

INTERFACE:

```
      SUBROUTINE GEN_ID(POMEGA,FZ,ZTAU,ZFLUX,RFL,PM,PM0
     &              ,B,CC,AA,A,H,C,  ND)
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)   ::  ND
      REAL(fp), INTENT(IN)  ::  POMEGA(M2_,N_),PM(M_,M2_),PM0(M2_)
      REAL(fp), INTENT(IN)  ::  ZFLUX,RFL
      REAL(fp), INTENT(IN),DIMENSION(N_) :: FZ,ZTAU
```

OUTPUT PARAMETERS:

```
      REAL(fp), INTENT(OUT),DIMENSION(M_,M_,N_) ::  B,AA,CC
      REAL(fp), INTENT(OUT),DIMENSION(M_,N_)    ::  A,C,H
```

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.4 jratet

Subroutine JRATET calculates temperature-dependent J-rates.

INTERFACE:

```
      SUBROUTINE JRATET(PPJ,TTJ,FFF,VALJL,LCTM,LCHEM,NJXU)
```

USES:

INPUT PARAMETERS:

```
      integer, intent(in)     :: LCTM,LCHEM,NJXU
      real(fp), intent(in)    ::  PPJ(JXL1_+1),TTJ(JXL1_+1)
      real(fp), intent(inout) ::  FFF(W_,LCTM)
  !OUTPUT VARIABLES:
      real(fp), intent(out), dimension(LCTM,NJXU) ::  VALJL
```

REMARKS:

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
   02 Apr 2013 - S. D. Eastham - Now only assign J-rates on
                                 levels within the chemistry grid.
```

7.4.5 x_interp

Subroutine X_INTERP is an up-to-three-point linear interp. function for cross-sections.

INTERFACE:

```
      SUBROUTINE X_INTERP (TINT,XINT,T1,X1,T2,X2,T3,X3,L123)
```

USES:

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)  ::  TINT,T1,T2,T3, X1,X2,X3
      INTEGER,  INTENT(IN)  ::  L123
  !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) ::  XINT
```

REMARKS:

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.6 sphere2

Subroutine SPHERE2 is an AMF2.

INTERFACE:

```
      SUBROUTINE SPHERE2 (U0,ZHL,AMF2,L1U,LJX1U)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)   ::   L1U, LJX1U
      REAL(fp), INTENT(IN)  ::   U0,ZHL(L1U+1)
   !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) ::   AMF2(2*LJX1U+1,2*LJX1U+1)
```

REMARKS:

```
   Quoting from the original:
    New v6.2: does AirMassFactors for mid-layer, needed for SZA ~ 90
    This new AMF2 does each of the half-layers of the CTM separately,
       whereas the original, based on the pratmo code did the whole layers
       and thus calculated the ray-path to the CTM layre edges, NOT the middle.
    Since fast-JX is meant to calculate the intensity at the mid-layer, the
       solar beam at low sun (interpolated between layer edges) was incorrect.
    This new model does make some approximations of the geometry of the layers:
       the CTM layer is split evenly in mass (good) and in height (approx).

                                                                             .
    Calculation of spherical geometry; derive tangent heights, slant path
    lengths and air mass factor for each layer. Not called when
    SZA > 98 degrees.  Beyond 90 degrees, include treatment of emergent
    beam (where tangent height is below altitude J-value desired at).

                                                                             .
    ------------------------------------------------------------------------
    Inputs:
       U0      cos(solar zenith angle)
       RAD  radius of Earth mean sea level (cm)
       ZHL(L)  height (cm) of the bottom edge of CTM level L
       ZZHT    scale height (cm) used above top of CTM (ZHL(L_+1))
       L1U     dimension of CTM = levels +1 (L+1 = above-CTM level)
    Outputs:
       AMF2(I,J) = air mass factor for CTM level I for sunlight reaching J
           ( these are calculated for both layer middle and layer edge)
    ------------------------------------------------------------------------
```

REVISION HISTORY:

```
    28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
    04 Dec 2014 - R. Yantosca   - Now use SQRT instead of DSQRT
```

7.4.7 extral

Subroutine EXTRAL adds sub-layers to thick cloud/aerosol layers using log-spacing for sub-layers of increasing thickness ATAU.

INTERFACE:

```
      SUBROUTINE EXTRAL (DTAUX,L1X,L2X,NX,JXTRA)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)   ::  L1X,L2X         !index of cloud/aerosol
      integer, intent(in)   ::  NX              !Mie scattering array size
      real(fp),  intent(in) ::  DTAUX(L1X)      !cloud+3aerosol OD in each layer
  !OUTPUT VARIABLES:
      integer, intent(out)::  JXTRA(L2X+1)    !number of sub-layers to be added
```

REMARKS:

```
      DTAUX(L=1:L1X) = Optical Depth in layer L (generally 600 nm OD)
         This can be just cloud or cloud+aerosol, it is used only to set
         the number in levels to insert in each layer L
         Set for log-spacing of tau levels, increasing top-down.

      N.B. the TTAU, etc calculated here are NOT used elsewhere

    The log-spacing parameters have been tested for convergence and chosen
      to be within 0.5% for ranges OD=1-500, rflect=0-100%, mu0=0.1-1.0
      use of ATAU = 1.18 and min = 0.01, gives at most +135 pts for OD=100
      ATAU = 1.12 now recommended for more -accurate heating rates (not J's)
```

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.8 exitc

Subroutine EXITC forces an error in GEOS-Chem and quits.

INTERFACE:

```
      SUBROUTINE EXITC (T_EXIT)
```

USES:

```
      USE ERROR_MOD, ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      CHARACTER(LEN=*), INTENT(IN) ::  T_EXIT
  !OUTPUT VARIABLES:
```

REMARKS:

REVISION HISTORY:

```
    28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.9 int_fjx

Subroutine INIT_FJX initializes Fast-JX variables.

INTERFACE:

```
      SUBROUTINE INIT_FJX( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE CMN_DIAG_MOD,       ONLY : ND64
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE inquireMod,         ONLY : findFreeLUN
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
    05 Mar 2014 - R. Yantosca - Use correct filenames for use w/ ESMF
```

7.4.10 rd_xxx

Subroutine RD_XXX reads in wavelength bins, solar fluxes, Rayleigh and temperature-dependent cross-sections.

INTERFACE:

```
      SUBROUTINE RD_XXX (NUN,NAMFIL,am_I_Root)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: NUN
      CHARACTER(*), INTENT(IN) ::  NAMFIL
      LOGICAL,      INTENT(IN) :: am_I_Root
  !OUTPUT VARIABLES:
```

REMARKS:

```
     NEW v-6.8  now allow 1 to 3 sets of X-sects for T or P
           LQQ = 1, 2, or 3 to determine interpolation with T or P
           IF the temperatures TQQQ are <0, then use as pressure interp (hPa)
           NB - the temperatures and pressures must be increasing
     NEW v-6.4  changed to collapse wavelengths & x-sections to Trop-only:
           WX_ = 18 should match the JX_spec.dat wavelengths
           W_ = 12 (Trop-only) or 18 (std) is set in (CMN_FJX.F).
       if W_=12 then drop strat wavels, and drop x-sects (e.g. N2O, ...)
           W_ = 8, reverts to quick fix:  fast-J (12-18) plus bin (5) scaled
                                                                             .
    ------------------------------------------------------------------
     NAMFIL   Name of spectral data file (FJX_spec.dat) >> j2 for fast-J2
     NUN      Channel number for reading data file
     NJX    Number of species to calculate J-values for
     NWWW     Number of wavelength bins, from 1:NWWW
     WBIN     Boundaries of wavelength bins
     WL       Centres of wavelength bins - 'effective wavelength'
     FL       Solar flux incident on top of atmosphere (cm-2.s-1)
     QRAYL    Rayleigh parameters (effective cross-section) (cm2)
     QO2      O2 cross-sections
     QO3      O3 cross-sections
     Q1D      O3 => O(1D) quantum yield
     TQQ      Temperature for supplied cross sections
     QQQ      Supplied cross sections in each wavelength bin (cm2)
    ------------------------------------------------------------------
```

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
   09 May 2014 - S. D. Eastham - Fixed bug when using <18 wavelengths
```

7.4.11 rd_mie

Subroutine RD_MIE retrieves aerosol scattering data for FJX.

INTERFACE:

```
      SUBROUTINE RD_MIE(NUN,NAMFIL,am_I_Root, Input_Opt )
```

USES:

```
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: NUN
      CHARACTER(*),   INTENT(IN) :: NAMFIL
      LOGICAL,        INTENT(IN) :: am_I_Root
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object

   !OUTPUT VARIABLES:
```

REMARKS:

```
     ------------------------------------------------------------------
      NAMFIL   Name of scattering data file (e.g., FJX_scat.dat)
      NUN      Channel number for reading data file
      NAA      Number of categories for scattering phase functions
      QAA      Aerosol scattering phase functions
      WAA      5 Wavelengths for the supplied phase functions
      PAA      Phase function: first 8 terms of expansion
      RAA      Effective radius associated with aerosol type
      SAA      Single scattering albedo
     ------------------------------------------------------------------
```

REVISION HISTORY:

```
    28 Mar 2013 - S. D. Eastham - Adapted from GEOS-Chem v9-1-3
    25 Jun 2015 - M. Sulprizio  - Add brown carbon optical properties from
                                  M. Hammer
```

7.4.12 rd_aod

Subroutine RD_AOD reads aerosol phase functions that are used to scale diagnostic output to an arbitrary wavelengh. This facilitates comparing with satellite observations.

INTERFACE:

```
      SUBROUTINE RD_AOD( NJ1, am_I_Root, Input_Opt )
```

USES:

```
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      IMPLICIT NONE
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN) :: NJ1         ! Unit # of file to open
TYPE(OptInput),   INTENT(IN) :: Input_Opt   ! Input Options object
LOGICAL,          INTENT(IN) :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

REMARKS:

```
The .dat files for each species contain the optical properties
at multiple wavelengths to be used in the online calculation of the aerosol
optical depth diagnostics.
These properties have been calculated using the same size and optical
properties as the FJX_spec.dat file used for the FAST-J photolysis
calculations (which is now redundant for aerosols, the values in the .dat
files here are now used). The file currently contains 11 wavelengths
for Fast-J and other commonly used wavelengths for satellite and
AERONET retrievals. 30 wavelengths follow that map onto RRTMG
wavebands for radiaitive flux calculations (not used if RRTMG is off).
A complete set of optical properties from 250-2000 nm for aerosols is
available at:
ftp://ftp.as.harvard.edu/geos-chem/data/aerosol_optics/hi_spectral_res
                                                                        .
   -- Colette L. Heald, 05/10/10)
   -- David A. Ridley, 05/10/13 (update for new optics files)
```

REVISION HISTORY:

```
10 May 2010 - C. Heald      - Initial version
06 Aug 2010 - C. Carouge    - Add an error check when opening the file
01 Aug 2012 - R. Yantosca   - Now restore NJ1 to INTENT(IN) status
31 Mar 2013 - S. D. Eastham - Added to Fast-JX v7.0 implementation
30 Mar 2015 - M. Sulprizio  - Removed NAMFIL argument. Now specify filenames
                              for aerosol LUT files in this routine.
02 Apr 2015 - C. Keller     - Append '.rc' to species files in ESMF mode.
12 May 2015 - R. Yantosca   - Bug fix: For PGI compiler, you need to have
                              exactly as many elements in the DATA statement
                              as there are elements in the SPECFIL array.
25 Jun 2015 - M. Sulprizio  - Add brown carbon optical properties from
                              M. Hammer
04 Aug 2015 - M. Long       - Removed ".rc" file specifier. Not necessary.
```

7.4.13 calc_aod

Subroutine CALC_AOD works out the closest tie points in the optics LUT wavelengths and the coefficients required to calculate the angstrom exponent for interpolating optics to the

requested wavelength. If the wavelength requested matches a standard wavelength in the LUT then we skip the interpolation (DAR 09/2013)

INTERFACE:

```
      SUBROUTINE CALC_AOD( am_I_Root )
```

USES:

```
      USE CMN_FJX_MOD, ONLY : NWVAA, NWVAA0, WVAA
      USE CMN_FJX_MOD, ONLY : WVSELECT, IWVSELECT, NWVSELECT
      USE CMN_FJX_MOD, ONLY : IRTWVSELECT
      USE CMN_FJX_MOD, ONLY : ACOEF_WV, BCOEF_WV, CCOEF_WV
      USE CMN_FJX_MOD, ONLY : ACOEF_RTWV, BCOEF_RTWV, CCOEF_RTWV
      USE CMN_FJX_MOD, ONLY : NWVREQUIRED, IWVREQUIRED
      USE CMN_FJX_MOD, ONLY : NRTWVREQUIRED, IRTWVREQUIRED
#if defined( RRTMG )
      USE PARRRTM,     ONLY : NBNDLW
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN) :: am_I_Root   ! Is this the root CPU?
```

REMARKS:

```
    Now the user is able to select any 3 wavelengths for optics
    output in the input.geos file we need to be able to interpolate
    to those wavelengths based on what is available in the optics
    look-up table.

    The standard lookup table currently has values for
    11 common wavelengths followed by 30 that are required by RRTMG.
    Only those required to interpolate to user requested
    wavelengths are selected from the standard wavelengths. RRTMG
    wavelengths are not used in the interpolation for AOD output
    (DAR 10/2013)

     UPDATE: because the RT optics output doesnt have access to the
     standard wavelengths we now calculate two sets of values: one
     for the ND21 and diag3 outputs that use the standard wavelengths
     and one for ND72 that interpolates the optics from RRTMG
     wavelengths. Perhaps a switch needs adding to switch off the RT
     optics output (and interpolation) if this ends up costing too
     much and is not used, but it is ideal to have an optics output
     that matches exactly what RRTMG uses to calculate the fluxes
```

REVISION HISTORY:

```
    18 Jun 2013 - D. Ridley   - Initial version
    15 Dec 2014 - M. Sulprizio- Added ProTeX headers
    02 Apr 2015 - C. Keller   - Added am_I_Root argument
```

7.4.14 rd_js_jx

Subroutine RD_JS_JX reads in 'FJX_j2j.dat', which defines the mapping of Fast-JX J's (TITLEJX(1:NJX)) onto the CTM reactions. Reaction number JJ, named T_REACT, uses Fast-JX's T_FJX (including scaling factor F_FJX).

INTERFACE:

```
SUBROUTINE RD_JS_JX(NUNIT,NAMFIL,TITLEJX,NJXX,am_I_Root)
```

USES:

```
USE CHARPAK_MOD, ONLY : CSTRIP
USE ERROR_MOD,   ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN)                  :: NUNIT
INTEGER,          INTENT(IN)                  :: NJXX
CHARACTER(LEN=*), INTENT(IN)                  :: NAMFIL
CHARACTER(LEN=6), INTENT(IN), DIMENSION(NJXX) :: TITLEJX
LOGICAL,          INTENT(IN)                  :: am_I_Root
```

REMARKS:

```
Now flag special reactions that are to be adjusted for FlexChem later.
```

REVISION HISTORY:

```
28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
31 Mar 2013 - S. D. Eastham - Modified to track number of branches
29 Mar 2016 - R. Yantosca   - Now flag rxn numbers for use in PHOTRATE_ADJ
27 Jun 2016 - M. Sulprizio  - Add RXN_NO2 flag for PARANOX
```

7.4.15 solar_jx

Subroutine SOLAR_JX handles solar zenith angles.

INTERFACE:

```
SUBROUTINE SOLAR_JX(NDAY,COSSZA,SZA,SOLFX)
```

USES:

```
USE PhysConstants,ONLY : PI
```

INPUT PARAMETERS:

```
    REAL(fp), INTENT(IN) ::   COSSZA
    INTEGER, INTENT(IN) ::  NDAY
!OUTPUT VARIABLES:
    REAL(fp), INTENT(OUT) ::  SZA,SOLFX
```

REMARKS:

```
------------------------------------------------------------------
   NDAY   = integer day of the year (used for solar lat and declin)
   SZA = solar zenith angle in degrees
   COSSZA = U0 = cos(SZA)
   SOLFX = Solar function
------------------------------------------------------------------
```

REVISION HISTORY:

```
28 Mar 2013 - S. D. Eastham - Adapted from Fast-JX v7.0
06 Jan 2016 - E. Lundgren   - Use global PI rather than local definition
```

7.4.16 photo_jx

Subroutine PHOTO_JX is the core subroutine of Fast-JX. calc J's for a single column atmosphere (aka Indep Colm Atmos or ICA) needs P, T, O3, clds, aersls; adds top-of-atmos layer from climatology needs day-fo-year for sun distance, SZA (not lat or long)

INTERFACE:

```
      SUBROUTINE PHOTO_JX( U0,             REFLB,     P_COL,
     &                     T_COL,          O3_COL,    O3_TOMS,
     &                     AOD999,         ODAER_COL, ODMDUST_COL,
     &                     ODCLOUD_COL_IN, ILON,      ILAT,
     &                     YLAT,           DAY_OF_YR, MONTH,
     &                     DAY,            am_I_Root, Input_Opt )
```

USES:

```
      USE CMN_DIAG_MOD,       ONLY : LD22, LD64, ND22, ND64
      USE DIAG_MOD,           ONLY : AD22, AD64, LTJV
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)                          :: ILON,ILAT
      INTEGER, INTENT(IN)                          :: DAY_OF_YR
      INTEGER, INTENT(IN)                          :: MONTH,DAY
      REAL(fp),  INTENT(IN)                        :: YLAT
      REAL(fp),  INTENT(IN)                        :: U0,REFLB
      REAL(fp),  INTENT(IN),DIMENSION(L1_+1)       :: P_COL
      REAL(fp),  INTENT(IN),DIMENSION(L1_)         :: T_COL
      REAL(fp),  INTENT(IN),DIMENSION(L1_)         :: O3_COL
      REAL(fp),  INTENT(IN)                        :: O3_TOMS
      REAL(fp),  INTENT(IN),DIMENSION(L_,A_)       :: ODAER_COL
      REAL(fp),  INTENT(IN),DIMENSION(L_,NDUST)    :: ODMDUST_COL
      REAL(fp),  INTENT(IN),DIMENSION(L_)          :: ODCLOUD_COL_IN
```

```
      LOGICAL, INTENT(IN)                          :: AOD999
      LOGICAL, INTENT(IN)                          :: am_I_Root
      TYPE(OptInput), INTENT(IN)                   :: Input_Opt
```

REMARKS:

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
   05 Mar 2014 - R. Yantosca - Now only save ND64 with LD64 specified levels
```

7.4.17 opmie

Subroutine OPMIE is a core Fast-JX scattering subroutine, specifically for Mie scattering.

INTERFACE:

```
      SUBROUTINE OPMIE (DTAUX,POMEGAX,U0,RFL,AMF2,JXTRA,
     &        FJACT,FJTOP,FJBOT,FSBOT,FJFLX,FLXD,FLXD0, LU)
```

USES:

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN) ::   DTAUX(JXL1_,W_),POMEGAX(8,JXL1_,W_)
      REAL(fp), INTENT(IN) ::   AMF2(2*JXL1_+1,2*JXL1_+1)
      REAL(fp), INTENT(IN) ::   U0,RFL(W_)
      INTEGER, INTENT(IN) ::  JXTRA(JXL2_+1), LU
   !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) ::  FJACT(JXL_,W_),FJTOP(W_)
      REAL(fp), INTENT(OUT) ::  FJBOT(W_),FSBOT(W_)
      REAL(fp), INTENT(OUT) ::  FJFLX(JXL_,W_),FLXD(JXL1_,W_),FLXD0(W_)
```

REMARKS:

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.18 miesct

Subroutine MIESCT is an adaptation of the Prather radiative transfer code (mjp, 10/95).

INTERFACE:

```
      SUBROUTINE MIESCT(FJ,FJT,FJB, POMEGA,FZ,ZTAU,ZFLUX,RFL,U0,ND)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) ::  ND
      REAL(fp), INTENT(IN)  ::  POMEGA(M2_,N_,W_),FZ(N_,W_),ZTAU(N_,W_)
     &                        ,RFL(W_),U0,ZFLUX(W_)
  !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) ::  FJ(N_,W_),FJT(W_),FJB(W_)
```

REMARKS:

```
      Prather, 1974, Astrophys. J. 192, 787-792.
          Solution of inhomogeneous Rayleigh scattering atmosphere.
          (original Rayleigh w/ polarization)
      Cochran and Trafton, 1978, Ap.J., 219, 756-762.
          Raman scattering in the atmospheres of the major planets.
          (first use of anisotropic code)
      Jacob, Gottlieb and Prather, 1989, J.Geophys.Res., 94, 12975-13002.
          Chemistry of a polluted cloudy boundary layer,
          (documentation of extension to anisotropic scattering)

     takes atmospheric structure and source terms from std J-code
     ALSO limited to 4 Gauss points, only calculates mean field! (M=1)
```

REVISION HISTORY:

```
   28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.19 legnd0

Subroutine LEGND0 calculates ordinary Legendre functions of X (real) from $P[0] = PL(1) = 1, P[1] = X, \ldots, P[N-1] = PL(N)$

INTERFACE:

```
      SUBROUTINE LEGND0 (X,PL,N)
```

USES:

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: N
      REAL(fp), INTENT(IN)  :: X
  !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) :: PL(N)
```

REMARKS:

REVISION HISTORY:

```
28 Mar 2013 - S. D. Eastham - Copied from Fast-JX v7.0
```

7.4.20 set_prof

Subroutine SET_PROF sets vertical profiles for a given latitude and longitude.

INTERFACE:

```
      SUBROUTINE SET_PROF (YLAT,     MONTH,  DAY,     T_CTM,  P_CTM,
     &                     CLDOD,    DSTOD,  AEROD,   O3_CTM, O3_TOMS,
     &                     AERCOL,   T_CLIM, O3_CLIM, Z_CLIM, AIR_CLIM,
     &                     Input_Opt )
```

USES:

```
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : AIRMW, AVO, g0, BOLTZ
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)       :: YLAT              ! Latitude (degrees)
      INTEGER,  INTENT(IN)       :: MONTH             ! Month
      INTEGER,  INTENT(IN)       :: DAY               ! Day *of month*
      REAL(fp), INTENT(IN)       :: T_CTM(L1_)        ! CTM temperatures (K)
      REAL(fp), INTENT(IN)       :: O3_TOMS           ! O3 column (DU)
      REAL(fp), INTENT(IN)       :: P_CTM(L1_+1)      ! CTM edge pressures (hPa)
      REAL(fp), INTENT(INOUT)    :: CLDOD(L_)         ! Cloud optical depth
      REAL(fp), INTENT(IN)       :: DSTOD(L_,NDUST)   ! Mineral dust OD
      REAL(fp), INTENT(IN)       :: AEROD(L_,A_)      ! Aerosol OD
      REAL(fp), INTENT(IN)       :: O3_CTM(L1_)       ! CTM ozone (molec/cm3)
      TYPE(OptInput), INTENT(IN) :: Input_Opt         ! Input options
!OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT)      :: AERCOL(A_,L1_)    ! Aerosol column
      REAL(fp), INTENT(OUT)      :: T_CLIM(L1_)       ! Clim. temperatures (K)
      REAL(fp), INTENT(OUT)      :: Z_CLIM(L1_+1)     ! Edge altitudes (cm)
      REAL(fp), INTENT(OUT)      :: O3_CLIM(L1_)      ! O3 column depth (#/cm2)
      REAL(fp), INTENT(OUT)      :: AIR_CLIM(L1_)     ! O3 column depth (#/cm2)
```

REMARKS:

REVISION HISTORY:

```
30 Mar 2013 - S. D. Eastham - Adapted from J. Mao code
05 Jan 2016 - E. Lundgren   - Use global physical parameters
```

7.4.21 set_aer

Subroutine SET_AER fills out the array MIEDX. Each entry connects a GEOS-Chem aerosol to its Fast-JX counterpart: MIEDX(Fast-JX index) = (GC index)

INTERFACE:

```
      SUBROUTINE SET_AER(am_I_Root)
```

USES:

INPUT PARAMETERS:

```
      LOGICAL, INTENT(IN) :: am_I_Root
  !OUTPUT VARIABLES:
```

REMARKS:

REVISION HISTORY:

```
   31 Mar 2013 - S. D. Eastham - Adapted from J. Mao FJX v6.2 implementation
```

7.4.22 rd_prof_nc

Subroutine RAD_PROF_NC reads in the reference climatology from a NetCDF file rather than an ASCII .dat.

INTERFACE:

```
      SUBROUTINE RD_PROF_NC( am_I_Root, Input_Opt, RC )
```

USES:

```
      ! Modules for netCDF read
      USE m_netcdf_io_open
      USE m_netcdf_io_read
      USE m_netcdf_io_readattr
      USE m_netcdf_io_close
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
This file was automatically generated by the Perl scripts in the
NcdfUtilities package (which ships w/ GEOS-Chem) and was subsequently
hand-edited.
```

REVISION HISTORY:

```
19 Apr 2012 - R. Yantosca - Initial version
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
10 Apr 2013 - S. D. Eastham - Adapted for Fast-JX v7.0
20 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
13 Mar 2015 - R. Yantosca - Replace DATA_DIR_1x1 w/ CHEM_INPUTS_DIR
```

7.4.23 photrate_adj

Subroutine PHOTRATE_ADJ adjusts certain photolysis rates for chemistry.

INTERFACE:

```
      SUBROUTINE PHOTRATE_ADJ( am_I_root, I,    J,
     &                         L,         AD,   TEMP,
     &                         C_H2O,     FRAC, RC      )
```

USES:

```
      USE CMN_DIAG_MOD,       ONLY : LD22, ND22
      USE DIAG_MOD,           ONLY : AD22, LTJV
      USE ErrCode_Mod
      USE Precision_Mod,      ONLY : fp
```

INPUT PARAMETERS:

```
      LOGICAL,   INTENT(IN)  :: am_I_Root  ! Is this the root CPU?
      INTEGER,   INTENT(IN)  :: I, J, L    ! Grid box indices (lon, lat, lev)
      REAL(fp),  INTENT(IN)  :: AD         ! Air number density [molec/m3] ??
      REAL(fp),  INTENT(IN)  :: TEMP       ! Temperature [K]
      REAL(fp),  INTENT(IN)  :: C_H2O      ! H2O conc [molec/cm3]
      REAL(fp),  INTENT(IN)  :: FRAC       ! Result of SO4_PHOTFRAC,
                                           !  called from flex_chemdr.F
```

OUTPUT PARAMETERS:

```
      INTEGER,   INTENT(OUT) :: RC         ! Success or failure
```

REMARKS:

```
%%%% NOTE: WE SHOULD UPDATE THE COMMENTS TO MAKE SURE THAT WE DO      %%%%
%%%% NOT KEEP ANY CONFLICTING OR INCORRECT INFORMATION (bmy, 3/28/16) %%%%
```

REVISION HISTORY:

```
10 Mar 2016 - M. Sulprizio- Added ProTeX header
18 Apr 2016 - R. Yantosca - Remove Input_Opt, State_Met, State_Chm args
                            and pass air density & temperature instead
18 Apr 2016 - R. Yantosca - Also prevent div-by-zero conditions
```

7.5 Fortran: Module Interface uvalbedo_mod.F90

Module UVALBEDO_MOD contains variables and routines for reading the UV Albedo data. This data is required by the FAST-JX photolysis module. UV albedo data will now be obtained from the HEMCO data structure.

INTERFACE:

```
MODULE UValbedo_Mod
```

USES:

```
USE Precision_Mod    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: Get_UValbedo
```

REMARKS:

```
References:
============================================================================
Herman, J.R and Celarier, E.A., "Earth surface reflectivity climatology
  at 340-380 nm from TOMS data", __J. Geophys. Res__, Vol. 102, D23,
  pp. 28003-28011, Dec 20, 1997.
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
 19 Apr 2002 - R. Yantosca - Initial version
(1 ) Now read uvalbedo file directly from DATA_DIR/uvalbedo_200111
      subdirectory.  (bmy, 4/2/02)
(2 ) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
      MODULE ROUTINES sections. (bmy, 5/28/02)
(3 ) Now references "error_mod.f" (bmy, 10/15/02)
(4 ) Minor modification in READ_UVALBEDO (bmy, 3/14/03)
(5 ) Now references "directory_mod.f" (bmy, 7/20/04)
(6 ) Bug fix for GCAP grid in READ_UVALBEDO (bmy, 8/16/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
24 Nov 2014 - M. Yannetti - Added PRECISION_MOD
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
12 Jan 2015 - R. Yantosca - Remove CLEANUP_UVALBEDO routine
04 Mar 2015 - R. Yantosca - UV albedo data now comes via HEMCO
```

7.5.1 get_uvalbedo

Copies the UV Albedo data from the HEMCO data structure into the State_Met derived type object.

INTERFACE:

```
SUBROUTINE Get_UValbedo( am_I_root, Input_Opt, State_Met, RC )
```

USES:

```
USE ErrCode_Mod
USE Error_Mod,          ONLY : Error_Stop
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

7.5.2 set_prof_o3

Subroutine SET_PROF_O3 sets up atmospheric profiles required by RRTMG in the stratosphere using a doubled version of the level scheme used in the CTM. First pressure and z* altitude are defined, then O3 and T are taken from the supplied climatology and integrated to the CTM levels (may be overwritten with values directly from the CTM, if desired). This is a stripped down version of SET_PROF; it does O3 only.

INTERFACE:

```
 SUBROUTINE SET_PROF_O3( YLAT,     MONTH,   DAY,      T_CTM,
&                        P_CTM,    O3_CTM,  O3_TOMS,  T_CLIM,
&                        O3_CLIM,  Z_CLIM,  AIR_CLIM, Input_Opt )
```

USES:

```
      USE CMN_FJX_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants            ! Physical constants
      USE PRECISION_MOD            ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)       :: YLAT             ! Latitude (degrees)
      INTEGER,  INTENT(IN)       :: MONTH            ! Month
      INTEGER,  INTENT(IN)       :: DAY              ! Day *of month*
      REAL(fp), INTENT(IN)       :: T_CTM(L1_)       ! CTM temperatures (K)
      REAL(fp), INTENT(IN)       :: O3_TOMS          ! O3 column (DU)
      REAL(fp), INTENT(IN)       :: P_CTM(L1_+1)     ! CTM edge pressures (hPa)
      REAL(fp), INTENT(IN)       :: O3_CTM(L1_)      ! CTM ozone (molec/cm3)
      TYPE(OptInput), INTENT(IN) :: Input_Opt        ! Input options
   !OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT)      :: T_CLIM(L1_)      ! Clim. temperatures (K)
      REAL(fp), INTENT(OUT)      :: Z_CLIM(L1_+1)    ! Edge altitudes (cm)
      REAL(fp), INTENT(OUT)      :: O3_CLIM(L1_)     ! O3 column depth (#/cm2)
      REAL(fp), INTENT(OUT)      :: AIR_CLIM(L1_)    ! O3 column depth (#/cm2)
```

AUTHOR:

```
    Oliver Wild & Michael Prather
```

REMARKS:

REVISION HISTORY:

```
    01 Jun 1996 - M. Prather & O. Wild - Initial version
    (1 ) Since we parallelize over columns, T, ODCOL, OPTDUST, and OPTAER
         are 1-D vectors. In the original code from Oliver Wild, these were
         3-D arrays.  Also P and SA are just scalars since we just pass one
         surface location at a time w/in the parallel loop. (bmy, 9/13/99)
    (2 ) Mineral dust profiles are also constructed (rvm, 06/04/00)
    (3 ) Other aerosol profiles are also constructed (rvm, bmy, 2/27/02)
    (4 ) Added NLON, NLAT, DAY to the arg list.  Now weight the O3 column by
         the observed monthly mean EP-TOMS data.  Also updated comments and
         added standard GEOS-CHEM documentation header. (mje, bmy, 7/13/03)
    (5 ) We don't need to initialize the PJ array with ETAA and ETAB anymore.
         PJ is now defined in "fast_j.f".  Updated comments. (bmy, 10/30/07)
    (6 ) Modified to use GEOS-5 O3 columns when TOMS/SBUV data don't exist,
         i.e. after 2008. (ccc, 7/13/09)
    08 Dec 2009 - R. Yantosca - Added ProTeX headers
    15 Dec 2014 - M. Sulprizio- Modified for Fast-JX. Now consistent with
```

```
                              subroutine SET_PROF in fast_jx_mod.F.
20 Mar 2015 - M. Sulprizio- Modified for flexible precision
05 Jan 2016 - E. Lundgren - Use global physical parameters
```

7.6 Fortran: Module Interface toms_mod.F

Module TOMS_MOD contains variables and routines for reading the TOMS/SBUV O3 column data from disk (for use w/ the FAST-J photolysis routines).

INTERFACE:

```
MODULE TOMS_MOD
```

USES:

```
USE CMN_SIZE_MOD     ! Size parameters
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: INIT_TOMS
PUBLIC :: READ_TOMS
PUBLIC :: COMPUTE_OVERHEAD_O3
PUBLIC :: GET_OVERHEAD_O3
PUBLIC :: CLEANUP_TOMS
```

PUBLIC DATA MEMBERS:

```
! First & last years for which TOMS/SBUV data is is available
! (update these as new data is added to the archive)
INTEGER, PUBLIC, PARAMETER :: FIRST_TOMS_YEAR = 1979
INTEGER, PUBLIC, PARAMETER :: LAST_TOMS_YEAR  = 2010
```

REMARKS:

```
References:
============================================================================
Version 8 Merged Ozone Data Sets
Total Ozone Revision 05
DATA THROUGH: MAR 2009
LAST MODIFIED: 01 MAY 2009
                                                                            .
http://acdb-ext.gsfc.nasa.gov/Data_services/merged/index.html
                                                                            .
TOMS/SBUV MERGED TOTAL OZONE DATA, Version 8, Revision 5.
Resolution:  5 x 10 deg.
                                                                            .
```

```
* Includes reprocessed N16 and N17 SBUV/2 data using latest calibration.
* OMI data updated from Collection 2 to Collection 3.
* New offsets derived based on revised data sets.
* 1970-1972 N4 BUV data added with no adjustments. User may wish to apply
  offset based on Comparisons between BUV and Dobson Measurements.
                                                                             .
Responsible NASA official:
Dr. Richard Stolarski (Richard.S.Stolarski@nasa.gov)
Stacey Frith          (Stacey.M.Frith@nasa.gov     )
```

REVISION HISTORY:

```
14 Jul 2003 - R. Yantosca - Initial version
(1 ) Now references "directory_mod.f" (bmy, 7/20/04)
(2 ) Now can read files for GEOS or GCAP grids (bmy, 8/16/05)
(3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4 ) Now always use 2002 TOMS O3 data for GCAP (swu, bmy, 10/3/06)
(5 ) Now reads from TOMS_200701 directory, w/ updated data (bmy, 2/1/07)
(6 ) Now don't replace any tokens in the DATA_DIR variable (bmy, 12/5/07)
(7 ) Latest year of TOMS data is now 2007 (bmy, 1/14/09)
01 Dec 2010 - R. Yantosca - Added ProTeX headers
06 Mar 2012 - R. Yantosca - Added function GET_TOTAL_O3
06 Mar 2012 - R. Yantosca - Added parameters FIRST_TOMS_YEAR, LAST_TOMS_YEAR
06 Mar 2012 - R. Yantosca - Updated comments
06 Mar 2012 - R. Yantosca - Now make TOMS, DTOMS1, DTOMS2 arrays PRIVATE
06 Mar 2012 - R. Yantosca - Add TO3_DAILY as a PRIVATE module array
25 Jun 2012 - S. Kim      - Now reads from TOMS_201203 directory, w/
                            updated data
03 Jul 2012 - R. Yantosca - Restrict reading from TOMS_201203 directory
                            to GEOS-5.7.2 met data for the time being.
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
21 Nov 2014 - M. Yannetti - Added PRECISION_MOD
16 Mar 2015 - R. Yantosca - Retire bpch input; now read TOMS via HEMCO
03 Nov 2016 - B. Henderson- Added fix for weird O3 in GEOS-5 simulations
```

7.6.1 read_toms

Subroutine READ_TOMS reads in TOMS O3 column data from a binary punch file for the given grid, month and year.

INTERFACE:

```
SUBROUTINE READ_TOMS( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE Error_Mod,          ONLY : Error_Stop
```

```
      USE HCO_Interface_Mod,  ONLY : HcoState
      USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
    TOMS/SBUV MERGED TOTAL OZONE DATA, Version 8, Revision 5.
    Resolution:  5 x 10 deg.

                                                                             .
    Methodology
    ---------------------------------------------------------------------------
    FAST-J comes with its own default O3 column climatology (from McPeters
    1992 & Nagatani 1991), which is stored in the input file "jv_atms.dat".
    These "FAST-J default" O3 columns are used in the computation of the
    actinic flux and other optical quantities for the FAST-J photolysis.

                                                                             .
    The TOMS/SBUV O3 columns and 1/2-monthly O3 trends (contained in the
    TOMS_200906 directory) are read into GEOS-Chem by routine READ_TOMS in
    "toms_mod.f".  Missing values (i.e. locations where there are no data)
    in the TOMS/SBUV O3 columns are defined by the flag -999.

                                                                             .
    After being read from disk in routine READ_TOMS, the TOMS/SBUV O3 data
    are then passed to the FAST-J routine "set_prof.F".  In "set_prof.F", a
    test is done to make sure that the TOMS/SBUV O3 columns and 1/2-monthly
    trends do not have any missing values for (lat,lon) location for the given
    month.  If so, then the TOMS/SBUV O3 column data is interpolated to the
    current day and is used to weight the "FAST-J default" O3 column.  This
    essentially "forces" the "FAST-J default" O3 column values to better match
    the observations, as defined by TOMS/SBUV.

                                                                             .
    If there are no TOMS/SBUV O3 columns (and 1/2-monthly trends) at a (lat,
    lon) location for given month, then FAST-J will revert to its own "default"
    climatology for that location and month.  Therefore, the TOMS O3 can be
    thought of as an  "overlay" data -- it is only used if it exists.

                                                                             .
    Note that there are no TOMS/SBUV O3 columns at the higher latitudes.
    At these latitudes, the code will revert to using the "FAST-J default"
    O3 columns.

                                                                             .
    As of March 2012, we have TOMS/SBUV data for 1979 thru 2008.  We will
    update to the latest TOMS/SBUV data set shortly.
```

```
This methodology was originally adopted by Mat Evans.

#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (05 Mar 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
10 Dec 2002 - M. Evans - Initial version
(1 ) Bundled into "toms_mod.f" (bmy, 7/14/03)
(2 ) Now references DATA_DIR from "directory_mod.f" (bmy, 7/20/04)
(3 ) Now can read files for GEOS or GCAP grids (bmy, 8/16/05)
(4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(5 ) Now always use 2002 TOMS O3 data for GCAP (swu, bmy, 10/3/06)
(6 ) Now reads from TOMS_200701 directory, w/ updated data.  Also always
     use 1979 data prior to 1979 or 2005 data after 2005. (bmy, 2/12/07)
(7 ) Bug fix: don't include DATA_DIR in filename, just in case someone's
     file path has replaceable tokens (e.g. hh, mm, MM etc.) (bmy, 12/5/07)
(8 ) Latest year of TOMS data is now 2007 (bmy, 1/14/09)
(9 ) Updated TOMS data in TOMS_200906. Latest year is 2008. (ccc, 6/15/09)
08 Dec 2009 - R. Yantosca - Added ProTeX headers
03 Jul 2012 - R. Yantosca - Restrict reading from TOMS_201203 directory
                            to GEOS-5.7.2 met data for the time being.
13 Dec 2013 - M. Sulprizio- Now pass USE_O3_FROM_MET logical flag so that
                            we bypass reading TOMS O3 data when using TO3
                            from the met fields.
05 Mar 2014 - M. Sulprizio- Now regrid TOMS O3 from the files on GEOS 1x1
                            grid (J. Lin)
20 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
23 Jun 2014 - R. Yantosca - Now use Input_Opt%DATA_DIR_1x1
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
05 Mar 2015 - R. Yantosca - Now read data w/r/t ExtData/CHEM_INPUTS
```

7.6.2 compute_overhead_o3

Subroutine COMPUTE_OVERHEAD_O3 returns the resultant total overhead O3 column for the FAST-J photolysis. This will be one of two options:

1. Default: TOMS/SBUV overhead O3 columns. These will be used be the FAST-J routine set_prof.F to overwrite the existing FAST-J climatology (cf McPeters & Nagatani 1992). Missing data (i.e. for months & locations where TOMS/SBUV data does not exist) is denoted by the value -999; FAST-J will skip over these points.
2. Overhead O3 columns taken directly from the met fields. These will be returned if the flag USE_O3_FROM_MET is set to TRUE.

INTERFACE:

```
      SUBROUTINE COMPUTE_OVERHEAD_O3( am_I_Root,       DAY,
     &                                USE_O3_FROM_MET, TO3 )
```

INPUT PARAMETERS:

```
      ! Root CPU?
      LOGICAL, INTENT(IN)  :: am_I_Root

      ! Day of month
      INTEGER, INTENT(IN)  :: DAY

      ! Switch to denote if we should use the default TO3
      ! directly from the met fields
      LOGICAL, INTENT(IN)  :: USE_O3_FROM_MET

      ! TO3 from the met fields [Dobsons]
      REAL(fp),  INTENT(IN)  :: TO3(IIPAR,JJPAR)
```

REMARKS:

```
   Reference for the TOMS/SBUV merged O3 columns:
                                                                             .
   1985 - 2005 are taken from:
                                                                             .
     http://code916.gsfc.nasa.gov/Data_services/merged/index.html
                                                                             .
     TOMS/SBUV MERGED TOTAL OZONE DATA, Version 8, Revision 3.
     Resolution:  5 x 10 deg.
                                                                             .
     Contact person for the merged data product:
     Stacey Hollandsworth Frith (smh@hyperion.gsfc.nasa.gov)
                                                                             .
   2006 and 2007 are taken from:
                                                                             .
      http://code916.gsfc.nasa.gov/Data_services/merged/index.html
                                                                             .
      Version 8 Merged Ozone Data Sets
      Revision 04
      DATA THROUGH: SEP 2008
      LAST MODIFIED: 20 OCT 2008
                                                                             .
    Methodology (bmy, 2/12/07)
    ---------------------------------------------------------------
    FAST-J comes with its own default O3 column climatology (from
    McPeters 1992 & Nagatani 1991), which is stored in the input
    file "jv_atms.dat".  These "FAST-J default" O3 columns are used
    in the computation of the actinic flux and other optical
    quantities for the FAST-J photolysis.
```

```
The TOMS/SBUV O3 columns and 1/2-monthly O3 trends (contained
in the TOMS_200701 directory) are read into GEOS-Chem by routine
READ_TOMS in "toms_mod.f".  Missing values (i.e. locations where
there are no data) in the TOMS/SBUV O3 columns are defined by
the flag -999.

After being read from disk in routine READ_TOMS, the TOMS/SBUV
O3 data are then passed to the FAST-J routine "set_prof.f".  In
"set_prof.f", a test is done to make sure that the TOMS/SBUV O3
columns and 1/2-monthly trends do not have any missing values
for (lat,lon) location for the given month.  If so, then the
TOMS/SBUV O3 column data is interpolated to the current day and
is used to weight the "FAST-J default" O3 column.  This
essentially "forces" the "FAST-J default" O3 column values to
better match the observations, as defined by TOMS/SBUV.

If there are no TOMS/SBUV O3 columns (and 1/2-monthly trends)
at a (lat,lon) location for given month, then FAST-J will revert
to its own "default" climatology for that location and month.
Therefore, the TOMS O3 can be thought of as an  "overlay" data
-- it is only used if it exists.

Note that there are no TOMS/SBUV O3 columns at the higher
latitudes.  At these latitudes, the code will revert to using
the "FAST-J default" O3 columns.

As of February 2007, we have TOMS/SBUV data for 1979 thru 2005.
2006 TOMS/SBUV data is incomplete as of this writing.  For years
2006 and onward, we use 2005 TOMS O3 columns.

This methodology was originally adopted by Mat Evans.  Symeon
Koumoutsaris was responsible for creating the downloading and
processing the TOMS O3 data files from 1979 thru 2005 in the
TOMS_200701 directory.
```

REVISION HISTORY:

```
06 Mar 2012 - R. Yantosca - Initial version, pulled code out from
                            the FAST-J routine SET_PROF; based on the
                            GEOS-Chem column code routine
22 Oct 2014 - C. Keller   - Added am_I_Root parameter.
```

7.6.3 get_overhead_o3

Function GET_OVERHEAD_O3 returns the total overhead O3 column [DU] (which is taken either from TOMS/SBUV or directly from the met fields) at a given surface grid box location (I,J).

INTERFACE:

```
FUNCTION GET_OVERHEAD_O3( I, J ) RESULT( OVERHEAD_O3 )
```

INPUT PARAMETERS:

```
INTEGER :: I             ! Grid box longitude index
INTEGER :: J             ! Grid box latitude index
```

RETURN VALUE:

```
REAL(fp)  :: OVERHEAD_O3   ! Total overhead O3 column [DU]
```

REVISION HISTORY:

```
06 Mar 2012 - R. Yantosca - Initial version
```

7.6.4 init_toms

Subroutine INIT_TOMS allocates and zeroes all module arrays.

INTERFACE:

```
SUBROUTINE INIT_TOMS( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root  ! root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input opts
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC         ! Failure or success
```

REVISION HISTORY:

```
14 Jul 2003 - R. Yantosca - Initial version
01 Dec 2010 - R. Yantosca - Added ProTeX headers
06 Mar 2012 - R. Yantosca - Now allocate TO3_DAILY
16 Mar 2015 - R. Yantosca - TOMS, DTOMS1, DTOMS2 are now pointers
16 Mar 2015 - R. Yantosca - Add Input_Opt, RC arguments for std interface
03 Nov 2016 - B. Henderson- Add extra fields to fix OH issue for GEOS-5
```

7.6.5 cleanup_toms

Subroutine CLEANUP_TOMS deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_TOMS
```

REVISION HISTORY:

```
14 Jul 2003 - R. Yantosca - Initial version
01 Dec 2010 - R. Yantosca - Added ProTeX headers
06 Mar 2012 - R. Yantosca - Now deallocate TO3_DAILY
03 Nov 2016 - R. Yantosca - Deallocate and nullify extra fields
```

7.7 Fortran: Module Interface flexchem_mod.F90

Module FlexChem_Mod contines arrays and routines for the FlexChem chemical solver.

INTERFACE:

```
MODULE FlexChem_Mod
```

USES:

```
USE Precision_Mod            ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: Do_FlexChem
PUBLIC :: Init_FlexChem
PUBLIC :: Cleanup_FlexChem
```

REVISION HISTORY:

```
14 Dec 2015 - M.S. Long   - Initial version
15 Jun 2016 - M. Sulprizio- Remove STTTOCSPEC mapping array. Species and
                            tracers have a 1:1 mapping currently so mapping
                            is not required
18 Jul 2016 - M. Sulprizio- Remove FAMILIES_KLUDGE routine. Family tracers
                            have been eliminated.
24 Aug 2016 - M. Sulprizio- Rename from flexchem_setup_mod.F90 to
                            flexchem_mod.F90
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

7.7.1 do_flexchem

Subroutine Do_FlexChem is the driver subroutine for full chemistry with KPP.

INTERFACE:

```
  SUBROUTINE Do_FlexChem( am_I_Root, Input_Opt, State_Met, State_Chm, RC  )
```

USES:

```
    USE AEROSOL_MOD,          ONLY : SOILDUST, AEROSOL_CONC, RDAER
    USE CHEMGRID_MOD,         ONLY : ITS_IN_THE_CHEMGRID
    USE CMN_FJX_MOD
    USE CMN_SIZE_MOD,         ONLY : IIPAR, JJPAR, LLPAR
    USE DIAG_MOD,             ONLY : AD65
    USE DIAG_OH_MOD,          ONLY : DO_DIAG_OH
    USE DIAG20_MOD,           ONLY : DIAG20, POx, LOx
    USE DUST_MOD,             ONLY : RDUST_ONLINE, RDUST_OFFLINE
    USE ErrCode_Mod
    USE ERROR_MOD
    USE FAST_JX_MOD,          ONLY : PHOTRATE_ADJ, FAST_JX
    USE FUTURE_EMISSIONS_MOD, ONLY : GET_FUTURE_YEAR
    USE GCKPP_HetRates,       ONLY : SET_HET
    USE GCKPP_Monitor,        ONLY : SPC_NAMES, FAM_NAMES
    USE GCKPP_Parameters
    USE GCKPP_Integrator,     ONLY : INTEGRATE, NHnew
    USE GCKPP_Function
    USE GCKPP_Model
    USE GCKPP_Global
    USE GCKPP_Rates,          ONLY : UPDATE_RCONST, RCONST
    USE GCKPP_Initialize,     ONLY : Init_KPP => Initialize
    USE GC_GRID_MOD,          ONLY : GET_YMID
    USE Input_Opt_Mod,        ONLY : OptInput
    USE PhysConstants,        ONLY : AVO
    USE PRESSURE_MOD
    USE Species_Mod,          ONLY : Species
    USE State_Chm_Mod,        ONLY : ChmState
    USE State_Chm_Mod,        ONLY : Ind_
    USE State_Met_Mod,        ONLY : MetState
    USE TIME_MOD,             ONLY : GET_TS_CHEM
    USE TIME_MOD,             ONLY : GET_MONTH
    USE TIME_MOD,             ONLY : GET_YEAR
    USE UnitConv_Mod
#if defined( UCX )
    USE UCX_MOD,              ONLY : CALC_STRAT_AER
    USE UCX_MOD,              ONLY : SO4_PHOTFRAC
    USE UCX_MOD,              ONLY : UCX_NOX
    USE UCX_MOD,              ONLY : UCX_H2SO4PHOT
#endif
#if   defined( TOMAS )
```

```
    USE TOMAS_MOD,            ONLY : H2SO4_RATE
#endif
```

INPUT PARAMETERS:

```
    LOGICAL,        INTENT(IN)    :: am_I_Root  ! Is this the root CPU?
    TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
    TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
    TYPE(ChmState), INTENT(INOUT) :: State_Chm  ! Chemistry State object
```

OUTPUT PARAMETERS:

```
    INTEGER,        INTENT(OUT)   :: RC         ! Success or failure
```

REVISION HISTORY:

```
    14 Dec 2015 - M.S. Long   - Initial version
    18 Dec 2015 - M. Sulprizio- Add calls to OHSAVE and DO_DIAG_OH
    22 Dec 2015 - M. Sulprizio- Set NUMDEN to State_Met%AIRNUMDEN for conversions
                                between v/v and molec/cm3
    28 Mar 2016 - R. Yantosca - Added several fixes for OpenMP parallelization
    30 Mar 2016 - R. Yantosca - Bug fix, now make sure to copy C back into
                                State_Chm%Species.  Also block out temp diags.
    16 May 2016 - M. Sulprizio- Remove call to RURALBOX. The implememention of
                                FlexChem has rendered the routine obsolete.
    31 May 2016 - E. Lundgren - Use species database MW instead of XNUMOL
    06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies and
                                NAMEGAS with SpcInfo%Name from species database
    14 Jun 2016 - M. Sulprizio- Replace loops over N_TRACERS with loops over
                                State_Chm%nSpecies and add checks for Is_Advected
                                and Is_Kpp to avoid introducing numerical noise
                                by applying unit conversions to non-KPP species
    16 Jun 2016 - M. Sulprizio- Now define IDTCH4 locally
    20 Jun 2016 - R. Yantosca - Renamed IDTCH4 to id_CH4 for consistency
    18 Jul 2016 - M. Sulprizio- Remove calls to FAMILIES_KLUDGE. Family tracers
                                have been eliminated. Also simplify code to copy
                                to/from STT so that unit conversions to/from
                                molec/cm3 are done in the same step as the copy.
    02 Aug 2016 - M. Sulprizio- Connect production and loss rates from KPP to
                                ND65 diagnostic
    16 Aug 2016 - E. Lundgren - Remove all references to tracers, including
                                STT and Input_Opt%N_TRACERS, and use routines in
                                unitconv_mod.F for species kg <-> molec/cm3
    24 Aug 2016 - M. Sulprizio- Replace CSPECTOKPP with State_Chm%Map_KppSpc
    24 Aug 2016 - M. Sulprizio- Move this subroutine to flexchem_mod.F90 and
                                rename from FLEX_CHEMDR to Do_FlexChem
    22 Sep 2016 - R. Yantosca - Add extra debug printout after FAST_JX
    14 Nov 2016 - E. Lundgren - Move UCX calls to after spc conversion to kg
```

7.7.2 init_flexchem

Subroutine Init_FlexChem is used to allocate arrays for the KPP solver.

INTERFACE:

```
SUBROUTINE Init_FlexChem( am_I_Root, Input_Opt, RC)
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE gckpp_Global,       ONLY : NREACT
USE gckpp_Monitor,      ONLY : EQN_NAMES
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC        ! Success or failure?
```

REVISION HISTORY:

```
14 Dec 2015 - M.S. Long   - Initial version
22 Dec 2015 - M. Sulprizio- Use State_Met%AIRNUMDEN to convert initial
                            species concentrations from v/v to molec/cm3
29 Jan 2016 - M. Sulprizio- Add calls to Register_Tracer and Register_Species
                            to populate Tracer_Name, Tracer_Id, Species_Name,
                            and Species_ID fields in State_Chm
06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies and
                            NAMEGAS with SpcInfo%Name from species database
06 Jun 2016 - M. Sulprizio- Replace Get_Indx with Spc_GetIndx to use the
                            fast-species lookup from the species database
06 Jun 2016 - M. Sulprizio- Remove calls to Register_Tracer and
                            Register_Species; these routines were made
                            obsolete by the species database
14 Jun 2016 - M. Sulprizio- Replace Spc_GetIndx with Ind_ (M. Long)
25 Jul 2016 - E. Lundgren - Add check that species was not in restart file
                            prior to v/v -> molec/cm3 conversion
02 Aug 2016 - E. Lundgren - Move unit conversion of species background
                            values to restart_mod
24 Aug 2016 - M. Sulprizio- Remove CSPECTOKPP array. State_Chm%Map_KppSpc is
                            now used instead.
20 Sep 2016 - R. Yantosca - Use fixed integer with in WRITE statement
```

7.7.3 cleanup_flexchem

Subroutine Cleanup_FlexChem deallocate module variables.

INTERFACE:

```
SUBROUTINE Cleanup_FlexChem()
```

REVISION HISTORY:

```
24 Aug 2016 - M. Sulprizio- Initial version
```

7.8 Fortran: Module Interface gckpp_HetRates

FlexChem module for heterogeneous chemistry, via KPP.

INTERFACE:

```
MODULE GCKPP_HETRATES
```

USES:

```
USE CMN_FJX_MOD,        ONLY : NDUST
USE CMN_FJX_MOD,        ONLY : NAER
USE CMN_SIZE_MOD,       ONLY : LLSTRAT
USE PHYSCONSTANTS,      ONLY : CONSVAP
USE ERROR_MOD,          ONLY : ERROR_STOP
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE ERROR_MOD,          ONLY : IS_SAFE_DIV
USE gckpp_Precision
USE gckpp_Parameters
USE gckpp_Global,       ONLY : HET
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE State_Met_Mod,      ONLY : MetState
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AVO
USE Precision_Mod,      ONLY : fp

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: SET_HET
```

PRIVATE MEMBER FUNCTIONS:

```
! These functions are used for all mechanisms
PRIVATE :: HETNO3
```

```
  PRIVATE :: HETNO2
  PRIVATE :: HETHO2
  PRIVATE :: HETHBr
  PRIVATE :: HETN2O5
  PRIVATE :: HETBrNO3
  PRIVATE :: HETHOBr
  PRIVATE :: HETHOBr_ice
  PRIVATE :: HETHBr_ice
  PRIVATE :: N2O5
  PRIVATE :: HO2
  PRIVATE :: CLD1K_BrNO3
  PRIVATE :: FCRO2HO2
  PRIVATE :: FYHORO
  PRIVATE :: FYRNO3
  PRIVATE :: ARSL1K

#if defined( UCX )
  ! These functions are only used for UCX-based mechanisms
  PRIVATE :: HETClNO3_PSC1
  PRIVATE :: HETClNO3_PSC2
  PRIVATE :: HETClNO3_PSC3
  PRIVATE :: HETBrNO3_PSC
  PRIVATE :: HETHOCl_PSC1
  PRIVATE :: HETHOCl_PSC2
  PRIVATE :: HETHOBr_PSC
  PRIVATE :: HETN2O5_PSC
#endif
  !PRIVATE DATA MEMBERS:
  ! Scalars
  INTEGER  :: NAERO
  LOGICAL  :: NATSURFACE,   PSCBOX,    STRATBOX
  REAL(fp) :: TEMPK,        RELHUM,    SPC_SO4
  REAL(fp) :: SPC_NIT,      GAMMA_HO2, XTEMP,   XDENA
  REAL(fp) :: CLD_BRNO3_RC, KI_HBR,    KI_HOBr, QLIQ
  REAL(fp) :: QICE

  ! Arrays
  REAL(fp) :: SCF2(3)
  REAL(fp) :: XAREA(25)
  REAL(fp) :: XRADI(25)
  REAL(fp) :: KHETI_SLA(11)

 $OMP THREADPRIVATE( NAERO,        NATSURFACE, PSCBOX,   STRATBOX )
 $OMP THREADPRIVATE( TEMPK,        RELHUM,     SPC_NIT,  SPC_SO4  )
 $OMP THREADPRIVATE( GAMMA_HO2,    XTEMP,      XDENA              )
 $OMP THREADPRIVATE( CLD_BRNO3_RC, KI_HBR,     KI_HOBr,  QLIQ     )
 $OMP THREADPRIVATE( QICE,         SCF2,       XAREA,    XRADI    )
 $OMP THREADPRIVATE( KHETI_SLA                                    )
```

DEFINED PARAMETERS:

```
REAL(fp), PARAMETER :: PSCMINLIFE = 1.e-3_fp
```

REMARKS:

```
Need
- TOTAREA (previously used for archiving N2O5 hydrolysis in the planeflight
          diagnostic only)
- Air NUM. DENSITY
- TEMPERATURE
- Aerosol Surface Area
- Aerosol Type
- Gamma (XSTKCF; sticking factor)
- ARR
- Species num density (mcl cm-3)
- Continental PBL or no?
- In stratosphere or no?
- Reaction index (e.g. NK1HBr, NK2HBr)
According to S. Eastham, we should also include
cloud and ice area explicitly, in addition to
aerosol area
```

REVISION HISTORY:

```
14 Dec 2015 - M. Long     - Initial version
29 Jan 2016 - M. Sulprizio- Update to include heterogeneous chemistry for
                            UCX mechanism
29 Mar 2016 - R. Yantosca - NOTE: SPC_HBR and SPC_HOBR are defined
                            for trop-only mechanisms
29 Mar 2016 - R. Yantosca - Added ProTeX headers
29 Mar 2016 - R. Yantosca - Moved all the UCX-based functions to the
                            end of the module, for clarity
01 Apr 2016 - R. Yantosca - Remove many global variables that can be
                            declared locally from the THREADPRIVATEs
06 Jun 2016 - M. Sulprizio- Replace Get_Indx with Spc_GetIndx to use the
                            fast-species lookup from the species database
14 Jun 2016 - M. Sulprizio- Replace Spc_GetIndx with Ind_
```

7.8.1 Set_Het

Main heterogenous chemistry driver routine. Sets up the vector of heterogeneous chemistry rates for the KPP chemistry solver.

INTERFACE:

```
SUBROUTINE SET_HET( I, J, L, SC, SM, IO, SCF )
```

INPUT PARAMETERS:

```
INTEGER        :: I, J, L   ! Lon, lat, level indices
TYPE(MetState) :: SM        ! Meteorology State object
TYPE(OptInput) :: IO        ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState) :: SC        ! Chemistry Sate object
REAL(fp)       :: SCF(3)    ! Coefficients (Need help documenting this)
```

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
01 Apr 2016 - R. Yantosca - Define many variables locally that don't
                            need to be in the THREADPRIVATE statements
01 Apr 2016 - R. Yantosca - Remove KII_KI; we now declare that locally
31 May 2016 - E. Lundgren - Replace IO%XNUMOL with emMW_g from species
                            database (emitted species g/mol)
```

7.8.2 HetNO3

Set the heterogenous chemistry rate for NO3.

INTERFACE:

```
FUNCTION HETNO3( A, B ) RESULT( HET_NO3 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_NO3
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.3 HetNO2

Set the heterogenous chemistry rate for NO2.

INTERFACE:

```
FUNCTION HETNO2( A, B ) RESULT( HET_NO2 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_NO2
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.4 HetHO2

Set the heterogenous chemistry rate for HO2.

INTERFACE:

```
FUNCTION HETHO2( A, B ) RESULT( HET_HO2 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HO2
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX headers
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.5 HetHBr

Set the heterogeneous rate for HBr.

INTERFACE:

```
FUNCTION HETHBr( A, B ) RESULT( HET_HBr )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HBr
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX headers
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Define local variable for educt adjustment
```

7.8.6 HetN2O5

Set heterogenous chemistry rate for N2O5.

INTERFACE:

```
FUNCTION HETN2O5( A, B ) RESULT( HET_N2O5 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_N2O5
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.7 HetBrNO3

Sets the heterogenous chemistry rate for BrNO3.

INTERFACE:

```
FUNCTION HETBrNO3( A, B ) RESULT( HET_BrNO3 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_BrNO3
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.8 HetHOBr

Sets the heterogenous chemistry rate for HOBr.

INTERFACE:

```
FUNCTION HETHOBr( A, B ) RESULT( HET_HOBr )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HOBr
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
```

7.8.9 HetHOBr_Ice

Sets the heterogenous chemistry rate for HOBr (on ice).

INTERFACE:

```
FUNCTION HETHOBr_ice( A, B ) RESULT( HET_HObr_ice )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HObr_ice
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
```

7.8.10 HetBr_Ice

Sets the heterogenous chemistry rate for HBr (on ice).

INTERFACE:

```
FUNCTION HETHBr_ice( A, B ) RESULT( HET_HBr_ice )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
!RETURN VALUE
REAL(fp)             :: HET_HBr_ice
```

REMARKS:

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX header
```

7.8.11 N2O5

Internal function N2O5 computes the GAMMA sticking factor for N2O5 hydrolysis. (mje, bmy, 8/7/03)

INTERFACE:

```
FUNCTION N2O5( AEROTYPE, TEMP, RH ) RESULT( GAMMA )
```

INPUT PARAMETERS:

```
INTEGER,   INTENT(IN) :: AEROTYPE  ! Denoting aerosol type (cf FAST_JX)
REAL(fp),  INTENT(IN) :: TEMP      ! Temperature [K]
REAL(fp),  INTENT(IN) :: RH        ! Relative humidity [1]
```

RETURN VALUE:

```
REAL(fp)              :: GAMMA
```

REMARKS:

```
Taken from the old SMVGEAR function calcrate.F.
```

REVISION HISTORY:

```
29 Mar 2016 - R. Yantosca - Added ProTeX headers
```

7.8.12 HO2

Function HO2 computes the GAMMA reaction probability for HO2 loss in aerosols based on the recommendation of Thornton, Jaegle, and McNeill, "Assessing Known Pathways For HO2 Loss in Aqueous Atmospheric Aerosols: Regional and Global Impacts on Tropospheric Oxidants" J. Geophys. Res., doi:10.1029/2007JD009236, 2008

INTERFACE:

```
FUNCTION HO2( RADIUS,          TEMP,     DENAIR,       &
              SQM,             HO2DENS,  AEROTYPE,     &
              CONTINENTAL_PBL, Input_Opt            )  &
              RESULT( GAMMA )
```

USES:

```
USE Input_Opt_Mod, ONLY : OptInput
```

INPUT PARAMETERS:

```
! Arguments
REAL(fp),       INTENT(IN) :: RADIUS          ! Aerosol radius [cm]
REAL(fp),       INTENT(IN) :: TEMP            ! Temperature [K]
REAL(fp),       INTENT(IN) :: DENAIR          ! Air density [molec/cm3]
```

```
      REAL(fp),       INTENT(IN) :: HO2DENS         ! HO2 density [molec/cm3]
      REAL(fp),       INTENT(IN) :: SQM             ! Square root of MW [g/mol]
      INTEGER,        INTENT(IN) :: AEROTYPE        ! Aerosol type (cf FAST-JX)
      INTEGER,        INTENT(IN) :: CONTINENTAL_PBL ! Flag set to 1 if the box
                                                    !  box is located in the
                                                    !  continenal boundary
                                                    !  layer, otherwise 0.
                                                    !  Also check for ICE/SNOW
                                                    !  (to disable this at
                                                    !  high latitudes).
      TYPE(OptInput), INTENT(IN) :: Input_Opt       ! Input Options object
```

RETURN VALUE:

```
      REAL(fp)                   :: GAMMA           ! Reaction probability
```

REMARKS:

```
    Taken from the old SMVGEAR routine calcrate.F.
    Gamma(HO2) is a function of aerosol type, radius, temperature.

    eferences:
    ------------------------------------------------------------
    (1) Jacob, D.J., Heterogeneous chemistry and tropospheric ozone,
         Atmos. Environ., 34, 2131-2159, 2000. [full text (pdf)]
    (2) J. Mao, Fan, S., Jacob, D. J., and Travis, K. R.: Radical
         loss in the atmosphere from Cu-Fe redox coupling in aerosols,
         Atmos. Chem. Phys., 13, 509-519, doi:10.5194/acp-13-509-2013,
         2013.
```

REVISION HISTORY:

```
    17 May 2013 - M. Payer    - Add improved HO2 uptake (J. Mao)
    22 May 2013 - M. Payer    - Added option to read GAMMA_HO2 from
                                input.geos. Recommended value is 0.2
                                based on Jacob et al (2000) and Mao
                                et al. (2013).
    20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
    29 Mar 2016 - R. Yantosca - Added ProTeX headers
```

7.8.13 Cld1k_BrNO3

Function CLD1K_BrNO3 calculates the rate constant for heterogeneous cycling of BrNO3 off of cloud particles.

INTERFACE:

```
     FUNCTION CLD1K_BrNO3( I,      J,        L,   DENAIR,         &
                           QL,     State_Met )    RESULT( cld1k )
```

USES:

```
USE State_Met_Mod, ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I         ! Longitude index
INTEGER,        INTENT(IN) :: J         ! Latitude  index
INTEGER,        INTENT(IN) :: L         ! Altitude  index
REAL(fp),       INTENT(IN) :: DENAIR    ! Density of air [#/cm3]
REAL(fp),       INTENT(IN) :: QL        ! Cloud water mixing ratio [kg/kg]
TYPE(MetState), INTENT(IN) :: State_Met ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)              :: cld1k          ! Rate constant for
                                        ! heterogeneous cycling
                                        ! of BrNO3 off of cloud
                                        ! particles
```

REMARKS:

```
The rate constant for heterogeneous cycling of BrNO3 off of cloud particles
is calculated assuming:
                                                                             .
  1. A sticking coefficient of 0.3 [Yang et al. 2005]
  2. uniform cloud droplet size for 2 types of clouds
     - continental warm clouds: r =  6d-4 [cm]
     - marine warm clouds:      r = 10d-4 [cm]
     * no distributions are assumed
** Calculation of a 1st order rate constent barrowed from the
   subroutine arsl1k.f. Below are comments from that code:
                                                                             .
     The 1st-order loss rate on wet aerosol (Dentener's Thesis, p. 14)
     is computed as:
                                                                             .
       ARSL1K [1/s] = area / [ radius/dfkg + 4./(stkcf * nu) ]
                                                                             .
     where nu   = Mean molecular speed [cm/s] = sqrt(8R*TK/pi/M) for Maxwell
           DFKG = Gas phase diffusion coeff [cm2/s] (order of 0.1)
```

REVISION HISTORY:

```
27 Feb 2011 - J. Parrella - Initial version
22 May 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
```

7.8.14 FcrO2HO2

!fgap, based on saunder 2003 k14

INTERFACE:

```
FUNCTION FCRO2HO2( XCARBN ) RESULT( FC_RO2HO2 )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: XCARBN
```

RETURN VALUE:

```
REAL(fp)             :: FC_RO2HO2
```

REVISION HISTORY:

```
24 Jul 2014 - R. Yantosca - Now inlined to calcrate.F
```

7.8.15 FyHORO

Overview

Function FYHORO returns returns the branching ratio between HOC2H4O oxidation and dissociation: (1) HOC2H4 –O2–¿ HO2 + GLYC (2) HOC2H4 ——¿ HO2 + 2CH2O

References

1. Orlando et al., 1998: *Laboratory and theoretical study of the oxyradicals in the OH- and Cl-initiated oxidation of ethene*, J. Phys. Chem. A, **102**, 8116-8123.

2. Orlando et al., 2003: *The atmospheric chemistry of alkoxy radicals*, Chem. Rev., **103**, 4657-4689.

INTERFACE:

```
FUNCTION FYHORO( ZDNUM, TT ) RESULT( FY_HORO )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: ZDNUM   ! Air density   [molec/cm3 ]
REAL(fp), INTENT(IN) :: TT      ! Temperature   [K         ]
```

RETURN VALUE:

```
REAL(fp)             :: FY_HORO
```

REVISION HISTORY:

```
(1 ) Branching ratio calculation (tmf, 2/6/05).
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
25 Jul 2014 - R. Yantosca - Now inlined into calcrate.F
```

7.8.16 FyrNO3

Function FYRNO3 returns organic nitrate yields YN = RKA/(RKA+RKB) from RO2+NO reactions as a function of the number N of carbon atoms.

INTERFACE:

```
FUNCTION FYRNO3( XCARBN, ZDNUM, TT ) RESULT( FYR_NO3 )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: XCARBN   ! Number of C atoms in RO2
REAL(fp), INTENT(IN) :: ZDNUM    ! Air density   [molec/cm3 ]
REAL(fp), INTENT(IN) :: TT       ! Temperature   [K         ]
```

RETURN VALUE:

```
REAL(fp)             :: FYR_NO3
```

REVISION HISTORY:

```
(1 ) Original code from Larry Horowitz, Jinyou Liang, Gerry Gardner,
     and Daniel Jacob circa 1989/1990.
(2 ) Updated following Atkinson 1990.
(3 ) Change yield from Isoprene Nitrate (ISN2) from 0.44% to 12%,
     according to Sprengnether et al., 2002. (amf, bmy, 1/7/02)
(4 ) Eliminate obsolete code from 1/02 (bmy, 2/27/02)
(5 ) Updated comment description of XCARBN (bmy, 6/26/03)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
25 Jul 2014 - R. Yantosca - Now inlined into calcrate.F
```

7.8.17 Arsl1k

Function ARSL1K calculates the 1st-order loss rate of species on wet aerosol surface.

INTERFACE:

```
FUNCTION ARSL1K( AREA, RADIUS, DENAIR, STKCF, STK, SQM ) &
     RESULT( ARS_L1K )
```

INPUT PARAMETERS:

```
! Surface  area of wet aerosols/volume of air [cm2/cm3]
REAL(fp), INTENT(IN) :: AREA

! Radius of wet aerosol [cm], order of 0.01-10 um;
! Note that radius here is Rd, not Ro
REAL(fp), INTENT(IN) :: RADIUS

! Density of air [#/cm3]
```

```
      REAL(fp), INTENT(IN) :: DENAIR

      ! Sticking coefficient [unitless], order of 0.1
      REAL(fp), INTENT(IN) :: STKCF

      ! Square root of temperature [K]
      REAL(fp), INTENT(IN) :: STK

      ! Square root of molecular weight [g/mole]
      REAL(fp), INTENT(IN) :: SQM
```

RETURN VALUE:

```
      REAL(fp)             :: ARS_L1K
```

REMARKS:

```
   The 1st-order loss rate on wet aerosol (Dentener's Thesis, p. 14)
   is computed as:

       ARSL1K [1/s] = area / [ radius/dfkg + 4./(stkcf * xmms) ]

   where XMMS = Mean molecular speed [cm/s] = sqrt(8R*TK/pi/M) for Maxwell
         DFKG = Gas phase diffusion coeff [cm2/s] (order of 0.1)
```

REVISION HISTORY:

```
   01 Jul 1994 - lwh, jyl, gmg, djj - Initial version
   04 Apr 2003 - R. Yantosca - Updated comments, cosmetic changes
   07 Apr 2004 - R. Yantosca - Now return w/ default value if RADIUS is zero
                               (i.e. is smaller than a very small number)
   03 Dec 2009 - R. Yantosca - Prevent div-by-zero errors by returning the
                               default value if any of the args are zero
   03 Dec 2009 - R. Yantosca - Added ProTeX Header
   20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
```

7.8.18 HetN2O5_Psc

Set heterogenous chemistry rate for N2O5(g) + HCl(l,s) in polar stratospheric clouds.

INTERFACE:

```
    FUNCTION HETN2O5_PSC( A, B ) RESULT( HET_N2O5_PSC )
```

INPUT PARAMETERS:

```
      ! Rate coefficients
      REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)              :: HET_N2O5_PSC
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.19 HetClNO3_Psc1

Set heterogenous chemistry rate for ClNO3(g) + H2O(l,s) in polar stratopsheric clouds.

INTERFACE:

```
FUNCTION HETClNO3_PSC1( A, B ) RESULT( HET_ClNO3_PSC1 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)            :: HET_ClNO3_PSC1
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.20 HetClNO3_Psc2

Sets the heterogenous chemistry rate for ClNO3(g) + HCl(l,s) in polar stratospheric clouds.

INTERFACE:

```
FUNCTION HETClNO3_PSC2( A, B ) RESULT( HET_ClNO3_PSC2 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_ClNO3_PSC2
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.21 HetClNO3_Psc3

Set heterogenous chemistry rate for ClNO3(g) + HBr(l,s) in polar stratospheric clouds.

INTERFACE:

```
FUNCTION HETClNO3_PSC3( A, B ) RESULT( HET_ClNO3_PSC3 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_ClNO3_PSC3
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.22 HetBrNo3_Psc

Set heterogenous chemistry rate for BrNO3(g) + HCl(l,s) in polar stratospheric clouds.

INTERFACE:

```
FUNCTION HETBrNO3_PSC( A, B ) RESULT( HET_BrNO3_PSC )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_BrNO3_PSC
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.23 HetHOCl_Psc1

Set heterogenous chemistry rate for HOCl(g) + HCl(l,s) in polar stratopsheric clouds.

INTERFACE:

```
FUNCTION HETHOCl_PSC1( A, B ) RESULT( HET_HOCl_PSC1 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)            :: HET_HOCl_PSC1
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.24 HetHocl_Psc2

Set heterogenous chemistry rate for HOCl(g) + HBr(l,s) in polar stratospheric clouds.

INTERFACE:

```
FUNCTION HETHOCl_PSC2( A, B ) RESULT( HET_HOCl_PSC2 )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HOCl_PSC2
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.25 HetHOBr_Psc

Set heterogenous chemistry rate for HOBr(g) + HCl(l,s) in polar stratospheric clouds.

INTERFACE:

```
FUNCTION HETHOBr_PSC( A, B ) RESULT( HET_HOBr_PSC )
```

INPUT PARAMETERS:

```
! Rate coefficients
REAL(fp), INTENT(IN) :: A, B
```

RETURN VALUE:

```
REAL(fp)             :: HET_HOBr_PSC
```

REMARKS:

```
This routine is only activated for UCX-based mechanisms.
```

REVISION HISTORY:

```
29 Jan 2016 - M. Sulprizio- Initial version, adapted from code previously
                            in calcrate.F
29 Mar 2016 - R. Yantosca - Added ProTeX header
01 Apr 2016 - R. Yantosca - Define N, XSTKCF, ADJUSTEDRATE locally
01 Apr 2016 - R. Yantosca - Replace KII_KI with DO_EDUCT local variable
04 May 2016 - M. Sulprizio- Add fixes for setting rate if not a STRATBOX
```

7.8.26 Check_Nat

Subroutine CHECK_NAT determines whether the solid PSC is composed of ice or NAT (nitric acid trihydrate) (needed for heterogeneous chemistry), or indeed if there is any direct PSC calculation at all. This is important for determining whether to use the JPP or Kirner scheme for ice cloud radii.

INTERFACE:

```
      SUBROUTINE CHECK_NAT( I, J, L, IS_NAT, IS_PSC, IS_STRAT, &
                            Input_Opt, State_Met, State_Chm )
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I,J,L      ! Grid indices
      TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input options
      TYPE(MetState), INTENT(IN)  :: State_Met  ! Meteorology State object
      TYPE(ChmState), INTENT(IN)  :: State_Chm  ! Chemistry State object
   !OUTPUT VARIABLES:
      LOGICAL,        INTENT(OUT) :: IS_NAT     ! Is surface NAT?
      LOGICAL,        INTENT(OUT) :: IS_PSC     ! Are there solid PSCs?
      LOGICAL,        INTENT(OUT) :: IS_STRAT   ! Are we in the strat?
```

REMARKS:

```
    This routine is only activated for UCX-based mechanisms
```

REVISION HISTORY:

```
    17 Apr 2013 - S. D. Eastham - Initial version
    21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                                  objects via the arg list
    08 Apr 2015 - R. Yantosca   - Remove call to READ_PSC_FILE, this is
                                  now done from DO_CHEMISTRY (chemistry_mod.F)
    29 Jan 2016 - M. Sulprizio  - Moved this routine from ucx_mod.F to
                                  gckpp_HetRates.F90
```

7.9 Fortran: Module Interface ucx_mod.F

Module UCX_MOD contains routines and variables which are associated with the addition of full stratospheric chemistry to GEOS-Chem (based on the NASA GMI implementation, forming the Unified Chemistry eXtension (UCX).

INTERFACE:

```
      MODULE UCX_MOD
```

USES:

```
      USE CMN_SIZE_MOD
      USE ERROR_MOD,     ONLY : DEBUG_MSG
```

```
      USE inquireMod,    ONLY : findFreeLUN
      USE PhysConstants       ! Physical constants
      USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

 #if !defined(ESMF_)
      ! NcdfUtil modules for netCDF I/O
      USE m_netcdf_io_open                    ! netCDF open
      USE m_netcdf_io_get_dimlen              ! netCDF dimension queries
      USE m_netcdf_io_read                    ! netCDF data reads
      USE m_netcdf_io_close                   ! netCDF close
 #endif

      IMPLICIT NONE
 #if !defined(ESMF_)
#     include "netcdf.inc"
 #endif

      PRIVATE
```

PUBLIC DATA MEMBERS:

```
      CHARACTER(LEN=255), PUBLIC :: AVG_FILE_ROOT ! Directory for diurnal avg data
      CHARACTER(LEN=255), PUBLIC :: NOON_FILE_ROOT ! Directory for noontime data
      CHARACTER(LEN=255), PUBLIC :: MONTREAL_FILE_ROOT ! Root directoy for WHO data
                          PUBLIC :: T_STS ! Max temperature of STS formation (K)
      REAL(fp),           PUBLIC :: T_NAT_SUPERCOOL ! NAT supercooling (K)
      REAL(fp),           PUBLIC :: P_ICE_SUPERSAT ! Ice supersaturation (-)
                          PUBLIC :: NDENS_AER ! See below
      INTEGER,            PUBLIC :: CFCYEAR ! Year for CFC emissions
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: SET_INITIAL_MIXRATIOS
      PUBLIC  :: SET_H2O_TRAC
      PUBLIC  :: SET_CLOCK_TRAC
      PUBLIC  :: EMISS_BASIC
      PUBLIC  :: SETTLE_STRAT_AER
      PUBLIC  :: SO4_PHOTFRAC
      PUBLIC  :: UCX_NOX
      PUBLIC  :: UCX_H2SO4PHOT
      PUBLIC  :: CALC_STRAT_AER
      PUBLIC  :: GET_STRAT_OPT
      PUBLIC  :: KG_STRAT_AER
      PUBLIC  :: RHO_STRAT_AER
      PUBLIC  :: INIT_UCX
      PUBLIC  :: DIAGINIT_UCX
      PUBLIC  :: CLEANUP_UCX
      PUBLIC  :: READ_PSC_FILE
```

```
      PUBLIC  :: WRITE_STATE_PSC
  PRIVATE MEMBER FUNCTIONS:
      PRIVATE :: APPLY_2DTRAC
      PRIVATE :: READ_SFC
      PRIVATE :: SET_MONTREAL
      PRIVATE :: SET_MONTREAL_NCDF
      PRIVATE :: GET_MONTREAL_NCDF
      PRIVATE :: MONTREAL_SCALEFAC
      PRIVATE :: TERNARY
      PRIVATE :: CARSLAW_DENSITY
      PRIVATE :: CALC_H2SO4_GAS
      PRIVATE :: CALC_SLA_GAMMA
      PRIVATE :: MOLEC_SPEED
      PRIVATE :: SFCMR_INIT
      PRIVATE :: SFCMR_READ
      PRIVATE :: SFCMR_GET
      PRIVATE :: NOXCOEFF_INIT
      PRIVATE :: GET_JJNOX
```

REVISION HISTORY:

```
  26 Mar 2013 - S. D. Eastham - Initial version
  04 Apr 2013 - S. D. Eastham - Rolled several routines into module
  20 Feb 2014 - M. Sulprizio  - Removed "define.h", this is now obsolete
  24 Nov 2014 - M. Yannetti   - Added PRECISION_MOD
  05 Dec 2014 - C. Keller     - Added SFCMR object for reading surface mixing
                                ratios to buffer (from ASCII file).
                                Now map NOx coefficients onto grids other than
                                4x5 or 2x25.
  14 Jan 2014 - C. Keller     - Now read and diagnose STATE_PSC through HEMCO.
  08 Apr 2015 - R. Yantosca   - Now make READ_PSC_FILE a PUBLIC routine
  08 May 2015 - C. Keller     - Added WRITE_STATE_PSC
  05 Jan 2016 - E. Lundgren   - Use global physical parameters AVO, PI, AIRMW,
                                RE, RSTARG, and ATM
  28 Jan 2016 - M. Sulprizio  - STATE_PSC and KHETI_SLA are now fields in
                                State_Chm instead of public arrays. These need
                                to be added to the derived type object to be
                                accessed in gckpp_HetRates.F90.
  28 Jan 2016 - M. Sulprizio  - Move routine CHECK_NAT to gckpp_HetRates.F90
  21 Jun 2016 - R. Yantosca   - Now store species ID flags as module variables
  23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                              compatible with the FlexChem implementation
  18 Jul 2016 - M. Sulprizio- Remove CFCX and HCFCX everywhere and replace with
                              their constituents. Family tracers have been
                              eliminated.
  29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

7.9.1 set_initial_mixratios

Subroutine SET_INITIAL_MIXRATIOS is a public interface. Concentrations of species are read from 2D estimates made using the AER 2D model.

INTERFACE:

```
      SUBROUTINE SET_INITIAL_MIXRATIOS( am_I_Root, Input_Opt, State_Met,
     &                                  State_Chm )
```

USES:

```
      USE ERROR_MOD,          ONLY : ALLOC_ERR,ERROR_STOP
      USE GC_GRID_MOD,        ONLY : GET_YMID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REMARKS:

```
    Concentrations of each of the following species are read from
    2D estimates made using the AER 2D model:

                                                                             .
       (# ) TRC                 = Constituents         < Controlled by
   ----------------------------------------------------------------------------
       (1 ) CH4                 = CH4                  < LSETCH4
       (2 ) N2O                 = N2O                  < LSETN2O
       (3 ) OCS                 = OCS                  < LSETOCS
       (4 ) SO4                 = H2SO4                < LSETH2SO4
       (5 ) CFC                 = CFC-113/114/115      < LSETCFC
       (6 ) HCFC                = HCFC-22/141b/142b    < LSETCFC
       (7 ) CFC11               = CFC-11               < LSETCFC
       (8 ) CFC12               = CFC-12               < LSETCFC
       (9 ) H1202               = Halon 1202           < LSETCFC
       (10) H1211               = Halon 1211           < LSETCFC
       (11) H1301               = Halon 1301           < LSETCFC
       (12) H2402               = Halon 2402           < LSETCFC
       (13) Cl2                 = Cl2                  < LSETCL
       (14) ClOx                = Cl + ClO             < LSETCL
       (15) CCl4                = CCl4                 < LSETCL
```

```
(16) CH3Cl              = CH3Cl              < LSETCL
(17) CH3CCl3            = CH3CCl3            < LSETCL
(18) HCl                = HCl                < LSETCL
(19) HOCl               = HOCl               < LSETCL
(20) Cl2O2              = Cl2O2              < LSETCL
(21) ClNO2              = ClNO2              < LSETCL
(22) ClONO2             = ClNO3              < LSETCL
(23) OClO               = OClO               < LSETCL
(24) ClOO               = ClOO               < LSETCL
(25) BrCl               = BrCl               < (LSETCL || LSETBR || LSETBRSTRAT)
(26) Br2                = Br2                < LSETBR || LSETBRSTRAT
(27) Br                 = Br                 < LSETBR || LSETBRSTRAT
(28) BrO                = BrO                < LSETBR || LSETBRSTRAT
(29) HOBr               = HOBr               < LSETBR || LSETBRSTRAT
(30) HBr                = HBr                < LSETBR || LSETBRSTRAT
(31) BrNO2              = BrNO2              < LSETBR || LSETBRSTRAT
(32) BrNO3              = BrNO3              < LSETBR || LSETBRSTRAT
(33) CHBr3              = CHBr3              < LSETBR || LSETBRSTRAT
(34) CH2Br2             = CH2Br2             < LSETBR || LSETBRSTRAT
(35) CH3Br              = CH3Br              < LSETBR || LSETBRSTRAT
```

REVISION HISTORY:

```
26 Mar 2013 - S. D. Eastham - Initial version
07 Feb 2014 - R. Yantosca   - !$OMP DO loops now go in L-J-I order
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
18 Jun 2014 - S. D. Eastham - Now read data for individual NOx species
24 Nov 2014 - C. Keller     - Update for stratospheric NOy (as suggested by
                              Seb Eastham)
16 Mar 2015 - E. Lundgren   - Change tracer units from kg to kg/kg
16 Jun 2016 - S. D. Eastham - Remove references to tracerid_mod.F
21 Jun 2016 - R. Yantosca   - Now use module variables for species ID's
21 Jun 2016 - R. Yantosca   - Add error checks to make sure that each
                              species ID flag has a valid value before
                              calling APPLY_2DRATIO routine
22 Jun 2016 - M. Yannetti   - Replace TCVV with spc db MW and phys constant
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
```

7.9.2 montreal_scalefac

Function MONTREAL_SCALEFAC calculates a scaling factor for long-lived species between a future year and a reference year, based on WMO projections.

INTERFACE:

```
 FUNCTION MONTREAL_SCALEFAC(MS_TRAC,MS_FUTRYR,
&                 MS_INITYR,MS_TARGMO) RESULT(SCALEFAC)
```

USES:

INPUT PARAMETERS:

```
      CHARACTER(*),INTENT(IN)     :: MS_TRAC
      INTEGER,INTENT(IN)          :: MS_FUTRYR  ! Future year
      INTEGER,INTENT(IN)          :: MS_INITYR  ! Future year
      INTEGER,INTENT(IN)          :: MS_TARGMO  ! Target month
  !OUTPUT VARIABLES:
      REAL(fp)                      :: SCALEFAC   ! Scaling factor
```

REMARKS:

```
(1) A remark
```

REVISION HISTORY:

```
 28 Mar 2013 - S. D. Eastham - Initial version
```

7.9.3 ucx_nox

Subroutine UCX_NOX calculates NOx and N2O loss rates above the chemistry grid, based on estimates of j-rates from a 2D model and simple photochemical assumptiones.

INTERFACE:

```
      SUBROUTINE UCX_NOX( Input_Opt, State_Met, State_Chm )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE GC_GRID_MOD,        ONLY : GET_YMID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
      USE TIME_MOD,           ONLY : GET_DAY_OF_YEAR
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : ITS_A_LEAPYEAR
      USE TIME_MOD,           ONLY : GET_HOUR
      USE TIME_MOD,           ONLY : GET_LOCALTIME
      USE TIME_MOD,           ONLY : GET_MINUTE
      USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
      USE CMN_FJX_MOD,        ONLY : ZPJ
      USE FAST_JX_MOD,        ONLY : RXN_NO, RXN_NO2, RXN_NO3, RXN_N2O
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
16 Jul 2013 - S. D. Eastham - Initial version
14 Feb 2014 - R. Yantosca   - Now pull computation of ZMID out of main
                              parallel DO loop.  Switch loop order to L-J-I.
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
24 Feb 2014 - E. Lundgren   - Replace GET_PCENTER, which retrieves wet
                              air pressure, with State_Met%PMID_DRY.
                              Remove dependency on PRESSURE_MOD.
16 Jun 2016 - S. D. Eastham - Remove references to tracerid_mod.F
21 Jun 2016 - R. Yantosca   - Use the module variables for species ID flags
22 Jun 2016 - M. Yannetti   - Replace TCVV with spc db MW and phys constant
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
11 Aug 2016 - R. Yantosca   - Remove temporary tracer-removal code
```

7.9.4 get_noxcoeff

Subroutine GET_NOXCOEFF reads in O1D and O3P mixing ratios along with NO, NO2, NO3 and N2O J-rates from 2D data, interpolating onto the 3D grid and storing in NOX_O and NOX_J.

INTERFACE:

```
SUBROUTINE GET_NOXCOEFF( TARG_MONTH, Input_Opt, State_Met )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
USE ERROR_MOD,          ONLY : ERROR_STOP
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: TARG_MONTH
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

REMARKS:

```
At some later point we should attempt to rewrite the parallel DO loop so
that the loop order is L-J-I.  Not sure how easy that is. (bmy, 2/14/14)
```

REVISION HISTORY:

```
26 Mar 2013 - S. D. Eastham - Initial version
14 Feb 2014 - R. Yantosca   - Parallelize main DO loop
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt and State_Met objects via
                              the arg list
24 Feb 2014 - E. Lundgren   - Replace GET_PCENTER, which retrieves wet
                              air pressure, with State_Met%PMID and
                              remove dependency on PRESSURE_MOD.
```

7.9.5 apply_2dtrac

Subroutine APPLY_2DTRAC reads in and applies 2D data from AER 2D model output to the 3D GEOS-Chem grid. Zonally-averaged mixing ratios vary by month, but no interpolation is performed.

INTERFACE:

```
      SUBROUTINE APPLY_2DTRAC( TRAC_ADD, STRAT_ONLY, SFC_ONLY, SCALEFAC,
     &                         Input_Opt, State_Met, State_Chm )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRATMESO
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: TRAC_ADD    ! Add (instead of overwrite)
      LOGICAL,        INTENT(IN)    :: STRAT_ONLY  ! Only write to stratosphere
      LOGICAL,        INTENT(IN)    :: SFC_ONLY    ! Only write to surface
      REAL(fp),         INTENT(IN)    :: SCALEFAC    ! Future scaling factor
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REMARKS:

```
At some later point we should attempt to rewrite the parallel DO loop so
that the loop order is L-J-I.  Not sure how easy that is. (bmy, 2/14/14)
```

REVISION HISTORY:

```
26 Mar 2013 - S. D. Eastham - Initial version
14 Feb 2014 - R. Yantosca   - Now parallelize main DO loop
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
24 Feb 2014 - E. Lundgren   - Replace GET_PCENTER, which retrieves wet
                              air pressure, with State_Met%PMID and
                              remove dependency on PRESSURE_MOD.
19 Mar 2015 - E. Lundgren   - Change tracer units from kg to kg/kg
25 Jul 2016 - M. Yannetti   - Pass State_Chem as argument to access spc db;
                              Replace TCVV with spc db MW and phys constant
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
```

7.9.6 emiss_basic

Subroutine EMISS_BASIC sets surface mixing ratios of N2O, OCS and ozone-depleting substances covered by the Montreal protocol.

INTERFACE:

```
  SUBROUTINE EMISS_BASIC( am_I_Root, Input_Opt, State_Met,
 &                        State_Chm, RC  )
```

USES:

```
  USE ErrCode_Mod
  USE ERROR_MOD,          ONLY : GC_Error
  USE Input_Opt_Mod,      ONLY : OptInput
  USE State_Chm_Mod,      ONLY : ChmState
  USE State_Met_Mod,      ONLY : MetState
  USE TIME_MOD,           ONLY : GET_MONTH
  USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
  LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
  TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
  TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
  TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
  INTEGER,          INTENT(INOUT)  :: RC       ! Failure or success
```

REMARKS:

REVISION HISTORY:

```
28 Mar 2013 - S. D. Eastham - Initial version
11 Feb 2014 - R. Yantosca   - Rewrote DO loop to be more efficient
14 Feb 2014 - R. Yantosca   - Now parallelize main DO loop
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
10 Sep 2015 - E. Lundgren   - Tracer units are now kg/kg dry air (prev v/v)
25 Jul 2016 - M. Yannetti   - Pass State_Chm as arg for spc db access;
                              Replace TCVV with spc db MW and phys constant
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
11 Aug 2016 - R. Yantosca   - Remove temporary tracer-removal code
```

7.9.7 read_sfc

Subroutine READ_SFC fills out the surface emissions for some species introduced as part of the unified chemistry upgrade.

INTERFACE:

```
      SUBROUTINE READ_SFC( am_I_Root, Input_Opt )
```

USES:

```
      USE GC_GRID_MOD,        ONLY : GET_YMID
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
   !OUTPUT VARIABLES:
```

REVISION HISTORY:

```
    04 Apr 2013 - S. D. Eastham - Initial version
    21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt object via the arg list
```

7.9.8 set_montreal_ncdf

Subroutine SET_MONTREAL_NCDF calls GET_MONTREAL_NCDF for the surface mixing ratio for a specific year, and applies it to GRID_EMIT.

INTERFACE:

```
      SUBROUTINE SET_MONTREAL_NCDF (TRAC_NAME,TARG_YR_NC,TARG_MO_NC,N)
```

USES:

INPUT PARAMETERS:

```
CHARACTER(LEN=20),INTENT(IN)   :: TRAC_NAME
INTEGER,INTENT(IN)             :: TARG_YR_NC
INTEGER,INTENT(IN)             :: TARG_MO_NC
INTEGER,INTENT(IN)             :: N
```

REVISION HISTORY:

```
10 Oct 2013 - S. D. Eastham - Wrapper built from edges of original GET
04 Mar 2014 - S. D. Eastham - Updated to NetCDF
```

7.9.9 get_montreal_ncdf

Function GET_MONTREAL_NCDF gets mean surface mixing ratio of a given species based on forecasts from WHO estimates. Values are interpolated between two monthly averages.

INTERFACE:

```
 FUNCTION GET_MONTREAL_NCDF (TRAC_NAME,TARG_YR_NC,TARG_MO_NC)
&                           RESULT (MEAN_MIXRATIO)
```

USES:

```
USE ERROR_MOD,   ONLY : ERROR_STOP, ALLOC_ERR
USE FILE_MOD,    ONLY : IOERROR
```

INPUT PARAMETERS:

```
REAL(fp)                        :: MEAN_MIXRATIO
CHARACTER*(*),INTENT(IN)       :: TRAC_NAME
INTEGER,INTENT(IN)             :: TARG_YR_NC
INTEGER,INTENT(IN)             :: TARG_MO_NC
```

REVISION HISTORY:

```
04 Apr 2013 - S. D. Eastham - Initial version
10 Oct 2013 - S. D. Eastham - Split into two routines (GET and SET)
04 Mar 2014 - S. D. Eastham - Added NetCDF compatibility
```

7.9.10 set_montreal

Subroutine SET_MONTREAL calls GET_MONTREAL for the surface mixing ratio for a specific year, and applies it to GRID_EMIT.

INTERFACE:

```
SUBROUTINE SET_MONTREAL (TRAC_NAME,TARG_LINE,N)
```

USES:

INPUT PARAMETERS:

```
CHARACTER(LEN=20),INTENT(IN)   :: TRAC_NAME
INTEGER,INTENT(IN)             :: TARG_LINE
INTEGER,INTENT(IN)             :: N
```

REVISION HISTORY:

```
10 Oct 2013 - S. D. Eastham - Wrapper built from edges of original GET
```

7.9.11 settle_strat_aer

Subroutine SETTLE_STRAT_AER performs gravitational settling of stratospheric aerosols. It is copied largely from GRAV_SETTLING in sulfate_mod.F. All of this is ignored if APM is active.

INTERFACE:

```
SUBROUTINE SETTLE_STRAT_AER( am_I_Root, Input_Opt, State_Met,
&                            State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRATMESO
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_DIAG_MOD             ! ND44
USE CMN_FJX_MOD,        ONLY : RAA, IND999
USE CMN_SIZE_MOD             ! Size parameters
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : IT_IS_NAN,ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_ELAPSED_SEC, GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
INTEGER,        INTENT(INOUT) :: RC          ! Return code
```

REVISION HISTORY:

```
11 Apr 2013 - S. D. Eastham - Initial version
07 Feb 2014 - R. Yantosca - Add missing variables to !$OMP PRIVATE statement
07 Feb 2014 - R. Yantosca - Cosmetic changes
21 Feb 2014 - M. Sulprizio- Now pass Input_Opt, State_Met, and State_Chm
                            objects via the arg list
24 Feb 2014 - E. Lundgren - Replace GET_PCENTER and GET_PEDGE with
                            State_Met%PMID and State_Met%PEDGE
24 Feb 2014 - E. Lundgren - Remove dependency on PRESSURE_MOD
24 Feb 2014 - E. Lundgren - Use State_Met%DELP in place of PEDGE difference
08 Apr 2015 - R. Yantosca - Remove call to READ_PSC_FILE, this is
                            now done from DO_CHEMISTRY (chemistry_mod.F)
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on KLOOP. WERADIUS,
                            is now a pointer that point to 3D fields in
                            in State_Chm.
31 May 2016 - E. Lundgren - Replace Input_Opt%TRACER_MW_G with species
                            database emMW_g (emitted species g/mol)
16 Jun 2016 - S.D.Eastham - Remove references to tracerid_mod.F
15 Jul 2016 - E. Lundgren - Replace tracer pointer with species pointer
```

7.9.12 calc_h2so4_gas

Subroutine CALC_H2SO4_GAS calculates the fraction of strat. SO4 aerosol which can be considered to be gaseous H2SO4.

INTERFACE:

```
SUBROUTINE CALC_H2SO4_GAS( Input_Opt, State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
TYPE(ChmState), INTENT(IN) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
11 Apr 2013 - S. D. Eastham - Initial version
07 Feb 2014 - R. Yantosca   - Cosmetic changes
14 Feb 2014 - R. Yantosca   - Changed parallel DO loop order to L-J-I,
                              which is the most efficient configuration
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
```

```
24 Feb 2015 - E. Lundgren   - Replace GET_PCENTER with State_Met%PMID_DRY
24 Feb 2015 - E. Lundgren   - Remove dependency on PRESSURE_MOD
26 Mar 2015 - E. Lundgren   - Now use moist and dry air partial pressures
31 May 2016 - E. Lundgren   - Replace Input_Opt%TRACER_MW_G with species
                              database emMW_g (emitted species g/mol)
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
```

7.9.13 so4_photfrac

FUNCTION SO4_PHOTFRAC returns the fraction of H2SO4 which is available for photolysis.

INTERFACE:

```
REAL(fp) FUNCTION SO4_PHOTFRAC(I,J,L)
```

INPUT PARAMETERS:

```
INTEGER,INTENT(IN)          :: I,J,L      ! Location indices
!OUTPUT VARIABLES:
 REAL(fp), INTENT(OUT)         :: PHOTFRAC   ! Gaseous fraction of H2SO4
```

REVISION HISTORY:

```
11 Apr 2013 - S. D. Eastham - Initial version
```

7.9.14 calc_strat_aer

Subroutine CALC_STRAT_AER calculates aerosol properties stratosphere using the thermodynamic parameterization described in Kirner et al. ('Simulation of polar stratospheric clouds in the chemistry-climate-model EMAC via the submodel PSC', Geosci. Mod. Dev., 4, 169-182, 2011).

INTERFACE:

```
SUBROUTINE CALC_STRAT_AER( am_I_Root, Input_Opt,
&                          State_Met, State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRATMESO
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE ERROR_MOD,          ONLY : ERROR_STOP
USE ERROR_MOD,          ONLY : IS_SAFE_DIV
USE GC_GRID_MOD,        ONLY : GET_YMID
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
13 Apr 2013 - S. D. Eastham - Initial version
06 Feb 2014 - R. Yantosca   - Add missing variables to OpenMP loop
14 Feb 2014 - R. Yantosca   - Make the L-loop the outermost DO loop
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
06 Nov 2014 - R. Yantosca   - Now use State_Met%CLDF(I,J,L)
24 Feb 2014 - E. Lundgren   - Replace GET_PCENTER, which retrieves wet
                              air pressure, with State_Met%PMID_DRY and
                              remove dependency on PRESSURE_MOD.
08 Apr 2015 - R. Yantosca   - Remove call to READ_PSC_FILE, this is
                              now done from DO_CHEMISTRY (chemistry_mod.F)
31 May 2016 - E. Lundgren   - Replace Input_Opt%TRACER_MW_G with emMW_g
                              from species database (emitted species g/mol)
16 Jun 2016 - S. D. Eastham - Remove references to tracerid_mod.F
21 Jun 2016 - R. Yantosca   - Now use module variables for species ID flags
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
11 Aug 2016 - R. Yantosca   - Remove temporary tracer removal code
```

7.9.15 kg_strat_aer

Function KG_STRAT_AER returns the calculated mass of a stratospheric aerosol. The routine is essentially just an interface to allow external routines to "see" the arrays.

INTERFACE:

```
REAL(fp) FUNCTION KG_STRAT_AER (I,J,L,IAER)
```

INPUT PARAMETERS:

```
INTEGER,INTENT(IN)          :: I,J,L      ! Grid indices
INTEGER,INTENT(IN)          :: IAER       ! Aerosol index
                                          ! 1 = SSA (pure H2SO4)
                                          ! 2 = STS
                                          ! 3 = Solid PSC
```

REVISION HISTORY:

```
18 Apr 2013 - S. D. Eastham - Initial version
```

7.9.16 rho_strat_aer

Function RHO_STRAT_AER returns the calculated stratospheric aerosol mass density.

INTERFACE:

```
REAL(fp) FUNCTION RHO_STRAT_AER (I,J,L,IAER)
```

INPUT PARAMETERS:

```
INTEGER,INTENT(IN)          :: I,J,L      ! Grid indices
INTEGER,INTENT(IN)          :: IAER       ! Aerosol index:
                                          ! 1 = Liquid aerosol
                                          ! 2 = Solid aerosol
```

REVISION HISTORY:

```
18 Apr 2013 - S. D. Eastham - Initial version
```

7.9.17 get_strat_opt

Subroutine GET_STRAT_OPT returns local optical properties for a given stratospheric aerosol. The routine is essentially just an interface to allow external routines to "see" the arrays. However, local aerosol radius is adjusted from liquid to effective radius for aerosol optical depth calculations with liquid aerosols.

INTERFACE:

```
SUBROUTINE GET_STRAT_OPT (I,J,L,IAER,RAER,REFF,SAD,XSA)
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN)  :: I, J, L    ! Grid indices
INTEGER,  INTENT(IN)  :: IAER       ! Aerosol index
                                    ! 1 = Liquid aerosols
                                    ! 2 = Solid PSC
!OUTPUT VARIABLES:
    REAL(fp), INTENT(OUT) :: REFF       ! Effective radius (cm)
    REAL(fp), INTENT(OUT) :: RAER       ! Physical radius (cm)
    REAL(fp), INTENT(OUT) :: SAD        ! Surface area density (cm2/cm3)
    REAL(fp), INTENT(OUT) :: XSA        ! X-S area density (m2/m3)
```

REMARKS:

```
Seb Eastham writes: "I would edit GET_STRAT_OPT so that, when SAD is less
than some small value (say 1 nm2/cm3,  which is a vanishingly small surface
area), it returns SADSTRAT=XSASTRAT=0.d0 and RAER=REFF=0.1d0 for safety's
sake. I think that will prevent code blow-up later on."
```

REVISION HISTORY:

```
17 Apr 2013 - S. D. Eastham - Initial version
07 Apr 2015 - R. Yantosca   - Add error check to prevent div-by-zero errors
                              in other areas of GEOS-Chem caused by low SAD
```

7.9.18 ternary

Subroutine TERNARY calculates the composition of SSA/STS aerosols using a paramaterization from Carslaw et al. "A Thermodynamic Model of the System HCl-HNO3-H2SO4-H2O, Including Solubilities of HBr, from ¡200 to 328 K". The bulk of this code was taken directly from the Global Modeling Initiative implementation by David Considine.

INTERFACE:

```
      SUBROUTINE TERNARY (PCENTER_IN,TCENTER_IN,H2OSUM_IN,H2SO4SUM,
     &                    HNO3SUM,HClSUM,HOClSUM,HBRSum,HOBrSUM,
     &                    W_H2SO4,W_H2O,W_HNO3,W_HCl,W_HOCl,W_HBr,W_HOBr,
     &                    HNO3GASFRAC,HClGASFRAC,HOClGASFRAC,
     &                    HBrGASFRAC,HOBrGASFRAC,SLA_VOL,SLA_RHO)
```

USES:

```
      ! Temporary - for debug
      USE ERROR_MOD,     ONLY : IT_IS_NAN,ERROR_STOP     ! Test for NaN
      USE ERROR_MOD,     ONLY : SAFE_EXP,SAFE_DIV, DEBUG_MSG
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)  :: PCENTER_IN   ! Pressure (hPa)
      REAL(fp), INTENT(IN)  :: TCENTER_IN   ! Temperature (K)
      REAL(fp), INTENT(IN)  :: H2OSUM_IN    ! Total H2O mixing ratio
      REAL(fp), INTENT(IN)  :: H2SO4SUM     ! Liquid H2SO4 mixing ratio
      REAL(fp), INTENT(IN)  :: HNO3SUM      ! Total HNO3 mixing ratio
      REAL(fp), INTENT(IN)  :: HClSUM       ! Total HCl mixing ratio
      REAL(fp), INTENT(IN)  :: HOClSUM      ! Total HOCl mixing ratio
      REAL(fp), INTENT(IN)  :: HBrSUM       ! Total HBr mixing ratio
      REAL(fp), INTENT(IN)  :: HOBrSUM      ! Total HOBr mixing ratio
!OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) :: W_H2SO4      ! kg H2SO4/kg SLA
      REAL(fp), INTENT(OUT) :: W_H2O        ! kg H2O  /kg SLA
      REAL(fp), INTENT(OUT) :: W_HNO3       ! kg HNO3 /kg SLA
      REAL(fp), INTENT(OUT) :: W_HCl        ! kg HCl  /kg SLA
      REAL(fp), INTENT(OUT) :: W_HOCl       ! kg HOCl /kg SLA
      REAL(fp), INTENT(OUT) :: W_HBr        ! kg HBr  /kg SLA
      REAL(fp), INTENT(OUT) :: W_HOBr       ! kg HOBr /kg SLA
      REAL(fp), INTENT(OUT) :: HNO3GASFRAC  ! Gas fraction HNO3
      REAL(fp), INTENT(OUT) :: HClGASFRAC   ! Gas fraction HCl
      REAL(fp), INTENT(OUT) :: HOClGASFRAC  ! Gas fraction HOCl
      REAL(fp), INTENT(OUT) :: HBrGASFRAC   ! Gas fraction HBr
```

```
      REAL(fp), INTENT(OUT) :: HOBrGASFRAC  ! Gas fraction HOBr
      REAL(fp), INTENT(OUT) :: SLA_VOL      ! Aerosol volume (m3/m3)
      REAL(fp), INTENT(OUT) :: SLA_RHO      ! Aer. mass density (kg/m3)
```

REVISION HISTORY:

```
    19 Apr 2013 - S. D. Eastham - Initial version
    16 Apr 2015 - M. Yannetti   - Changed EXP to SAFE_EXP in H_HCL
    01 Jan 2016 - E. Lundgren   - Calculate R_ATM from global params
```

7.9.19 carslaw_density

Function CARSLAW_DENSITY determines the density of a sol'n through a relationship from Carslaw et al.. Result is in kg/m3.

INTERFACE:

```
      REAL(fp) FUNCTION CARSLAW_DENSITY(CS,CN,T)
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN) :: CS         ! H2SO4 molality (mol H2SO4/kg solvent)
      REAL(fp), INTENT(IN) :: CN         ! HNO3 molality (mol HNO3/kg solvent)
      REAL(fp), INTENT(IN) :: T          ! Temperature (K)
```

REVISION HISTORY:

```
    19 Apr 2013 - S. D. Eastham - Initial version
```

7.9.20 calc_fallvel

Function CALC_FALLVEL calculates the terminal velocity of a solid particle.

INTERFACE:

```
      FUNCTION CALC_FALLVEL(DENSITY,RADIUS,TCENTER,PCENTER) RESULT(VEL)
```

USES:

```
      USE ERROR_MOD,       ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      REAL(fp),INTENT(IN)   :: RADIUS  ! Particle radius (cm)
      REAL(fp),INTENT(IN)   :: DENSITY ! Particle density (kg/m3)
      REAL(fp),INTENT(IN)   :: TCENTER ! Local temperature (K)
      REAL(fp),INTENT(IN)   :: PCENTER ! Local pressure (kPa)
  !OUTPUT VARIABLES:
      REAL(fp)              :: VEL ! Fall velocity (m/s)
```

REMARKS:

```
(1) A remark
```

REVISION HISTORY:

```
11 Aug 2012 - S. D. Eastham - Initial version
```

7.9.21 cacl_sla_gamma

Subroutine CALC_SLA_GAMMA calculates 11 different sticking coefficients on the surface of local stratospheric liquid aerosols, relevant to each of the 11 reactions listed in Kirner's paper.

INTERFACE:

```
      SUBROUTINE CALC_SLA_GAMMA( NDENS, T, P, WT_FRC, H2OSUM, HClSUM,
     &                           HBrSUM, HOBrSUM, ClNO3SUM, BrNO3SUM,
     &                           RHO, ARAD, RXNGAMMA )
```

USES:

```
      ! Temporary - for debug
      USE ERROR_MOD,     ONLY : IT_IS_NAN,ERROR_STOP     ! Test for NaN
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)  :: NDENS    ! Air number density (molec/cm3)
      REAL(fp), INTENT(IN)  :: T        ! Temperature (K)
      REAL(fp), INTENT(IN)  :: P        ! Pressure (hPa)
      REAL(fp), INTENT(IN)  :: WT_FRC   ! Weight fraction of H2SO4 (kg/kg)
      REAL(fp), INTENT(IN)  :: H2OSUM   ! H2O mixing ratio
      REAL(fp), INTENT(IN)  :: HClSUM   ! HCl mixing ratio
      REAL(fp), INTENT(IN)  :: HBrSUM   ! HBr mixing ratio
      REAL(fp), INTENT(IN)  :: HOBrSUM  ! HOBr mixing ratio
      REAL(fp), INTENT(IN)  :: ClNO3SUM ! ClNO3 mixing ratio
      REAL(fp), INTENT(IN)  :: BrNO3SUM ! BrNO3 mixing ratio
      REAL(fp), INTENT(IN)  :: RHO      ! STS density (g/cm3)
      REAL(fp), INTENT(IN)  :: ARAD     ! SLA radius (cm)
!OUTPUT VARIABLES:
      REAL(fp), INTENT(OUT) :: RXNGAMMA(11) ! Premultiplying factors
```

REVISION HISTORY:

```
10 Oct 2012 - S. D. Eastham - Initial version
15 Apr 2015 - M. Yannetti   - Adjustment to f8 from fp due to overflow concerns
```

7.9.22 molec_speed

Function MOLEC_SPEED calculates the mean velocity of gas phase particles based on temperature and molecular mass.

INTERFACE:

```
REAL(fp) FUNCTION MOLEC_SPEED(T,MOLMASS)
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN)          :: T       ! Temperature (K)
REAL(fp), INTENT(IN)          :: MOLMASS ! Molecular mass (g/mol)
```

REVISION HISTORY:

```
10 Oct 2012 - S. D. Eastham - Initial version
```

7.9.23 read_psc_file

Subroutine READ_PSC_FILE initializes PSC state information from a checkpoint file (binary punch file format).

INTERFACE:

```
SUBROUTINE READ_PSC_FILE( am_I_Root, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_ERROR_MOD
USE HCO_RESTART_MOD,    ONLY : HCO_RestartGet
USE HCO_CLOCK_MOD,      ONLY : HcoClock_First
USE HCO_CLOCK_MOD,      ONLY : HcoClock_Rewind
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
INTEGER,        INTENT(INOUT) :: RC
```

REVISION HISTORY:

```
28 Apr 2013 - S. D. Eastham - Initial version, based on READ_CSPEC_FILE
14 Feb 2014 - R. Yantosca   - Reorder DO loops for efficiency
16 Apr 2014 - M. Sulprizio  - Now get PSC restart file path from Input_Opt
23 Jul 2014 - R. Yantosca   - Remove reference to obsolete CMN_mod.F
14 Jan 2015 - C. Keller     - Now read from HEMCO
 4 Mar 2015 - R. Yantosca   - Declare pointer args to HCO_GetPtr w/ REAL(f4)
25 Mar 2015 - C. Keller     - Now use HEMCO restart module
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

7.9.24 set_clock_trac

Subroutine SET_CLOCK_TRAC sets the clock species mixing ratio within the bottom five grid levels, increasing by a fixed rate of 0.5 ppbv/day

INTERFACE:

```
SUBROUTINE SET_CLOCK_TRAC( STEPLEN, State_Chm )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: STEPLEN     ! Step length (min)
```

OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(OUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
16 Oct 2013 - S. D. Eastham - Initial version
14 Feb 2014 - R. Yantosca   - Reorder DO loop for efficiency
21 Feb 2014 - M. Sulprizio  - Now pass State_Chm object via the arg list
```

7.9.25 set_h2o_trac

Subroutine SET_H2O_TRAC sets the H2O species throughout the selected domain (either troposphere only or the full grid).

INTERFACE:

```
SUBROUTINE SET_H2O_TRAC ( am_I_Root, SETSTRAT, Input_Opt,
&                         State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
      USE CMN_SIZE_MOD
      USE DAO_MOD,            ONLY : AIRQNT
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      LOGICAL,        INTENT(IN)    :: SETSTRAT    ! Set strat H2O?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    28 Mar 2013 - S. D. Eastham - Initial version
    14 Feb 2014 - R. Yantosca   - Reordered DO loop for efficiency
    21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                                  objects via the arg list
    24 Feb 2015 - E. Lundgren   - Replace GET_PCENTER with State_Met%PMID and
                                  remove dependency on PRESSURE_MOD
    24 Mar 2015 - E. Lundgren   - Change tracer units from kg to kg/kg
    29 Apr 2015 - E. Lundgren   - Now pass am_I_Root and RC to SET_H2O_TRAC
    29 Apr 2015 - E. Lundgren   - Now use grid box moist air mass ADMOIST
                                  with SPHU since AD is now dry air mass
    29 Apr 2015 - E. Lundgren   - Replace RH calculation method with Nordquist,
                                  1973 and call AirQnt if moisture vars
                                  are updated using H2O tracer concentration
    28 Oct 2015 - E. Lundgren   - Tracer units are now kg/kg dry air
    07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
    18 Jul 2016 - E. Lundgren   - Remove dependency on grid box mass
    11 Aug 2016 - R. Yantosca   - Remove temporary tracer-removal code
```

7.9.26 ucx_h2so4phot

Subroutine UCX_H2SO4PHOT propagates the calculated H2SO4 photolysis (J) rate at the top of the chemistry grid through to the top of the transport grid, approximating H2SO4 photolysis in the mesosphere.

INTERFACE:

```
SUBROUTINE UCX_H2SO4PHOT( Input_Opt, State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
USE CMN_FJX_MOD,        ONLY : ZPJ
USE FAST_JX_MOD,        ONLY : RXN_H2SO4
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REMARKS:

```
(1) A remark
```

REVISION HISTORY:

```
17 Aug 2013 - S. D. Eastham - Initial version
14 Feb 2014 - R. Yantosca   - Reorder DO loops for efficiency
21 Feb 2014 - M. Sulprizio  - Now pass Input_Opt, State_Met, and State_Chm
                              objects via the arg list
31 May 2016 - E. Lundgren   - Replace Input_Opt%TRACER_MW_G with species
                              database emMW_g (emitted species g/mol)
21 Jun 2016 - R. Yantosca   - Remove reference to tracerid_mod.F
27 Jun 2016 - M. Sulprizio  - Obtain photolysis rate directly from ZPJ array
                              and remove reference to FJXFUNC and obsolete
                              SMVGEAR variables like NKSO4PHOT, NAMEGAS, etc.
07 Jul 2016 - E. Lundgren   - Replace tracer pointer with species pointer
```

7.9.27 get_ucx_ch4

Subroutine GET_UCX_CH4 retrieves zonal mean surface mixing ratios for 4 equal-area regions (90S-30S,30S-0,0-30N,30N-90N)

INTERFACE:

```
SUBROUTINE GET_UCX_CH4( CH4_YEAR, MR90S, MR30S, MR30N, MR90N,
&                       am_I_Root, Input_Opt )
```

USES:

```
      USE FUTURE_EMISSIONS_MOD, ONLY : GET_FUTURE_YEAR
      USE Input_Opt_Mod,        ONLY : OptInput
      USE TIME_MOD,             ONLY : GET_MONTH
      USE TIME_MOD,             ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: CH4_YEAR    ! Target year
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input options
   !OUTPUT VARIABLES:
      REAL(fp),         INTENT(OUT) :: MR90S
      REAL(fp),         INTENT(OUT) :: MR30S
      REAL(fp),         INTENT(OUT) :: MR30N
      REAL(fp),         INTENT(OUT) :: MR90N
```

REVISION HISTORY:

```
    18 Dec 2013 - S. D. Eastham - Initial version
```

7.9.28 sfcmr_init

Subroutine SFCMR_INIT initializes the surface mixing ratio derived type object. This reads in all the mixing ratios from ASCII files and saves them in the SFCMR object.

INTERFACE:

```
      SUBROUTINE SFCMR_INIT( am_I_Root, Input_Opt )
```

USES:

```
      USE ERROR_MOD,          ONLY : ALLOC_ERR
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
      LOGICAL,          INTENT(IN) :: am_I_Root          ! Root CPU?
      TYPE(OptInput),   INTENT(IN) :: Input_Opt          ! Input options
   !OUTPUT VARIABLES:
```

REVISION HISTORY:

```
    05 Dec 2014 - C. Keller - Initial version
```

7.9.29 sfcmr_read

Subroutine SFCMR_READ reads the surface mixing rations from ASCII file and stores the values in the next available SFCMR object. The ascii file is expected to be in the following format: C2CL3F3 MIXING RATIO BOUNDARY CONDITIONS FOR WMO-2006 1.0E-12 time CFC113 1959.04 0.99 1959.12 1.00 1959.21 1.01 1959.29 1.02

INTERFACE:

```
SUBROUTINE SFCMR_READ( am_I_Root, Input_Opt, iName, iID, iMR )
```

USES:

```
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,            INTENT(IN   ) :: am_I_Root          ! Root CPU?
TYPE(OptInput),     INTENT(IN   ) :: Input_Opt          ! Input options
CHARACTER(LEN=*),   INTENT(IN   ) :: iName              ! species name
INTEGER,            INTENT(IN   ) :: iID                ! species ID
REAL(fp), OPTIONAL, INTENT(IN   ) :: iMR                ! fixed MR
```

REVISION HISTORY:

```
05 Dec 2014 - C. Keller - Initial version
```

7.9.30 sfcmr_get

Subroutine SFCMR_GET returns the surface mixing ratio of the given species for the given year and month. The value of the closest available date in the past is taken, and no interpolation between dates is performed.

INTERFACE:

```
FUNCTION SFCMR_GET( TRAC_NAME, YEAR, MONTH ) RESULT( MR )
```

USES:

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN) :: TRAC_NAME          ! species name
INTEGER,          INTENT(IN) :: YEAR               ! desired year
INTEGER,          INTENT(IN) :: MONTH              ! desired month
!INPUT/OUTPUT VARIABLES:
REAL(fp)                     :: MR
```

REVISION HISTORY:

```
05 Dec 2014 - C. Keller - Initial version
```

7.9.31 noxcoeff_init

Subroutine NOXCOEFF_INIT initializes the NOX 2D interpolation values.

INTERFACE:

```
SUBROUTINE NOXCOEFF_INIT ( am_I_Root, Input_Opt )
```

USES:

```
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,          INTENT(IN) :: am_I_Root          ! Root CPU?
TYPE(OptInput),   INTENT(IN) :: Input_Opt          ! Input options
!OUTPUT VARIABLES:
```

REVISION HISTORY:

```
05 Dec 2014 - C. Keller - Initial version
```

7.9.32 get_jjnox

Subroutine GET_JJNOX maps grid box at location IISIM, JJSIM of the simulation grid onto the latitude grid of the NOXCOEFF array. JJNOX can differ from JJSIM if it's not a 4x5 or 2x25 simulation.

This routine simply returns the index of the NOx latitude vector that covers the latitude value of interest. No grid box weighting, etc. is performed.

INTERFACE:

```
FUNCTION GET_JJNOX( IISIM, JJSIM ) RESULT ( JJNOX )
```

USES:

```
USE GC_GRID_MOD, ONLY : GET_YMID
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN) :: IISIM    ! Latitude index on simulation grid
INTEGER,          INTENT(IN) :: JJSIM    ! Latitude index on simulation grid
!OUTPUT VARIABLES:
INTEGER                      :: JJNOX    ! Latitude index on NOXCOEFF grid
```

REVISION HISTORY:

```
05 Dec 2014 - C. Keller - Initial version
```

7.9.33 init_ucx

Subroutine INIT_UCX initializes module arrays.

INTERFACE:

```
SUBROUTINE INIT_UCX( am_I_Root, Input_Opt, State_Chm )
```

USES:

```
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : IS_SAFE_DIV
USE ERROR_MOD,          ONLY : ERROR_STOP
USE GC_GRID_MOD,        ONLY : GET_YEDGE
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : PI_180
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN) :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input options
TYPE(ChmState), INTENT(IN) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
04 Apr 2013 - S. D. Eastham - Initial version
21 Jun 2016 - R. Yantosca   - Now declare species ID's during INIT phase
21 Jun 2016 - R. Yantosca   - Remove reference to tracerid_mod.F
24 Jun 2016 - R. Yantosca   - Bug fix: get advected species index for H2
20 Sep 2016 - R. Yantosca   - Now avoid using SIND, convert the argument
                              to radians and use the SIN function instead
```

7.9.34 diaginit_ucx

Subroutine DIAGINIT_UCX initializes diagnostics containers for the UCX module.

INTERFACE:

```
SUBROUTINE DIAGINIT_UCX( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_RESTART_MOD,    ONLY : HCO_RestartDefine
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_ERROR_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?!
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(INOUT) :: RC          ! Success or failure
```

REVISION HISTORY:

```
14 Jan 2015 - C. Keller     - Initial version
25 Mar 2015 - C. Keller     - Now use HEMCO restart module
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

7.9.35 write_state_psc

Subroutine WRITE_STATE_PSC saves the STATE_PSC array into diagnostics. This is only of relevance in an ESMF environment, where STATE_PSC is not automatically written into the HEMCO restart diagnostics but needs to be passed explicitly to the internal state. This should be done on every time step to make sure that replay simulations will always have the most current STATE_PSC values in the internal state (important for checkpointing!).

INTERFACE:

```
SUBROUTINE WRITE_STATE_PSC ( am_I_Root, State_Chm, RC )
```

USES:

```
USE ErrCode_Mod
USE HCO_ERROR_MOD
USE HCO_RESTART_MOD,   ONLY : HCO_RestartWrite
USE HCO_INTERFACE_MOD, ONLY : HcoState
USE State_Chm_Mod,     ONLY : ChmState

!INPUT ARGUMENTS:
    LOGICAL,        INTENT(IN)    :: am_I_Root

!INPUT/OUTPUT ARGUMENTS:
    TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
    INTEGER,        INTENT(INOUT) :: RC
```

REVISION HISTORY:

```
08 May 2015 - C. Keller   - Initial version
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

7.9.36 cleanup_ucx

Subroutine CLEANUP_UCX deallocates module variables.

INTERFACE:

```
      SUBROUTINE CLEANUP_UCX ( am_I_Root )

   !INPUT ARGUMENTS:
      LOGICAL, INTENT(IN)     :: am_I_Root
```

REVISION HISTORY:

```
    04 Apr 2013 - S. D. Eastham - Initial version
    13 Apr 2013 - S. D. Eastham - Added PSC arrays
```

7.10 Fortran: Module Interface bromocarb_mod.F

Module BROMOCARB_MOD contains variables and routines for the GEOS-Chem bromocarbon simulation.

INTERFACE:

```
      MODULE BROMOCARB_MOD
```

USES:

```
      USE PRECISION_MOD

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC :: SET_CH3Br
      PUBLIC :: SET_BrO
```

REMARKS:

```
    HEMCO has made most of this routine obsolete.  HEMCO reads in the
    data files in netCDF format and tracks them in its data structure.
```

REVISION HISTORY:

```
    13 Aug 2007 - J. Parrella - Initial version
    22 May 2012 - M. Payer    - Added ProTeX headers
    27 Aug 2012 - M. Payer    - Now parallelize DO loops
    20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
    24 Jun 2014 - R. Yantosca - Removed code made obsolete by HEMCO
    24 Jun 2014 - R. Yantosca - Removed INIT_BROMOCARB, CLEANUP_BROMOCARB
    06 Nov 2015 - M. Yannetti - Added PRECISION_MOD
    29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

7.10.1 set_ch3br

Subroutine SET_CH3Br set CH3Br Concentrations in the planetary boundary layer. Based on latitude bands (1) 90-55N, (2) 55N-0, (3) 0-55S, (4) 55-90S. Values for setting pbl flux were determined by surface measurements from NOAA 2006 data.

INTERFACE:

```
 SUBROUTINE SET_CH3Br( am_I_Root, Input_Opt, State_Met,
&                      State_Chm, RC         )
```

USES:

```
 USE CMN_SIZE_MOD
 USE ErrCode_Mod
 USE ERROR_MOD
 USE GC_GRID_MOD,        ONLY : GET_YMID
 USE Input_Opt_Mod,      ONLY : OptInput
 USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
 USE PhysConstants,      ONLY : AIRMW
 USE State_Chm_Mod,      ONLY : ChmState
 USE State_Chm_Mod,      ONLY : Ind_
 USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
 LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
 TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
 TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
 TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
 INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
1) Spc is converted back and forth between units of [kg] and
   [v/v]. Placement of the call to SET_CH3Br in main.f (it's
   with the emissions) means that it should be in [kg].
```

REVISION HISTORY:

```
12 Feb 2008 - J. Parrella - Initial version
22 May 2012 - M. Payer    - Added ProTeX headers
27 Aug 2012 - M. Payer    - Added parallel DO loop
28 Aug 2012 - M. Payer    - Add error check for CH3Br to avoid OOB error
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

```
24 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Met,
                            State_Chm.  Get fields from these objects.
10 Sep 2015 - E. Lundgren - Modification for State_Chm%TRACERS units
                            now in kg/kg dry air (previously kg/box)
10 Sep 2015 - E. Lundgren - Remove passed argument 'unitflag'
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
25 Jul 2016 - M. Yannetti - Replaced TCVV with MW from spec db and phys const
```

7.10.2 set_bro

Subroutine SET_BRO sets BrO concentrations in the planetary boundary layer. Based on latitude bands (1) 90-55N, (2) 55N-0, (3) 0-55S, (4) 55-90S. Values for setting pbl flux were determined by surface measurements from NOAA 2006 data.

INTERFACE:

```
 SUBROUTINE SET_BRO( am_I_Root, Input_Opt, State_Met,
&                    State_Chm, RC         )
```

USES:

```
USE CMN_SIZE_MOD
USE DAO_MOD,            ONLY : IS_WATER
USE ErrCode_Mod
USE ERROR_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
USE PhysConstants,      ONLY : AIRMW
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Met State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
1) Spc is converted back and forth between units of [kg] and
   [v/v]. Placement of the call to SET_Bro in main.f (it's
   with the emissions) means that it should be in [kg].
```

REVISION HISTORY:

```
12 Feb 2008 - J. Parrella - Initial version
22 May 2012 - M. Payer    - Added ProTeX headers
27 Aug 2012 - M. Payer    - Added parallel DO loop
28 Aug 2012 - M. Payer    - Add error check for BrO to avoid OOB error
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
27 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
24 Jun 2014 - R. Yantosca - Remove IJLOOP, it's not used anymroe
06 Nov 2014 - M. Yannetti - Changed REAL*8 to REAL(fp)
10 Sep 2015 - E. Lundgren - Modification for State_Chm%TRACERS units
                            now in kg/kg dry air (previously kg/box)
10 Sep 2015 - E. Lundgren - Remove passed argument 'unitflag'
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
25 Jul 2016 - M. Yannetti - Replaced TCVV with MW from spec db and phys const
```

7.11 Fortran: Module Interface cldice_hbrhobr_rxn.F

Subroutine CLDICE_HBrHOBr_RXN calculates the rate constants for HBr and HOBr pseudo-reactions with ice.

INTERFACE:

```
 SUBROUTINE CLDICE_HBrHOBr_RXN( I,      J,      L,    DENAIR,
&                               QI,     hbr,    hobr,
&                               k_hbr,  k_hobr, AREA, State_Met )
```

USES:

```
 USE ERROR_MOD,          ONLY : IS_SAFE_DIV, IT_IS_NAN
 USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
 USE PRECISION_MOD            ! For GEOS-Chem Precision (fp)
 USE State_Met_Mod,      ONLY : MetState


 IMPLICIT NONE
```

INPUT PARAMETERS:

```
 INTEGER,        INTENT(IN)  :: I         ! Longitude index
 INTEGER,        INTENT(IN)  :: J         ! Latitude  index
 INTEGER,        INTENT(IN)  :: L         ! Altitude  index
```

```
      REAL(fp),       INTENT(IN)  :: DENAIR    ! Density of air         [#/cm3]
      REAL(fp),       INTENT(IN)  :: QI        ! Cloud ice mixing ratio [kg/kg]
      REAL(fp),       INTENT(IN)  :: hbr       ! Concentration of HBr   [#/cm3]
      REAL(fp),       INTENT(IN)  :: hobr      ! Concentration of HOBr  [#/cm3]
      TYPE(MetState), INTENT(IN)  :: State_Met ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT) :: k_hbr     ! Rate constant for HBr  + ice
                                               !   pseudo-rxn [cm3/s]
      REAL(fp),       INTENT(OUT) :: k_hobr    ! Rate constant for HOBr + ice
                                               !   pseudo-rxn [cm3/s]
      REAL(fp),       INTENT(OUT) :: AREA      ! Surface area [cm2/cm3]
```

REMARKS:

```
    The rate constant is calculated assuming:

                                                                             .
      1. A sticking coefficient of 0.1 [JPL 2006], Abbatt [1994],
         Chai et al. [2000]
      2. An effective radius is assumed as a function of (i) temperature and
         ice water content (IWC). This relationship is taken from Wyser [1998].

                                                                             .
    ** Calculations of a 1st order rate constent are borrowed from the
       subroutine arsl1k.F. Below are comments from that code:

                                                                             .
         The 1st-order loss rate on wet aerosol (Dentener's Thesis, p. 14)
         is computed as:

                                                                             .
           ARSL1K [1/s] = area / [ radius/dfkg + 4./(stkcf * nu) ]

                                                                             .
         where nu   = Mean molecular speed [cm/s] = sqrt(8R*TK/pi/M) for Maxwell
               DFKG = Gas phase diffusion coeff [cm2/s] (order of 0.1)
```

REVISION HISTORY:

```
    16 Jun 2011 - J. Parrella - Initial version
    22 May 2012 - M. Payer    - Added ProTeX headers
    26 Sep 2012 - R. Yantosca - For now, comment out debug print statements
    23 Oct 2012 - R. Yantosca - Add better error checks to prevent div-by-zero
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
    05 Sep 2013 - R. Yantosca - Now exit if IWC <= 0, this will cause the
                                logarithm to choke
    26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
    06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
    19 Dec 2014 - R. Yantosca - Now perform internal computations w/ REAL*8
    11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS-FP
    04 Jan 2016 - E. Lundgren - Remove grid box area-dependence
```

7.12 Fortran: Module Interface get_global_ch4.F

Subroutine GET_GLOBAL_CH4 computes the latitudinal gradient in CH4 corresponding to year.

INTERFACE:

```
      SUBROUTINE GET_GLOBAL_CH4( THISYEAR,  VARIABLE_CH4,
     &                           A3090S,    A0030S,
     &                           A0030N,    A3090N,
     &                           am_I_Root, Input_Opt )
```

USES:

```
      USE FUTURE_EMISSIONS_MOD, ONLY : GET_FUTURE_SCENARIO
      USE Input_Opt_Mod,        ONLY : OptInput
      USE PRECISION_MOD

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: THISYEAR      ! Current year
      LOGICAL,        INTENT(IN)  :: VARIABLE_CH4  ! =T: Use time-varying CH4
                                                   ! =F: Use constant CH4
      LOGICAL,        INTENT(IN)  :: am_I_Root     ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt     ! Input Options object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT) :: A3090S        ! CH4 [ppbv], 90S - 30S lat
      REAL(fp),       INTENT(OUT) :: A0030S        ! CH4 [ppbv], 30S - 00  lat
      REAL(fp),       INTENT(OUT) :: A0030N        ! CH4 [ppbv], 00  - 30N lat
      REAL(fp),       INTENT(OUT) :: A3090N        ! CH4 [ppbv], 30N - 90N lat
```

REMARKS:

```
(1) 2007 was the prior default year for CH4 emissions.  This has now been
    changed to 2013.
(2) The FUTURE_SCENARIO option is probably now obsolete, as most scale
    factors are now handled by HEMCO.  But we shall leave this intact
    until further notice.
```

REVISION HISTORY:

```
03 Jan 2001 - J. Wang     - Initial version
(1 ) GET_GLOBAL_CH4 only has to be called at the start of the new year,
     as long as A3090S, A0030S, A0030N, A3090N are saved in the
     calling program (bmy, 1/3/01)
(2 ) Also need to compute yearly gradients for CH4 beyond 1997 --
     will do this later (bmy, 1/3/01)
(3 ) Bug fix: add missing comma to FORMAT statement (bmy, 3/23/03)
```

```
(4 ) Place WRITE statments w/in an !$OMP CRITICAL block, so as to make
     sure that only one processor at a time writes them.  Also now use
     F90 REPEAT intrinsic function.  Also replaced old CH4 gradient values
     with updated values for 1983-2001.  Use data for 2001 as a proxy for
     years past 2001, since data for those years has not been reported
     yet. (mje, bmy, 7/7/03)
(5 ) Split off from module "global_ch4_mod.f".  Updated for IPCC future
     emissions scenarios. (swu, bmy, 5/30/06)
(6 ) Add the preindustrial CH4 scenarios.  Also set 2001 as the default
     in case we are running 2030 or 2050 met but present-day emissions.
     (swu, havala, bmy, 1/25/08)
(7 ) Updated CH4 vales with version 2008-07-02 for 1983-2007. Also use
     2007 for years past 2007 (jaf, 4/15/09)
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LFUTURE instead of LFUTURE
                            from logical_mod.F
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
13 Nov 2014 - M. Yannetti - Added PRECISION_MOD
06 Jan 2015 - R. Yantosca - Initial version
12 May 2015 - K. Travis   - Updated CH4 values with Version: 2014-06-24
                            for 2008-2013.
12 May 2015 - R. Yantosca - Added ProTeX headers
```

7.13 Fortran: Module Interface strat_chem_mod.F90

Module STRAT_CHEM_MOD contains variables and routines for performing a simple linearized chemistry scheme in the stratosphere, using archived 3D monthly climatological production rates and loss frequencies are applied from the GMI combo model.
In the original schem code (schem.F), only the following species were destroyed by photolysis in the stratosphere: PAN, H2O2, ACET, MEK, ALD2, RCHO, MVK, MACR, R4N2, CH2O, N2O5, HNO4, MP and by reaction with OH: ALK4, ISOP, H2O2, ACET, MEK, ALD2, RCHO, MVK, MACR, PMN, R4N2, PRPE, C3H8, CH2O, C2H6, HNO4, MP
The updated code includes at least all of these, and many more. The code is flexible enough to automatically apply the rate to any new species for future simulations that share the name in species_mod with the GMI name. (See Documentation on wiki).
The prod rates and loss frequencies are now read via HEMCO. They are stored in a data structure of flexible length (PLVEC). The file containing the prod rates and loss frequencies need to be specified in the HEMCO configuration file for each species of interest. They are then automatically read and remapped onto the simulation grid. The field names assigned to the production and loss fields are expected to be 'GMI_PROD_XXX' and 'GMI_LOSS_XXX', respectively, where XXX is the species name. Production rates must be given in units of v/v/s, and loss frequencies in s-1. The module variable PLMUSTFIND (set below) determines the behavior if no production rates and/or loss frequencies can be found for any of the GMI species defined in this module. IF PLMUSTFIND is set to TRUE, the code stops with an error if no entry is found. Otherwise, stead-state values are used for all species with no explicitly given values.

The (monthly) OH concentrations are also obtained through HEMCO. The field name must be 'STRAT_OH', and values must be in v/v.

INTERFACE:

```
MODULE Strat_Chem_Mod
```

USES:

```
  for precisions
  USE HCO_Error_Mod
  USE Precision_Mod    ! For GEOS-Chem Precision (fp, f4, f8)

  IMPLICIT NONE
  PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: Init_Strat_Chem
  PUBLIC  :: Do_Strat_Chem
  PUBLIC  :: Cleanup_Strat_Chem
  PUBLIC  :: Calc_STE
```

PRIVATE MEMBER FUNCTIONS:

```
  PRIVATE :: Set_BryPointers
  PRIVATE :: Set_PLVEC
  PRIVATE :: Do_Synoz
```

PUBLIC DATA MEMBERS:

REMARKS:

```
   References:
 ============================================================================
   (1 )
```

REVISION HISTORY:

```
   01 Feb 2011 - L. Murray   - Initial version
   20 Jul 2012 - R. Yantosca - Reorganized declarations for clarity
   20 Jul 2012 - R. Yantosca - Correct compilation error in GET_RATES_INTERP
   07 Aug 2012 - R. Yantosca - Fix parallelization problem in Bry do loop
   05 Oct 2012 - R. Yantosca - Add bug fix for IFORT 12 compiler in CALC_STE
   14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                               partitioning
   20 Nov 2014 - M. Yannetti - Added PRECISION_MOD
   30 Dec 2014 - C. Keller   - Now read Bry data through HEMCO
   16 Jan 2015 - C. Keller   - Now read all prod/loss fields and OH conc.
                               through HEMCO.
    4 Mar 2015 - R. Yantosca - Declare pointer args for HCO_GetPtr as REAL(f4)
   06 Apr 2016 - C. Keller   - Add Minit_Is_Set and SET_MINIT.
   03 Oct 2016 - R. Yantosca - Now dynamically allocate BrPtrDay, BrPtrNight
   03 Oct 2016 - R. Yantosca - Dynamically allocate BrPtrDay, BrPtrNight
```

7.13.1 Do_Strat_Chem

Function DO_STRAT_CHEM is the driver routine for computing the simple linearized stratospheric chemistry scheme.

INTERFACE:

```
SUBROUTINE DO_STRAT_CHEM( am_I_Root, Input_Opt,          &
                          State_Met, State_Chm, errCode )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : GET_TPAUSE_LEVEL
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE LINOZ_MOD,          ONLY : DO_LINOZ
USE PhysConstants,      ONLY : XNUMOLAIR, AIRMW
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH
USE TIME_MOD,           ONLY : TIMESTAMP_STRING
USE UnitConv_Mod

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(INOUT) :: errCode     ! Success or failure
```

REMARKS:

REVISION HISTORY:

```
01 Feb 2011 - L. Murray   - Initial version
18 Jul 2012 - R. Yantosca - For compatibility w/ the GEOS-5/GCM, we cannot
                            assume a minimum tropopause level anymore
18 Jul 2012 - R. Yantosca - Make sure I is the innermost DO loop
                            wherever expedient
20 Jul 2012 - R. Yantosca - Reorganized declarations for clarity
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
07 Aug 2012 - R. Yantosca - Make BEFORE a local variable for parallel loop
26 Oct 2012 - R. Yantosca - Now pass the Chemistry State object for GIGC
09 Nov 2012 - R. Yantosca - Now pass the Input Options object for GIGC
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
27 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                            partitioning
18 Mar 2013 - R. Yantosca - Now pass Input_Opt via the arg list
19 Mar 2013 - R. Yantosca - Now only copy Input_Opt%TCVV(1:N_TRACERS)
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
30 Dec 2014 - C. Keller   - Now get Bry data through HEMCO.
24 Mar 2015 - E. Lundgren - Replace dependency on tracer_mod with
                            CMN_GTCM_MOD for XNUMOLAIR
30 Sep 2015 - E. Lundgren - Now use UNITCONV_MOD for unit conversion
05 Mar 2016 - C. Keller   - Allow O3 P/L be done by GMI if both LINOZ and
                            SYNOZ are disabled. This is primarily for
                            testing/data assimilation applications.
16 Jun 2016 - M. Yannetti - Replaced TRACERID_MOD.\
20 Jun 2016 - R. Yantosca - Now make species ID flags module variables
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
12 Jul 2016 - R. Yantosca - Bug fix: ISBR2 should be held !$OMP PRIVATE
18 Jul 2016 - M. Yannetti - Replaced TCVV with spec db and phys constant
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

7.13.2 Set_BryPointers

Subroutine SET_BryPointers gets the Bry stratospheric data read by HEMCO. The pointers only need to be established once. Target data is automatically updated through HEMCO.

INTERFACE:

```
SUBROUTINE Set_BryPointers( am_I_Root, Input_Opt, State_Chm, State_Met, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
```

```
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorological State object
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(INOUT) :: RC          ! Success or failure
```

REVISION HISTORY:

```
30 Dec 2014 - C. Keller   - Initial version
```

7.13.3 Set_Plvec

Subroutine SET_PLVEC gets the production and loss terms of all strat chem species from HEMCO. The pointers only need to be established once. Target data is automatically updated through HEMCO.

INTERFACE:

```
SUBROUTINE Set_PLVEC ( am_I_Root, Input_Opt, State_Chm, State_Met, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorological State object
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(INOUT) :: RC          ! Success or failure
```

REVISION HISTORY:

```
16 Jan 2015 - C. Keller   - Initial version
```

7.13.4 Calc_Ste

Subroutine CALC_STE estimates what the stratosphere-to- troposphere exchange flux must have been since the last time it was reset

INTERFACE:

```
SUBROUTINE Calc_STE( am_I_Root, Input_Opt, State_Chm, State_Met, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GC_Error
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,   ONLY : GET_TAU, GET_NYMD, GET_NHMS, EXPAND_DATE
USE UnitConv_Mod

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
28 Apr 2012 - L. Murray   - Initial version
18 Jul 2012 - R. Yantosca - Make sure I is the innermost DO loop
                            (wherever expedient)
20 Jul 2012 - R. Yantosca - Reorganized declarations for clarity
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
```

```
                            running with the traditional driver main.F
05 Oct 2012 - R. Yantosca - Bug fix for IFORT 12: extend the #if statement
                            to avoid including code for nested-grid sims
25 Mar 2013 - R. Yantosca - Now accept Input_Opt, State_Chm, RC arguments
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
10 Aug 2015 - E. Lundgren - Input tracer concentraiton units are now [kg/kg]
25 May 2016 - E. Lundgren - Replace input_opt%TRACER_MW_KG with species
                            database field emMW_g (emitted species g/mol)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

7.13.5 Init_Strat_Chem

Subroutine INIT_STRAT_CHEM allocates all module arrays. It also opens the necessary rate files.

INTERFACE:

```
SUBROUTINE INIT_STRAT_CHEM( am_I_Root, Input_Opt, State_Chm, State_Met, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR, GC_Error
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TAU
USE TIME_MOD,           ONLY : GET_NYMD
USE TIME_MOD,           ONLY : GET_NHMS
USE TIME_MOD,           ONLY : GET_TS_CHEM

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
01 Feb 2011 - L. Murray   - Initial version
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
26 Oct 2012 - R. Yantosca - Now pass Chemistry State object for GIGC
09 Nov 2012 - R. Yantosca - Now pass Input Options object for GIGC
05 Nov 2013 - R. Yantosca - Now update tracer flags for tagOx simulation
03 Apr 2014 - R. Yantosca - PROD, LOSS, STRAT_OH, MINIT, SCHEM_TEND are
                            now REAL*4, so use 0e0 to initialize
11 Aug 2015 - E. Lundgren - Tracer units are now kg/kg and are converted
                            kg for assignment of MInit
16 Jun 2016 - M. Yannetti - Replaced TRACERID_MOD.
20 Jun 2016 - R. Yantosca - Now save species ID flags as module variables
                            and only define them in the INIT phase.
12 Jul 2016 - R. Yantosca - Now also store advected species ID's
11 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
20 Sep 2016 - R. Yantosca - Rewrote GMI_TrName statement for Gfortran
```

7.13.6 Set_Minit

Sets the MINIT array to current values in State_Chm

INTERFACE:

```
SUBROUTINE SET_MINIT( am_I_Root, Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE ERROR_MOD,     ONLY : GC_ERROR
USE ErrCode_Mod
USE Input_Opt_Mod, ONLY : OptInput
USE State_Chm_Mod, ONLY : ChmState
USE State_Met_Mod, ONLY : MetState
USE UnitConv_Mod

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REVISION HISTORY:

```
06 Apr 2016 - C. Keller   - Initial version: moved outside of
                            INIT_STRAT_CHEM so that it can be called from
                            within DO_STRAT_CHEM (for ESMF applications).
```

7.13.7 Cleanup_Strat_Chem

Subroutine CLEANUP_STRAT_CHEM deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_STRAT_CHEM
```

USES:

```
IMPLICIT NONE
```

REVISION HISTORY:

```
01 Feb 2011 - L. Murray   - Initial version
03 Oct 2016 - R. Yantosca - Deallocate BrPtrDay and BrPtrNight
05 Oct 2016 - R. Yantosca - Now make deallocations more robust
```

7.13.8 Do_Synoz

Subroutine Do_Synoz establishes the flux boundary condition for Ozone coming down from the stratosphere, using the Synoz algorithm of McLinden et al, 2000.

INTERFACE:

```
SUBROUTINE Do_Synoz( am_I_Root, Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : GET_TPAUSE_LEVEL
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_YEAR

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Reference:
============================================================================
C. A. McLinden, S. Olsen, B. Hannegan, O. Wild, M. J. Prather, and
J. Sundet, "Stratospheric Ozone in 3-D models: A simple chemistry
and the cross-tropopause flux".

                                                                           .
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%% NOTE: This SYNOZ scheme is now obsolete, replaced by LINOZ   %%%%
%%%% We keep this for backwards compatibility w/ older met fields %%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
13 Dec 1999 - Q. Li, R. Martin - Initial version
(1 ) The parameter Rdg0 from "CMN_GCTM" = R / g0 = 28.97.
(2 ) Pass PW = PS - PTOP to UPBDFLX via "CMN".
(3 ) Now pass IORD, JORD, KORD as arguments (bmy, 12/6/00)
(4 ) Now compute the proper value of PO3_vmr that will yield 475 Tg O3/yr
     for various settings of IORD, JORD, KORD (rvm, bey, bmy, 12/5/00)
                                                                           .
     ************************************************************
     ***** You must use this version of UPBDFLX_O3 if you are *****
     ***** using the Parallel Processor TPCORE v. 7.1         *****
     ************************************************************
                                                                           .
(5 ) Added to "upbdflx_mod.f".  Also updated comments and made some
     cosmetic changes. (bmy, 6/28/01)
(6 ) Now reference CMN_SETUP for LSPLIT.  Also store strat O3 into
     tracer #11 for multi-tracer Ox run. (amf, bmy, 7/3/01)
(7 ) Removed IREF, JREF -- these are obsolete.  Also T(IREF,JREF,L) is
     now T(I,J,L). (bmy, 9/27/01)
(8 ) Also replace PW(I,J) with P(I,J) (bmy, 10/3/01)
(9 ) Removed obsolete commented out code from 9/01 (bmy, 10/24/01)
(10) Removed obsolete commented out code from 7/01 (bmy, 11/26/01)
```

```
(11) Now write file names to stdout (bmy, 4/3/02)
(12) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
     to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(13) Now use GET_PEDGE and GET_PCENTER from "pressure_mod.f" to compute
     the pressure at the bottom edge and center of grid box (I,J,L).
     Also removed obsolete, commented-out code.  Removed G_SIG and
     G_SIGE from the arg list. (dsa, bdf, bmy, 8/21/02)
(14) Now reference BXHEIGHT and T from "dao_mod.f".  Also reference routine
     ERROR_STOP from "error_mod.f".  Now references IDTOX from F90 module
     "tracerid_mod.f" instead of from "comtrid.h". (bmy, 11/6/02)
(15) Now define J30S and J30N for 1x1 nested grid (bmy, 3/11/03)
(16) Make sure to pass AD via "dao_mod.f" for GEOS-1 (bnd, bmy, 4/14/03)
(17) On the first timestep, print how much O3 flux is coming down from the
     stratosphere in Tg/yr. (mje, bmy, 8/15/03)
(18) Change O3 flux to 500 Tg/yr for GEOS-3 (mje, bmy, 9/15/03)
(19) Now calls routine ADD_STRAT_POX from "tagged_ox_mod.f" in order to
     pass stratospheric flux of Ox to the proper tagged tracer w/o
     resorting to hardwiring w/in this routine. (bmy, 8/18/03)
(20) Add GEOS_4 to the #if defined block. (bmy, 1/29/04)
(21) Activated parallel DO-loops.  Now made STFLUX a local array
     in order to facilitate parallelization. (bmy, 4/15/04)
(22) Removed IORD, JORD, KORD from the arg list.  Now reference STT and
     ITS_A_TAGOX_SIM from "tracer_mod.f".  (bmy, 7/20/04)
(23) Use an #ifdef block to comment out an EXIT statement from w/in a
     parallel loop for COMPAQ compiler.  COMPAQ seems to have some
     problems with this.  Now supports 1x125 grid. (auvray, bmy, 12/1/04)
(24) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(25) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(26) Now set J30S and J30N for GEOS-5 nested grid (yxw, dan, bmy, 11/6/08)
(27) Remove support for COMPAQ compiler (bmy, 7/8/09)
(28) Now do not call ADD_STRAT_POx for tagged Ox (dbj, bmy, 10/16/09)
13 Aug 2010 - R. Yantosca - Treat MERRA like GEOS-5 (bmy, 8/13/10)
02 Dec 2010 - R. Yantosca - Added ProTeX headers
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.2 in the same way as MERRA
10 Feb 2012 - R. Yantosca - Modified for 0.25 x 0.3125 grids
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
28 Apr 2012 - L. Murray - Moved from upbdflx_mod.F to here, modified to
              F90, renamed from UPBDFLX_O3 to DO_SYNOZ. Use chem timestep
              now. Also, removed INIT_UPBDFLX, which was last used for
              GEOS-3.
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
04 Feb 2013 - M. Payer    - Replace all JJPAR with values for nested grids
                            since JJPAR is no longer a parameter
14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                            partitioning
25 Mar 2013 - R. Yantosca - Now use explicit numbers for J30S, J30N
31 May 2013 - R. Yantosca - Now pass Input_Opt, RC as arguments
```

```
    20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
    26 Sep 2013 - R. Yantosca - Remove SEAC4RS C-preprocessor switch
    26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
    05 Nov 2013 - R. Yantosca - Rename IDTOxStrt to id_O3Strat
    23 Jan 2014 - M. Sulprizio- Linoz does not call UPBDFLX_O3. Synoz does.
                                Now uncomment ADD_STRAT_POx (jtl,hyl,dbj,11/3/11)
    26 Feb 2015 - E. Lundgren - Replace GET_PEDGE and GET_PCENTER with
                                State_Met%PEDGE and State_Met%PMID. Remove
                                dependency on pressure_mod.
    03 Mar 2015 - E. Lundgren - Use virtual temperature in hypsometric eqn
    12 Aug 2015 - R. Yantosca - Add placeholder values for 0.5 x 0.625 grids
    16 Jun 2016 - M. Yannetti - Replaced TRACERID_MOD.
    20 Jun 2016 - R. Yantosca - Now make species ID flags module variables
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    12 Jul 2016 - R. Yantosca - Remove references to ADD_STRAT_POX
```

7.14 Fortran: Module Interface linoz_mod.F

Module LINOZ_MOD contains routines to perform the Linoz stratospheric ozone chemistry.

INTERFACE:

```
      MODULE LINOZ_MOD
```

USES:

```
      USE ERROR_MOD, ONLY : DEBUG_MSG  ! Routine for debug output
      USE PRECISION_MOD                ! For GEOS-Chem Precision (fp, f4, f8)

      IMPLICIT NONE
      PRIVATE
   !PRIVATE DATA MEMBERS:
      REAL(fp), ALLOCATABLE :: TLSTT(:,:,:,:)
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CLEANUP_LINOZ
      PUBLIC  :: DO_LINOZ
      PUBLIC  :: INIT_LINOZ
      PUBLIC  :: LINOZ_READ
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: LINOZ_CHEM3
      PRIVATE :: LINOZ_STRATL
      PRIVATE :: LINOZ_STRT2M
      PRIVATE :: LINOZ_SOMLFQ
      PRIVATE :: LINOZ_INTPL
```

REMARKS:

```
LINOZ Climatology:
============================================================================
The LINOZ stratospheric chemistry tables for ozone consist of:

.

7 tables, each a function of:
  12 months,
  18 latitudes (-85 to 85 in 10 deg. increments)
  25 altitudes ( z*=10-58 km in 2 km increments)

.

The 7 data fields are:
  1- ozone (Logan climatology), v/v
  2- Temperature climatology, K
  3- Column ozone climatology, Logan ozone integrated above box, DU
  4- ozone (P-L) for climatological ozone, v/v/s
  5- d(P-L) / dO3, 1/s
  6- d(P-L) / dT, v/v/s/K
  7- d(P-L) / d(column O3), v/v/s/DU

.

Implementation notes:
============================================================================
Dylan Jones (dbj@atmosp.physics.utoronto.ca) wrote:

.

  Testing this code [in v8-02-04] was more difficult that I thought.
  I began by trying to compare the output of v8-02-04 with our previous
  runs with v8-02-01.  I accounted for the changes in the transport_mod.f
  and I tried to undo the changes in when the diagnostics are archived in
  v8-02-04, but I was still getting large differences between v8-02-04
  and v8-02-01. I finally gave up on this since I may have made a mistake
  in reverting to the old way of doing the diagnostics in v8-02-04.  In
  the end I took the new linoz code from v8-02-04 and used it in v8-02-01.
  I ran two GEOS-5 full chemistry simulations for 2007 and the output
  were consistent over the full year.

.

  I think that it is safe to release [Linoz in v8-02-04].  However, we
  should acknowledge that it was [only] tested in v8-02-01, since I was
  not able to assess the quality of the output in v8-02-04.

.

Bob Yantosca (yantosca@seas.harvard.edu) wrote:

.

   We have also modified the code for use within the GEOS-5 GCM.  We now
   declare the TPARM array as part of the Input_Opt object.  The LINOZ
   climatology ASCII file is now read on the root CPU and MPI-broadcasted
   to the non-root CPUs.  Also, the INIT_LINOZ routine is now called
   not on the first chemistry timestep but rather in the initialization
   phase at the start of the run. (bmy, 3/18/13)
```

```
REVISION HISTORY:
 23 Mar 2000 - P. Cameron-Smith    - Initial version adapted heavily
                                     from McLinden's original file.
 24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
 28 May 2009 - D. Jones            - Further modifications
 18 Nov 2009 - D. Jones            - Further modifications
 01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
 01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
 15 Mar 2013 - R. Yantosca - Now use fields from Input_Opt and made other
                             modifications for GIGC interface to GEOS-5 GCM
 18 Mar 2013 - R. Yantosca - Comment out STRAT_INIT, it's not called
 20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
 17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
 19 Oct 2015 - C. Keller   - TLSTT is now 4D to work on curvilinear grids
 29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

7.14.1 do_linoz

Subroutine DO_LINOZ is the main driver for the Linoz stratospheric Ozone chemistry package.

INTERFACE:

```
      SUBROUTINE DO_LINOZ( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
10 Jun 2012 - L. Murray - Move call to DO_LINOZ from transport code to
              chemistry code, so the use of DT_TS_CHEM is now correct.
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
18 Mar 2013 - R. Yantosca - Now accept Input_Opt, RC as arguments
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
```

7.14.2 linoz_chem3

Subroutine LINOZ_CHEM3 applies linearized chemistry based on tables from PRATMO model using climatological T, O3, time of year

INTERFACE:

```
      SUBROUTINE LINOZ_CHEM3( DTCHEM,    am_I_Root, Input_Opt,
     &                        State_Met, State_Chm, RC         )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : GET_CHEMGRID_LEVEL
      USE CHEMGRID_MOD,       ONLY : GET_MAX_CHEMGRID_LEVEL
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : AIRMW, AVO
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Chm_Mod,      ONLY : Ind_
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      REAL(fp),       INTENT(IN)    :: DTCHEM      ! Time step [seconds]
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
   !OUTPUT PARAMETERS
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Replace fields from tracer_mod.f with fields from Input_Opt.  When we
use GEOS-Chem within the GEOS-5 GCM, the fields within Input_Opt will
be read on the root CPU and MPI-broadcasted to all other CPUs.
```

REVISION HISTORY:

```
24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
18 Nov 2009 - D. Jones            - For now, set tagged stratospheric
                                    tracer to total O3 in the overworld
                                    to avoid issues with spin ups
08 Feb 2010 - R. Yantosca         - Deleted obsolete local variables
22 Oct 2010 - R. Yantosca         - Added OMP parallel loop
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                            partitioning
18 Mar 2013 - R. Yantosca - Now accept Input_Opt, RC as arguments
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS)
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
06 Nov 2013 - R. Yantosca - Now activate the parallel loop.  Unit testing
                            revealed that this no longer causes errors.
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER and GET_PEDGE with
                            State_Met%PMID and State_Met%PEDGE. Remove
                            dependency on pressure_mod.
19 Oct 2015 - C. Keller   - TLSTT is now 4D to work on curvilinear grids
06 Jan 2016 - E. Lundgren - Use global physical parameters
16 Jun 2016 - R. Silvern  - Now define species ID of O3 with Ind_ function
17 Jun 2016 - R. Yantosca - Only look up species ID of O3 on first call
22 Jun 2016 - M. Yannetti - Replace TCVV with spc db and physical constant
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
11 Jul 2016 - R. Yantosca - Bug fix: SPC now points to State_Chm%Species
```

7.14.3 linoz_stratl

Subroutine LINOZ_STRATL performs a monthly fixup of chemistry parameters for the Linoz stratospheric ozone chemistry.

INTERFACE:

```
SUBROUTINE LINOZ_STRATL( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE GC_GRID_MOD,        ONLY : GET_YMID
USE Input_Opt_Mod,      ONLY : OptInput
USE PRESSURE_MOD
USE TIME_MOD,           ONLY : GET_MONTH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
    Replace size fields NLAT_LINOZ etc. with fields from Input_Opt.  When we
    use GEOS-Chem within the GEOS-5 GCM, the fields within Input_Opt will
    be read on the root CPU and MPI-broadcasted to all other CPUs.

    The LINOZ climatology array is Input_Opt%LINOZ_TPARM(25,18,12,N),
    which has the following dimensions
      * 25 layers from 58 km to 10 km by 2 km intervals
      * 18 latitudes (85S, 75S, ...85N)
      * 12 months
      *  N fields (currently N=7)
```

REVISION HISTORY:

```
    24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
    01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    18 Mar 2013 - R. Yantosca - Accept Input_Opt, RC arguments.  Use fields
                                from Input_Opt to facilitate GC/GEOS-5 interface
    18 Mar 2013 - R. Yantosca - Cosmetic changes, updated comments
    19 Oct 2015 - C. Keller   - TLSTT is now 4D to work on curvilinear grids
```

7.14.4 linoz_strt2m

Subroutine LINOZ_STRT2M interpolates quantities from the LINOZ vertical grid to the GEOS-Chem vertical grid. It also computes the 1st & 2nd moments of the distribution.

INTERFACE:

```
      SUBROUTINE LINOZ_STRT2M( am_I_Root, Input_Opt, NSTRT,
     &                         STRTX,     POL,       STRTOL,
     &                         STRT1L,    STRT2L,    RC      )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
!-----------------------------------------------------------------
! am_I_Root : Are we on the root CPU?
! Input_Opt : Input Options object
! NSTRT     : # of levels in the GEOS-Chem grid (= LLPAR)
! STRTX     : Quantity on the LINOZ vertical grid
!             (i.e. fields #1-7 of the LINOZ climatology)
! POL       : Pressure edges on the GEOS-Chem grid
!-----------------------------------------------------------------
LOGICAL,        INTENT(IN)  :: am_I_Root
TYPE(OptInput), INTENT(IN)  :: Input_Opt
INTEGER,        INTENT(IN)  :: NSTRT
REAL(fp),         INTENT(IN)  :: STRTX(Input_Opt%LINOZ_NLEVELS)
REAL(fp),         INTENT(IN)  :: POL(LLPAR+1)
```

OUTPUT PARAMETERS:

```
!-----------------------------------------------------------------
! STRT0L    : 0th moment of distribution, on GEOS-Chem grid edges
! STRT1L    : 1st moment of distribution, on GEOS-Chem grid edges
! STRT2L    : 2nd moment of distribution, on GEOS-Chem grid edges
! RC        : Success or failure?
!-----------------------------------------------------------------
REAL(fp),         INTENT(OUT) :: STRT0L(LLPAR+1)
REAL(fp),         INTENT(OUT) :: STRT1L(LLPAR+1)
REAL(fp),         INTENT(OUT) :: STRT2L(LLPAR+1)
INTEGER,        INTENT(OUT) :: RC
```

REMARKS:

```
Comments from Chris McLinden to Peter Cameron-Smith:
=====================================================================
CALL SOMLFQ(P1,P2,F0,F1,F2,PS,F,NL)
- P1,P2 are the pressure EDGES for the CTM layer onto which the
  coefficients will be mapped. [P1>P2 I believe {PJC}]
- F0,F1,F2 are the CTM layer vertical moments determined in SOMLFQ
- PS are the pressure layer edges of the original [ie Linox] grid
- F is the column of coefficients (on the original grid); note
  F is flipped relative to STRTX and since the coefficients begin
  at z*=10, F(1)=F(2)=...=F(5)=0
- NL is 30; size of F()

 The box model calculations were performed at z*=10km, 12km, ... and
 so these would represent the centres with the corresponding edges at
 9,11km ; 11,13km; ...
 PS() represents the edges (although PS(1) is set to 1000mb).
 The first few values are:
   PS(1)=1000
   PS(2)=874.947105    (note PS(2) is not quite 1000 exp(-1/16) as the
   PS(3)=656.117767     the average pressure is used - not the pressure
```

```
      PS(4)=492.018914     at the average z*)
      PS(5)=368.96213
      PS(6)=276.68257
      PS(7)=207.48266
      ...
      PS(30)=0.276682568
      PS(31)=0.0

      F(1) spans PS(1)-PS(2)
      F(2) spans PS(2)-PS(3)
      ...
      F(30) spans PS(30)-PS(31)
```

REVISION HISTORY:

```
    24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
    18 Mar 2013 - R. Yantosca - Now pass am_I_root, Input_Opt, RC arguments
    18 Mar 2013 - R. Yantosca - Rearrange argument list so that inputs are
                                all listed before outputs
    18 Mar 2013 - R. Yantosca - Now make NL a local varable and set its
                                value from Input_Opt%LINOZ_NLEVELS
```

7.14.5 linoz_somlfq

subroutine LINOZ_SOMLFQ calculates loss freq moments from a set of loss frequencies at std z*, given a CTM model interval pressure range: P1 ¿ P2 (decreasing up)

INTERFACE:

```
      SUBROUTINE LINOZ_SOMLFQ(P1,P2,F0,F1,F2,PS,F,NL)
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)  :: NL
      REAL(fp),  INTENT(IN)  :: F(NL)
      REAL(fp),  INTENT(IN)  :: PS(NL+1)
      REAL(fp),  INTENT(IN)  :: P1
      REAL(fp),  INTENT(IN)  :: P2
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT) :: F0
      REAL(fp),  INTENT(OUT) :: F1
      REAL(fp),  INTENT(OUT) :: F2
  REMARKS:
  The pressure levels BETWEEN z* values are:
       PS(i) > PS(i+1) bounds z*(i)
```

```
NL:  z* levels, ==> PS(NL+1) = 0  (extrapolate chemical loss to top)
     Z1 = 16.D0*LOG10(1000.D0/P1)
     Z2 = 16.D0*LOG10(1000.D0/P2)

The MOMENTS for a square-wave or 'bar': F(x)=f0  b<=x<=c, =0.0 else
     S0 =   f0 (x)                      [from x=b to x=c]
     S1 = 3 f0 (x^2 - x)                [from x=b to x=c]
     S2 = 5 f0 (2x^3 - 3x^2 + x)        [from x=b to x=c]
```

REVISION HISTORY:

```
24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
19 Mar 2013 - R. Yantosca - P1, P2 are now declared as INTENT(IN)
```

7.14.6 linoz_read

Subroutine LINOZ_READ reads the input data file for the Linoz stratospheric ozone chemistry.

INTERFACE:

```
SUBROUTINE LINOZ_READ( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE InquireMod,         ONLY : findFreeLun
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
LINOZ_READ is called from "main.f" at the start of the simulation.
LINOZ_READ will also call INIT_LINOZ to initialize the arrays.
```

REVISION HISTORY:

```
24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
16 Oct 2009 - R. Yantosca         - Now use IU_FILE instead of IU_LINOZ
16 Oct 2009 - R. Yantosca         - Read file from DATA_DIR_1x1
01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
15 Mar 2013 - R. Yantosca - Now call INIT_LINOZ from GIGC_Init_Extra
 5 Mar 2015 - R. Yantosca - Now read data relative to ExtData/CHEM_INPUTS
```

7.14.7 linoz_intpl

Subroutine LINOZ_INTPL does some kind of interpolation.

INTERFACE:

```
SUBROUTINE LINOZ_INTPL(KE,IE,ND,NE,XI,XN,YI,YN)
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)  :: KE
INTEGER, INTENT(IN)  :: IE
INTEGER, INTENT(IN)  :: ND
INTEGER, INTENT(IN)  :: NE
REAL(fp),  INTENT(IN)  :: XI(IE)
REAL(fp),  INTENT(IN)  :: XN(ND)
REAL(fp),  INTENT(IN)  :: YI(KE,IE)
```

OUTPUT PARAMETERS:

```
REAL(fp),  INTENT(OUT) :: YN(KE,ND)
```

REVISION HISTORY:

```
24 Jun 2003 - B. Field & D. Jones - Further updates for GEOS-Chem
```

7.14.8 init_linoz

Subroutine INIT_LINOZ allocates and zeroes the module arrays used in the Linoz stratospheric ozone algorithm.

INTERFACE:

```
SUBROUTINE INIT_LINOZ( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
16 Oct 2009 - R. Yantosca - Initial version
18 Mar 2013 - R. Yantosca - Remove TPARM array since that is now carried
                            within the Input_Opt object.
18 Mar 2013 - R. Yantosca - Accept am_I_Root, Input_Opt, RC arguments
14 Mar 2013 - M. Payer    - Replace Ox with O3 for full-chemistry simulation
19 Oct 2015 - C. Keller   - TLSTT is now 4D to work on curvilinear grids
```

7.14.9 cleanup_linoz

Subroutine CLEANUP_LINOZ deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_LINOZ
```

REVISION HISTORY:

```
16 Oct 2009 - R. Yantosca - Initial version
```

8 Aerosol modules

These modules contain routines to perform chemistry or removal of the various aerosol species.

8.1 Fortran: Module Interface aerosol_mod.F

Module AEROSOL_MOD contains variables and routines for computing optical properties for aerosols which are needed for both the FAST-J photolysis and ND21 optical depth diagnostics. (bmy, 7/20/04, 2/10/09)

INTERFACE:

```
MODULE AEROSOL_MOD
```

USES:

```
USE PRECISION_MOD

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: AEROSOL_CONC
PUBLIC :: CLEANUP_AEROSOL
PUBLIC :: INIT_AEROSOL
PUBLIC :: RDAER
```

PUBLIC DATA MEMBERS:

```
!=============================================================================
! BCPI        : Hydrophilic black carbon aerosol   [kg/m3]
! BCPO        : Hydrophobic black carbon aerosol   [kg/m3]
! OCPI        : Hydrophilic organic carbon aerosol [kg/m3]
! OCPO        : Hydrophilic organic carbon aerosol [kg/m3]
! OCPISOA     : Hydrophilic OC + SOA aerosol       [kg/m3]
! SALA        : Accumulation mode seasalt aerosol  [kg/m3]
! SALC        : Coarse mode seasalt aerosol        [kg/m3]
! SO4_NH4_NIT : Lumped SO4-NH4-NIT aerosol         [kg/m3]
! SO4         : Sulfate aerosol                    [kg/m3]
! NH4         : Ammonium aerosol                   [kg/m3]
! NIT         : Inorganic nitrate aerosol          [kg/m3]
! SOILDUST    : Mineral dust aerosol from soils    [kg/m3]
! SLA         : Stratospheric liquid aerosol       [kg/m3]
! SPA         : Stratospheric particulate aerosol  [kg/m3]
! TSOA        : Terpene SOA                        [kg/m3]
! ISOA        : Isoprene SOA                       [kg/m3]
! ASOA        : Aromatic + IVOC SOA                [kg/m3]
! OPOA        : Aerosol product of SVOC oxidation  [kg/m3]
! SOAG        : SOA product of GLYX                [kg/m3]
! SOAM        : SOA product of MYLY                [kg/m3]
! PM25        : Particulate matter < 2.5 um        [kg/m3]
!=============================================================================
REAL(fp), ALLOCATABLE, PUBLIC :: BCPI(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: BCPO(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: OCPI(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: OCPO(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: OCPISOA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SALA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SALC(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SO4_NH4_NIT(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SO4(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: NH4(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: NIT(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: FRAC_SNA(:,:,:,:)
```

```
REAL(fp), ALLOCATABLE, PUBLIC :: SOILDUST(:,:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SLA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SPA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: TSOA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: ISOA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: ASOA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: OPOA(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SOAG(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: SOAM(:,:,:)
REAL(fp), ALLOCATABLE, PUBLIC :: PM25(:,:,:)
```

DEFINED PARAMETERS:

```
REAL(fp), PARAMETER, PUBLIC :: OCFPOA  = 1.4e+0_fp ! OM/OC for POA
REAL(fp), PARAMETER, PUBLIC :: OCFOPOA = 2.1e+0_fp ! OM/OC for OPOA, OCPI,
                                                   !  and OCPO

! For SOAG, assume the total aerosol mass/glyoxal mass = 1.d0
! for now (tmf, 1/7/09)
REAL(fp), PARAMETER, PUBLIC :: OCFG = 1.e+0_fp

! For SOAM, assume the total aerosol mass/methylglyoxal mass = 1.d0
! for now (tmf, 1/7/09)
REAL(fp), PARAMETER, PUBLIC :: OCFM = 1.e+0_fp
```

REMARKS:

```
References:
============================================================================
(1 ) Pye, H.O.T., and J.H. Seinfeld, "A global perspective on aerosol from
      low-volatility organic compounds", Atmos. Chem. & Phys., Vol 10, pp
      4377-4401, 2010.
```

REVISION HISTORY:

```
(1 ) Added AEROSOL_RURALBOX routine (bmy, 9/28/04)
(2 ) Now convert ABSHUM from absolute humidity to relative humidity in
       AEROSOL_RURALBOX, using the same algorithm as in "gasconc.f".
       (bmy, 1/27/05)
(3 ) Now references "tropopause_mod.f" (bmy, 8/22/05)
(4 ) Now add contribution of SOA4 into Hydrophilic OC (dkh, bmy, 5/18/06)
(5 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(6 ) Add support for variable tropopause (bdf, phs, 9/14/06)
(7 ) Now set OCF=2.1 in AEROSOL_CONC for consistency w/ carbon_mod.f
     (tmf, 2/10/09)
(8 ) Add WTAREA and WERADIUS for dicarbonyl SOA production.
     WTAREA is the same as TAREA, but excludes dry dust, BCPO and OCPO;
     use same units as TAREA.
     WERADIUS is same as ERADIUS, but excludes dry dust, BCPO and OCPO;
```

```
      use same units as ERADIUS. (tmf, 3/2/09)
  (9 ) Add SOAG and SOAM species. (tmf, ccc, 3/2/09)
  (10) Modify AOD output to wavelength specified in jv_spec_aod.dat
       (clh, 05/07/10)
  22 Dec 2011 - M. Payer    - Added ProTeX headers
  05 Mar 2013 - R. Yantosca - Now make INIT_AEROSOL a public routine
  20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
```

8.1.1 aerosol_conc

Subroutine AEROSOL_CONC computes aerosol concentrations in kg/m3 from the tracer mass in kg in the Species array. These are needed to compute optical properties for photolysis, for the optical depth diagnostics, and for the SOA concentration diagnostics. (bmy, 7/20/04, 2/10/09)

INTERFACE:

```
      SUBROUTINE AEROSOL_CONC( am_I_Root, Input_Opt,
     &                         State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
      USE CMN_FJX_MOD,        ONLY : REAA
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE UCX_MOD,            ONLY : KG_STRAT_AER
      USE UnitConv_Mod
#if   defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure
```

REMARKS:

```
This code was originally included in "chemdr.f", but the same computation
also needs to be done for offline aerosol simulations.  Therefore, we have
split this code off into a separate subroutine which can be called by both
fullchem and offline aerosol simulations.
```

REVISION HISTORY:

```
(1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(2 ) Now add contribution from SOA4 into Hydrophilic OC (dkh, bmy, 5/18/06)
(3 ) Now set OCF=2.1 to be consistent w/ "carbon_mod.f" (tmf, 2/10/09)
22 Dec 2011 - M. Payer    - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
13 Nov 2012 - R. Yantosca - Now pass am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Remove call to INIT_AEROSOL, this is now done
                            in the initialization stage
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
17 Jun 2014 - J. Pierce   - Now allow bulk dust in TOMAS simulations
07 Apr 2015 - R. Yantosca - Add check to prevent div-by-zero errors
25 Jun 2015 - E. Lundgren - Use L. Zhang dust size distribution params for
                            mineral dust aerosols (non-TOMAS)
13 Aug 2015 - E. Lundgren - Convert tracer units to kg if input units are
                            mixing ratio
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
18 Nov 2016 - M. Sulprizio- Move calculation of SOA and PM2.5 concentrations
                            here from diag42_mod.F
22 Nov 2016 - M. Sulprizio- Add online calculation of aerosol growth factors
                            at 35% RH
```

8.1.2 rdaer

Subroutine RDAER reads global aerosol concentrations as determined by Mian Chin. Calculates optical depth at each level for "set_prof.f". Also calculates surface area for heterogeneous chemistry. It uses aerosol parameters in FAST-J input file "jv_spec.dat" for these calculations. (rvm, rjp, tdf, bmy, 11/04/01, 7/20/04)

INTERFACE:

```
      SUBROUTINE RDAER( am_I_Root, Input_Opt, State_Met,  State_Chm,
     &                  RC,        MONTH,     YEAR,       ODSWITCH   )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_FJX_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD21
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : CONSVAP
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
      USE TIME_MOD,           ONLY : SYSTEM_TIMESTAMP
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D
      USE UCX_MOD,            ONLY : GET_STRAT_OPT
      USE UCX_MOD,            ONLY : NDENS_AER

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root     ! Are we on root CPU?
      TYPE(MetState), INTENT(IN)  :: State_Met     ! Meteorology State
      INTEGER,        OPTIONAL    :: MONTH         ! # of current month
      INTEGER,        OPTIONAL    :: YEAR          ! 4-digit year
      INTEGER,        OPTIONAL    :: ODSWITCH      ! Logical indicator
                                                   !  = 0: AOD computed
                                                   !       at 999 nm
                                                   !  = 1: AOD computed
                                                   !       at wavelength set
                                                   !       in Radiation Menu
      TYPE(OptInput), INTENT(IN)  :: Input_Opt     ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC            ! Success or failure?
```

REVISION HISTORY:

```
    (1 ) At the point in which "rdaer.f" is called, ABSHUM is actually
         absolute humidity and not relative humidity (rvm, bmy, 2/28/02)
    (2 ) Now force double-precision arithmetic by using the "D" exponent.
         (bmy, 2/28/02)
    (3 ) At present aerosol growth is capped at 90% RH.  The data
         in jv_spec.dat could be used to allow a particle to grow to
         99% RH if desired. (rvm, 3/15/02)
```

```
(4 ) Bug fix: TEMP2 needs to be sized (IIPAR,JJPAR,LLPAR) (bmy, 5/30/02)
(5 ) Now reference BXHEIGHT from "dao_mod.f".  Also references ERROR_STOP
     from "error_mod.f".  Delete local declaration of TIME, since that
     is also declared w/in comode.h -- this causes compile-time errors
     on the ALPHA platform. (gcc, bmy, 11/6/02)
(6 ) Now use the online SO4, NH4, NIT aerosol, taken from the STT array,
     and passed via SO4_NH4_NIT argument if sulfate chemistry is turned on.
     Otherwise, read monthly mean sulfate from disk.  (rjp, bmy, 3/23/03)
(7 ) Now call READ_BPCH2 with QUIET=.TRUE., which prevents info from being
     printed to stdout.  Also made cosmetic changes. (bmy, 3/27/03)
(8 ) Add BCPI, BCPO, OCPI, OCPO to the arg list.  Bug fix: for online
     sulfate & carbon aerosol tracers, now make sure these get updated
     every timestep.  Now references "time_mod.f".  Now echo info about
     which online/offline aerosols we are using.  Updated comments.
     (bmy, 4/9/04)
(9 ) Add SALA, SALC to the arg list (rjp, bec, bmy, 4/20/04)
(10) Now references DATA_DIR from "directory_mod.f".  Now references LSULF,
     LCARB, LSSALT from "logical_mod.f".  Added minor bug fix for
     conducting the appropriate scaling for optical depth for ND21
     diagnostic.  Now make MONTH and YEAR optional arguments.  Now bundled
     into "aerosol_mod.f".  (rvm, aad, clh, bmy, 7/20/04)
(11) Now remove FWET from extinction efficiency computation (avd, 8/3/10)
(12) Include third input argument to determine the wavelength at which
     the AOD should be computed. This will set the optical properties
     that are used for the calculation of the AOD. The ND21 diagnostic
     should only be updated when WAVELENGTH = 1. (skim, 02/03/11)
09 Mar 2011 - R. Yantosca - Set MSDENS(2) = 1800 for APM (G. Luo)
22 Dec 2011 - M. Payer    - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
13 Nov 2012 - R. Yantosca - Now pass Input_Opt, RC arguments for GIGC
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
27 Mar 2013 - S.D. Eastham- Upgraded from Fast-J to Fast-JX
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
05 Mar 2015 - R. Yantosca - Remove DO_READ_DATA option.  We can no longer
                            have binary punch input in HPC environments.
31 Mar 2015 - R. Yantosca - Bug fix: Declare LINTERP as !$OMP PRIVATE
07 Apr 2015 - R. Yantosca - Bug fix: Add error check to JLOOP do-loop
                            so that we cycle if JLOOP <= 0
24 Jun 2015 - M. Sulprizio- Update organic aerosol density MSDENS(3) from
                            1800 to 1300 kg/m3 (E. Marais, M. Hammer)
15 Oct 2015 - C. Keller   - Empty ODAER before refilling.
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. ABSHUM
                            is now a 3D field in State_Met. ERADIUS, TAREA
                            WERADIUS, WTAREA are now pointers that point to
                            3D fields in State_Chm.
```

```
16 May 2016 - M. Sulprizio- Remove JLOOP entirely and loop over LLPAR, JJPAR,
                            IIPAR instead.
28 Jun 2016 - M. Sulprizio- Make IOUT a local variable to remove dependence
                            on comode_loop_mod.F
22 Nov 2016 - M. Sulprizio- Now define aerosol densities in species database
                            and use SpcData%Info%Density to populate MSDENS
```

8.1.3 init_aerosol

Subroutine INIT_AEROSOL allocates and zeroes module arrays

INTERFACE:

```
SUBROUTINE INIT_AEROSOL( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
20 Jul 2004 - R. Yantosca - Initial version
22 Dec 2011 - M. Payer    - Added ProTeX headers
05 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC arguments
17 Jun 2016 - R. Yantosca - Now use locally-defined species ID flags,
```

8.1.4 cleanup_aerosol

Subroutine CLEANUP_AEROSOL deallocates all module arrays (bmy, 7/20/04)

INTERFACE:

```
SUBROUTINE CLEANUP_AEROSOL
```

REVISION HISTORY:

```
22 Dec 2011 - M. Payer    - Added ProTeX headers
```

8.2 Fortran: Module Interface carbon_mod.F

Module CARBON_MOD contains arrays and routines for performing a carbonaceous aerosol simulation. Original code taken from Mian Chin's GOCART model and modified accordingly. (rjp, bmy, 4/2/04, 6/30/10)

INTERFACE:

```
      MODULE CARBON_MOD
```

USES:

```
      USE AEROSOL_MOD, ONLY : OCFPOA, OCFOPOA
      USE HCO_ERROR_MOD     ! For HEMCO error reporting
      USE PhysConstants     ! Physical constants
      USE PRECISION_MOD     ! For GEOS-Chem Precisions

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC :: CHEMCARBON
      PUBLIC :: EMISSCARBON
      PUBLIC :: CLEANUP_CARBON
      PUBLIC :: INIT_CARBON
#if defined ( TOMAS )
      PUBLIC :: EMISSCARBONTOMAS
#endif
```

PUBLIC DATA MEMBERS:

```
      ! SOAupdate: for branching ratio diagnostic (hotp 5/24/10)
      PUBLIC :: BETANOSAVE

       ! Make BIOG_SESQ array public so that it can be used by HEMCO
       ! (ckeller, 05/19/14)
       PUBLIC :: BIOG_SESQ
```

REMARKS:

```
   4 Aerosol species : Organic and Black carbon
                     : hydrophilic (soluble) and hydrophobic of each

   For secondary organic aerosol (SOA) simulation orginal code developed
   by Chung and Seinfeld [2002] and Hong Liao from John Seinfeld's group
   at Caltech was taken and further modified accordingly (rjp, bmy, 7/15/04)

   SOAupdate: Traditional SOA simulation updated by hotp 7/2010
     New code treats semivolatile or nonvolatile POA, aerosol from IVOCs,
       and has updated biogenic SOA
     For more detailes on the updated SOA/POA simulation, see comments
```

```
    in SOA_CHEMISTRY, Pye and Seinfeld ACP 2010, Pye et al. in prep
    for ACP 2010
  Note that modifications were made throughout the code for SOAupdate
                                                                      .
References:
========================================================================
```


(1) Bond, T.C., E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D.G. Streets, and N.M. Trautmann, "Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850-2000", Global Biogeochem. Cycles, 21, GB2018, doi:10.1029/2006GB002840, 2007.

(2) Chan, A.W.H., K.E. Kautzman, P.S. Chhabra, J.D. Surratt, M.N. Chan, J.D. Crounse, A. Kurten, P.O. Wennberg, R.C. Flagan, and J.H. Seinfeld, "Secondary orgainc aerosol formation from photooxidation of naphthlene and alkylnaphthalenes: implications for oxidation of intermediate volatility orgainc compounds (IVOCs)", Atmos. Chem. Phys, Vol 9, 3049-3060, doi:10.5194/acp-9-3049-2009, 2009.

(3) Chung, S.H., and J.H. Seinfeld. "Global distribution and climate forcing of carbonaceous aerosols", J. Geophys. Res., Vol 107(D19), 4407, doi:10.1029/2001JD001397, 2002.

(4) Grieshop, A.P., J.M. Logue, N.M. Donahue, and A.L. Robinson, "Laboratory investigation of photochemical oxidation of organic aerosol deom wood fires 1: Measurement and simulation of organic aerosol evolution", Atmos. Chem. Phys., Vol 9, 1263-1277, doi:10.5194/acp-9-1263-2009, 2009.

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(6) Henze, D.K., and J.H. Seinfeld, "Global secondary organic aerosol from isoprene oxidation", Geophys. Res. Lett., Vol 33, L09812, doi:10.1029/2006GL025976, 2006.

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(8) Kroll, J.H., N.L. Ng, S.M. Murphy, R.C. Flagan, and J.H. Seinfeld, "Secondary orgainc aerosol formation from isoprene photooxidation", Environ. Sci. Technol, Vol 40, 1869-1877, doi:10.1021/Es0524301, 2006.

(9) Liao, H., D.K. Henze, J.H. Seinfeld, S.L Wu, and L.J. Mickley, "Biogenic secondary aerosol over the United States: Comparison of climatological simulations with observations, J. Geophys. Res. Vol 112, D06201, doi:10.1029/2006JD007813, 2007.

(10) Ng, N.L., P.S. Chhabra, A.W.H. Chan, J.D. Surratt, J.H. Kroll, A.J. Kwan, D.C. McCabe, P.O. Wennberg, A. Sorooshian, S.M. Murphy, N.F. Dalleska, R.C. Flagan, and J.H. Seinfeld, "Effect of NOx level on secondary orgainc aerosol (SOA) formation from the photooxidation of terpenes", Atmos. Chem. Phys., Vol 7, 5159-5174, doi:10.5194/acp-7-5195-2007, 2007a.

(11) Ng, N.L., J.H. Kroll, A.W.H. Chan, P.S. Chhabra, R.C. Flagan, and J.H. Seinfeld, "Secondary orgainc aerosol formation from m-xylene, toluele, and benzene", Atmos. Chem. Phys., Vol 7, 3909-3922, doi:10.5194/acp-7-3909-2007, 2007b.

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(15) Shilling, J.E., Q. Chen, S.M. King, T. Rosenoern, J.H. Kroll, D.R. Worsnop, K.A. McKinney, S.T., Martin, "Particle mass yield in secondary orgainc aerosol formed by the dark ozonolysis of a-pinene", Atmos Chem Phys, Vol 8, 2073-2088, doi: 10.5194/acp-8-2073-2008, 2008.

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(17) Zhang, J.Y., K.E.H. Hartz, S.N. Pandis, N.M. Donahue, "Secondary organic aerosol formation from limonene ozonolysis: Homogeneous and heterogeneous influences as a function of NOx", J. Phys. Chem. A, Vol 110, 11053-11063, doi:10.1021/Jp06286f, 2006.

.

Base Year is 2000. More at http://www.hiwater.org

REVISION HISTORY:

(1) Added code from the Caltech group for SOA chemistry (rjp, bmy, 7/15/04)

(2) Now references "directory_mod.f", "logical_mod.f", "tracer_mod.f". (bmy, 7/20/04)

(3) Now read data from carbon_200411/ subdir of DATA_DIR. Also added some extra debug output. Now read T. Bond yearly emissions as default, but overwrite N. America with the monthly Cooke/RJP emissions. Added module variables I1_NA, I2_NA, J1_NA, J2_NA. (rjp, bmy, 12/1/04)

(4) Now can read seasonal or interannual BCPO, OCPO biomass emissions. Also parallelize loop in OHNO3TIME. (rjp, bmy, 1/18/05)

(5) Now references "pbl_mix_mod.f". Bug fix: now make sure only to save up to LD07 levels for the ND07 diagnostic in SOA_LUMP. (bmy, 3/4/05)

(6) Now can read data for both GEOS and GCAP grids (bmy, 8/16/05)

(7) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)

(8) Now references "megan_mod.f". Also now references XNUMOL and XNUMOLAIR from "tracer_mod.f" (tmf, bmy, 10/25/05)

(9) Bug fix for GCAP in BIOGENIC_OC (bmy, 4/11/06)

```
(10) Updated for SOA production from ISOP (dkh, bmy, 5/22/06)
(11) Updated for IPCC future emission scale factors.  Also added function
     GET_DOH to return ISOP that has reacted w/ OH. (swu, dkh, bmy, 6/1/06)
(12) Now add SOG condensation onto SO4, NH4, NIT (rjp, bmy, 8/3/06)
(13) Minor fix for 20 carbon tracers. (phs, 9/14/06)
(14) Now remove reading of biomass emissions from "carbon_mod.f", since
     they are better done in gc_biomass_mod.f.  This will allow us to
     standardize treatment of GFED2 or default BB emissions.  Also applied
     a typo fix in SOA_LUMP. (tmf, bmy, 10/16/06)
(15) Prevent seg fault error in BIOMASS_CARB_GEOS (bmy, 11/3/06)
(16) Corrected typos in SOA_LUMP.  Now also save GPROD and APROD to disk
     for each new diagnostic interval. (dkh, tmv, havala, bmy, 2/6/07)
(17) Modifications for 0.5 x 0.666 nested grids (yxw, dan, bmy, 11/6/08)
(18) Now account for various GFED2 products (yc, phs, 12/23/08)
(19) Now add future scaling to BIOMASS_CARB_GEOS (hotp, swu, 2/19/09)
(20) Added SOA production from dicarbonyls (tmf, 3/2/09)
(21) Bugfix: cleanup ORVC_TERP and ORVC_SESQ (tmf, 3/2/09)
(22) Replace USE_MONTHLY_BIOB with USE_BOND_BIOBURN, since this hardwired
     flag is a switc b/w annual Bond biomass burning emissions, and default
     GC source, which can be monthly/8 days/3hr.
     Implement changes for reading new Bond files (eml, phs, 5/18/09)
(23) Add option for non-local PBL scheme (lin, 06/09/08)
(24) Now added NESTED_EU grid.  Updated formulation of SOG condensation
     onto OC aerosol, according to recommendations of Aerosol Working
     Group. (amv, clh, bmy, 12/21/09)
(25) Bug fix for EMIS_SAVE in EMITHIGH (bmy, 1/11/10)
(26) Modifications for TOMAS (win, bmy, 1/25/10)
(27) Bug fix: call SOA_PARA_INIT (ensberg, bmy, 6/30/10)
(28) Modified to include GFED3 (psk, 1/5/11)
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
30 Jul 2012 - R. Yantosca - Modifications for grid-independence
28 Nov 2012 - R. Yantosca - Replace SUNCOS array with State_Met%SUNCOS and
                            SUNCOS_MID array with State_Met%SUNCOSmid
04 Mar 2013 - R. Yantosca - Now call INIT_CARBON from the init stage
                            which facilitates connection to GEOS-5 GCM
05 Mar 2013 - R. Yantosca - Remove reference to LNLPBL from logical_mod.F
                            and replace with Input_Opt%LNLPBL
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
20 Jun 2014 - R. Yantosca - Removed obsolete code; we now use HEMCO
23 Sep 2014 - M. Sulprizio- Get OH, NO3, and O3 fields for offline aerosol
                            simulation from HEMCO
06 Nov 2014 - M. Yannetti - Added PRECISION_MOD
13 Nov 2014 - C. Keller   - Added EMISSCARBON to make sure that SESQ and POA
                            emissions are properly passed from HEMCO.
05 Jan 2016 - E. Lundgren - Use global physical parameters (AIRMW and AVO)
```

```
    14 Jan 2016 - M. Sulprizio- POAEMISS(:,:,:,1) now represents POG1 and
                                POAEMISS(:,:,:,2) now represents POG2
    17 Jun 2016 - J.D.Maaasakkers - Now use Ind_ to define species ID's
    17 Jun 2016 - R. Yantosca - Now declare all species ID's as module
                                variables, and initialize them at startup
    28 Jun 2016 - M. Sulprizio- Add species ID's for L*RO2N/H and LISOP* to
                                replace uses of IL*RO2N/H and ILISOP* from
                                comode_loop_mod.F
```

8.2.1 chemcarbon

Subroutine CHEMCARBON is the interface between the GEOS-Chem main program and the carbon aerosol chemistry routines that calculates dry deposition, chemical conversion between hydrophilic and hydrophobic, and SOA production.

INTERFACE:

```
      SUBROUTINE CHEMCARBON( am_I_Root, Input_Opt,
     &                       State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
#if   defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS                        !(win, 1/25/10)
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

REVISION HISTORY:

```
01 Apr 1994 - R. Park - Initial version
(1 ) Added code from the Caltech group for SOA chemistry.  Also now
     reference "global_oh_mod.f", "global_o3_mod.f", "global_no3_mod.f".
     (rjp, bmy, 7/8/04)
(2 ) Now reference LSOA and LEMIS from CMN_SETUP.  Now only call OHNO3TIME
     if it hasn't been done before w/in EMISSCARBON. (rjp, bmy, 7/15/04)
(3 ) Now reference LSOA, LEMIS, LPRT from "logical_mod.f".  Now reference
     STT and ITS_AN_AEROSOL_SIM from "tracer_mod.f" (bmy, 7/20/04)
(4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(5 ) Now updated for SOA production from ISOP. (dkh, bmy, 6/1/06)
(6 ) Bug fix for aerosol sim w/ 20 tracers (phs, 9/14/06)
(7 ) Add subroutine call AGING_CARB for converting H-phobic 30-bin EC or OC
     to H-philic EC or OC. (win, 1/25/10)
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
15 Nov 2012 - R. Yantosca - Added ProTeX headers
04 Mar 2013 - R. Yantosca - Remove call to INIT_CARBON
04 Mar 2013 - R. Yantosca - Now pass Input_Opt to SOA_CHEMISTRY
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
23 Sep 2014 - M. Sulprizio- Get OH, NO3, and O3 fields for offline aerosol
                            simulation from HEMCO
16 Jun 2016 - J.D.Maasakkers- Now define species ID's with Ind_ function
23 Jun 2016 - R. Yantosca - Add more error checks to make sure each id_*
                            species flag is defined before using it
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

8.2.2 chem_bcpo

Subroutine CHEM_BCPO converts hydrophobic BC to hydrophilic BC and calculates the dry deposition of hydrophobic BC.

INTERFACE:

```
SUBROUTINE CHEM_BCPO( am_I_Root, Input_Opt, TC, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD07_BC
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! H-phobic BC [kg]
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

```
    Drydep is now applied in mixing_mod.F90.
```

REVISION HISTORY:

```
    01 Apr 2004 - R. Park - Initial version
    (1 ) Remove reference to "CMN", it's obsolete (bmy, 7/20/04)
    (2 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP
         from "pbl_mix_mod.f" (bmy, 2/17/05)
    (3 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
    (4 ) Add option for non-local PBL scheme (lin, 06/09/08)
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
    26 Nov 2012 - R. Yantosca - Added ProTeX headers
    05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
    19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
    04 Mar 2015 - C. Keller   - Now do dry dep in mixing_mod.F90
    12 Jun 2015 - R. Yantosca - Remove orphaned ND44 drydep variables
    12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                                so we can greatly collapse this code
    23 Sep 2015 - R. Yantosca - Remove reference to DRYBCPO, it's obsolete
```

8.2.3 chem_bcpi

Subroutine CHEM_BCPI calculates dry deposition of hydrophilic BC.

INTERFACE:

```
      SUBROUTINE CHEM_BCPI( am_I_Root, Input_Opt, TC, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! H-philic BC [kg]
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

```
Drydep is now applied in mixing_mod.F90.
```

REVISION HISTORY:

```
01 Apr 2004 - R. Park - Initial version
(1 ) Remove reference to "CMN", it's obsolete (bmy, 7/20/04)
(2 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
      "pbl_mix_mod.f" (bmy, 2/17/05)
(3 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
26 Nov 2012 - R. Yantosca - Added ProTeX Headers
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
04 Mar 2015 - C. Keller   - Now do dry dep in mixing_mod.F90
12 Jun 2015 - R. Yantosca - Remove orphaned ND44 drydep variables
12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                            so we can greatly collapse this code
23 Sep 2015 - R. Yantosca - Remove reference to DRYBCPI, it's obsolete
```

8.2.4 chem_ocpo

Subroutine CHEM_OCPO converts hydrophobic OC to hydrophilic OC and calculates the dry deposition of hydrophobic OC.

INTERFACE:

```
SUBROUTINE CHEM_OCPO( am_I_Root, Input_Opt, TC, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG_MOD,           ONLY : AD07_OC
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! H-phobic OC [kg]
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

REVISION HISTORY:

```
01 Apr 2004 - R. Park - Initial version
(1 ) Remove reference to "CMN", it's obsolete (bmy, 7/20/04)
(2 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
     "pbl_mix_mod.f" (bmy, 2/17/05)
(3 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
26 Nov 2012 - R. Yantosca - Added ProTeX headers
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
04 Mar 2015 - C. Keller   - Now do dry dep in mixing_mod.F90
12 Jun 2015 - R. Yantosca - Remove orphaned ND44 drydep variables
23 Sep 2015 - R. Yantosca - Remove reference to DRYOCPO, it's obsolete
```

8.2.5 chem_ocpi

Subroutine CHEM_BCPI calculates dry deposition of hydrophilic OC.

INTERFACE:

```
SUBROUTINE CHEM_OCPI( am_I_Root, Input_Opt, TC, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! H-philic OC [kg]
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

REVISION HISTORY:

```
01 Apr 2004 - R. Park - Initial version
(1 ) Remove reference to "CMN", it's obsolete (bmy, 7/20/04)
(2 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
     "pbl_mix_mod.f" (bmy, 2/17/05)
(3 ) Bug fix: add BL_FRAC to the PRIVATE list (mak, bmy, 10/3/05)
(4 ) Now refrerences XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
26 Nov 2012 - R. Yantosca - Added ProTeX headers
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
04 Mar 2015 - C. Keller   - Now do dry dep in mixing_mod.F90
12 Jun 2015 - R. Yantosca - Remove orphaned ND44 drydep variables
23 Sep 2015 - R. Yantosca - Remove reference to DRYOCPI, it's obsolete
```

8.2.6 aging_carb

Subroutine AGING_CARB converts the size-resolved hydrophobic EC or OC to hydrophilic EC or OC with an assumed e-folding time. (win, 9/11/07)

INTERFACE:

```
SUBROUTINE AGING_CARB( MIL, MOB )
```

USES:

```
      USE CMN_SIZE_MOD
      USE TIME_MOD,     ONLY : GET_TS_CHEM    ! [=] minute
      USE TOMAS_MOD,    ONLY : IBINS
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp), INTENT(INOUT) :: MIL(IIPAR,JJPAR,LLPAR, IBINS)
      REAL(fp), INTENT(INOUT) :: MOB(IIPAR,JJPAR,LLPAR, IBINS)
```

REMARKS:

```
   20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.7 soag_liggio_diff

Subroutine SOAG_LIGGIO_DIFF produces SOA on aqueous aerosol surfaces from GLYX following the uptake model used for N2O5, and the gamma from Liggio et al. [2005]. (tmf, 5/30/06)

INTERFACE:

```
      SUBROUTINE SOAG_LIGGIO_DIFF( am_I_Root, Input_Opt,
     &                             State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_O3_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD07_SOAGM
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_MONTH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
(1 ) SOAG (SOA product of GLYX is produced at existing hydrophilic aerosol
     surface.
```

REVISION HISTORY:

```
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
21 Dec 2015 - M. Sulprizio- Get air density directly from State_Met
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. WERADIUS,
                            WTAREA are now pointers that point to 3D fields
                            in State_Chm.
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.8 soam_liggio_diff

Subroutine SOAM_LIGGIO_DIFF produces SOA on aqueous aerosol surfaces from GLYX following the uptake model used for N2O5, and the gamma from Liggio et al. [2005]. (tmf, 5/30/06)

INTERFACE:

```
      SUBROUTINE SOAM_LIGGIO_DIFF( am_I_Root, Input_Opt,
     &                             State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_O3_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD07_SOAGM
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_MONTH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
(1 ) SOAM (SOA product of MGLY) is produced at existing hydrophilic aerosol
     surface.
```

REVISION HISTORY:

```
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
 5 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt arguments
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
21 Dec 2015 - M. Sulprizio- Get air density directly from State_Met
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. WERADIUS,
                            WTAREA are now pointers that point to 3D fields
                            in State_Chm.
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.9 soa_chemistry

Subroutine SOA_CHEMISTRY performs SOA formation. This code is from the Caltech group (Hong Liao, Serena Chung, et al) and was modified for GEOS-CHEM. (rjp, bmy, 7/8/04, 12/21/09)

INTERFACE:

```
      SUBROUTINE SOA_CHEMISTRY( am_I_Root, Input_Opt,
     &                          State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_O3_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD07_HC
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TS_CHEM,      GET_MONTH
      USE TIME_MOD,           ONLY : ITS_TIME_FOR_BPCH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Procedure:
    ============================================================================
    (1 ) Read in NO3, O3, OH in CHEM_SOA
    (2 ) Scales these fields using OHNO3TIME in sulfate_mod.f (see GET_OH)
    (3 ) Calculate reaction rates (Serena's OCHEMPARAETER)
    (4 ) CALCULATE DELHC
    (5 ) get TOM gas products
    (6 ) equilibrium calculation
                                                                             .
    As of 5/20/10: Havala's New formulation
                                                                             .
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % FOR SEMIVOLATILE POA and IVOC (aka SOA_SVPOA) simulations:      %
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    GEOS-Chem treats formation of aerosol from 11 parent hydrocarbons
    and oxidation by OH, O3, and NO3:
                                                                             .
    The parent hydrocarbons are lumped into 5 semivolatile systems:
    TSOA/G: the lumped semivolatile oxidation products of
            monoterpene and sesquiterpene oxidation
    ISOA/G: the lumped semivolatile oxidation products of isoprene ox
    ASOA/G: the lumped semivolatile (and nonvolatile) products of
            benzene, toluene, xylene, and naphthalene (IVOC surrogate)
            oxidation
    POA/G : the lumped primary semivolatile emissions
    OPOA/G: the lumped products of primary semivolatile oxidation
                                                                             .
    Parent HC      Oxidized by       Products
    =============  ================  ==================================
    MTPA           OH, O3, NO3       TSOA/G0-3
    LIMO           OH, O3, NO3       TSOA/G1-3
    MTPO           OH, O3, NO3       TSOA/G0-3
    SESQ           OH, O3, NO3       TSOA/G1-3
    ISOP           OH, NO3           ISOA/G1-3
    BENZ           OH, (+NO,HO2)     ASOAN, ASOA/G1-3
```

```
TOLU           OH, (+NO,HO2)     ASOAN, ASOA/G1-3
XYLE           OH, (+NO,HO2)     ASOAN, ASOA/G1-3
SVOC/POA       OH                POA/G1-2
O-SVOC/OPOA    OH                OPOA/G1-2
NAP            OH, (+NO,HO2)     ASOAN, ASOA/G1-3

Species that must be defined in input.geos (in addition to standard
full chem species) (34 additional):
TSOA1      TSOG1      ISOA1      ISOG1      ASOA1      ASOG1
TSOA2      TSOG2      ISOA2      ISOG2      ASOA2      ASOG2
TSOA3      TSOG3      ISOA3      ISOG3      ASOA3      ASOG3
ASOAN      TSOA0      TSOG0
BENZ       TOLU       XYLE       MTPA       LIMO       MTPO
NAP
POA1       POG1       POA2       POG2
OPOA1      OPOG1      OPOA2      OPOG2

The following should NOT be defined for semivol POA: OCPI, OCPO

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% FOR NON-VOLATILE TRADITIONAL POA (aka SOA) simulations:         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
GEOS-Chem treats formation of aerosol from 8 parent hydrocarbons
and oxidation by OH, O3, and NO3:

Two non-volatile,traditional primary OC species exist:
OCPO: hydrophobic POA
OCPI: hydrophillic POA

The parent hydrocarbons are lumped into 3 semivolatile systems:
TSOA/G: the lumped semivolatile oxidation products of
        monoterpene and sesquiterpene oxidation
ISOA/G: the lumped semivolatile oxidation products of isoprene ox
ASOA/G: the lumped semivolatile (and nonvolatile) products of
        benzene, toluene, and xylene oxidation

Parent HC      Oxidized by       Products
=============  ================  ==================================
MTPA           OH, O3, NO3       TSOA/G0-3
LIMO           OH, O3, NO3       TSOA/G1-3
MTPO           OH, O3, NO3       TSOA/G0-3
SESQ           OH, O3, NO3       TSOA/G1-3
ISOP           OH, NO3           ISOA/G1-3
BENZ           OH, (+NO,HO2)     ASOAN, ASOA/G1-3
TOLU           OH, (+NO,HO2)     ASOAN, ASOA/G1-3
XYLE           OH, (+NO,HO2)     ASOAN, ASOA/G1-3

Species that must be defined in input.geos (in addition to standard
```

```
full chem species) (25 additional):
TSOA1      TSOG1      ISOA1      ISOG1      ASOA1      ASOG1
TSOA2      TSOG2      ISOA2      ISOG2      ASOA2      ASOG2
TSOA3      TSOG3      ISOA3      ISOG3      ASOA3      ASOG3
ASOAN      TSOA0      TSOG0
BENZ       TOLU       XYLE       MTPA       LIMO       MTPO
                                                                    .
The following should NOT be defined for traditional POA:
   NAP, POA/G OPOA/G
                                                                    .
References (see above for full citations):
=========================================================================
Monoterpenes and sesquiterpenes:
  Experimental Data:
    Griffin et al. 1999 JGR      (sesquiterps low NOx)
    Shilling et al. 2008 ACP     (a-pinene ozonolysis for MTPO/MTPA)
    Zhang et al. 2006 JPhysChemA (limonene ozonolysis)
    Ng et al. 2007 ACP           (data for NOx effect on sesq aerosol)
  Modeling:
    Chung and Seinfeld 2002 JGR  (original formulation in GEOS-Chem)
    Liao et al. 2007 JGR         (comparison to measurements)
    Pye et al. in prep 2010      (new lumping scheme, NOx effect)
Isoprene
    Kroll et al. 2006 ES&T       (low NOx experiments)
    Ng et al. 2008 ACP           (isoprene + NO3 experiments)
    Henze et al. 2006 GRL        (low NOx isoprene modeling in GEOS-Chem)
    Pye et al. in prep 2010      (new lumping scheme and isop+no3 modeling)
Aromatics: benz, tolu, xyle
    Ng et al. 2007 ACP           (experiments)
    Henze et al. 2008 ACP        (global modeling)
POA/OPOA
    Shrivastava et al. 2006 ES&T (POA experiments)
    Grieshop et al. 2009 ACP     (POA/SVOC oxidation experiments)
    Pye and Seinfeld 2010 ACP    (global modeling)
IVOC/Naphthalene
    Chan et al. 2009 ACP         (experiments)
    Pye and Seinfeld 2010 ACP    (global modeling)
```

REVISION HISTORY:

```
(1 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now modified for SOG4, SOA4 -- products of oxidation by isoprene.
      (dkh, bmy, 6/1/06)
(3 ) Now consider SOG condensation onto SO4, NH4, NIT aerosols (if SO4,
      NH4, NIT are defined as tracers). (rjp, bmy, 8/3/06)
(4 ) Updated formulation of SOG condensation onto OC aerosol, according
      to recommendations of Aerosol Working Group (clh, bmy, 12/21/09)
(5 ) Now only print out debug info when LPRT=T (bmy, 4/21/10)
```

```
(6 ) Bug fix: call SOA_PARA_INIT (ensberg, bmy, 6/30/10)
05 Oct 2011 - R. Yantosca - SUNCOS is not needed, so remove
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Now pass Input_Opt to SOA_DEPO
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LPRT
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
12 Jun 2015 - R. Yantosca - Removed SOA_DEPO; ND44 is now done in mixing_mod
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.10 soa_equil

Function SOA_EQUIL solves SOAeqn=0 to determine Mnew (= mass) See Eqn (27) on page 70 of notes. Originally written by Serena Chung at Caltech, and modified for inclusion into GEOS-CHEM. (rjp, bmy, 7/8/04)

INTERFACE:

```
 FUNCTION SOA_EQUIL( MASS, MPOC, AEROSOL, GAS, KOM )
&         RESULT( SOA_MASS )
```

INPUT/OUTPUT PARAMETERS:

```
 REAL(fp), INTENT(IN) :: MASS                ! Pre-existing aer mass [ug/m3]
 REAL(fp), INTENT(IN) :: MPOC                ! POA Mass [ug/m3]
 REAL(fp), INTENT(IN) :: AEROSOL(MPROD,MSV)  ! Aerosol concentration [ug/m3]
 REAL(fp), INTENT(IN) :: GAS(MPROD,MSV)      ! Gas-phase conc [ug/m3]
 REAL(fp), INTENT(IN) :: KOM(MPROD,MSV)      ! Equilibrium gas-aerosol
                                             !  partition coeff. [m3/ug]
```

RETURN VALUE:

```
 REAL(fp)             :: SOA_MASS
```

REMARKS:

```
This version does NOT assume that the gas and aerosol phases are in
equilibrium before chemistry; therefore, gas phase concentrations are
needed explicitly.  The gas and aerosol phases are assumed to be in
equilibrium after chemistry.

Note: Unlike FUNCTION SOA, this function assumes no reactions.  It only
considers the partitioning of existing products of VOC oxidation.
```

```
.
HC_JHC + OXID_IOXID - >
  alpha(1,IOXID,JHC) [SOAprod_gas(1,IOXID,JHC)+SOAprod(1,IOXID,JHC)]+
  alpha(2,IOXID,JHC) [SOAprod_gas(2,IOXID,JHC)+SOAprod(2,IOXID,JHC)]
.
SOAprod_gas(IPR,IOXID,JHC) <--> SOAprod(IPR,IOXID,JHC)
                                        (aerosol phase)
.
w/ equilibrium partitioning:
.
                                  SOAprod(IPR,IOXID,JHC)
  SOAprod_gas(IPR,IOXID,JHC) = ------------------------
                                    Kom(IPR,IOXID,JHC)
NOTES:
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.11 zeroin

Function ZEROIN computes a zero of the function f(x) in the interval ax,bx.

INTERFACE:

```
-----------------------------------------------------------------------------

    FUNCTION ZEROIN(AX,BX,TOL,MPOC,AEROSOL,GAS,KOM) RESULT( MNEW )
```

INPUT PARAMETERS:

```
    REAL(fp), INTENT(IN) :: ax
    REAL(fp), INTENT(IN) :: bx
    REAL(fp), INTENT(IN) :: tol
    REAL(fp), INTENT(IN) :: Mpoc
    REAL(fp), INTENT(IN) :: Aerosol(MPROD,MSV)
    REAL(fp), INTENT(IN) :: Gas(MPROD,MSV)
    REAL(fp), INTENT(IN) :: Kom(MPROD,MSV)
```

RETURN VALUE:

```
    REAL(fp)             :: MNEW
```

REMARKS:

```
  NOTE: This function may be problematic -- it uses GOTO's, which are not
  good for parallelization. (bmy, 7/8/04)
.
  shc I got this code from http://www.netlib.org
.
```

```
    a zero of the function  f(x)  is computed in the interval ax,bx .
                                                                      .
input..                                                               .
ax     left endpoint of initial interval
bx     right endpoint of initial interval
f      function subprogram which evaluates f(x) for any x in
       the interval  ax,bx
tol    desired length of the interval of uncertainty of the
       final result ( .ge. 0.0e+0_fp)
                                                                      .
output..                                                              .
zeroin abcissa approximating a zero of  f  in the interval ax,bx      .
    it is assumed  that   f(ax)   and   f(bx)   have  opposite  signs
without  a  check.  zeroin  returns a zero  x  in the given interval
ax,bx  to within a tolerance  4*macheps*abs(x) + tol, where macheps
is the relative machine precision.
    this function subprogram is a slightly  modified  translation  of
the algol 60 procedure  zero  given in  richard brent, algorithms for
minimization without derivatives, prentice - hall, inc. (1973).
```

REVISION HISTORY:

```
(1 ) Change dabs to ABS and dsign to SIGN, in order to avoid conflicts
      with intrinsic function names on the PGI compiler. (bmy, 12/2/04)
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.12 rtbis

Function RTBIS finds the root of the function SOA_EQUIL via the bisection method. Original algorithm from "Numerical Recipes" by Press et al, Cambridge UP, 1986. Modified for inclusion into GEOS-CHEM. (bmy, 7/8/04)

INTERFACE:

```
      FUNCTION RTBIS( X1,   X2,      XACC,
     &                MPOC, AEROSOL, GAS, KOM ) RESULT( ROOT )
```

USES:

```
      USE ERROR_MOD, ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN) :: X1                ! Endpoint #1
```

```
      REAL(fp), INTENT(IN) :: X2                ! Endpoint #2
      REAL(fp), INTENT(IN) :: XACC              ! Desired accuracy of solution
      REAL(fp), INTENT(IN) :: MPOC              ! POA mass [ug/m3]
      REAL(fp), INTENT(IN) :: AEROSOL(MPROD,MSV) ! Aerosol concentration [ug/m3]
      REAL(fp), INTENT(IN) :: GAS(MPROD,MSV)    ! Gas-phase concentration [ug/m3]
      REAL(fp), INTENT(IN) :: KOM(MPROD,MSV)    ! Equilibrium gas-aerosol
                                               !  partition coeff. [m3/ug]
```

RETURN VALUE:

```
      REAL(fp)             :: ROOT
```

REVISION HISTORY:

```
    13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                                semivolatile POA simulations (H. Pye)
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.13 soa_para

Subroutine SOA_PARA gves mass-based stoichiometric coefficients for semi-volatile products from the oxidation of hydrocarbons. It calculates secondary organic aerosol yield parameters. Temperature effects are included. Original code from the CALTECH group and modified for inclusion to GEOS-CHEM. (rjp, bmy, 7/8/04, 6/30/08)

INTERFACE:

```
      SUBROUTINE SOA_PARA( TEMP, KO3, KOH, KNO3,   KOM,
     &                     II,   JJ,  LL,  KRO2NO, KRO2HO2, State_Met )
```

USES:

```
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      ! Arguments
      INTEGER,         INTENT(IN)  :: II             ! Longitude index
      INTEGER,         INTENT(IN)  :: JJ             ! Latitude index
      INTEGER,         INTENT(IN)  :: LL             ! Altitude index
      REAL(fp),        INTENT(IN)  :: TEMP           ! Temperature [k]
      TYPE(MetState), INTENT(IN)  :: State_Met       ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),        INTENT(OUT) :: KO3(MHC)       ! Rxn rate for HC oxidation
                                                     !  by O3 [cm3/molec/s]
      REAL(fp),        INTENT(OUT) :: KOH(MHC)       ! Rxn rate for HC oxidation
                                                     !  by OH [cm3/molec/s]
      REAL(fp),        INTENT(OUT) :: KNO3(MHC)      ! Rxn rate for HC oxidation
                                                     !  by NO3 [cm3/molec/s]
```

```
      REAL(fp),       INTENT(OUT) :: KOM(MPROD,MSV)  ! Equilibrium gas-aerosol
                                                     !  partition coeff [m3/ug]

      ! RO2+NO,HO2 rate constants (hotp 5/7/10)
      REAL(fp),       INTENT(OUT) :: KRO2NO          ! RO2+NO  rate constant
      REAL(fp),       INTENT(OUT) :: KRO2HO2         ! RO2+HO2 rate constant
```

REMARKS:

```
      References:
      ============================================================================
      PHOTO-OXIDATION RATE CONSTANTS OF ORGANICS come from:
      (1 ) Atkinson, el al., Int. J. Chem.Kinet., 27: 941-955 (1995)
      (2 ) Shu and Atkinson, JGR 100: 7275-7281 (1995)
      (3 ) Atkinson, J. Phys. Chem. Ref. Data 26: 215-290 (1997)
      (4 ) Some are reproduced in Table 1 of Griffin, et al., JGR 104: 3555-3567
      (5 ) Chung and Seinfeld (2002)
                                                                              .
      ACTIVATION ENERGIES come from:
      (6 ) Atkinson, R. (1994) Gas-Phase Tropospheric Chemistry of Organic
           Compounds.  J. Phys. Chem. Ref. Data, Monograph No.2, 1-216.
      (7 ) They are also reproduced in Tables B.9 and B.10 of Seinfeld and
           Pandis (1988).
                                                                              .
      PARAMETERS FOR ISOPRENE:
      (8 ) Kroll et al., GRL, 109, L18808 (2005)
      (9 ) Kroll et al., Environ Sci Tech, in press (2006)
      (10) Henze and Seinfeld, GRL, submitted (2006)
```

REVISION HISTORY:

```
      (1 ) Now use temporary variables TMP1, TMP2, TMP3 to pre-store the values
           of exponential terms outside of DO-loops (bmy, 7/8/04)
      (2 ) Add parameters for isoprene.  Now include grid cell location in
           subroutine arguments.  Define a reference temperature at 295.
           Now use ITS_IN_THE_TROP to determine if we are in a tropospheric
           grid box.  Now pass II, JJ, LL via the argument list.
           (dkh, bmy, 5/22/06)
      (3 ) Corrected confusing documentation. (clh, bmy, 6/30/08)
      (4 ) Add paramters for aromtics. Add high NOx low NOx index to every
           parameter, NNOX (dkh, 10/29/06)
      09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                  derived type object
      13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                                  semivolatile POA simulations (H. Pye)
      20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.14 soa_para_init

Subroutine SOA_PARA_INIT initializes the ALPHAS and KOMS, the latter at their reference temperature. It is faster to define these seperately as it only needs to be done once. (dkh, 11/12/06)

INTERFACE:

```
SUBROUTINE SOA_PARA_INIT( Input_Opt )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

REMARKS:

```
NOTE: REFT for KOM_REF depends on hydrocarbon.
```

REVISION HISTORY:

```
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.15 chem_nvoc

Subroutine CHEM_NVOC computes the oxidation of Hydrocarbon by O3, OH, and NO3. This comes from the Caltech group (Hong Liao, Serena Chung, et al) and was incorporated into GEOS-CHEM. (rjp, bmy, 7/6/04,6/1/06)

INTERFACE:

```
SUBROUTINE CHEM_NVOC( I,         J,         L,
&                     KO3,       KOH,       KNO3,
&                     GMO,       KNO,       KHO2,
&                     Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DIAG_MOD,           ONLY : AD07_HC
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_MONTH
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: I             ! Longitude index
      INTEGER,        INTENT(IN)    :: J             ! Latitude index
      INTEGER,        INTENT(IN)    :: L             ! Altitude index
      REAL(fp),       INTENT(IN)    :: KO3(MHC)      ! Rxn rate for HC oxidation
                                                     !  by O3 [cm3/molec/s]
      REAL(fp),       INTENT(IN)    :: KOH(MHC)      ! Rxn rate for HC oxidation
                                                     !  by OH [cm3/molec/s]
      REAL(fp),       INTENT(IN)    :: KNO3(MHC)     ! Rxn rate for HC oxidation
                                                     !  by NO3 [cm3/molec/s]
      ! RO2+NO, RO2+HO2 rate constants (hotp 5/7/10)
      REAL(fp),       INTENT(IN)    :: KNO           ! RO2+NO  rate constant
      REAL(fp),       INTENT(IN)    :: KHO2          ! RO2+HO2 rate constant
      TYPE(OptInput), INTENT(IN)    :: Input_Opt     ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met     ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(INOUT) :: GM0(MPROD,MSV)! Gas mass for HCs and
                                                     !  oxidation products [kg]
      TYPE(ChmState), INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC            ! Success or failure?
```

REMARKS:

```
SVOCs should immediately partition upon emission
SVOCs also react in the gas-phase
If SVOCs were emitted before reactions, we wouldn't know how
much to put in each phase
H.O.T. Pye decided to emit them after the existing SVOCs
react in the gas-phase. Thus the order of operations is:
  SVOC + OH in gas-phase
  SVOC emission (added to gas-phase GM0)
  partitioning
  dry dep
  wet dep
  etc
```

REVISION HISTORY:

```
(1 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(3 ) Updated for SOA from isoprene.  Now calls GET_DOH. (dkh, bmy, 6/1/06)
(4 ) Updated for SOA from aromatics. (dkh, 10/29/06)
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
```

```
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
12 Dec 2014 - M. Yannetti - Changed DEXP to EXP for compatability
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
22 Sep 2016 - R. Yantosca - Avoid array size mismatch for GLOB_DARO2
```

8.2.16 soa_partition

Subroutine SOA_PARTITION partitions the mass of gas and aerosol species according to five Hydrocarbon species and three oxidants. (rjp, bmy, 7/7/04, 5/22/06)

Revised purpose: SOA_PARTITION assigns the mass in the chemical species array to the GM0 and AM0 arrays (hotp 5/13/10)

INTERFACE:

```
SUBROUTINE SOA_PARTITION( I, J, L, GM0, AM0, State_Chm )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN)  :: I              ! Longitude index
INTEGER,  INTENT(IN)  :: J              ! Latitude index
INTEGER,  INTENT(IN)  :: L              ! Altitude index
```

OUTPUT PARAMETERS:

```
REAL(fp), INTENT(OUT) :: GM0(MPROD,MSV) ! Gas mass for HCs and
                                        !  oxidation products [kg]
REAL(fp), INTENT(OUT) :: AM0(MPROD,MSV) ! Aer mass for HCs and
                                        !  oxidation products [kg]
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm      ! Chemistry State object
```

REMARKS:

```
NOTE: GPROD and APROD are mass ratios of individual oxidation
      products of gas/aerosol to the sum of all.
```

REVISION HISTORY:

```
(1 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(3 ) Updated for SOG4, SOA4 (bmy, 5/22/06)
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
```

```
                            semivolatile POA simulations (H. Pye)
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.17 soa_lump

Subroutine SOA_LUMP returns the organic gas and aerosol back to the STT array. (rjp, bmy, 7/7/04, 2/6/07)

INTERFACE:

```
      SUBROUTINE SOA_LUMP( I, J, L, GM0, AM0, State_Chm )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD07_HC
      USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: I              ! Longitude index
      INTEGER,        INTENT(IN)    :: J              ! Latitude index
      INTEGER,        INTENT(IN)    :: L              ! Altitude index
      REAL(fp),       INTENT(IN)    :: GM0(MPROD,MSV) ! Gas mass for HCs and
                                                      !  oxidation products [kg]
      REAL(fp),       INTENT(IN)    :: AM0(MPROD,MSV) ! Aer mass for HCs and
                                                      !  oxidation products [kg]
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm      ! Chemistry State object
```

REVISION HISTORY:

```
    (1 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
    (2 ) Bug fix: make sure L <= LD07 before saving into AD07 array, or else
         we will get an out-of-bounds error. (bmy, 3/4/05)
    (3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (4 ) Updated for SOG4, SOA4 (dkh, bmy, 5/22/06)
    (5 ) Typo fix: GPROD should be APROD in a couple places (tmf, bmy, 10/16/06)
    (6 ) Bug fix: For SOA4, GPROD and APROD should have default values of 0.5,
         instead of 1.0 (dkh, bmy, 2/6/07)
    13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.18 emitsgc

Subroutine EMITSGC calculates sub-grid coagulation for the size distribution of emission. (win, 10/6/07)

INTERFACE:

```
      SUBROUTINE EMITSGC( EMISMASS,  CTYPE,
     &                    Input_Opt, State_Met, State_Chm )
```

USES:

```
      USE CMN_SIZE_MOD
      USE CMN_DIAG_MOD             ! ND59
      USE DIAG_MOD,           ONLY : AD59_ECIL,   AD59_ECOB
      USE DIAG_MOD,           ONLY : AD59_OCIL,   AD59_OCOB
      USE DIAG_MOD,           ONLY : AD59_NUMB
      USE ERROR_MOD,          ONLY : IT_IS_NAN
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL,  GET_PBL_MAX_L
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TOMAS_MOD,          ONLY : IBINS,    AVGMASS,  ICOMP,   IDIAG
      USE TOMAS_MOD,          ONLY : SRTECIL,  SRTECOB,  SRTOCIL
      USE TOMAS_MOD,          ONLY : SRTOCOB,  SRTSO4,   SRTNH4
      USE TOMAS_MOD,          ONLY : SRTH2O,   MNFIX
      USE TOMAS_MOD,          ONLY : SUBGRIDCOAG
      USE TOMAS_MOD,          ONLY : NH4BULKTOBIN
```

INPUT PARAMETERS:

```
      REAL(fp),       INTENT(IN) :: EMISMASS(IIPAR, JJPAR, IBINS)
      INTEGER,        INTENT(IN) :: CTYPE       ! 1 = EC and 2 = OC
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
    26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID and
                                remove dependency on pressure_mod.
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
```

8.2.19 scalecarb

Function SCALECARB split the carbonaceous emission from each source into the TOMAS aerosol size bins using different mass distribution for fossil fuel and biomass burning+biofuel. The mass size distributions are different for EC and OC. (win, 9/4/07)

INTERFACE:

```
FUNCTION SCALECARB( BULKEMIS, STYPE, CTYPE ) RESULT( VALUE )
```

USES:

```
USE CMN_SIZE_MOD
USE TOMAS_MOD,   ONLY : IBINS
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: BULKEMIS(IIPAR, JJPAR)
INTEGER, INTENT(IN) :: STYPE,  CTYPE
```

RETURN VALUE:

```
REAL(fp)              :: VALUE(IIPAR, JJPAR, IBINS)
```

REMARKS:

```
STYPE (source type): 1 = Fossil fule
                     2 = Biofuel
                     3 = Biomass burning
CTYPE (carbon type): 1 = EC
                     2 = OC

Array ECSCALE30 and OCSCALE100 specify how mass is distributed into bins
for a 30 nm number peak and a 100 nm peak.  Similary for OC size split.

This function is adapted from emisOCbond.f and emisBCbond.f by Jeff Pierce
(Jan, 2007) used in GISS GCM-II'.  Introduced to GEOS-Chem by Win T.(9/4/07)
```

REVISION HISTORY:

```
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.20 emisscarbon

Subroutine EMISSCARBON is the emissions routine for the carbon module. All carbon emissions, incl. SESQ and SVOC, are calculated through HEMCO and this module simply makes sure that the SESQ and SVOC emissions (if defined) are properly passed to the internal arrays.

INTERFACE:

```
      SUBROUTINE EMISSCARBON( am_I_Root, Input_Opt,
     &                        State_Met, RC )
```

USES:

```
      USE CMN_SIZE_MOD,          ONLY : IIPAR, JJPAR
      USE ErrCode_Mod
      USE GC_GRID_MOD,           ONLY : GET_AREA_M2
      USE HCO_INTERFACE_MOD,     ONLY : HcoState, GetHcoID, GetHcoVal
      USE HCO_ERROR_MOD
      USE Input_Opt_Mod,         ONLY : OptInput
      USE PBL_MIX_MOD,           ONLY : GET_PBL_MAX_L
      USE PBL_MIX_MOD,           ONLY : GET_FRAC_OF_PBL
      USE State_Met_Mod,         ONLY : MetState
      USE TIME_MOD,              ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
      LOGICAL,         INTENT(IN   )  :: am_I_Root   ! Root CPU?
      TYPE(OptInput),  INTENT(IN   )  :: Input_Opt   ! Input Options object
      TYPE(MetState),  INTENT(IN   )  :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,         INTENT(INOUT)  :: RC          ! Failure?
```

REMARKS:

SVOC emissions are expected to be fully calculated by HEMCO, i.e. its emissions need be specified in the HEMCO configuration file. In the original code, the emissions were calculated by scaling anthropogenic, biofuel and biomass burning OC emissions. The same behavior can be achieved in HEMCO by assigning the desired SVOC species name to the given source type, e.g.:
0 BOND_ANTH_POG1 Bond_fossil.nc OC 2000/1-12/1/0 C xy kg/m2/s POG1 74 1 1
All POG1 emissions (anthropogenic + biofuel + biomass burning) will go into POAEMISS(:,:,:,1) and all POG2 emissions will go into POAEMISS(:,:,:,2). SVOC emissions are assigned to POG1 and POG2 in HEMCO using a ratio of 0.49:0.51. We no longer separate anthropogenic from biofuel and biomass burning since this appears to have been done only for debugging purposes. Routine CHEM_NVOC handles passing POAEMISS to the two gas-phase semivolatile species in the GMO array.
IMPORTANT: The SVOC emissions scale factor should be applied through HEMCO. In the example above, scale factor 74 represents the scale factor POGSCAL. The SCALING_POG1 scale factor is applied to the GFED biomass burning extensions. The two scale factors should be set to the same value in the HEMCO configuration file. The recommended value is 1.27.

REVISION HISTORY:

11 Nov 2014 - C. Keller - Initial version
11 Sep 2015 - E. Lundgren - Remove State_Chm from arguments since not used

```
    14 Jan 2016 - M. Sulprizio- Emit SVOC emissions as POG1 and POG2 (not POA1
                                and POG1) in HEMCO to better reflect that these
                                emissions are added to the gas-phase species
    29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

8.2.21 emisscarbontomas

Subroutine emisscarbontomas scales BULK HEMCO emissions into TOMAS arrays. Only use for TOMAS simulations. This is essential a re-write of the TOMAS portions of the v9 emisscarbon (JKodros 6/2/15)

INTERFACE:

```
      SUBROUTINE EMISSCARBONTOMAS( am_I_Root, Input_Opt,
     &                             State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,        ONLY : GET_XOFFSET, GET_YOFFSET
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE UnitConv_Mod
  TOMAS DIAGNs:
      USE PRESSURE_MOD,       ONLY : GET_PCENTER
      USE TOMAS_MOD,          ONLY : IBINS,     AVGMASS, SOACOND
      USE TOMAS_MOD,          ONLY : ICOMP,     IDIAG, xSOA

      ! HEMCO update
      USE HCO_INTERFACE_MOD,  ONLY : HcoState, GetHcoDiagn
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
12 Jun 2015 - J. Kodros   - Initial version
12 Jun 2015 - R. Yantosca - Bug fix: also add reference to DEBUG_MSG
10 Jul 2015 - R. Yantosca - Fixed typo in ProTeX header
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

8.2.22 emithigh2

Subroutine EMITHIGH2 mixes species completely from the surface to the PBL top. This is a copy of subroutine EMITHIGH modified to work with 30-bin EC and OC mass and also aerosol number. (win, 9/4/07)

INTERFACE:

```
      SUBROUTINE EMITHIGH2( BCSRC, OCSRC, NUMBSRC,
     &                      Input_Opt, State_Chm )
```

USES:

```
      USE CMN_SIZE_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL,  GET_PBL_MAX_L
      USE State_Chm_Mod,      ONLY : ChmState
      USE TOMAS_MOD,          ONLY : IBINS
```

INPUT PARAMETERS:

```
      REAL(fp),       INTENT(IN)  :: BCSRC(IIPAR,JJPAR,IBINS, 2) !Total BC [kg]
      REAL(fp),       INTENT(IN)  :: OCSRC(IIPAR,JJPAR,IBINS, 2) !Total OC [kg]
      REAL(fp),       INTENT(IN)  :: NUMBSRC(IIPAR,JJPAR,IBINS)
      TYPE(OptInput), INTENT(IN)  :: Input_Opt                   !Input Options
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1 ) Now also mix ALPH, LIMO, ALCO tracers (rjp, bmy, 7/8/04)
(2 ) Now reference STT from "tracer_mod.f" (bmy, 7/20/04)
(3 ) Remove references to "dao_mod.f", "pressure_mod.f", and "error_mod.f".
     Rewrote for computational expediency using routines from
     "pbl_mix_mod.f".  (bmy, 2/17/05)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.23 ohno3time

Subroutine OHNO3TIME computes the sum of cosine of the solar zenith angle over a 24 hour day, as well as the total length of daylight. This is needed to scale the offline OH and NO3 concentrations. (rjp, bmy, 12/16/02, 1/18/05)

INTERFACE:

```
SUBROUTINE OHNO3TIME
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD, ONLY : GET_XMID,    GET_YMID_R
USE TIME_MOD,    ONLY : GET_NHMSb,   GET_ELAPSED_SEC
USE TIME_MOD,    ONLY : GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT
```

REVISION HISTORY:

```
(1 ) Copy code from COSSZA directly for now, so that we don't get NaN
     values.  Figure this out later (rjp, bmy, 1/10/03)
(2 ) Now replace XMID(I) with routine GET_XMID from "grid_mod.f".
     Now replace RLAT(J) with routine GET_YMID_R from "grid_mod.f".
     Removed NTIME, NHMSb from the arg list.  Now use GET_NHMSb,
     GET_ELAPSED_SEC, GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT from
     "time_mod.f". (bmy, 3/27/03)
(3 ) Now store the peak SUNCOS value for each surface grid box (I,J) in
     the COSZM array. (rjp, bmy, 3/30/04)
(4 ) Also added parallel loop over grid boxes (bmy, 1/18/05)
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R(I,J,L) from grid_mod.F90
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
16 May 2016 - M. Sulprizio- Remove IJLOOP and change SUNTMP array dimensions
                            from (MAXIJ) to (IIPAR,JJPAR)
```

8.2.24 get_oh

Function GET_OH returns OH from State_Chmcoupled runs) or monthly mean OH (for offline runs). Imposes a diurnal variation on OH for offline simulations. (bmy, 7/9/04)

INTERFACE:

```
FUNCTION GET_OH( I, J, L, Input_Opt, State_Chm, State_Met )
&         RESULT( OH_MOLEC_CM3 )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_SIZE_MOD
```

```
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I           ! Longitude index
      INTEGER,        INTENT(IN)  :: J           ! Latitude index
      INTEGER,        INTENT(IN)  :: L           ! Altitude index
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
      REAL(fp)                    :: OH_MOLEC_CM3
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDOH (bmy, 11/1/02)
(2 ) Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(3 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
28 Nov 2012 - R. Yantosca - Add State_Met to the argument list
 4 Mar 2013 - R. Yantosca - Add Input_Opt to the argument list
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
23 Sep 2014 - M. Sulprizio- Now get OH for offline aerosol sim from HEMCO
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
07 Sep 2016 - M. Sulprizio- Bug fix: Convert State_Chm%Species from kg to
                            molec/cm3
```

8.2.25 get_no3

Function GET_NO3 returns NO3 from State_Chmcoupled runs) or monthly mean OH (for offline runs). For offline runs, the concentration of NO3 is set to zero during the day. (rjp, bmy, 12/16/02, 7/20/04)

INTERFACE:

```
      FUNCTION GET_NO3( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( NO3_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
```

```
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I           ! Longitude index
      INTEGER,        INTENT(IN)  :: J           ! Latitude index
      INTEGER,        INTENT(IN)  :: L           ! Altitude index
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
      REAL(fp)                    :: NO3_MOLEC_CM3
```

REVISION HISTORY:

```
    (1 ) Now references ERROR_STOP from "error_mod.f".  We also assume that
         SETTRACE has been called to define IDNO3.  Now also set NO3 to
         zero during the day. (rjp, bmy, 12/16/02)
    (2 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
    04 Mar 2013 - R. Yantosca - Add Input_Opt to the argument list
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
    23 Jul 2014 - R. Yantosca - Remove reference to obsolete CMN_MOD
    24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
    23 Sep 2014 - M. Sulprizio- Now get NO3 for offline aerosol sims from HEMCO
    22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
    28 Jul 2016 - R. Yantosca - Now convert NO3 from kg to molec/cm3
    07 Sep 2016 - M. Sulprizio- Get MolecRatio and NO3_MW_kg from species DB
```

8.2.26 get_o3

Function GET_O3 returns monthly mean O3 for offline sulfate aerosol simulations. (bmy, 12/16/02, 7/20/04)

INTERFACE:

```
      FUNCTION GET_O3( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( O3_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
```

```
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I           ! Longitude index
      INTEGER,        INTENT(IN)  :: J           ! Latitude index
      INTEGER,        INTENT(IN)  :: L           ! Altitude index
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
      REAL(fp)                    :: O3_MOLEC_CM3
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDO3. (bmy, 12/16/02)
(2 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
(3 ) Now reference XNUMOLAIR from "tracer_mod.f" (bmy, 10/20/05)
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
04 Mar 2013 - R. Yantosca - Add Input_Opt to the argument list
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
18 Sep 2014 - M. Sulprizio- Now get O3 for offline aerosol sim from HEMCO
24 Mar 2015 - E. Lundgren - Replace dependency on tracer_mod with
                            CMN_GTCM_MOD for XNUMOLAIR
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
06 Jan 2016 - E. Lundgren - Use global physical parameter AVO
28 Jul 2016 - R. Yantosca - Now convert O3 from kg to molec/cm3
07 Sep 2016 - M. Sulprizio- Get MolecRatio and NO3_MW_kg from species DB
```

8.2.27 get_daro2

Function GET_DARO2 returns the amount of aromatic peroxy radical that reacted with HO2 or NO during the last chemistry timestep. (dkh, 11/10/06)

INTERFACE:

```
      FUNCTION GET_DARO2( I, J, L, NOX, JHC, Input_Opt,
     &                    State_Chm, State_Met )
     &         RESULT( DARO2 )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_O3_MOD
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AVO
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,         INTENT(IN)  :: I           ! Longitude index
INTEGER,         INTENT(IN)  :: J           ! Latitude index
INTEGER,         INTENT(IN)  :: L           ! Altitude index
INTEGER,         INTENT(IN)  :: NOX
INTEGER,         INTENT(IN)  :: JHC
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: DARO2
```

REVISION HISTORY:

```
04 Mar 2013 - R. Yantosca - Add Input_Opt to the argument list
13 Aug 2013 - M. Sulprizio- Add NAP for SOA + semivolatile POA (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
21 Dec 2015 - M. Sulprizio- Get grid box volume directly from State_Met
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Met%Species
17 May 2016 - R. Yantosca - Now get MolecRatio from species database
31 May 2016 - E. Lundgren - Now get molecular weight from species database
07 Sep 2016 - M. Sulprizio- Bug fix: Convert State_Chm%Species from kg LARO2
                            to kg AROM
```

8.2.28 get_doh

Function GET_DOH returns the amount of isoprene [kg] that has reacted with OH during the last chemistry time step. (dkh, bmy, 6/01/06)

INTERFACE:

```
FUNCTION GET_DOH( I, J, L, Input_Opt, State_Chm, State_Met )
&         RESULT( DOH )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AVO
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I           ! Longitude index
INTEGER,        INTENT(IN)  :: J           ! Latitude index
INTEGER,        INTENT(IN)  :: L           ! Altitude index
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: DOH
```

REVISION HISTORY:

```
04 Mar 2013 - R. Yantosca - Now use fields from Input_Opt object
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
21 Dec 2015 - M. Sulprizio- Get grid box volume directly from State_Met
17 May 2016 - R. Yantosca - Now get MolecRatio from species database
31 May 2016 - E. Lundgren - Now get molecular weight from species database
07 Sep 2016 - M. Sulprizio- Bug fix: Convert State_Chm%Species from kg ISOPOH
                            to kg ISOP
```

8.2.29 get_vcldf

Subroutine GET_VCLDF computes the volume cloud fraction for SO2 chemistry. (rjp, bdf, bmy, 9/23/02)

INTERFACE:

```
SUBROUTINE GET_VCLDF( State_Met )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REMARKS:

```
References:
============================================================================
(1) Sundqvist et al. [1989]
```

REVISION HISTORY:

```
(1 ) Copied from 'sulfate_mod.f' for cloud uptake of GLYX and MGLY (tmf,
     2/26/07)
14 Jan 2011 - R. Yantosca - Return if VCLDF is not allocated
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
26 Feb 2015 - E. Lundgren - Replace GET_PEDGE and GET_PCENTER with
                            State_Met%PEDGE and State_Met%PMID.
                            Remove dependency on pressure_mod.
```

8.2.30 get_lwc

Function GET_LWC returns the cloud liquid water content [g H2O/m3 air] at a GEOS-CHEM grid box as a function of temperature. (rjp, bmy, 10/31/02, 1/14/03)

INTERFACE:

```
FUNCTION GET_LWC( T ) RESULT( LWC )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: T     ! Temperature [K]
```

RETURN VALUE:

```
REAL(fp)             :: LWC   ! Cloud liquid water content [g H2O/m3 air]
```

REVISION HISTORY:

```
(1 ) Copied from 'sulfate_mod.f' for cloud uptake of GLYX and MGLY (tmf, 2/26/07)
18 Jan 2011 - R. Yantosca - Updated comments
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.2.31 soag_cloud

Subroutine SOAG_CLOUD produces SOAG from GLYX during a cloud event. Mimics the SO2 -¿ SO4 process from 'sulfate_mod.f'. (tmf, 2/26/07)

INTERFACE:

```
SUBROUTINE SOAG_CLOUD( State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE DAO_MOD,            ONLY : IS_LAND
USE DIAG_MOD,           ONLY : AD07_SOAGM
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
! Arguments
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1 ) SOAG (SOA product of GLYX is produced at existing hydrophilic aerosol
     surface. (tmf, 2/26/07)
(2 ) Assume marine and continental cloud droplet size (tmf, 2/26/07)
14 Jan 2011 - R. Yantosca - Now compute cloud fraction and liquid water
                            content directly from GEOS-5 & MERRA met fields
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS-FP
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.32 soam_cloud

Subroutine SOAM_CLOUD produces SOAM from MGLY during a cloud event. Mimics the SO2 -¿ SO4 process from 'sulfate_mod.f'. (tmf, 2/26/07)

INTERFACE:

```
SUBROUTINE SOAM_CLOUD( State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
```

```
      USE DAO_MOD,            ONLY : IS_LAND
      USE DIAG_MOD,           ONLY : AD07_SOAGM
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
    (1 ) SOAM (SOA product of MGLY is produced at existing hydrophilic aerosol
         surface. (tmf, 2/26/07)
    (2 ) Assume typical marine and continental cloud droplet size (tmf, 2/26/07)
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    20 Aug 2013 - M. Sulprizio- Added ProTeX headers
    06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
    06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
    11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS-FP
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
```

8.2.33 check_eqlb

Subroutine CHECK_EQLB makes sure aerosols are at equilibrium (checks SOA=SOG*KOM*Mo). Called inside SOA_SVPOA_CHEMISTRY I, J, L loop after SOA_SVPOA_LUMP. Created by Havala Pye (5/18/10).

INTERFACE:

```
      SUBROUTINE CHECK_EQLB( I,   J,   L, KOMIJL, CONVFAC, MSOACHEM,
     &                       LOW, TOL, ASOANGAS, ASOANAER, OCPIOCPO,
     &                       State_Chm )
```

USES:

```
      USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I           ! Longitude index
      INTEGER,        INTENT(IN)  :: J           ! Latitude index
      INTEGER,        INTENT(IN)  :: L           ! Altitude index
      REAL(fp),       INTENT(IN)  :: KOMIJL(MPROD,MSV) ! KOM at grid box (adj T)
```

```
REAL(fp),       INTENT(IN)  :: CONVFAC     ! Conversion factor kg to ug/m3
REAL(fp),       INTENT(IN)  :: OCPIOCPO    ! POA mass [ug/m3]

! Arguments for debugging
REAL(fp),       INTENT(IN)  :: MSOACHEM    ! MNEW from calling prog
REAL(fp),       INTENT(IN)  :: LOW         ! Lower bound on soln
REAL(fp),       INTENT(IN)  :: TOL         ! Tolerance on soln
REAL(fp),       INTENT(IN)  :: ASOANGAS    ! Gas phase ASOAN (should =0)
REAL(fp),       INTENT(IN)  :: ASOANAER    ! Aer phase ASOAN [ug/m3]

TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REMARKS:

```
Note: There are some deviations from equilibrium due to the fact
that ASOAN is supposed to be nonvolatile, but is modeled with a KOM of
10^6. An adjustment is made in SOA_CHEMISTRY to force all ASOAN to
the aerosol phase. This was found to lead to error up to 1e-5 ug/m3
in Mo. This error is small, but the effects can be investigated
here if you're interested!

As of 6/2010, KOM for ASOAN was increased and the error in Mo reduced.
```

REVISION HISTORY:

```
(1)  Updated for TSOA and ISOA (hotp 5/24/10)
(2)  Add OCPIOCPO and remove NOX (hotp 6/9/10)
(3)  Add TSOA0 (hotp 6/12/10)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.34 save_oaginit

Subroutine SAVE_OAGINIT saves total SOA+SOG before partitioning for diagnostic purposes. Units are the same as the STT array ([kg] or [kgC per box]). created hotp 5/17/10

INTERFACE:

```
SUBROUTINE SAVE_OAGINIT( State_Chm )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1) added TSOA and ISOA (hotp 5/24/10)
(2) OAGINITSAVE dimensions changes from (I,J,L,NOx,NPROD,JSV) to
    (I,J,L,NPROD,JSV)
(3) Add compatability with non-vol sim (hotp 6/7/10)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.35 check_mb

Subroutine CHECK_MB checks total SOA+SOG mass balance for diagnostic/debugging purposes. Units are the same as the STT array ([kg] or [kgC per box]). Routine also prints helpful budget info. Created by Havala Pye (5/18/10).

INTERFACE:

```
SUBROUTINE CHECK_MB( am_I_Root, Input_Opt, State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRAT
USE CMN_SIZE_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1) added monoterpene, sesq, isoprene SOA (hotp 5/24/10)
(2) updated OAGINITSAVE dimensions (hotp 5/24/10)
(3) keeps track and prints to screen amount of parent HC reacted
    with each oxidant cumulative (hotp 5/24/10)
(4) Add non-volatile compatability (hotp 6/9/10)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.2.36 get_no

Function GET_NO returns NO from State_Chm(for coupled runs). (hotp 5/7/2010)

INTERFACE:

```
      FUNCTION GET_NO( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( NO_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I              ! Longitude index
      INTEGER,        INTENT(IN) :: J              ! Latitude index
      INTEGER,        INTENT(IN) :: L              ! Altitude index
      TYPE(OptInput), INTENT(IN) :: Input_Opt      ! Input Options object
      TYPE(ChmState), INTENT(IN) :: State_Chm      ! Chemistry State object
      TYPE(MetState), INTENT(IN) :: State_Met      ! Meteorology State object
   !RETURN VALUE
      REAL(fp)                   :: NO_MOLEC_CM3   ! NO conc [molec/cm3]
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDNO (bmy, 11/1/02)
(3 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
(4 ) Based on GET_OH (hotp 5/7/2010)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
25 Jun 2014 - R. Yantosca - Remove references to tracer_mod.F
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
28 Jul 2016 - R. Yantosca - Now convert NO from kg to molec/cm3
07 Sep 2016 - M. Sulprizio- Get MolecRatio and NO3_MW_kg from species DB
```

8.2.37 get_ho2

Function GET_HO2 returns HO2 from State_Chm(for coupled runs). Created by Havala Pye (5/7/2010).

INTERFACE:

```
      FUNCTION GET_HO2( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( HO2_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I              ! Longitude index
      INTEGER,        INTENT(IN) :: J              ! Latitude index
      INTEGER,        INTENT(IN) :: L              ! Altitude index
      TYPE(OptInput), INTENT(IN) :: Input_Opt      ! Input Options object
      TYPE(ChmState), INTENT(IN) :: State_Chm      ! Chemistry State object
      TYPE(MetState), INTENT(IN) :: State_Met      ! Meteorology State object
  !RETURN VALUE
      REAL(fp)                   :: HO2_MOLEC_CM3  ! HO2 conc [molec/cm3]
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDHO2 (bmy, 11/1/02)
(3 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
(4 ) Based on GET_OH (hotp 5/6/2010)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
25 Jun 2014 - R. Yantosca - Remove references to tracer_mod.F
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
```

8.2.38 get_isopno3

Modification of GET_DOH that returns the amount of isoprene [kgC] that has reacted with NO3 during the last chemistry time step. (hotp 5/22/10)

INTERFACE:

```
      FUNCTION GET_ISOPNO3( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( ISOPNO3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : AVO
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I           ! Longitude index
      INTEGER,        INTENT(IN) :: J           ! Latitude index
      INTEGER,        INTENT(IN) :: L           ! Altitude index
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
      TYPE(ChmState), INTENT(IN) :: State_Chm   ! Chemistry State object
      TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
   !RETURN VALUE
      REAL(fp)                   :: ISOPNO3     ! ISOP replaced w/ NO3 [kg C]
```

REVISION HISTORY:

```
   (1) IDLISOPNO3 is declared in tracerid_mod.f and initialized by SETTRACE
       in tracerid_mod (called in chemdr). Before each chemistry call,
       CSPEC(JLOOP,IDLISOPNO3) is zeroed so that the CSPEC array only stores
       the parent HC reacted during that timestep. (hotp 6/1/10)
   20 Aug 2013 - M. Sulprizio- Added ProTeX headers
   25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
   25 Jun 2014 - R. Yantosca - Remove references to tracer_mod.F
   21 Dec 2015 - M. Sulprizio- Get grid box volume directly from State_Met
   22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Met%Species
   17 May 2016 - R. Yantosca - Now get MolecRatio from species database
   31 May 2016 - E. Lundgren - Now get molecular weight from species database
   07 Sep 2016 - M. Sulprizio- Bug fix: Convert State_Chm%Species from kg ISOPOH
                               to kg ISOP
```

8.2.39 init_carbon

Subroutine INIT_CARBON initializes all module arrays. (rjp, bmy, 4/1/04, 12/19/09)

INTERFACE:

```
      SUBROUTINE INIT_CARBON( am_I_Root, Input_Opt, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ALLOC_ERR, ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : Ind_
      USE TIME_MOD,           ONLY : GET_NYMDb, GET_NHMSb, GET_TAUb
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure
```

REVISION HISTORY:

```
(1 ) Also added arrays for secondary organic aerosols (rjp, bmy, 7/8/04)
(2 ) Remove reference to CMN, it's obsolete (bmy, 7/20/04)
(3 ) Now reference LSOA from "logical_mod.f" not CMN_SETUP.  Now call
     GET_BOUNDING_BOX from "grid_mod.f" to compute the indices I1_NA,
     I2_NA, J1_NA, J2_NA which define the N. America region. (bmy, 12/1/04)
(4 ) Now call READ_GPROD_APROD to read GPROD & APROD from disk.
     (tmf, havala, bmy, 2/6/07)
(5 ) Now set I1_NA, I2_NA, J1_NA, J2_NA appropriately for both 1 x 1 and
     0.5 x 0.666 nested grids (yxw, dan, bmy, 11/6/08)
(6 ) Now set parameters for NESTED_EU grid (amv, bmy, 12/19/09)
14 Jan 2011 - R. Yantosca - If we are using GEOS-5 or MERRA met, then get
                            the cloud fraction directly from the met fields.
01 Mar 2012 - R. Yantosca - Now use GET_BOUNDING_BOX from grid_mod.F90
04 Mar 2013 - R. Yantosca - Now take am_I_Root, Input_Opt, RC as arguments
04 Mar 2013 - R. Yantosca - Now search for drydep flags here
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LSOA
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
26 Sep 2013 - R. Yantosca - Removed SEAC4RS Cpp switch, this is supplanted
                            by NESTED_NA
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
11 Aug 2015 - R. Yantosca - Add support for MERRA2 data
23 Sep 2015 - R. Yantosca - Remove reference to DRY* flags, they're obsolete
```

8.2.40 cleanup_carbon

Subroutine CLEANUP_CARBON deallocates all module arrays (rjp, bmy, 4/1/04, 7/8/04)

INTERFACE:

```
      SUBROUTINE CLEANUP_CARBON
```

REVISION HISTORY:

```
(1 ) Now deallocate arrays for secondary organic aerosols (rjp, bmy, 7/8/04)
13 Aug 2013 - M. Sulprizio- Add modifications for updated SOA and SOA +
                            semivolatile POA simulations (H. Pye)
20 Aug 2013 - M. Sulprizio- Added ProTeX headers
```

8.3 Fortran: Module Interface dust_mod.F

Module DUST_MOD contains routines for computing dust aerosol emissions, chemistry, and optical depths.

INTERFACE:

```
      MODULE DUST_MOD
```

USES:

```
      USE inquireMod,    ONLY : findFreeLUN
      USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CHEMDUST
#if   defined( TOMAS )
      PUBLIC  :: SETTLEDUST
#endif
      PUBLIC  :: RDUST_ONLINE
      PUBLIC  :: RDUST_OFFLINE
      PUBLIC  :: GET_DUST_ALK
      PUBLIC  :: INIT_DUST
      PUBLIC  :: CLEANUP_DUST
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: DRY_SETTLING
```

REVISION HISTORY:

```
   30 Mar 2004 - T. D. Fairlie - Initial version
   (1 ) Bug fix in SRC_DUST_DEAD (bmy, 4/14/04)
   (2 ) Now references "logical_mod.f", "directory_mod.f", and "tracer_mod.f"
        Added comments. (bmy, 7/2/04)
   (3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
   (4 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
   (5 ) Bug fix in snow height computation (bmy, 11/18/05)
   (6 ) Now only do drydep if LDRYD=T (bmy, 5/23/06)
   (7 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
   (8 ) Updated output print statement in SRC_DUST_DEAD (bmy, 1/23/07)
   (9 ) Modifications for GEOS-5 (bmy, 1/24/07)
   (10) Modified to archive only hydrophilic aerosol/aqueous dust surface area
        (excluding BCPO and OCPO) for aqueous chemistry calculations
        Dust surfaces are considered aqueous only when RH > 35% (tmf, 3/6/09)
   (11) Add AOD output for all dust size bins (clh, 5/7/10)
   (12) Modify AOD output to wavelength specified in jv_spec_aod.dat
       (clh, 05/07/10)
   25 Aug 2010 - R. Yantosca - Added ProTeX headers
   03 Sep 2010 - R. Yantosca - Bug fix in SRC_DUST_DEAD
```

```
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x
01 Mar 2012 - R. Yantosca - Now reference the new grid_mod.F90
01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
14 Nov 2012 - R. Yantosca - Add modifications for GIGC
04 Mar 2013 - R. Yantosca - Now call INIT_DUST from the init stage
                            which facilitates connection to GEOS-5 GCM
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
20 Jun 2014 - R. Yantosca - Remove obsolete emissions code; we now use HEMCO
13 Nov 2014 - M. Yannetti - Added PRECISION_MOD
01 Apr 2015 - R. Yantosca - Remove obsolete DUSTMIX, DRY_DEPOSITION routines
16 Jun 2016 - J. Kaiser   - Move tracerIDs into variable names
20 Jun 2016 - R. Yantosca - Rename IDT* species ID's to id_*
20 Jun 2016 - R. Yantosca - Now only define species ID's in the INIT phase
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

8.3.1 chemdust

Subroutine CHEMDUST is the interface between the GEOS-Chem main program and the dust chemistry routines that mostly calculates dust dry deposition.

INTERFACE:

```
      SUBROUTINE CHEMDUST( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
      USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
   30 Mar 2004 - T. D. Fairlie - Initial version
   (1 ) Now references STT from "tracer_mod.f" and LDUST from "logical_mod.f"
        (bmy, 7/20/04)
   (5 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
   (6 ) Now only do dry deposition if LDRYD = T (bmy, 5/23/06)
   25 Aug 2010 - R. Yantosca - Added ProTeX headers
   30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                               running with the traditional driver main.F
   14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
   15 Nov 2012 - M. Payer    - Now pass State_Met as an argument
   05 Mar 2013 - R. Yantosca - Add ND70 debug print output
   25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
   12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                               aerosols (T.D. Fairlie)
   01 Apr 2015 - R. Yantosca - Remove call to DRY_DEPOSITION, this is now
                               done in mixing_mod.F90.
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                               species ID from State_Chm%Map_Advect.
   10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

8.3.2 settledust

Subroutine SETTLEDUST is the interface between the size-resolved dry deposition subroutine AERO_DRYDEP and the dust module. This is to call only gravitational settling and deals with removal of aerosol number with the dust mass. (win, 7/17/09)

INTERFACE:

```
      SUBROUTINE SETTLEDUST( am_I_Root, Input_Opt,
     &                       State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE CMN_DIAG_MOD             ! ND44
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : AVO
```

```
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
      USE TOMAS_MOD,          ONLY : IBINS, Xk, SRTDUST
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    17 Jul 2009 - W. Trivitayanurak - Initial version
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    13 Dec 2012 - M. Payer    - Add am_I_Root, Input_Opt, RC as arguments
    31 May 2013 - R. Yantosca - Now pass State_Chm via the arg list
    16 Jul 2015 - R. Yantosca - Now pass INDEX and IDISP to DRY_SETTLING
    31 May 2016 - E. Lundgren - Replace Input_Opt%XNUMOL with AVO/(emMW_g*1e-3)
                                where emMW_g is from species database
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

8.3.3 emissdust

Subroutine EMISSDUST is the driver routine for the dust emission module. You may call either the GINOUX or the DEAD dust source function.

INTERFACE:

```
      SUBROUTINE EMISSDUST( am_I_Root, Input_Opt,
     &                      State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD             ! ND59
      USE CMN_SIZE_MOD             ! Size parameters
      USE DIAG_MOD,           ONLY : AD59_DUST, AD59_NUMB  !(win, 7/17/09)
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : ERROR_STOP
```

```
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_EMIS
      USE TOMAS_MOD,          ONLY : IBINS, XK             !(win, 7/17/09)
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    30 Mar 2004 - T. D. Fairlie - Initial version
    (1 ) Now reference LDEAD, LDUST, LPRT from "logical_mod.f".  Now reference!
         STT from "tracer_mod.f" (bmy, 7/20/04)
    (2 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (3 ) Add if condition for selecting between emitting 4-bin or 30-bin
         dust.  Add emission diagnostic calculation for 30bin dust(win, 7/17/09)
    25 Aug 2010 - R. Yantosca - Added ProTeX headers
    26 Nov 2012 - R. Yantosca - Now pass am_I_Root, Input_Opt, State_Met as args
    26 Feb 2013 - R. Yantosca - Now pass Input_Opt to SRC_DUST_GINOUX
    26 Feb 2013 - R. Yantosca - Changed INPUT_OPT to INTENT(IN), since we are
                                now no longer calling INIT_DUST from here,
                                it is now called in the init stage
    29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    11 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

8.3.4 dry_settling

Subroutine DRY_SETTLING computes the dry settling of dust species.

INTERFACE:

```
      SUBROUTINE DRY_SETTLING( am_I_Root, Input_Opt, State_Met,
     &                         State_Chm, TC, RC, INDEX, IDISP )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
      USE ErrCode_Mod
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
      USE Species_Mod,        ONLY : Species
#if defined( NC_DIAG )
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_ERROR_MOD,      ONLY : HCO_SUCCESS
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)   :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)   :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)   :: State_Met   ! Meteorology State object
      INTEGER,        INTENT(IN)   :: INDEX       ! Species index
      INTEGER,        INTENT(IN)   :: IDISP       ! Displacement index for IIDEP

   !INPUT/OUTPUT PARAMETERS

      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR,NDSTBIN) ! Dust [kg]
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)  :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    30 Mar 2004 - T. D. Fairlie - Initial version
    (1 ) Updated comments, cosmetic changes (bmy, 3/30/04)
    (2 ) Remove reference to CMN, it's not needed (bmy, 7/20/04)
    (3 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
    25 Aug 2010 - R. Yantosca - Added ProTeX headers
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
    15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
```

```
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID and
                            remove dependency on pressure_mod
25 Jan 2016 - E. Lundgren - Update netcdf drydep flux diagnostic
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
31 May 2016 - E. Lundgren - Use TCVV instead of XNUMOL for molecular weights
22 Jun 2016 - M. Yannetti - Replace TCVV with species db MW and phys constant
```

8.3.5 rdust_online

Subroutine RDUST_ONLINE reads global mineral dust concentrations as determined by P. Ginoux. Calculates dust optical depth at each level for the FAST-J routine "set_prof.f".

INTERFACE:

```
      SUBROUTINE RDUST_ONLINE( am_I_Root, Input_Opt,  State_Met,
     &                         State_Chm, DUST,       ODSWITCH,
     &                         RC )
```

USES:

```
      USE CMN_FJX_MOD
      USE CMN_SIZE_MOD
      USE CMN_DIAG_MOD
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE DIAG_MOD,           ONLY : AD21
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
      REAL(fp),       INTENT(IN)  :: DUST(IIPAR,JJPAR,LLPAR,NDUST) !Dust [kg/m3]
      INTEGER,        INTENT(IN)  :: ODSWITCH
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC       ! Success or failure?
```

REVISION HISTORY:

```
01 Apr 2004 - R. Martin, R. Park - Initial version
(1 ) Bundled into "dust_mod.f" (bmy, 4/1/04)
(2 ) Now references DATA_DIR from "directory_mod.f".  Now parallelize over
     the L-dimension for ND21 diagnostics. (bmy, 7/20/04)
(3 ) Archive only hydrophilic aerosol/aqueous dust surface area
    (excluding BCPO and OCPO), WTAREA and WERADIUS. (tmf, 3/6/09)
25 Aug 2010 - R. Yantosca - Added ProTeX headers
03 Feb 2011 - S. Kim.     - Include wavelength argument to determine the
                            wavelength at which the AOD should be computed.
                            This will set the optical properties that are
                            used for the calculation of the AOD. The ND21
                            diagnostic should only be updated when
                            WAVELENGTH = 1. (skim, 02/03/11)
04 Sep 2012 - D. Ridley   - WAVELENGTH now ODSWITCH for clarity now
                            that multiple wavelengths can be
                            calculated at once.
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. ERADIUS,
                            TAREA, WERADIUS, WTAREA are now pointers that
                            point to 3D fields in State_Chm.
16 May 2016 - M. Sulprizio- Remove JLOOP entirely and loop over LLPAR, JJPAR,
                            IIPAR instead.
```

8.3.6 rdust_offline

Subroutine RDUST_OFFLINE reads global mineral dust concentrations as determined by P. Ginoux. Calculates dust optical depth at each level for the FAST-J routine "set_prof.f".

INTERFACE:

```
 SUBROUTINE RDUST_OFFLINE( am_I_Root, Input_Opt, State_Met,
&                          State_Chm, THISMONTH, THISYEAR,
&                          ODSWITCH,  RC )
```

USES:

```
 USE BPCH2_MOD,          ONLY : GET_NAME_EXT, GET_RES_EXT
 USE BPCH2_MOD,          ONLY : GET_TAU0,     READ_BPCH2
 USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
 USE CMN_FJX_MOD
 USE CMN_DIAG_MOD
 USE DIAG_MOD,           ONLY : AD21
 USE ErrCode_Mod
 USE ERROR_MOD,          ONLY : ERROR_STOP
```

```
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root  ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input Options object
      TYPE(MetState), INTENT(IN)  :: State_Met  ! Meteorology State object
      INTEGER,        INTENT(IN)  :: THISMONTH  ! Current month (1-12)
      INTEGER,        INTENT(IN)  :: THISYEAR   ! Current year  (YYYY format)
      INTEGER,        INTENT(IN)  :: ODSWITCH   ! Determine which wavelength to
                                                !  use for optical properties
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC         ! Success or failure?
```

REMARKS:

```
#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (05 Mar 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
(1 ) RDUST was patterned after rdaerosol.f (rvm, 9/30/00)
(2 ) Don't worry about rewinding the binary file...reading from
     binary files is pretty fast.  And it's only done once a month.
(3 ) Now references punch file utility routines from F90 module
     "bpch2_mod.f".  Also reference variable DATA_DIR from the
      header file "CMN_SETUP". (bmy, 9/30/00)
(4 ) Now selects proper GEOS-STRAT dust field for 1996 or 1997.
     Also need to pass THISYEAR thru the arg list. (rvm, bmy, 11/21/00)
(5 ) CONC is now declared as REAL(fp) (rvm, bmy, 12/15/00)
(6 ) Removed obsolete code from 12/15/00 (bmy, 12/21/00)
(7 ) CONC(IIPAR,JJPAR,LGLOB,NDUST) is now CONC(IIPAR,JJPAR,LLPAR,NDUST).
     Now use routine TRANSFER_3D from "transfer_mod.f" to cast from REAL*4
     to REAL(fp) and also to convert from {IJL}GLOB to IIPAR,JJPAR,LLPAR
     space.  Use 3 arguments in call to GET_TAU0.  Updated comments.
     (bmy, 9/26/01)
(8 ) Removed obsolete code from 9/01 (bmy, 10/24/01)
(9 ) Now reference ERADIUS, IXSAVE, IYSAVE, IZSAVE, TAREA from
```

```
      "comode_mod.f".  Compute ERADIUS and TAREA for the NDUST dust
      size bins from FAST-J.  Renamed CONC to DUST to avoid conflicts.
      Also reference NTTLOOP from "comode.h".  Also added parallel
      DO-loops.  Also renamed MONTH and YEAR to THISMONTH and THISYEAR
      to avoid conflicts w/ other variables. (bmy, 11/15/01)
(10) Bug fix: Make sure to use 1996 dust data for Dec 1995 for the
      GEOS-STRAT met field dataset.  Set off CASE statement with an
      #if defined( GEOS_STRAT ) block. (rvm, bmy, 1/2/02)
(11) Eliminate obsolete code from 1/02 (bmy, 2/27/02)
(12) Now report dust optical depths in ND21 diagnostic at 400 nm.  Now
     report dust optical depths as one combined diagnostic field instead
      of 7 separate fields.  Now reference JLOP from "comode_mod.f".
      Now save aerosol surface areas as tracer #5 of the ND21 diagnostic.
      (rvm, bmy, 2/28/02)
(13) Remove declaration for TIME, since that is also defined in the
      header file "comode.h" (bmy, 3/20/02)
(14) Now read mineral dust files directly from the DATA_DIR/dust_200203/
      subdirectory (bmy, 4/2/02)
(15) Now reference BXHEIGHT from "dao_mod.f".  Also reference ERROR_STOP
      from "error_mod.f". (bmy, 10/15/02)
(16) Now call READ_BPCH2 with QUIET=TRUE to suppress extra informational
      output from being printed.  Added cosmetic changes. (bmy, 3/14/03)
(17) Since December 1997 dust data does not exist, use November 1997 dust
      data as a proxy. (bnd, bmy, 6/30/03)
(18) Bundled into "dust_mod.f" and renamed to RDUST_OFFLINE. (bmy, 4/1/04)
(19) Now references DATA_DIR from "directory_mod.f".  Now parallelize over
      the L-dimension for ND21 diagnostic. (bmy, 7/20/04)
(20) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(21) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(22) Archive only hydrophilic aerosol/aqueous dust surface area
     (excluding BCPO and OCPO), WTAREA and WERADIUS. (tmf, 3/6/09)
25 Aug 2010 - R. Yantosca - Added ProTeX headers
03 Feb 2011 - S. Kim      - Include third input argument to determine the
                            wavelength at which the AOD should be computed.
                            This will set the optical properties that are
                            used for the calculation of the AOD.  The ND21
                            diagnostic should only be updated when
                            WAVELENGTH = 1.
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
04 Sep 2012 - D. Ridley   - WAVELENGTH now ODSWITCH for clarity now
                            that multiple wavelengths can be
                            calculated at once.
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
05 Mar 2015 - R. Yantosca - Add Input_Opt%RES_DIR to data path
```

```
23 Oct 2015 - E. Lundgren - Fix index for dust in ODAER/LUT arrays if UCX on
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. ERADIUS,
                            TAREA, WERADIUS, WTAREA are now pointers that
                            point to 3D fields in State_Chm.
16 May 2016 - M. Sulprizio- Remove JLOOP entirely and loop over LLPAR, JJPAR,
                            IIPAR instead.
```

8.3.7 get_dust_alk

Subroutine GET_DUST_ALK returns: (1) dust alkalinity, ALK_d(NDSTBIN) [v/v], (2) rate coefficients, KTS(NDSTBIN), KTN(NDSTBIN), for uptake of SO2 and HNO3 on dust for use in sulfate_mod.f for chemistry on dust aerosols, (3) fraction, KTH(NDSTBIN), of the size-weighted total area of aerosols in the grid box. GET_DUST_ALK is analogous to GET_ALK for seasalt (bec, 12/7/04; tdf 04/08/08)

INTERFACE:

```
      SUBROUTINE GET_DUST_ALK( I, J, L, ALK_d, KTS, KTN, KTH,
     &                         Input_Opt, State_Met, State_Chm )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE ERROR_MOD,          ONLY : IT_IS_NAN
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : PI, AIRMW
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: I, J, L        ! Grid box indices
      TYPE(OptInput), INTENT(IN)    :: Input_Opt      ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met      ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm      ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT)   :: ALK_d(NDSTBIN) ! Dust alkalinity [v/v]
      REAL(fp),       INTENT(OUT)   :: KTS  (NDSTBIN) ! Rate coef for uptake of
                                                      ! SO2 on dust [s-1]
      REAL(fp),       INTENT(OUT)   :: KTN  (NDSTBIN) ! Rate coef for uptake of
                                                      ! HNO3 on dust [s-1]
      REAL(fp),       INTENT(OUT)   :: KTH  (NDSTBIN) ! Fraction of the size-
                                                      ! weighted total area
                                                      ! of aerosols in grid box
```

REVISION HISTORY:

```
    08 Apr 2008 - T.D. Fairlie- Initial version
    16 Sep 2013 - M. Sulprizio- Added ProTeX headers
    17 Sep 2013 - M. Sulprizio- Now pass Input_Opt, State_Met, and State_Chm
                                as arguments
    14 Nov 2013 - M. Sulprizio- Bug fix: Avoid div-by-zero in calculation of
                                gas-to-particle rate constants for SO2 and HNO3
    05 Jan 2016 - E. Lundgren - Use global PI
    12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. ERADIUS,
                                TAREA, are now pointers that point to 3D fields
                                fields in State_Chm.
    22 Jun 2016 - M. Yannetti - Replace TCVV with species db MW and phys constant
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
```

8.3.8 init_dust

Subroutine INIT_DUST allocates all module arrays.

INTERFACE:

```
      SUBROUTINE INIT_DUST( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ALLOC_ERR
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants,      ONLY : PI, AIRMW
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Chm_Mod,      ONLY : Ind_
#if   defined( TOMAS )
      USE TOMAS_MOD,          ONLY : IBINS, Xk
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(INOUT) :: Input_Opt   ! Input Options object
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
30 Mar 2004 - R. Yantosca - Initial version
(1 ) Now references LDEAD from "logical_mod.f" (bmy, 7/20/04)
(2 ) Modify to work with 30bin dust. Reference to IBINS from tomas_mod
     for number of total bi}n = 30 bins.  (win, 7/17/09)
25 Aug 2010 - R. Yantosca - Added ProTeX headers
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
26 Feb 2013 - M. Long     - Now use fields from Input_Opt
12 Sep 2013 - M. Sulprizio- Add modifications for acid uptake on dust
                            aerosols (T.D. Fairlie)
23 Sep 2015 - R. Yantosca - Now accept State_Chm as an argument so that
                            we can use the species database
30 Sep 2015 - R. Yantosca - DD_A_Density is now renamed to Density
30 Sep 2015 - R. Yantosca - DD_A_Radius is now renamed to Radius
05 Jan 2016 - E. Lundgren - Use global parameter PI
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
16 Jun 2016 - J. Kaiser   - Now define species ID's with Ind_() function
20 Jun 2016 - R. Yantosca - Only define species ID's in the INIT phase
24 Jun 2016 - R. Yantosca - Add error checks for dust uptake species
```

8.3.9 cleanup_dust

Subroutine CLEANUP_DUST deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_DUST
```

REVISION HISTORY:

```
30 Mar 2004 - R. Yantosca - Initial version
25 Aug 2010 - R. Yantosca - Added ProTeX headers
26 Feb 2013 - R. Yantosca - Now use Input_Opt instead of local arrays
```

8.4 Fortran: Module Interface seasalt_mod.F

Module SEASALT_MOD contains arrays and routines for performing either a coupled chemistry/aerosol run or an offline seasalt aerosol simulation. Original code taken from Mian Chin's GOCART model and modified accordingly. (bec, rjp, bmy, 6/22/00, 11/23/09)

INTERFACE:

```
MODULE SEASALT_MOD
```

USES:

```
USE HCO_ERROR_MOD
```

```
      USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)
      USE PHYSCONSTANTS

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CHEMSEASALT
      PUBLIC  :: CLEANUP_SEASALT
      PUBLIC  :: INIT_SEASALT
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: WET_SETTLING
      PRIVATE :: CHEM_MOPO
      PRIVATE :: CHEM_MOPI
```

PUBLIC DATA MEMBERS:

```
      PUBLIC  :: SALT_V
      PUBLIC  :: DMID
```

REMARKS:

```
   Seasalt aerosol species: (1) Accumulation mode (usually 0.1 -  0.5 um)
                            (2) Coarse mode       (usually 0.5 - 10.0 um)
                                                                             .
   NOTE: You can change the bin sizes for accumulation mode and coarse
         mode seasalt in the "input.geos" file in v7-yy-zz and higher.
   References:
   ============================================================================
   (1 ) Chin, M., P. Ginoux, S. Kinne, B. Holben, B. Duncan, R. Martin,
         J. Logan, A. Higurashi, and T. Nakajima, "Tropospheric aerosol
         optical thickness from the GOCART model and comparisons with
         satellite and sunphotometers measurements", J. Atmos Sci., 2001.
   (2 ) Gong, S., L. Barrie, and J.-P. Blanchet, "Modeling sea-salt
         aerosols in the atmosphere. 1. Model development", J. Geophys. Res.,
         v. 102, 3805-3818, 1997.
```

REVISION HISTORY:

```
   (1 ) Now references "logical_mod.f" and "tracer_mod.f".  Comment out
         SS_SIZE, this has been replaced by SALA_REDGE_um and SALC_REDGE_um
         from "tracer_mod.f".  Increased NR_MAX to 200. (bmy, 7/20/04)
   (2 ) Added error check in EMISSSEASALT (bmy, 1/20/05)
   (3 ) Now references "pbl_mix_mod.f" (bmy, 2/22/05)
   (4 ) Added routine GET_ALK to account for alkalinity. (bec, bmy, 4/13/05)
   (5 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
   (6 ) Now only call dry deposition routine if LDRYD=T (bec, bmy, 5/23/06)
   (7 ) Remove unused variables from GET_ALK.  Also fixed variable declaration
         bug in WET_SETTLING. (bec, bmy, 9/5/06)
```

```
(8 ) Extra error check for low RH in WET_SETTLING (phs, 6/11/08)
(9 ) Bug fix to remove a double-substitution in GET_ALK (bec, bmy, 7/18/08)
(10) Save surface emissions separately (emis_save) for non-local scheme.
     (ccc, 5/14/09)
(11) Bug fixes in GET_ALK and SRCSALT (bec, lyj, bmy, 11/23/09)
(12) Add size-resolved emission subroutine SRCSALT30 and reference to
     tomas_mod.f. (win, 7/17/09)
22 Dec 2011 - M. Payer    - Added ProTeX headers
16 Feb 2012 - R. Yantosca - Moved SRCSALT30 to end of module
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
04 Mar 2013 - R. Yantosca - Now call INIT_SULFATE from the init stage
                            which facilitates connection to GEOS-5 GCM
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
23 Jun 2014 - R. Yantosca - Remove code now made obsolete by HEMCO
03 Nov 2014 - C. Keller   - Moved GET_ALK to sulfate_mod.F.
20 Nov 2014 - M. Yannetti - Added PRECISION_MOD
12 Jun 2015 - R. Yantosca - Removed DRY_DEPOSITION routine, because we
                            now apply drydep in mixing_mod.F90
16 Jun 2016 - C. Miller   - Now define species ID's with Ind_ function
17 Jun 2016 - R. Yantosca - Add species ID's as module variables
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

8.4.1 chemseasalt

Subroutine CHEMSEASALT is the interface between the GEOS-CHEM main program and the seasalt chemistry routines that mostly calculates seasalt dry deposition (rjp, bmy, 1/24/02, 5/23/06)

INTERFACE:

```
SUBROUTINE CHEMSEASALT( am_I_Root, Input_Opt,
&                       State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Dry deposition is now handled in mixing_mod.F90.  We have removed
    the calls to the DRY_DEPOSITION routine here. (bmy, 6/12/15)
```

REVISION HISTORY:

```
    (1 ) Now reference STT from "tracer_mod.f".  Now references LPRT from
         "logical_mod.f" (bmy, 7/20/04)
    (2 ) Now only call DRY_DEPOSITION if LDRYD=T (bec, bmy, 5/23/06)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    13 Nov 2012 - R. Yantosca - Now add Input_Opt, RC arguments for GIGC
    15 Nov 2012 - M. Payer    - Now pass met fields via State_Met object
    25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
    12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                                so we can greatly collapse this code
    17 Jun 2016 - R. Yantosca - Add error checks before calling routines
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
    20 Sep 2016 - R. Yantosca - Bug fix: rewrite invalid ( LMPOA > 0 ) test
```

8.4.2 wet_settling

Subroutine WET_SETTLING performs wet settling of sea salt. (bec, rjp, bmy, 4/20/04, 6/11/08)

INTERFACE:

```
      SUBROUTINE WET_SETTLING( am_I_Root, Input_Opt, State_Met,
     &                         State_Chm, TC,        N,
     &                         RC         )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
```

```
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PhysConstants
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
#if defined( NC_DIAG )
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE HCO_ERROR_MOD,      ONLY : HCO_SUCCESS
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: N                    ! 1=accum mode;
                                                            ! 2=coarse mode
      LOGICAL,        INTENT(IN)    :: am_I_Root            ! Root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt            ! Input Options
      TYPE(MetState), INTENT(IN)    :: State_Met            ! MeteorologyState
      TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! Sea salt [kg]
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC                   ! Success/failure
```

REVISION HISTORY:

```
    (1 ) Now references SALA_REDGE_um and SALC_REDGE_um from "tracer_mod.f"
         (bmy, 7/20/04)
    (2 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
    (3 ) Bug fix: DTCHEM has to be REAL(fp), not integer. (bmy, 9/7/06)
    (4 ) Now limit relative humidity to [tiny(real(fp)),0.99] range for DLOG
          argument (phs, 5/1/08)
    (5 ) Update sea salt density calculation using Tang et al. (1997) (bec,
         jaegle 5/11/11)
    (6 ) Update hygroscopic growth for sea salt using Lewis and Schwartz (2006)
         and and density calculation based on Tang et al. (1997) (bec, jaegle
         5/11/11)
    (7 ) Itegrate settling velocity over entire size distribution (jaegle
         5/11/11)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
```

```
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%XNUMOL(1:N_TRACERS)
12 Jun 2013 - R. Yantosca - Bug fix: SALT_MASS needs to be !OMP PRIVATE
12 Jun 2013 - R. Yantosca - Reformatted some comments for clarity
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID.
                            Remove dependency on pressure_mod.
25 Jan 2016 - E. Lundgren - Update netcdf drydep flux diagnostic
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
31 May 2016 - E. Lundgren - Remove usage of Input_Opt%XNUMOL
22 Jun 2016 - M. Yannetti - Replaced TCVV with spec db and phys constant
```

8.4.3 chem_mopo

Subroutine CHEM_MOPO modifies hydrophobic marine organic aerosol concentrations based on the conversion to hydrophilic marine organic aerosols.

INTERFACE:

```
SUBROUTINE CHEM_MOPO( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

REVISION HISTORY:

```
10 Jul 2015 - E. Lundgren - Initial version (based on routine Chem_OCPO)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.4.4 chem_mopi

Subroutine CHEM_MOPI modifies hydrophilic marine organic aerosol concentrations based on the conversion from hydrophobic marine organic aerosols.

INTERFACE:

```
SUBROUTINE CHEM_MOPI( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root             ! Root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt             ! Input Options
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC                    ! Success?
```

REMARKS:

REVISION HISTORY:

```
10 Jul 2015 - E. Lundgren - Initial version (based on routine Chem_OCPI)
```

8.4.5 init_seasalt

Subroutine INIT_SEASALT initializes and zeroes all module arrays (bmy, 4/26/04, 4/13/05)

INTERFACE:

```
SUBROUTINE INIT_SEASALT( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root
TYPE(OptInput), INTENT(IN)  :: Input_Opt
TYPE(ChmState), INTENT(IN)  :: State_Chm
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC
```

REVISION HISTORY:

```
(1 ) Now exit if we have allocated arrays before.  Now also allocate
     ALK_EMIS & N_DENS.  Now reference CMN_SIZE. (bec, bmy, 4/13/05)
(2 ) Added SALT_V and DMID (jaegle 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
04 Mar 2013 - R. Yantosca - Now pass am_I_Root, Input_Opt, RC as arguments
04 Mar 2013 - R. Yantosca - Now test for DEPSALA, DEPSALC here
12 Jun 2015 - R. Yantosca - Remove obsolete, commented-out code
23 Sep 2015 - R. Yantosca - Now accept State_Chm as an argument so that
                            we can use the species database
30 Sep 2015 - R. Yantosca - DD_A_Density is renamed to Density
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
17 Jun 2016 - R. Yantosca - Now define species ID's on the first call
13 Oct 2016 - R. Yantosca - Now allocate OCCONV for marine-POA simulations
```

8.4.6 cleanup_seasalt

Subroutine CLEANUP_SEASALT deallocates all module arrays (bmy, 4/26/04, 4/13/05)

INTERFACE:

```
SUBROUTINE CLEANUP_SEASALT
```

REVISION HISTORY:

```
(1 ) Now deallocates ALK_EMIS, N_DENS, SRC_N (bec, bmy, 4/13/05)
(2 ) Deallocated SALT_V and DMID (jaegle 5/11/11)
22 Dec 2011 - M. Payer    - Added ProTeX headers
13 Oct 2016 - R. Yantosca - Bug fix: now deallocate OCCONV array
```

8.4.7 srcsalt30

Subroutine SRCSALT30 emits sea-salt into the 30-bin sea-salt mass and aerosol number arrays. Sea-salt emission parameterization of Clarke et al. [2006] (win, 7/17/09)

INTERFACE:

```
SUBROUTINE SRCSALT30( TC1, TC2, State_Met )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE CMN_DIAG_MOD             ! ND59
USE DAO_MOD,            ONLY : IS_WATER
USE DIAG_MOD,           ONLY : AD59_NUMB, AD59_SALT
USE ERROR_MOD,          ONLY : ERROR_STOP
USE ERROR_MOD,          ONLY : IT_IS_NAN
USE GC_GRID_MOD,        ONLY : GET_AREA_M2
USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_TOP_L
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_EMIS
USE TOMAS_MOD,          ONLY : IBINS, Xk
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
! TC1 : Aerosol number tracer array [no.]
! TC2 (REAL(fp) ) : Sea salt tracer array [kg]
REAL(fp),  INTENT(INOUT) :: TC1(IIPAR,JJPAR,LLPAR,IBINS)
REAL(fp),  INTENT(INOUT) :: TC2(IIPAR,JJPAR,LLPAR,IBINS)
```

AUTHOR:

```
Contact: Win Trivitayanurak (win@cmu.edu)

Arguments as Input/Output:
============================================================================
```

REMARKS:

```
References:
============================================================================
(1 ) Clarke, A.D., Owens, S., Zhou, J. " An ultrafine sea-salt flux from
      breaking waves: Implications for CCN in the remote marine atmosphere"
      JGR, 2006
```

REVISION HISTORY:

```
(1 ) Originally from emisnaN3clarke.f in GISS GCM-II' (win, 7/18/07)
(2 ) Now partition emission throughout the PBL (win, 7/18/07)
(3 ) Add COEF to adjust emission in a 1x1 nested-grid (win, 4/27/08)
16 Feb 2012 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - A_M2 is now a scalar
10 Mar 2014 - J. Pierce   - Avoid sea salt emissions over ice
25 Jul 2014 - R. Yantosca - Remove reference to function SFCWINDSQR
```

8.5 Fortran: Module Interface sulfate_mod.F

Module SULFATE_MOD contains arrays and routines for performing either a coupled chemistry/aerosol run or an offline sulfate aerosol simulation. Original code taken from Mian Chin's GOCART model and modified accordingly. (rjp, bdf, bmy, 6/22/00, 8/26/10)

INTERFACE:

```
      MODULE SULFATE_MOD
```

USES:

```
      USE HCO_ERROR_MOD    ! For HEMCO error handling
      USE PhysConstants    ! Physical constants
      USE PRECISION_MOD    ! For GEOS-Chem Precision (fp, f4, f8)

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC :: CHEMSULFATE
      PUBLIC :: CLEANUP_SULFATE
      PUBLIC :: INIT_SULFATE
#if defined( TOMAS )
      PUBLIC :: EMISSSULFATETOMAS ! JKodros (6/2/15 - this is to connect TOMAS to HEMCO)
#endif
```

REMARKS:

```
   References:
   ============================================================================
   (1 ) Andreae, M.O. & P. Merlet, "Emission of trace gases and aerosols from
        biomass burning", Global Biogeochem. Cycles, 15, 955-966, 2001.
   (2 ) Nightingale et al [2000a], J. Geophys. Res, 14, 373-387
   (3 ) Nightingale et al [2000b], Geophys. Res. Lett, 27, 2117-2120
   (4 ) Wanninkhof, R., "Relation between wind speed and gas exchange over
        the ocean", J. Geophys. Res, 97, 7373-7382, 1992.
```

REVISION HISTORY:

```
   (1 ) All module variables are declared PRIVATE (i.e., they can only
        be seen from within this module (bmy, 6/2/00)
   (2 ) The routines in "sulfate_mod.f" assume that we are doing chemistry
        over the global region (e.g. IIPAR=IIPAR, JJPAR=JJPAR). (bmy, 6/8/00)
   (3 ) Removed obsolete code from DRYDEP_SULFATE (bmy, 12/21/00)
   (4 ) Removed obsolete commented-out code from module routines (bmy, 4/23/01)
   (5 ) Now read data files from DATA_DIR/sulfate_sim_200106/ (bmy, 6/19/01)
   (6 ) Updated comments (bmy, 9/4/01)
   (7 ) XTRA2(IREF,JREF,5) is now XTRA2(I,J).  Now reference COSSZA from
```

```
      "dao_mod.f". (bmy, 9/27/01)
(8 ) Removed obsolete commented out code from 9/01 (bmy, 10/24/01)
(9 ) Minor fixes to facilitate compilation on ALPHA (bmy, 11/15/01)
(11) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
      MODULE ROUTINES sections.  Updated comments (bmy, 5/28/02)
(12) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
      to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(13) Now reference "file_mod.f" (bmy, 6/27/02)
(14) Now references GET_PEDGE from "pressure_mod.f", which computes P at
      the bottom edge of grid box (I,J,L).  Also deleted obsolete,
      commented-out code. (dsa, bdf, bmy, 8/21/02)
(15) Added updated code from Rokjin Park and Brendan Field, in order to
      perform coupled chemistry-aerosol simulations.  Also added parallel
      DO-loops in several subroutines.  Updated comments, cosmetic
      changes.  Now reference "error_mod.f" and "wetscav_mod.f".
      Now only do chemistry below the tropopause. (rjp, bdf, bmy, 12/6/02)
(16) Added ENH3_na array to hold natural source NH3 emissions.  Also now
      facilitate passing DMS, SO2, SO4, NH3 to SMVGEAR for fullchem
      simulations.  Added subroutine READ_NATURAL_NH3. (rjp, bmy, 3/23/03)
(17) Now references "grid_mod.f" and "time_mod.f".  Also made other minor
      cosmetic changes. (bmy, 3/27/03)
(18) Updated chemistry routines to apply drydep losses throughout the
      entire PBL. (rjp, bmy, 8/1/03)
(19) Now accounts for GEOS-4 PBL being in meters (bmy, 1/15/04)
(20) Fix ND44 diag so that we get same results for sp or mp (bmy, 3/24/04)
(21) Added COSZM array.  Now use diurnal varying JH2O2 in CHEM_H2O2.
      (rjp, bmy, 3/39/04)
(22) Added more parallel DO-loops (bmy, 4/14/04)
(23) Now add SO2 from ships (bec, bmy, 5/20/04)
(24) Now references "directory_mod.f", "logical_mod.f" and "tracer_mod.f".
      Now removed IJSURF. (bmy, 7/20/04)
(25) Can overwrite USA with EPA/NEI99 emissions (rjp, rch, bmy, 11/16/04)
(26) Modified for AS, AHS, LET, SO4aq, NH4aq (cas, bmy, 1/11/05)
(27) Now also references "pbl_mix_mod.f".  NOTE: Comment out phase
      transition  code for now since it is still under development and
      will take a while to be rewritten. (bmy, 3/15/05)
(28) Modified for SO4s, NITs chemistry (bec, 4/13/05)
(29) Now reads updated files for SST and offline chemistry.  Now read data
      for both GCAP and GEOS grids.  Now references "tropopause_mod.f".
      (bmy, 8/22/05)
(30) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(31) Now references XNUMOL & XNUMOLAIR from "tracer_mod.f" (bmy, 10/25/05)
(32) Now read int'annual SST data on GEOS 1x1 grid (bmy, 11/17/05)
(33) Bug fix for offline aerosol sim in SEASALT_CHEM (bec, bmy, 3/29/06)
(34) Bug fix in INIT_DRYDEP (bmy, 5/23/06)
(35) Now references "bravo_mod.f" (rjp, kfb, bmy, 6/26/06)
(36) Now references "streets_anthro_mod.f" (yxw, bmy, 8/17/06)
(37) Now references "biomass_mod.f" (bmy, 9/27/06)
```

```
(38) Now prevent seg fault error in READ_BIOFUEL_SO2 (bmy, 11/3/06)
(39) Bug fix in SEASALT_CHEM (havala, bec, bmy, 12/8/06)
(40) Extra error check for low RH in GRAV_SETTLING (phs, 6/11/08)
(41) Now references "cac_anthro_mod.f".  And apply SO2 yearly scale factor
     to SO2 from GEIA (amv, phs, 3/11/08)
(41) Bug fixes in reading EDGAR data w/ the right tracer number,
     when we are doing offline or nonstd simulations (dkh, 10/31/08)
(42) Bug fix for AD13_SO2_sh in SRCSO2 (phs, 2/27/09)
(43) Bug fix: need to add CAC_AN to PRIVATE statements (bmy, 5/27/09)
(44) Constrain surface emissions to the first level and save them into
     emis_save (lin, 5/29/09)
(45) Last year of SST data is now 2008 (see READ_SST) (bmy, 7/13/09)
(46) Updated rxns in CHEM_DMS and CHEM_SO2 to JPL 2006 (jaf, bmy, 10/15/09)
(47) Added new volcanic emissions of SO2 (jaf, bmy, 10/15/09)
(48) Now accounts for NEI 2005 emissions, and multilevels SOxan emissions
     (amv, phs, 10/15/2009)
(49) Fixes in SRCSO2 for SunStudio compiler (bmy, 12/3/09)
(50) Add new subroutine SRCSF30 for emission to 30bin sulfate (win, 1/25/10)
(51) Add new array PSO4_SO2AQ for SO4 produced via aqueous chemistry of SO2
     excluding that from heterogeous reaction on sea-salt. (win, 1/25/10)
(52) Standardized patch in READ_ANTHRO_NH3 (dkh, bmy, 3/5/10)
(53) Use LWC from GEOS-5 met fields (jaf, bmy, 6/30/10)
(54) Add module parameters MNYEAR_VOLC and MXYEAR_VOLC to define the 1st
    and last year with data for volcanic emissions. (ccc, 9/30/10)
(55) Use updated volcanic emissions from 1979 to 2009
26 Aug 2010 - R. Yantosca   - Add modifications for MERRA
12 Nov 2010 - R. Yantosca   - Avoid div-by-zero when computing L2S, L3S
07 Sep 2011 - P. Kasibathla - Modified to include GFED3
22 Dec 2011 - M. Payer      - Added ProTeX headers
08 Feb 2012 - R. Yantosca   - Add modifications for GEOS-5.7.2 met
01 Mar 2012 - R. Yantosca   - Now reference new grid_mod.F90
13 Mar 2012 - M. Cooper     - Changed regrid algorithm to map_a2a
28 Nov 2012 - R. Yantosca   - Use SUNCOS fields from the State_Met object
04 Mar 2013 - R. Yantosca   - Now call INIT_SULFATE from the init stage
                              which facilitates connection to GEOS-5 GCM
05 Mar 2013 - R. Yantosca   - Now use Input_Opt%LNLPBL instead of LNLPBL
                              from logical_mod.F
13 Mar 2013 - R. Yantosca   - Bug fix: make sure we pass values to the
                              SOIL_DRYDEP routine even when ND44 is off
30 May 2013 - S. Farina     - Merged TOMAS code into sulfate_mod.F
20 Aug 2013 - R. Yantosca   - Removed "define.h", this is now obsolete
12 Sep 2013 - M. Sulprizio  - Add modifications for acid uptake on dust
                              aerosol (T.D. Fairlie)
18 Sep 2014 - M. Sulprizio  - Get oxidant fields for offline aerosol
                              simulation from HEMCO
03 Nov 2014 - C. Keller     - Incorporated GET_ALK from seasalt_mod.F
20 Nov 2014 - M. Yannetti   - Added PRECISION_MOD
04 Mar 2015 - R. Yantosca   - Remove obsolete, commented-out code
```

```
04 Mar 2015 - R. Yantosca   - Use REAL(f4) for pointer args to HCO_GetPtr
22 May 2015 - R. Yantosca   - Remove variables made obsolete by HEMCO
12 Jun 2015 - R. Yantosca   - Now remove orphaned ND44 variables
12 Jun 2015 - R. Yantosca   - Remove CHEM_NH3 and CHEM_NH4 routines
                              because drydep is now done in mixing_mod.F90
23 Sep 2015 - R. Yantosca   - Remove DRY* flags for most species except
                              for those used in GRAV_SETTLING
05 Jan 2016 - E. Lundgren   - Use global physical parameters
04 Aug 2016 - M. Yannetti   - Replace TCVV with spc db MW and phys constant
29 Nov 2016 - R. Yantosca   - grid_mod.F90 is now gc_grid_mod.F90
```

8.5.1 get_vcldf

Subroutine GET_VCLDF computes the volume cloud fraction for SO2 chemistry. (rjp, bdf, bmy, 9/23/02)

INTERFACE:

```
SUBROUTINE GET_VCLDF( am_I_Root, State_Met, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
References:
============================================================================
(1) Sundqvist et al. [1989]
```

REVISION HISTORY:

```
14 Jan 2011 - R. Yantosca - Return if VCLDF is not allocated
22 Dec 2011 - M. Payer    - Added ProTeX headers
14 Nov 2012 - R. Yantosca - Added am_I_Root, RC arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER and GET_PEDGE with
                            State_Met%PMID and State_Met%PEDGE.
                            Remove dependency on pressure_mod.
```

8.5.2 get_lwc

Function GET_LWC returns the cloud liquid water content [m3 H2O/m3 air] at a GEOS-CHEM grid box as a function of temperature. (rjp, bmy, 10/31/02, 1/14/03)

INTERFACE:

```
FUNCTION GET_LWC( T ) RESULT( LWC )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: T ! Temperature value at a GEOS-CHEM grid box [K]
```

RETURN VALUE:

```
REAL(fp)             :: LWC
```

REVISION HISTORY:

```
18 Jan 2011 - R. Yantosca - Updated comments
22 Dec 2011 - M. Payer    - Added ProTeX header
```

8.5.3 chemsulfate

Subroutine CHEMSULFATE is the interface between the GEOS-CHEM main program and the sulfate chemistry routines. The user has the option of running a coupled chemistry-aerosols simulation or an offline aerosol simulation. (rjp, bdf, bmy, 5/31/00, 3/16/06)

INTERFACE:

```
SUBROUTINE CHEMSULFATE( am_I_Root, Input_Opt,
&                       State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD
USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH
USE TIME_MOD,           ONLY : GET_TS_CHEM
USE TIME_MOD,           ONLY : GET_ELAPSED_SEC
USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
USE UCX_MOD,            ONLY : SETTLE_STRAT_AER
USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

(1) Now reference all arguments except FIRSTCHEM and RH from either F90 modules or from common block header files. Updated comments, cosmetic changes. Added NH3, NH4, NITRATE chemistry routines. Also call MAKE_RH and CONVERT_UNITS from "dao_mod.f". Now references IDTDMS, IDTSO2 etc. from "tracerid_mod.f". Now make FIRSTCHEM a local SAVEd variable. Now reference DEPSAV from "drydep_mod.f". Also get rid of extraneous dimensions of DEPSAV. Added NTIME, NHMSb arrays for OHNO3TIME. (rjp, bdf, bmy, 12/16/02)
(2) CHEM_DMS is now only called for offline sulfate simulations. (rjp, bmy, 3/23/03)
(3) Now remove NTIME, NHMSb from the arg list and call to OHNO3TIME. Now references functions GET_MONTH, GET_TS_CHEM, and GET_ELAPSED_SEC from the new "time_mod.f". (bmy, 3/27/03)
(4) Now reference STT, TCVV, N_TRACERS, ITS_AN_AEROSOL_SIM from "tracer_mod.f". Now reference ITS_A_NEW_MONTH from "time_mod.f". Now references LPRT from "logical_mod.f". (bmy, 7/20/04)
(5) Updated for AS, AHS, LET, SO4aq, NH4aq. Now references LCRYST from logical_mod.f. Now locate species in the DEPSAV array w/in INIT_SULFATE. (bmy, 12/21/04)
(6) Now handle gravitational settling of SO4s, NITs (bec, bmy, 4/13/05)
(7) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8) Remove reference to MAKE_RH, it's not needed here (bmy, 3/16/06)
(9) Reference to LTOMAS and add call CHEM_SO4_AQ using aqueous oxidation which is one of the TOMAS microphysics subroutine (win, 1/25/10)
05 Oct 2011 - R. Yantosca - SUNCOS is no longer needed here
22 Dec 2011 - M. Payer - Added ProTeX headers
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when running with the traditional driver main.F
14 Nov 2012 - R. Yantosca - Add Input_Opt, RC as arguments
15 Nov 2012 - M. Payer - Replaced all met field arrays with State_Met derived type object
04 Mar 2013 - R. Yantosca - Remove call to INIT_SULFATE
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS)
25 Mar 2013 - M. Payer - Now pass State_Chm object via the arg list
23 Apr 2013 - R. Yantosca - Remove LTOMAS logical, since we now invoke TOMAS

```
                              with either TOMAS=yes or TOMAS40=yes
   31 May 2013 - R. Yantosca - Now pass am_I_root, Input_Opt, State_Chm
                              and RC to TOMAS routine CHEM_SO4_AQ
   12 Sep 2013 - M. Sulprizio- Include gravitational settling of dust_sulfate
                              and dust_nitrate. Changes made to CHEM_SO2 and
                              CHEM_SO4 (tdf, 04/07/08)
   23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
   18 Sep 2014 - M. Sulprizio- Get oxidant fields for offline aerosol
                              simulation from HEMCO
   30 Sep 2015 - E. Lundgren - Now use UNITCONV_MOD conversion routines
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
   16 Jun 2016 - M. Long     - Remove references to TRACERID_MOD and replace
                              with STATE_CHM_MOD::Ind_()
   30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                              species ID from State_Chm%Map_Advect.
   11 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

8.5.4 emisssulfatetomas

Subroutine EMISSSULFATETOMAS connects HEMCO bulk emissions to the TOMAS tracers. Only use this for TOMAS sims. This should be quite similar to the TOMAS relevant parts of 'emisssulfate' in v9 (Jkodros 6/2/15)

INTERFACE:

```
      SUBROUTINE EMISSSULFATETOMAS( am_I_Root, Input_Opt,
     &                          State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TOMAS_MOD,          ONLY : IBINS,      ICOMP,   IDIAG
      USE TOMAS_MOD,          ONLY : NH4BULKTOBIN
      USE TOMAS_MOD,          ONLY : SRTNH4
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State objectt
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?

   Local variables
      ! Fields for TOMAS simulation
      REAL*8        :: BINMASS(IIPAR,JJPAR,LLPAR,IBINS*ICOMP)
      REAL*8        :: tempnh4(ibins)
      INTEGER       :: TID, I, J, L
      REAL*8        :: MK_TEMP(IBINS)
      INTEGER       :: ii=53, jj=29, ll=1

      ! SAVEd scalars
      LOGICAL, SAVE :: FIRST = .TRUE.

      ! Pointers
      REAL*8, POINTER :: Spc(:,:,:,:)

      !=================================================================
      ! EMISSSULFATETOMAS begins here!
      !=================================================================

      ! First-time setup
      IF ( FIRST ) THEN


         ! Reset first-time flag
         FIRST  = .FALSE.
      ENDIF

      ! Convert species from [kg/kg dry air] to [kg] for TOMAS.
      ! This will be removed once TOMAS uses mixing ratio instead of mass
      ! as tracer units (ewl, 9/11/15)
      CALL ConvertSpc_KgKgDry_to_Kg( am_I_Root, State_Met,
     &                               State_Chm, RC         )
      IF ( RC /= GC_SUCCESS ) THEN
         CALL GC_Error('Unit conversion error', RC,
     &                 'Routine EMISSSULFATETOMAS in sulfate_mod.F')
         RETURN
      ENDIF

      ! Point to chemical species array [kg]
      Spc => State_Chm%Species

      IF (id_SF1 > 0 .and. id_NK1 > 0 ) THEN
```

```
      !!!  Get NH4 and aerosol water into the same array
         BINMASS(:,:,:,1:IBINS*(ICOMP-IDIAG)) =
     &        Spc(:,:,:,id_SF1:id_SF1+IBINS*(ICOMP-IDIAG) - 1)

         IF ( SRTNH4 > 0 ) THEN
            TID = IBINS*(ICOMP-IDIAG) + 1

%%%OMP PARALLEL DO
%%%OMP+DEFAULT( SHARED )
%%%OMP+PRIVATE( I, J, L, TMPNH4, MKTEMP )
%%%OMP+SCHEDULE( DYNAMIC )
            DO L=1,LLPAR
            DO J=1,JJPAR
            DO I=1,IIPAR

               ! Take a slice of size IBINS from Spc
               MK_TEMP = Spc(I,J,L,id_SF1:id_SF1-1+IBINS)

               ! Avoid array tmeporaries in subroutine call (bmy, 1/29/14)
               CALL NH4BULKTOBIN( MK_TEMP, Spc(I,J,L,id_NH4), TEMPNH4 )

               BINMASS(I,J,L,TID:TID+IBINS-1) = TEMPNH4(1:IBINS)
            Enddo
            ENDDO
            ENDDO
%%%OMP END PARALLEL DO

         ENDIF

         TID = IBINS*(ICOMP-1) +1
         BINMASS(:,:,:,TID:TID+IBINS-1) =
     &           Spc(:,:,:,id_AW1:id_AW1+IBINS-1)

      !IF ( id_SF1 > 0 ) THEN
         CALL SRCSF30(  Spc(:,:,:,id_NK1:id_NK1+IBINS-1),
     &         BINMASS(:,:,:,:), am_I_Root, Input_Opt, State_Met, RC )

         ! Return the aerosol mass after emission subroutine to Spc
         ! excluding the NH4 aerosol and aerosol water (win, 9/27/08)
         Spc(:,:,:,id_SF1:id_SF1+IBINS*(ICOMP-IDIAG)-1) =
     &        BINMASS(:,:,:,1:IBINS*(ICOMP-IDIAG))
      ENDIF

      ! Free pointer
      NULLIFY( Spc )

      ! Convert species back to kg (ewl, 9/11/15)
```

```
      CALL ConvertSpc_Kg_to_KgKgDry( am_I_Root, State_Met,
     &                               State_Chm, RC         )
      IF ( RC /= GC_SUCCESS ) THEN
         CALL GC_Error('Unit conversion error', RC,
     &                 'Routine EMISSSULFATETOMAS in sulfate_mod.F')
         RETURN
      ENDIF

      END SUBROUTINE EMISSSULFATETOMAS
 EOC
#endif
 ------------------------------------------------------------------------------
                  Jack Kodros re-writing this
 ------------------------------------------------------------------------------
#if defined( TOMAS )
      SUBROUTINE SRCSF30( TC1, TC2,
     &     am_I_Root, Input_Opt, State_Met, RC )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE CMN_DIAG_MOD             ! ND13 (for now)
      USE DIAG_MOD,           ONLY : AD59_SULF,     AD59_NUMB
      USE ERROR_MOD,          ONLY : ERROR_STOP,  IT_IS_NAN
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_TOP_L
      USE State_Met_Mod,      ONLY : MetState
      USE TOMAS_MOD,          ONLY : IBINS, AVGMASS, ICOMP
      USE TOMAS_MOD,          ONLY : Xk,  SUBGRIDCOAG, MNFIX
      USE TOMAS_MOD,          ONLY : SRTSO4, SRTNH4,  DEBUGPRINT
      USE HCO_INTERFACE_MOD,  ONLY : HcoState, GetHcoDiagn
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      REAL*8,  INTENT(INOUT) :: TC1(IIPAR,JJPAR,LLPAR,IBINS)
      REAL*8,  INTENT(INOUT) :: TC2(IIPAR,JJPAR,LLPAR,IBINS*ICOMP)
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?

   Local variables
      INTEGER               :: I, J, K, L, DOW_LT, NTOP, C
      REAL*8                :: SO4(LLPAR), DTSRCE  , EFRAC(LLPAR)
      REAL*8                :: TSO4,       FEMIS
```

```
      REAL*8                 :: AREA_CM2
      REAL*8                 :: SO4an(IIPAR,JJPAR,2)
      REAL*8                 :: SO4bf(IIPAR,JJPAR)
      REAL*8                 :: SO4anbf(IIPAR,JJPAR,2)
      REAL*8 BFRAC(IBINS)     ! Mass fraction emitted to each bin

#if  defined( TOMAS12) || defined( TOMAS15)
      DATA BFRAC/
# if  defined( TOMAS15)
     &           0.0d0     , 0.0d0     , 0.0d0,
# endif
     &           4.3760E-02, 6.2140E-02, 3.6990E-02, 1.8270E-02,
     &           4.2720E-02, 1.1251E-01, 1.9552E-01, 2.2060E-01,
     &           1.6158E-01, 7.6810E-02, 2.8884E-02, 2.0027E-04/

#else

      DATA BFRAC/
# if  defined( TOMAS40)
     &           0.000d00 , 0.000d00 , 0.000d00 , 0.000d00 , 0.000d00 ,
     &           0.000d00 , 0.000d00 , 0.000d00 , 0.000d00 , 0.000d00 ,
# endif
     &           1.728d-02, 2.648d-02, 3.190d-02, 3.024d-02, 2.277d-02,
     &           1.422d-02, 9.029d-03, 9.241d-03, 1.531d-02, 2.741d-02,
     &           4.529d-02, 6.722d-02, 8.932d-02, 1.062d-01, 1.130d-01,
     &           1.076d-01, 9.168d-02, 6.990d-02, 4.769d-02, 2.912d-02,
     &           1.591d-02, 7.776d-03, 3.401d-03, 1.331d-03, 4.664d-04,
     &           1.462d-04, 4.100d-05, 1.029d-05, 2.311d-06, 4.645d-07/
#endif

      REAL*8                  :: NDISTINIT(IBINS)
      REAL*8                  :: NDISTFINAL(IBINS)
      REAL*8                  :: MADDFINAL(IBINS)
      REAL*8                  :: NDIST(IBINS),  MDIST(IBINS,ICOMP)
      REAL*8                  :: NDIST2(IBINS), MDIST2(IBINS,ICOMP)
      REAL*4                  :: TSCALE, BOXVOL, TEMP, PRES

      REAL*8                  :: N0(LLPAR,IBINS), M0(LLPAR,IBINS)

      REAL(fp)                :: AREA(IIPAR, JJPAR)
      REAL(fp)                :: AREA3D(IIPAR, JJPAR,2)

      ! Pointers
      REAL(f4),        POINTER :: Ptr2D(:,:  )
      REAL(f4),        POINTER :: Ptr3D(:,:,:)

      INTEGER                   :: N_TRACERS
```

```
LOGICAL                :: ERRORSWITCH, SGCOAG = .TRUE.
INTEGER                :: FLAG, ERR
logical                :: pdbug !(temporary) win, 10/24/07
!integer                :: ii, jj, ll
!data ii, jj, ll / 61, 1, 7 /
INTEGER                :: ii=53, jj=29, ll=1

! Ratio of molecular weights: S/SO4
REAL*8,  PARAMETER     :: S_SO4 = 32d0 / 96d0

! debugging
real*8   dummy

! For fields from Input_Opt
LOGICAL :: LPRT, LNLPBL
LOGICAL                 :: jkdbg=.true.

! Strings
CHARACTER(LEN= 63)       :: DgnName
CHARACTER(LEN=255)       :: MSG
CHARACTER(LEN=255)       :: LOC='srcsf30 (sulfate_mod.F)'

!=================================================================
! SRCSF30 begins here!
!=================================================================

! Free pointers
Ptr2D    => NULL()
Ptr3D    => NULL()

! COpy values from Input_Opt
LPRT    = Input_Opt%LPRT
LNLPBL  = Input_Opt%LNLPBL

! Import emissions from HEMCO (through HEMCO state)
IF ( .NOT. ASSOCIATED(HcoState) ) THEN
   CALL ERROR_STOP ( 'HcoState not defined!', LOC )
ENDIF

! Emission timestep [seconds]
DTSRCE = HcoState%TS_EMIS

! Grid box aarea
AREA = HcoState%Grid%AREA_M2%Val(:,:)
AREA3D(:,:,1) = AREA(:,:)
AREA3D(:,:,2) = AREA(:,:)

!=================================================================
```

```
      ! READ IN HEMCO EMISSIONS
      !=================================================================
      DgnName = 'SO4_ANTH'
      CALL GetHcoDiagn( am_I_Root, DgnName, .FALSE., ERR,
     &  Ptr3D=Ptr3D )
      IF ( .NOT. ASSOCIATED(Ptr3D) ) THEN
         CALL HCO_WARNING('Not found: '//TRIM(DgnName),ERR,THISLOC=LOC)
      ELSE
         SO4_ANTH = Ptr3D(:,:,:)
      ENDIF
      Ptr3D => NULL()

      DgnName = 'SO4_BIOF'
      CALL GetHcoDiagn( am_I_Root, DgnName, .FALSE., ERR,
     &  Ptr2D=Ptr2D )
      IF ( .NOT. ASSOCIATED(Ptr2D) ) THEN
         CALL HCO_WARNING('Not found: '//TRIM(DgnName),ERR,THISLOC=LOC)
      ELSE
         SO4_BIOF = Ptr2D(:,:)
      ENDIF
      Ptr2D => NULL()

      ! convert to kg/box/sec
      SO4an = SO4_ANTH(:,:,:) * AREA3d(:,:,:)
      SO4bf = SO4_BIOF(:,:) * AREA(:,:)

      !=================================================================
      ! Compute SO4 emissions
      !=================================================================
$OMP PARALLEL DO
$OMP+DEFAULT( SHARED )
$OMP+PRIVATE( I, J, NTOP, SO4, TSO4, L, FEMIS, EFRAC, N0, M0, K )
$OMP+PRIVATE( NDISTINIT, NDIST, MDIST, NDISTFINAL, MADDFINAL )
$OMP+PRIVATE( NDIST2, MDIST2, C )
$OMP+PRIVATE( BOXVOL, TEMP, PRES, TSCALE, pdbug )
$OMP+SCHEDULE( DYNAMIC )
      DO J = 1, JJPAR
      DO I = 1, IIPAR

         ! Top level of boundary layer at (I,J)
         NTOP = CEILING( GET_PBL_TOP_L( I, J ) )

         ! Zero SO4 array at all levels
         DO L = 1, LLPAR
            SO4(L) = 0.0
         ENDDO

         ! Compute total anthro SO4 (surface + 100m) plus biofuel SO4
```

```
      TSO4 = 0.d0
      TSO4 = SUM( SO4an(I,J,:) ) + SO4bf(I,J)
      IF ( TSO4 == 0d0 ) CYCLE


debug       if(i==60.and.j==35) print *,'TSO4',TSO4
      !=================================================================
      ! First calculate emission distribution vertically within PBL
      !=================================================================
      ! EFRAC(30) = fraction of total emission splitted for each
      !             level until reaching PBL top.
      EFRAC = 0d0
      !=================================================================
      ! Partition the total anthro SO4 emissions thru the entire
      ! boundary layer (if PBL top is higher than level 2)
      !=================================================================
      ! Add option for non-local PBL (Lin, 03/31/09)
      IF (.NOT. LNLPBL) THEN
      IF ( NTOP > 2 ) THEN

         ! Loop thru boundary layer
         DO L = 1, NTOP

            ! Fraction of PBL spanned by grid box (I,J,L) [unitless]
            EFRAC(L)  = GET_FRAC_OF_PBL( I, J, L )

         ENDDO
      ELSE
         EFRAC(1) = ( SO4an(I,J,1) + SO4bf(I,J) ) / TSO4
         EFRAC(2) = SO4an(I,J,2) / TSO4
      ENDIF

      IF ( ABS( SUM( EFRAC(:)) - 1.d0 ) > 1.D-5 ) THEN
         PRINT*, '### ERROR in SRCSF30!'
         PRINT*, '### I, J : ', I, J
         print*, 'EFRAC',EFRAC(:)
         PRINT*, '### SUM(EFRAC) : ', SUM( EFRAC(:) )
         PRINT*, '### This should exactly 1.00'
         CALL ERROR_STOP( 'Check SO4 redistribution',
     &                    'SRCSF30 (sulfate_mod.f)' )
      ENDIF

      ELSE
         ! stop the program for now since I don't totally implement
         ! the subgrid coagulation option w/ Lin's new PBL scheme (win, 1/25/10)
         print *,'If the program stops here, that means you are ',
     &        'running TOMAS simulation with the new PBL scheme ',
     &        'implemented since GEOS-Chem v.8-02-01.',
```

```
     &           '-----> Try not using the non-local PBL option'
            CALL ERROR_STOP( 'Code does not support new PBL scheme',
     &                       'SRCSF30 (sulfate_mod.f)')

          ENDIF  ! .not. LNLPBL
          !=================================================================
          ! Add the size-resolved SO4 emission to tracer array
          ! Having the options to do sub-grid coagulation or simply
          ! emit.
          ! Sub-grid coagulation reduces the number being emitted
          ! and modifies the mass size distribution of existing particle
          ! as well as the size distribution being emitted.
          ! (win, 10/4/07)
          !=================================================================
          IF ( SGCOAG ) THEN

             N0(:,:) = TC1(I,J,:,:)
             M0(:,:) = TC2(I,J,:,1:IBINS)

           DO L = 1, LLPAR
             SO4(L) = TSO4 * EFRAC(L) * DTSRCE
             IF ( SO4(L) == 0.d0 ) CYCLE
             DO K = 1, IBINS
                NDISTINIT(K) = SO4(L) * BFRAC(K) /
     &                               ( SQRT( XK(K)*XK(K+1) ) )
                NDIST(K) = TC1(I,J,L,K)
                DO C = 1, ICOMP
                   MDIST(K,C) = TC2(I,J,L,K+(C-1)*IBINS)
                   IF( IT_IS_NAN( MDIST(K,C) ) ) THEN
                      PRINT *,'+++++++ Found NaN in SRCSF30  +++++++'
                      PRINT *,'Location (I,J,L):',I,J,L,'Bin',K,'comp',C
                      CALL  ERROR_STOP('SRCSF30 SGCCOAG','sulfate_mod.f')
                   ENDIF
                ENDDO
                NDISTFINAL(K) = 0
                MADDFINAL(K)  = 0
             ENDDO
             CALL MNFIX( NDIST, MDIST, ERRORSWITCH )
             IF( ERRORSWITCH ) PRINT *,'SRCSF30: MNFIX found error ',
     &            'before SUBGRIDCOAG at ',I,J,L
             ERRORSWITCH = .FALSE.

             ! Overwrite number and mass before emission for diagnostic
             ! just in case there was any change by MNFIX (win, 10/27/08)
             N0(L,:) = NDIST(:)
             M0(L,:) = MDIST(:,SRTSO4)

 debug            if (I== ii .and. J==jj .and. L==ll)
```

```
      &           CALL DEBUGPRINT(NDIST,MDIST,I,J,L,
      &           'SRCSF30 Before SUBGRIDCOAG ')


      ! Define subgrid coagulation timescale (win, 10/28/08)
#if   defined( GRID4x5   )
            TSCALE = 10.*3600.  ! 10 hours
#elif defined( GRID2x25  )
            TSCALE = 5.*3600.
#elif defined( GRID1x125 )
            TSCALE = 2.*3600.
#elif defined( GRID1x1   )
            TSCALE = 2.*3600.
#elif defined( GRID05x0625 )
            TSCALE = 1.*3600.  ! Placeholder: the 0.5 x 0.666 value
#elif defined( GRID05x0666 )
            TSCALE = 1.*3600.
#elif defined( GRID025x03125 )
            !%%% KLUDGE, just copied the 0.5 x 0.666 value
            !%%% Someone needs to add the right value (bmy, 2/16/12)
            TSCALE = 1.*3600.
#endif
            !Prior to 10/28/08 (win)
            !TSCALE = 10.*3600.
            BOXVOL  = State_Met%AIRVOL(I,J,L) * 1.e6 !convert from m3 -> cm3
            TEMP    = State_Met%T(I,J,L)
            PRES    = State_Met%PMID(i,j,l)*100.0 ! in Pa

             print *, 'Now doing subgrid coag with timescale ',
      &           TSCALE/3600.,'hr'
            pdbug=.false.
 debug            if (I.eq.II.and.J.eq.JJ .and. L==LL) pdbug=.true.

            CALL SUBGRIDCOAG( NDISTINIT, NDIST, MDIST, BOXVOL,TEMP,
     &                       PRES, TSCALE, NDISTFINAL, MADDFINAL,pdbug)
            DO K = 1, IBINS
               NDIST(K) = NDIST(K) + NDISTFINAL(K)
               MDIST(K,SRTSO4) = MDIST(K,SRTSO4) +
     &                           NDISTFINAL(K) * (SQRT(XK(K)*XK(K+1)))+
     &                           MADDFINAL(K)
 debug               if (I.eq.II.and.J.eq.JJ .and. L==ll) then
                    print *,(NDISTFINAL(K) * (SQRT(XK(K)*XK(K+1)))+
      &                 MADDFINAL(K) )
                endif
 debug---
            ENDDO
            DO K= 1, IBINS
               NDIST2(K) = NDIST(K)
```

```
               DO C = 1, ICOMP
                  MDIST2(K,C) = MDIST(K,C)
               ENDDO
            ENDDO
debug            if(i==ii.and.j==jj.and.l==ll  )
     &          CALL DEBUGPRINT(NDIST2,MDIST2,I,J,L,
     &                          'SRCSF30 : After SUBGRIDCOAG')


            ERRORSWITCH = .FALSE.
debug            if(i==ii.and.j==ii.and.l==ll) errorswitch=.true.
      print *, 'mnfix in sulfate_mod:6430'
            CALL MNFIX( NDIST2, MDIST2, ERRORSWITCH )

            IF( ERRORSWITCH ) PRINT *,'SRCSF30: MNFIX found error ',
    &           'after SUBGRIDCOAG at ',I,J,L

debug            if(i==ii .and.j==jj .and.l==ll)
     &          CALL DEBUGPRINT(NDIST2,MDIST2,I,J,L,
     &                          'SRCSF30 : After MNFIX')

            DO K = 1, IBINS
               TC1(I,J,L,K) = NDIST2(K)
               DO C=1,ICOMP
                  TC2(I,J,L,K+(C-1)*IBINS) = MDIST2(K,C)
               ENDDO
            ENDDO

         ENDDO ! L loop
           !=================================================================
           ! ND59 Diagnostic: Size-resolved primary sulfate emission in
           !                 [kg S/box/timestep] and the corresponding
           !                  number emission [no./box/timestep]
           !=================================================================
            IF ( ND59 > 0 ) THEN
               !print*, 'JACK IN ND59 SULFATE'
               DO L = 1, LLPAR
               DO K = 1, IBINS
                  if(TC2(I,J,L,K)-M0(L,K) < 0d0)
    &               print *,'Negative SF emis ',TC2(I,J,L,K)-M0(L,K),
    &                  'at',I,J,L,K
                  if(TC1(I,J,L,K)-N0(L,K) < 0d0)
    &               print *,'Negative NK emis ',TC1(I,J,L,K)-N0(L,K),
    &                  'at',I,J,L,K
               !   if(I==ii .and. J==jj) then
               !      print*, 'TC2: ', TC2(ii,jj,0,:)
               !      print*, 'M0: ', M0(0,:)
               !      print*, 'S_SO4: ', S_SO4
```

```
          !   ENDIF
              AD59_SULF(I,J,1,K) = AD59_SULF(I,J,1,K) +
&                                  (TC2(I,J,L,K)-M0(L,K))*S_SO4
              AD59_NUMB(I,J,1,K) = AD59_NUMB(I,J,1,K) +
&                                  TC1(I,J,L,K)-N0(L,K)
           ENDDO
           ENDDO
        ENDIF

     ELSE
     ! Distributing primary emission without sub-grid coagulation
     !=============================================================
     ! Add SO4 emissions to tracer array
     ! For SF: Convert from [kg SO4/box/s] -> [kg SO4/box/timestep]
     ! For NK: Convert from [kg SO4/box/s] -> [No.   /box/timestep]
     !=============================================================
        DO L = 1, LLPAR
           SO4(L) = TSO4 * EFRAC(L)
           DO K = 1, IBINS
              TC1(I,J,L,K) = TC1(I,J,L,K) +
&                    ( SO4(L) * DTSRCE * BFRAC(K) / AVGMASS(K) )
              TC2(I,J,L,K) = TC2(I,J,L,K) +
&                    ( SO4(L) * DTSRCE * BFRAC(K)               )
           ENDDO
        ENDDO

       !=============================================================
       ! ND59 Diagnostic: Size-resolved primary sulfate emission in
       !                  [kg S/box/timestep] and the corresponding
       !                   number emission [no./box/timestep]
       !=============================================================
        IF ( ND59 > 0 ) THEN
           SO4anbf(:,:,1) = SO4an(:,:,1) + SO4bf(:,:)
           SO4anbf(:,:,2) = SO4an(:,:,2)

           DO L = 1, 2
           DO K = 1, IBINS
              AD59_SULF(I,J,L,K) = AD59_SULF(I,J,L,K) +
&                                ( SO4anbf(I,J,L) * BFRAC(K)
&                                    * S_SO4 * DTSRCE         )
              AD59_NUMB(I,J,L,K) = AD59_NUMB(I,J,L,K) +
&                                ( SO4anbf(I,J,L) * BFRAC(K)
&                                    / AVGMASS(K) * DTSRCE   )
           ENDDO
           ENDDO

        ENDIF
```

```
         ENDIF !SGCOAG

       ENDDO
       ENDDO
  $OMP END PARALLEL DO
       IF ( LPRT ) print *,'   ### Finish SRCSF30'

       END SUBROUTINE SRCSF30
 #endif

  EOC
  ------------------------------------------------------------------------------
                    GEOS-Chem Global Chemical Transport Model                  !
  ------------------------------------------------------------------------------
%//////////////////////////////////////////////////////////////

\mbox{}\hrulefill\


  \subsubsection [grav\_settling] {grav\_settling}


  Subroutine GRAV\_SETTLING performs gravitational settling of
    sulfate and nitrate in coarse sea salt (SO4S and NITS).
    (bec, rjp, bmy, 4/20/04, 7/20/04, 10/25/05)
  \\
  \\{\bf INTERFACE:}
\begin{verbatim}       SUBROUTINE GRAV_SETTLING( am_I_Root, Input_Opt, State_Met,
      &                           State_Chm,
      &                           TC,        N,         RC         )
```

USES:

```
       USE CMN_DIAG_MOD
       USE CMN_SIZE_MOD
 #if defined( BPCH_DIAG )
       USE DIAG_MOD,           ONLY : AD44
 #endif
       USE ErrCode_Mod
       USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
       USE Input_Opt_Mod,      ONLY : OptInput
       USE State_Chm_Mod,      ONLY : ChmState
       USE State_Met_Mod,      ONLY : MetState
       USE TIME_MOD,           ONLY : GET_ELAPSED_SEC
       USE TIME_MOD,           ONLY : GET_TS_CHEM
 #if defined( NC_DIAG )
       USE HCO_INTERFACE_MOD,  ONLY : HcoState
       USE ERROR_MOD,          ONLY : ERROR_STOP
       USE HCO_ERROR_MOD,      ONLY : HCO_SUCCESS
```

```
      USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
#endif
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
      INTEGER,        INTENT(IN)    :: N           ! N=1 is SO4S; N=2 is NITS
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

INPUT/OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(INOUT) :: TC(IIPAR,JJPAR,LLPAR) ! Tracer [kg]
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REMARKS:

```
    N=1 is SO4S; N=2 is NITS

    tdf Include Coarse Mode DUST size bins
    N=3 is SO4d2; N=4  is NIT_d1
    N=5 is SO4d3; N=6  is NIT_d2
    N=7 is SO4d4; N=8  is NIT_d3
    N=9 is SO4d4; N=10 is NIT_d4
    tdf Treat these coated DUSTs as DRY for now
```

REVISION HISTORY:

```
    (1 ) Now references SALA_REDGE_um and SALC_REDGE_um from "tracer_mod.f"
         (bmy, 7/20/04)
    (2 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
    (3 ) Now limit relative humidity to [tiny(real(fp)),0.99] range for DLOG
          argument (phs, 5/1/08)
    (4 ) Bug fixes to the Gerber hygroscopic growth for sea salt aerosols
         (jaegle, 5/5/11)
    (5 ) Update hygroscopic growth to Lewis and Schwartz formulation (2006) and
         density calculation based on Tang et al. (1997) (bec, jaegle 5/5/11)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    14 Nov 2012 - R. Yantosca - Now pass am_I_Root, Input_Opt, RC as arguments
    15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    12 Sep 2013 - M. Sulprizio- Include Coarse Mode DUST size bins (T.D. Fairlie)
    06 Jan 2015 - M. Yannetti - Changed some variables to f8 as needed
    26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID and
                                remove dependency on pressure_mod.
    22 Jan 2016 - E. Lundgren - Update netcdf drydep flux diagnostics
```

```
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
31 May 2016 - E. Lundgren - Remove usage of Input_Opt%XNUMOL
24 Jun 2016 - R. Yantosca - Now return if id_SO4d1<0 or id_NITd1<0 (not ==0)
```

8.5.5 chem_dms

Subroutine CHEM_DMS is the DMS chemistry subroutine from Mian Chin's GOCART model, modified for use with the GEOS-CHEM model. (rjp, bdf, bmy, 5/31/00, 10/15/09)

INTERFACE:

```
      SUBROUTINE CHEM_DMS( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD05
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Reaction List (by Mian Chin, chin@rondo.gsfc.nasa.gov)
    ============================================================================
                                                                              .
    R1:    DMS + OH  -> a*SO2 + b*MSA                OH addition channel
           k1 = { 1.7e-42*exp(7810/T)*[O2] / (1+5.5e-31*exp(7460/T)*[O2] }
           a = 0.75, b = 0.25
                                                                              .
    R2:    DMS + OH  ->   SO2 + ...                  OH abstraction channel
```

```
        k2 = 1.2e-11*exp(-260/T)
                                                                        .
        DMS_OH = DMS0 * exp(-(r1+r2)* NDT1)
        where DMS0 is the DMS concentration at the beginning,
        r1 = k1*[OH], r2 = k2*[OH].
                                                                        .
R3:     DMS + NO3 ->   SO2 + ...
        k3 = 1.9e-13*exp(500/T)
                                                                        .
        DMS = DMS_OH * exp(-r3*NDT1)
        where r3 = k3*[NO3].
                                                                        .
R4:     DMS + X   ->   SO2 + ...
        assume to be at the rate of DMS+OH and DMS+NO3 combined.
                                                                        .
The production of SO2 and MSA here, PSO2_DMS and PMSA_DMS, are saved
for use in CHEM_SO2 and CHEM_MSA subroutines as a source term.  They
are in unit of [v/v/timestep].
```

REVISION HISTORY:

```
(1 ) Now reference AD, AIRDEN, and SUNCOS from "dao_mod.f".  Added
     parallel DO-loops.  Also now extract OH and NO3 from SMVGEAR
     for coupled chemistry-aerosol runs. (rjp, bdf, bmy, 9/16/02)
(2 ) Bug fix: remove duplicate definition of RK3 (bmy, 3/23/03)
(3 ) Now use function GET_TS_CHEM from "time_mod.f".  (bmy, 3/27/03)
(4 ) Now reference STT and ITS_A_FULLCHEM_SIM from "tracer_mod.f"
     Now replace IJSURF w/ an analytic function. (bmy, 7/20/04)
(5 ) Shift rows 8,9 in AD05 to 9,10 in to make room for P(SO4) from O3
     oxidation in sea-salt aerosols (bec, bmy, 4/13/05)
(6 ) Now remove reference to CMN, it's obsolete.  Now reference
     ITS_IN_THE_STRAT from "tropopause_mod.f". (bmy, 8/22/05)
(7 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(8 ) Now correctly records P(SO2) from OH in AD05 (pjh)
(9 ) Update reaction rate to match JPL06 and full chem (jaf, bmy, 10/15/09)
22 Dec 2011 - M. Payer    - Added ProTeX headers
31 Jul 2012 - R. Yantosca - Now loop from 1..LLPAR for GIGC compatibility
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
24 Jun 2016 - R. Yantosca - Now Return if id_DMS < 0 (not == 0)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.5.6 chem_h2o2

Subroutine CHEM_H2O2 is the H2O2 chemistry subroutine for offline sulfate simulations. For coupled runs, H2O2 chemistry is already computed by the SMVGEAR module. (rjp, bmy, 11/26/02, 10/25/05)

INTERFACE:

```
      SUBROUTINE CHEM_H2O2( am_I_Root, Input_Opt,
     &                      State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_SIZE_MOD
      USE CMN_DIAG_MOD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : GET_TS_CHEM
      USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    (1 ) Bug fix: need to multiply DXYP by 1d4 for cm2 (bmy, 3/23/03)
    (2 ) Now replace DXYP(JREF)*1d4 with routine GET_AREA_CM2 of "grid_mod.f"
         Now use functions GET_MONTH and GET_TS_CHEM from "time_mod.f".
         (bmy, 3/27/03)
    (3 ) Now references PBLFRAC from "drydep_mod.f".  Now apply dry deposition
         throughout the entire PBL.  Added FREQ variable. (bmy, 8/1/03)
    (4 ) Now use ND44_TMP array to store vertical levels of drydep flux, then
```

```
        sum into AD44 array.  This preents numerical differences when using
        multiple processors. (bmy, 3/24/04)
    (5 ) Now use diurnally-varying JO1D.  Now use new unit conversion for
        the ND44 diagnostic. (rjp, bmy, 3/30/04)
    (6 ) Now use parallel DO-loop to zero ND44_TMP.  Now uses ITS_A_NEW_MONTH
        from time_mod.f. (bmy, 4/14/04)
    (7 ) Now reference STT & TCVV from "tracer_mod.f".  Also replace IJSURF
        with an analytic function.  Now references DATA_DIR from
        "directory_mod.f". (bmy, 7/20/04)
    (8 ) Now suppress output from READ_BPCH with QUIET keyword (bmy, 1/25/05)
    (9 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP
        from "pbl_mix_mod.f" (bmy, 2/22/05)
    (10) Now read offline files from "sulfate_sim_200508/offline".  Now remove
        reference to CMN, it's obsolete.  Now reference ITS_IN_THE_STRAT from
        "tropopause_mod.f". (bmy, 8/22/05)
    (11) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
    (12) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
    30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                                running with the traditional driver main.F
    31 Jul 2012 - R. Yantosca - Now loop from 1..LLPAR for GIGC compatibility
    31 Jul 2012 - R. Yantosca - Declare temp drydep arrays w/ LLPAR (not LLTROP)
    14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
    15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    26 Nov 2012 - R. Yantosca - Dimension ND44_TMP array with LLPAR, not LLTROP
    28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
    05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
    19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS) and
                                Input_Opt%XNUMOL(1:N_TRACERS) -- avoid OOB errs
    25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
    18 Sep 2014 - M. Sulprizio- Now get J(H2O2) and PH2O2m from HEMCO
    06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
    12 Jun 2015 - R. Yantosca - Now remove orphaned ND44 variables
    23 Sep 2015 - R. Yantosca - Remove reference to obsolete DRYH2O2 flag
    24 Jun 2016 - R. Yantosca - Now return if id_H2O2 < 0 (not == 0)
    30 Jun 2016 - R. Yantosca - Remove instances of Spc.  Now get the advected
                                species ID from State_Chm%Map_Advect.
  EOC
  ------------------------------------------------------------------------------
  BOC
```

DEFINED PARAMETERS:

```
      REAL(fp),  PARAMETER :: A = 2.9e-12_fp
```

LOCAL VARIABLES:

```
      ! SAVEd Scalars
```

```
      LOGICAL            :: FIRST     = .TRUE.
      INTEGER, SAVE      :: LASTMONTH = -99

      ! Scalars
      INTEGER            :: I,     J,    L
      REAL(fp)           :: DT,    Koh,  DH2O2, M,    F ,   XTAU
      REAL(fp)           :: H2O2O, H2O2, ALPHA, FREQ, PHOTJ

      ! Strings
      CHARACTER(LEN=255) :: FILENAME

      ! Arrays
      REAL*4             :: ARRAY(IIPAR,JJPAR,LLCHEM)

      ! Pointers
      REAL(fp), POINTER  :: Spc(:,:,:,:)

      !=================================================================
      ! CHEM_H2O2 begins here!
      !=================================================================
      IF ( id_H2O2 < 0 ) RETURN

      ! Assume success
      RC        = GC_SUCCESS

      ! Point to chemical species array [v/v dry]
      Spc       => State_Chm%Species

      ! Chemistry timestep [s]
      DT        = GET_TS_CHEM() * 60e+0_fp

      ! Factor to convert AIRDEN from kgair/m3 to molecules/cm3:
      F         = 1000.e+0_fp / AIRMW * AVO * 1.e-6_fp

      !=================================================================
      ! Loop over tropopsheric grid boxes and do chemistry
      !=================================================================
$OMP PARALLEL DO
$OMP+DEFAULT( SHARED )
$OMP+PRIVATE( I, J, L, M, H2O2O, KOH, FREQ, ALPHA, DH2O2, H2O2 )
$OMP+PRIVATE( PHOTJ )
$OMP+SCHEDULE( DYNAMIC )
      DO L  = 1, LLPAR
      DO J  = 1, JJPAR
      DO I  = 1, IIPAR

         ! Initialize for safety's sake
         FREQ = 0e+0_fp
```

```
         ! Skip non-chemistry boxes
         IF ( ITS_IN_THE_NOCHEMGRID( I, J, L, State_Met ) ) CYCLE

         ! Density of air [molec/cm3]
         M     = State_Met%AIRDEN(I,J,L) * f

         ! Initial H2O2 [v/v]
         H2O20 = Spc(I,J,L,id_H2O2)

         ! Loss frequenty due to OH oxidation [s-1]
         KOH   = A * EXP( -160.e+0_fp / State_Met%T(I,J,L) ) *
     &           GET_OH( I, J, L, Input_Opt, State_Chm, State_Met )

         ! Now do all dry deposition in mixing_mod.F90 (ckeller, 3/5/15)
         FREQ = 0.e+0_fp

         ! Impose a diurnal variation of jH2O2 by multiplying COS of
         ! solar zenith angle normalized by maximum solar zenith angle
         ! because the archived JH2O2 is for local noon time
         IF ( COSZM(I,J) > 0.e+0_fp ) THEN
            PHOTJ = JH2O2(I,J,L) * State_Met%SUNCOS(I,J) / COSZM(I,J)
            PHOTJ = MAX( PHOTJ, 0e+0_fp )
         ELSE
            PHOTJ = 0e+0_fp
         ENDIF

         ! Compute loss fraction from OH, photolysis, drydep [unitless].
         ALPHA = 1.e+0_fp + ( KOH + PHOTJ + FREQ ) * DT

         ! Delta H2O2 [v/v]
         ! PH2O2m is in kg/m3 (from HEMCO), convert to molec/cm3/s (mps,9/18/14)
         DH2O2 = ( PH2O2m(I,J,L) / TS_EMIS * XNUMOL_H2O2 / CM3PERM3 )
     &           * DT / ( ALPHA * M )

         ! Final H2O2 [v/v]
         H2O2  = ( H2O20 / ALPHA + DH2O2 )
         IF ( H2O2 < SMALLNUM ) H2O2 = 0e+0_fp

         ! Store final H2O2 in Spc
         Spc(I,J,L,id_H2O2) = H2O2

      ENDDO
      ENDDO
      ENDDO
$OMP END PARALLEL DO

      ! Free pointer
```

```
      Spc => NULL()

      END SUBROUTINE CHEM_H2O2
  EOC
  ------------------------------------------------------------------------------
                  GEOS-Chem Global Chemical Transport Model                   !
  ------------------------------------------------------------------------------
%//////////////////////////////////////////////////////////////

\mbox{}\hrulefill\


  \subsubsection [chem\_so2] {chem\_so2}


  Subroutine CHEM\_SO2 is the SO2 chemistry subroutine.
    (rjp, bmy, 11/26/02, 8/26/10)
  \\
  \\{\bf INTERFACE:}
\begin{verbatim}       SUBROUTINE CHEM_SO2( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DAO_MOD,            ONLY : IS_WATER
      USE DIAG_MOD,           ONLY : AD05
      USE DUST_MOD,           ONLY : GET_DUST_ALK      ! tdf 04/08/08
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : IS_SAFE_EXP
      USE ERROR_MOD,          ONLY : SAFE_DIV
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PRESSURE_MOD,       ONLY : GET_PCENTER
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_MONTH
      USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
      USE WETSCAV_MOD,        ONLY : H2O2s
      USE WETSCAV_MOD,        ONLY : SO2s
      USE HCO_INTERFACE_MOD,  ONLY : GetHcoDiagn
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(INOUT) :: RC          ! Success or failure?
```

REMARKS:

```
    Reaction List (by Rokjin Park, rjp@io.harvard.edu)
    ============================================================================
    (1 ) SO2 production:
         DMS + OH, DMS + NO3 (saved in CHEM_DMS)

                                                                               .
    (2 ) SO2 loss:
         (a) SO2 + OH  -> SO4
         (b) SO2       -> drydep
         (c) SO2 + H2O2 or O3 (aq) -> SO4

                                                                               .
    (3 ) SO2 = SO2_0 * exp(-bt) +  PSO2_DMS/bt * [1-exp(-bt)]

                                                                               .
         where b is the sum of the reaction rate of SO2 + OH and the dry
         deposition rate of SO2, PSO2_DMS is SO2 production from DMS in
         MixingRatio/timestep.

                                                                               .
    If there is cloud in the gridbox (fraction = fc), then the aqueous
    phase chemistry also takes place in cloud. The amount of SO2 oxidized
    by H2O2 in cloud is limited by the available H2O2; the rest may be
    oxidized due to additional chemistry, e.g, reaction with O3 or O2
    (catalyzed by trace metal).
```

REVISION HISTORY:

```
    (1 ) Removed duplicate definition of Ki (bmy, 11/15/01)
    (2 ) Eliminate duplicate HPLUS definition.  Make adjustments to facilitate
          SMVGEAR chemistry for fullchem runs (rjp, bmy, 3/23/03)
    (3 ) Now replace DXYP(J+J0)*1d4 with routine GET_AREA_CM2 of "grid_mod.f"
          Now use function GET_TS_CHEM from "time_mod.f".
    (4 ) Now apply dry deposition to entire PBL.  Now references PBLFRAC array
          from "drydep_mod.f". (bmy, 8/1/03)
    (5 ) Now use ND44_TMP array to store vertical levels of drydep flux, then
          sum into AD44 array.  This preents numerical differences when using
          multiple processors. (bmy, 3/24/04)
    (6 ) Now use parallel DO-loop to zero ND44_TMP (bmy, 4/14/04)
    (7 ) Now reference STT, TCVV, & ITS_AN_AEROSOL_SIM from "tracer_mod.f".
          Now reference DATA_DIR from "directory_mod.f" (bmy, 7/20/04)
    (8 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
          "pbl_mix_mod.f" (bmy, 2/22/05)
    (9 ) Modified for SO4s, NITs.  Also modified for alkalinity w/in the
```

```
      seasalt chemistry. (bec, bmy, 4/13/05)
(10) Now remove reference to CMN, it's obsolete.  Now reference
      ITS_IN_THE_STRAT from "tropopause_mod.f" (bmy, 8/22/05)
(11) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(12) Updated to match JPL 2006 + full chem (jaf, bmy, 10/15/09)
(13) Now prevent floating-point exceptions when taking the exponential
      terms. (win, bmy, 1/4/10)
(14) Save aqueous production rate to PSO4_SO2AQ for TOMAS microphyics
      (win, 1/25/10)
(15) Added extra error checks to prevent negative L2S, L3S (bmy, 4/28/10)
(16) Use liq. water content from met fields in GEOS-5 (jaf, bmy, 6/30/10)
26 Aug 2010 - R. Yantosca - Use liquid water content from MERRA
12 Nov 2010 - R. Yantosca - Prevent div-by-zero when computing L2S and L3S
27 May 2011 - L. Zhang    - Divide LWC by cloud fraction for GEOS/MERRA
                            and adjust the L2S and L3S rates accordingly
22 Dec 2011 - M. Payer    - Added ProTeX headers
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.2 in the same way as MERRA
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
31 Jul 2012 - R. Yantosca - Now loop over 1..LLPAR for GIGC compatibility
31 Jul 2012 - R. Yantosca - Declare temp drydep arrays w/ LLPAR (not LLTROP)
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS) and
                            Input_Opt%XNUMOL(1:N_TRACERS) -- avoid OOB errs
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
05 Sep 2013 - M. Sulprizio- Add modifications for cloud pH (B. Alexander)
06 Sep 2013 - M. Sulprizio- Bug fix: Prevent divide-by-zero if LWC=0. Only
                            do aqueous SO2 chemistry when LWC>0.
12 Sep 2013 - M. Sulprizio- Modified for SO4d, NITd.  Also modified for
                            alkalinity w/in the dust chemistry. (tdf 4/07/08)
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
28 Jan 2014 - R. Yantosca - Bug fix for TOMAS. Set ALKdst=0 since TOMAS
                            carries its own dust tracers instead of DST1-4.
25 Jun 2014 - R. Yantosca - Now pass Input_Opt to GET_ALK
18 Sep 2014 - M. Sulprizio- Now get HNO3 for offline aerosol sim from HEMCO
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
12 Jan 2015 - C. Keller   - Now allow NDENS_SALA and NDENS_SALC to be empty.
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID_DRY.
                            Remove dependency on pressure_mod.
12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
23 Sep 2015 - R. Yantosca - Remove reference to obsolete DRYSO2 flag
24 Jun 2016 - R. Yantosca - Now return id_H2O2 < 0 or id_SO2 < 0 (not == 0)
```

8.5.7 seasalt_chem

Subroutine SEASALT_CHEM computes SO4 formed from S(IV) + O3 on seasalt aerosols as a function of seasalt alkalinity. (bec, bmy, 4/13/05, 10/7/08)

INTERFACE:

```
 SUBROUTINE SEASALT_CHEM ( I,         J,         L,
&                          ALK1,      ALK2,      SO2_cd,
&                          Kt1,       Kt2,       Kt1N,
&                          Kt2N,      SO2_ss,    PSO4E,
&                          PSO4F,     am_I_Root, Input_Opt,
&                          State_Met, State_Chm, RC )
```

USES:

```
!-----------------------------------------------------------------
! DIAGNOSTICS -- leave commented out for now (bec, bmy, 4/13/05)
!USE CMN_DIAG_MOD          ! ND19
!USE DIAG_MOD,        ONLY : AD09
!-----------------------------------------------------------------
USE CMN_DIAG_MOD             ! ND05, LD05
USE CMN_SIZE_MOD
USE DIAG_MOD,           ONLY : AD05
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE ERROR_MOD,          ONLY : IT_IS_NAN
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
USE TIME_MOD,           ONLY : GET_ELAPSED_SEC
USE TIME_MOD,           ONLY : GET_MONTH
USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
```

INPUT PARAMETERS:

```
INTEGER,         INTENT(IN)   :: I, J, L    ! Grid box indices
REAL(fp),        INTENT(IN)   :: SO2_cd     ! SO2 mixing ratio [v/v] after
                                            !  gas phase chemistry and
                                            !  dry deposition
REAL(fp),        INTENT(IN)   :: Kt1, Kt2   ! Rate constant [s-1] for
                                            !  sulfate formation on sea
                                            !  salt aerosols from GET_ALK
                                            !  (1=fine; 2=coarse)
REAL(fp),        INTENT(IN)   :: Kt1N, Kt2N
REAL(fp),        INTENT(IN)   :: ALK1, ALK2 ! Alkalinity [kg] from
                                            !  seasalt_mod
TYPE(MetState), INTENT(IN)    :: State_Met  ! Meteorology State object
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
LOGICAL,         INTENT(IN)   :: am_I_Root  ! Are we on the root CPU?
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT)   :: SO2_ss    ! SO2 mixing ratio [v/v]
                                                 !  after sea salt chemistry
      REAL(fp),       INTENT(OUT)   :: PSO4E     ! SO4E (sulfate produced by
                                                 !  S(IV)+O3 on fine seasalt)
                                                 !  mixing ratio [v/v]
      REAL(fp),       INTENT(OUT)   :: PSO4F     ! SO4F (sulfate produced by
                                                 !  S(IV)+O3 on coarse seasalt)
      INTEGER,        INTENT(OUT)   :: RC        ! Success or failure?
```

REMARKS:

```
    Chemical reactions:
    ============================================================================
    (R1) SO2 + O3 + ALK => SO4 + O2
         Modeled after Chamedies and Stelson, 1992?
```

REVISION HISTORY:

```
    (1 ) Now references XNUMOLAIR from "tracer_mod.f" (bmy, 10/25/05)
    (2 ) Bug fix: now avoid seg fault error if IDTHNO3 is zero, as it would
         be for an offline aerosol simulation. (bmy, 3/29/06)
    (3 ) Fixed typo in FALK_A_SO2 equation: C_FLUX_C should be C_FLUX_A.
         (havala, bec, bmy, 12/8/06)
    (4 ) Bug fix for mass balance, replace TITR_HNO3 w/ HNO3_SSC in the
         expression for HNO3_ss.  Bug fix: now do equivalent computation
         for GET_GNO3, which is now no longer called because it's in
         "isoropia_mod.f". (bec, bmy, 7/30/08)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
    12 Sep 2013 - M. Sulprizio- Added loss of HNO3 on sea salt diagnostic
                                (T.D. Fairlie)
    18 Sep 2014 - M. Sulprizio- Now get HNO3 for offline aerosol sim from HEMCO
    24 Mar 2015 - E. Lundgren - Remove dependency on tracer_mod since
                                XNUMOLAIR now defined in CMN_GTCM_MOD
    06 Jan 2016 - E. Lundgren - Use global physical parameters
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
    11 Oct 2016 - R. Yantosca - Bug fix: make sure that MW_HNO3 is defined
                                for aerosol-only sims (where id_HNO3 < 0)
```

8.5.8 dust_chem

Subroutine DUST_CHEM computes SO4 formed from S(IV) + O3 on dust aerosols as a function of dust alkalinity (tdf 3/28/2K8) Based on routine SEASALT_CHEM (bec, bmy, 4/13/05, 10/25/05)

INTERFACE:

```
 SUBROUTINE DUST_CHEM ( I,         J,         L,
&                       ALK,       SO2_cd,    H2SO4_cd,
&                       KTS,       KTN,       KTH,
&                       SO2_gas,   H2SO4_gas, PSO4d,
&                       PH2SO4d,   PNITd,     ALKA,
&                       Input_Opt, State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
USE ERROR_MOD,          ONLY : IT_IS_NAN
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM,        GET_ELAPSED_SEC
USE TIME_MOD,           ONLY : GET_ELAPSED_SEC,    GET_MONTH
USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: I, J, L       ! Grid box indices
REAL(fp),       INTENT(IN)    :: SO2_cd        ! SO2 mixing ratio after
                                               !  gas phase chemistry and
                                               !  dry deposition [v/v]
REAL(fp),       INTENT(IN)    :: H2SO4_cd      ! H2SO4 mixing ratio after
                                               !  gas phase chemistry and
                                               !  dry deposition [v/v]
REAL(fp),       INTENT(IN)    :: ALK(NDSTBIN)  ! Dust Alkalinity [v/v]
REAL(fp),       INTENT(IN)    :: KTS(NDSTBIN)  ! Rate constant for uptake
                                               !  of SO2 on dust [s-1]
REAL(fp),       INTENT(IN)    :: KTN(NDSTBIN)  ! Rate constant for uptake
                                               !  of HNO3 on dust [s-1]
REAL(fp),       INTENT(IN)    :: KTH(NDSTBIN)  ! Size- and area-weighted
                                               !  FRACTION for uptake of
                                               !  H2SO4 on dust
TYPE(MetState), INTENT(IN)    :: State_Met     ! Meteorology State object
TYPE(OptInput), INTENT(IN)    :: Input_Opt     ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT)   :: SO2_gas         ! SO2 mixing ratio after
                                                       !  dust chem [v/v]
      REAL(fp),       INTENT(OUT)   :: PSO4d(NDSTBIN)  ! Sulfate produced by
                                                       !  S(IV)+O3 on dust in
                                                       !  each size bin
      REAL(fp),       INTENT(OUT)   :: H2SO4_gas       ! H2SO4 mixing ratio
                                                       !  after dust chem [v/v]
      REAL(fp),       INTENT(OUT)   :: PNITd (NDSTBIN) ! Nitrate produced by
                                                       !  HNO3 uptake on dust
                                                       !  in each size bin
      REAL(fp),       INTENT(OUT)   :: PH2SO4d(NDSTBIN)! Sulfate produced by
                                                       !  uptake of H2SO4 on
                                                       !  dust in each size bin
      REAL(fp),       INTENT(OUT)   :: ALKA(NDSTBIN)   ! Dust Alkalinity after
                                                       !  dust chemistry [v/v]
      INTEGER,        INTENT(OUT)   :: RC              ! Success or failure?
```

REMARKS:

```
    Chemical reactions:
    ============================================================================
    (R1) SO2 + O3 + CaCO3 => CaSO4 + O2 + CO2

                                                                              .
    (R2) 2(HNO3) + CaCO3 => Ca(NO3)2 + CO2 + H2O

                                                                              .
   Added sulfate production due to H2SO4 adsorption tdf 2/13/2K9
    (R3) H2SO4  + CaCO3 => CaSO4 + H2O + CO2
```

REVISION HISTORY:

```
    28 Mar 2008 - T.D. Fairlie- Initial version
    16 Sep 2013 - M. Sulprizio- Added ProTeX headers
    17 Sep 2013 - M. Sulprizio- Now pass Input_Opt, State_Met, State_Chm, and RC
                                as arguments
    30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                                species ID from State_Chm%Map_Advect.
```

8.5.9 get_hplus

Subroutine GET_HPLUS computes H+ concentrations in cloud liquid water for pH dependent cloud chemistry. (bec, 4/11/11)

INTERFACE:

```
      SUBROUTINE GET_HPLUS( SO4nss, TNH3, TNO3, SO2,
     &                      T,      PRES, LWC,  iHPLUS, HPLUS )
```

USES:

```
USE ERROR_MOD,       ONLY : IT_IS_NAN, GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN)    :: SO4nss ! Total nss sulfate mixing ratio [M]
REAL(fp),  INTENT(IN)    :: TNO3   ! Total nitrate (gas+particulate) mixing
                                   ! ratio [v/v]
REAL(fp),  INTENT(IN)    :: TNH3   ! NH3 mixing ratio [v/v]
REAL(fp),  INTENT(IN)    :: SO2    ! SO2 mixing ratio [v/v]
REAL(fp),  INTENT(IN)    :: T      ! Temperature [K]
REAL(fp),  INTENT(IN)    :: PRES   ! Dry air partial ressure [atm]
REAL(fp),  INTENT(IN)    :: LWC    ! Cloud liquid water content [m3/m3]
REAL(fp),  INTENT(IN)    :: iHPLUS ! Initial [H+] [M]
```

OUTPUT PARAMETERS:

```
REAL(fp),  INTENT(OUT)   :: HPLUS  ! Calculated [H+] [M]
```

REMARKS:

```
Calculation:
============================================================================
Solve the following electroneutrality equation:
[H+] = 2[SO4]nss + [Cl] + [OH] + [HCO3] + 2[CO3] + [HSO3] + 2[SO3] + [NO3]
      - [Na] - 2[Ca] - [K] - 2[Mg] - [NH4]
Aqueous concentrations of [Cl], [Na], [Ca], [K], and [Mg] come from
ISORROPIA II
Let concentrations of [HCO3], [CO3], [HSO3], [SO3], [NO3] and [NH4] evolve
according to Henry's law equilibrium.
Assume [S(VI)] = [SO4]nss (this applies for pH > 3)
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
06 Jan 2015 - M. Yannetti - Set some variables to f8 that required it
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.10 kCO21

Function kCO21

INTERFACE:

```
FUNCTION kCO21 ( P, T, LWC, HPLUS ) RESULT ( KCO2p )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS
```

OUTPUT PARAMETERS:

```
      REAL(fp)              :: KCO2p, KCO2p2
```

REVISION HISTORY:

```
    25 Jan 2012 - M. Payer    - Added ProTeX headers
    28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.11 kCO22

Function kCO22

INTERFACE:

```
      FUNCTION kCO22 ( P, T, LWC, HPLUS ) RESULT ( KCO2p2 )
```

INPUT PARAMETERS:

```
      REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS
```

OUTPUT PARAMETERS:

```
      REAL(fp)              :: KCO2p, KCO2p2
```

REVISION HISTORY:

```
    25 Jan 2012 - M. Payer    - Added ProTeX headers
    28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.12 kSO21

Function kSO21

INTERFACE:

```
      FUNCTION kSO21 ( P, T, LWC, HPLUS, SO2 ) RESULT ( KSO2p )
```

INPUT PARAMETERS:

```
      REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS, SO2
```

OUTPUT PARAMETERS:

```
      REAL(fp)              :: KSO2p, KSO2p2
```

REVISION HISTORY:

```
    25 Jan 2012 - M. Payer    - Added ProTeX headers
    28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.13 kSO22

Function kSO22

INTERFACE:

```
FUNCTION kSO22 ( P, T, LWC, HPLUS, SO2 ) RESULT ( KSO2p2 )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS, SO2
```

OUTPUT PARAMETERS:

```
REAL(fp)              :: KSO2p, KSO2p2
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.14 kHNO3

Function kNO3

INTERFACE:

```
FUNCTION kHNO3 ( P, T, LWC, HPLUS, HNO3 ) RESULT ( KHNO3p )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS, HNO3
```

OUTPUT PARAMETERS:

```
REAL(fp)              :: KHNO3p
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.15 kHCl

Function kHCl

INTERFACE:

```
FUNCTION kHCl ( P, T, LWC, HPLUS, Cl ) RESULT ( KHClp )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS, Cl
```

OUTPUT PARAMETERS:

```
REAL(fp)              :: KHClp
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.16 kNH3

Function kNH3

INTERFACE:

```
FUNCTION kNH3 ( P, T, LWC, HPLUS, NH3, Kw ) RESULT ( KNH3p )
```

INPUT PARAMETERS:

```
REAL(fp),  INTENT(IN) :: T, P, LWC, HPLUS, NH3, Kw
```

OUTPUT PARAMETERS:

```
REAL(fp)              :: KNH3p
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.17 cubic

Subroutine CUBIC finds the roots of a cubic equation / 3rd order polynomial

INTERFACE:

```
SUBROUTINE CUBIC( A2, A1, A0, NR, CRUTES )
```

USES:

```
 USE ERROR_MOD, ONLY : GEOS_CHEM_STOP !ERROR_STOP
```

INPUT PARAMETERS:

```
INTEGER           :: NR
REAL(f8)          :: A2, A1, A0
REAL(fp)          :: CRUTES(3)
```

REMARKS:

```
Formulae can be found in numer. recip.  on page 145
  kiran  developed  this version on 25/4/1990
  Dr. Francis S. Binkowski modified the routine on 6/24/91, 8/7/97
***
*** modified 2/23/98 by fsb to incorporate Dr. Ingmar Ackermann's
    recommendations for setting a0, a1,a2 as real(fp) variables.
Modified by Bob Yantosca (10/15/02)
- Now use upper case / white space
- force double precision with "D" exponents
- updated comments / cosmetic changes
- now call ERROR_STOP from "error_mod.f" to stop the run safely
```

REVISION HISTORY:

```
25 Jan 2012 - M. Payer    - Added ProTeX headers
06 Jan 2015 - M. Yannetti - Manual changes of some variables to f8
```

8.5.18 aqchem_so2

Subroutine AQCHEM_SO2 computes the reaction rates for aqueous SO2 chemistry. (rjp, bmy, 10/31/02, 12/12/02)

INTERFACE:

```
      SUBROUTINE AQCHEM_SO2( LWC, T,     P,       SO2, H2O2,
     &                       O3,  Hplus, KaqH2O2, KaqO3 )
```

INPUT PARAMETERS:

```
      REAL(fp), INTENT(IN)  :: LWC     ! Liq water content [m3/m3]=1.E-6*L [g/m3]
      REAL(fp), INTENT(IN)  :: T       ! Temperature [K]
      REAL(fp), INTENT(IN)  :: P       ! Dry air partial pressure [atm]
      REAL(fp), INTENT(IN)  :: SO2     ! SO2  mixing ratio [v/v]
      REAL(fp), INTENT(IN)  :: H2O2    ! H2O2 mixing ratio [v/v]
      REAL(fp), INTENT(IN)  :: O3      ! O3   mixing ratio [v/v]
      REAL(fp), INTENT(IN)  :: HPLUS   ! Concentration of H+ ion (i.e. pH) [v/v]
```

OUTPUT PARAMETERS:

```
      REAL(fp), INTENT(OUT) :: KaqH2O2 ! Reaction rate for H2O2
      REAL(fp), INTENT(OUT) :: KaqO3   ! Reaction rate for O3
```

REMARKS:

```
Chemical Reactions:
================================================================================
(R1) HSO3- + H2O2(aq) + H+ => SO4-- + 2H+ + H2O [Jacob, 1986]

                                                                             .
    d[S(VI)]/dt = k[H+][H2O2(aq)][HSO3-]/(1 + K[H+])
    [Seinfeld and Pandis, 1998, page 366]
```

```
(R2) SO2(aq) + O3(aq) =>
     HSO3-   + O3(aq) =>
     SO3--   + O3(aq) =>
     [Jacob, 1986; Jacobson, 1999]

     d[S(VI)]/dt = (k0[SO2(aq)] + k1[HSO3-] + K2[SO3--])[O3(aq)]
     [Seinfeld and Pandis, 1998, page 363]

Reaction rates can be given as
     Ra     = k [H2O2(ag)] [S(IV)]  [mole/liter*s]  OR
     Krate  = Ra LWC R T / P        [1/s]

Where:
     LWC = Liquid water content(g/m3)*10-6 [m3(water)/m3(gas)]
     R   = 0.08205  (atm L / mol-K), Universal gas const.
     T   = Temperature (K)
     P   = Pressure (atm)

Procedure:
=============================================================================
(a ) Given [SO2] which is assumed to be total SO2 (gas+liquid) in
      equilibrium between gas and liquid phase.

(b ) We can compute SO2(g) using Henry's law
        P(so2(g)) = Xg * [SO2]
        Xg = 1/(1 + Faq), Fraction of SO2 in gas
     where:
        Faq   = Kheff * R * T * LWC,
        KHeff = Effective Henry's constant

(c ) Then Calculate Aquous phase, S[IV] concentrations
      S[IV] = Kheff * P(so2(g) in atm) [M]

(d ) The exact same procedure is applied to calculate H2O2(aq)
```

REVISION HISTORY:

```
(1 ) Updated by Rokjin Park (rjp, bmy, 12/12/02)
22 Dec 2011 - M. Payer    - Added ProTeX headers
28 Apr 2015 - E. Lundgren - Input pressure is now dry air partial pressure
```

8.5.19 het_drop_chem

Subroutine HET_DROP_CHEM estimates the in-cloud sulfate production rate in heterogeneous cloud droplets based on the Yuen et al., 1996 parameterization. (bec, 6/16/11)

INTERFACE:

```
      SUBROUTINE HET_DROP_CHEM( I,    J,    L,      LSTOT, SSCvv,
     &                          aSO4, GNH3, SO2_sr, H2O2O, GNO3,
     &                          SR,   Input_Opt,    State_Met,
     &                          State_Chm                      )
```

USES:

```
      USE ERROR_MOD,          ONLY : IT_IS_FINITE, GEOS_CHEM_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I, J, L
      REAL(fp),       INTENT(IN)  :: LSTOT
      REAL(fp),       INTENT(IN)  :: SSCvv
      REAL(fp),       INTENT(IN)  :: aSO4
      REAL(fp),       INTENT(IN)  :: GNH3
      REAL(fp),       INTENT(IN)  :: SO2_sr
      REAL(fp),       INTENT(IN)  :: H2O2O
      REAL(fp),       INTENT(IN)  :: GNO3
      TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm     ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT) :: SR ! Sulfate production rate
```

REVISION HISTORY:

```
   25 Jan 2012 - M. Payer    - Added ProTeX headers
   05 Sep 2013 - M. Sulprizio- Now pass met fields using the State_Met object
   06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
   22 Jun 2016 - M. Yannetti - Pass State_Chm as arg for spc db access
```

8.5.20 chem_so4

Subroutine CHEM_SO4 is the SO4 chemistry subroutine from Mian Chin's GOCART model, modified for the GEOS-CHEM model. Now also modified to account for production of crystalline and aqueous sulfur tracers. (rjp, bdf, cas, bmy, 5/31/00, 5/23/06)

INTERFACE:

```
      SUBROUTINE CHEM_SO4( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
USE CMN_SIZE_MOD
USE CMN_DIAG_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

The only production is from SO2 oxidation (save in CHEM_SO2). Dry deposition is now handled in mixing_mod.F90, so we can must add the production from SO2 into the SO4 tracers.

.

REVISION HISTORY:

(1) Now reference AD from "dao_mod.f". Added parallel DO-loops. Updated comments, cosmetic changes. (rjp, bdf, bmy, 9/16/02)
(2) Now replace DXYP(JREF)*1d4 with routine GET_AREA_CM2 of "grid_mod.f" Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(3) Now reference PBLFRAC from "drydep_mod.f". Now apply dry deposition to the entire PBL. (rjp, bmy, 8/1/03)
(4) Now use ND44_TMP array to store vertical levels of drydep flux, then sum into AD44 array. This preents numerical differences when using multiple processors. (bmy, 3/24/04)
(5) Now use parallel DO-loop to zero ND44_TMP (bmy, 4/14/04)
(6) Now reference STT & TCVV from "tracer_mod.f" (bmy, 7/20/04)
(7) Now references LCRYST from "logical_mod.f". Modified for crystalline and aqueous sulfate2 tracers: AS, AHS, LET, SO4aq. Also changed name of ND44_TMP to T44 to save space. (cas, bmy, 12/21/04)
(8) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from "pbl_mix_mod.f" (bmy, 2/22/05)
(9) Now remove reference to CMN, it's obsolete. Now reference

```
       ITS_IN_THE_STRAT from "tropopause_mod.f" (bmy, 8/22/05)
(10) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(11) Rearrange error check to avoid SEG FAULTS (bmy, 5/23/06)
22 Dec 2011 - M. Payer    - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
30 Jul 2012 - R. Yantosca - Now accept am_I_Root as an argument when
                            running with the traditional driver main.F
31 Jul 2012 - R. Yantosca - Now loop from 1..LLPAR for GIGC compatibility
31 Jul 2012 - R. Yantosca - Declare temp drydep arrays w/ LLPAR (not LLTROP)
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS) and
                            Input_Opt%XNUMOL(1:N_TRACERS) -- avoid OOB errs
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
12 Sep 2013 - M. Sulprizio- Now include references to dust-sulfate chemistry
                            (tdf 04/07/08)
12 Jun 2015 - R. Yantosca - Now remove orphaned ND44 variables
12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                            so we can greatly collapse this code
23 Sep 2015 - R. Yantosca - Remove references to DRYSO4 and DRYSO4s
24 Jun 2016 - R. Yantosca - Now return if id_SO4<0 or id_SO4s<0 (not == 0)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.5.21 chem_so4_aq

Subroutine CHEM_SO4_AQ takes the SO4 produced via aqueous chemistry of SO2 and distribute onto the size-resolved aerosol number and sulfate mass as a part of the TOMAS aerosol microphysics module (win, 1/25/10)

INTERFACE:

```
      SUBROUTINE CHEM_SO4_AQ( am_I_Root, Input_Opt,
     &                        State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptINput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TOMAS_MOD,          ONLY : AQOXID, GETACTBIN
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
NOTE: This subroutine is ignored unless we compile for TOMAS microphysics.
```

REVISION HISTORY:

```
(1 ) As of now the SO4 produced via heterogeneous reaction on the 2-mode
     seasalt is not include in this treatment (win, 7/23/07)
(2 ) Change a fixed kmin = 8 (corresponding to the assumed activation dia.
     of 55nm to be varying with current chemical composition.  Take average
     of the activating bin for LS and CONV rains. (win, 9/25/07)
16 Feb 2012 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
31 May 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm
                            and RC arguments
31 May 2013 - R. Yantosca - Now pass State_Chm to TOMAS routines
30 Sep 2015 - E. Lundgren - Now use UNITCONV_MOD conversion routine
```

8.5.22 chem_msa

Subroutine CHEM_MSA is the SO4 chemistry subroutine from Mian Chin's GOCART model, modified for the GEOS-CHEM model. (rjp, bdf, bmy, 5/31/00, 10/25/05)

INTERFACE:

```
SUBROUTINE CHEM_MSA( am_I_Root, Input_Opt,
&                    State_Met, State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
The only production is from DMS oxidation (saved in CHEM_DMS).
Dry deposition is now treaded in mixing_mod.F90.
```

REVISION HISTORY:

```
(1 ) Now reference AD from "dao_mod.f".  Added parallel DO-loops.
     Updated comments, cosmetic changes. (rjp, bmy, bdf, 9/16/02)
(2 ) Now replace DXYP(JREF)*1d4 with routine GET_AREA_CM2 of "grid_mod.f"
     Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(3 ) Now reference PBLFRAC from "drydep_mod.f".  Now apply dry deposition
     to the entire PBL. (rjp, bmy, 8/1/03)
(4 ) Now use ND44_TMP array to store vertical levels of drydep flux, then
     sum into AD44 array.  This preents numerical differences when using
     multiple processors. (bmy, 3/24/04)
(5 ) Now use parallel DO-loop to zero ND44_TMP (bmy, 4/14/04)
(6 ) Now references STT & TCVV from "tracer_mod.f" (bmy, 7/20/04)
(7 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
     "pbl_mix_mod.f".  Also reference GET_PBL_MAX_L from "pbl_mix_mod.f"
     Vertical DO-loops can run up to PBL_MAX and not LLTROP.   Also
     remove reference to header file CMN. (bmy, 2/22/05)
(8 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(9 ) Change loop back to over entire troposphere to correctly add production
     of MSA (PMSA_dms) to the MSA tracer array.
    Added reference USE_TROPOPAUSE_MOD, ONLY : ITS_IN_THE_STRAT
     as a precaution.  (pjh, 8/19/2009)
22 Dec 2011 - M. Payer    - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
31 Jul 2012 - R. Yantosca - Now loop from 1..LLPAR for GIGC compatibility
31 Jul 2012 - R. Yantosca - Declare temp drydep arrays w/ LLPAR (not LLTROP)
14 Nov 2012 - R. Yantosca - Add am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS) and
```

```
                          Input_Opt%XNUMOL(1:N_TRACERS) -- avoid OOB errs
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
12 Jun 2015 - R. Yantosca - Now remove orphaned ND44 variables
12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                          so we can greatly collapse this code
23 Sep 2015 - R. Yantosca - Remove references to obsolete DRYMSA flag
24 Jun 2016 - R. Yantosca - Now return if id_MSA < 0 (not == 0)
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                          species ID from State_Chm%Map_Advect.
```

8.5.23 chem_nit

Subroutine CHEM_NIT removes SULFUR NITRATES (NIT) from the surface via dry deposition. (rjp, bdf, bmy, 1/2/02, 5/23/06)

INTERFACE:

```
      SUBROUTINE CHEM_NIT( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Dry deposition is now applied in mixing_mod.F90.  Therefore we can
```

REMARKS:

```
Reaction List:
============================================================================
(1 ) NIT = NIT_0 * EXP( -dt )  where d = dry deposition rate [s-1]
```

REVISION HISTORY:

```
(1 ) Now reference AD from "dao_mod.f".  Added parallel DO-loops.
     Updated comments, cosmetic changes. (rjp, bmy, bdf, 9/20/02)
(2 ) Now replace DXYP(J+J0)*1d4 with routine GET_AREA_CM2 from "grid_mod.f".
     Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(3 ) Now reference PBLFRAC from "drydep_mod.f".  Now apply dry deposition
     to the entire PBL.  Added L and FREQ variables.  Recode to avoid
     underflow from EXP(). (rjp, bmy, 8/1/03)
(4 ) Now use ND44_TMP array to store vertical levels of drydep flux, then
     sum into AD44 array.  This preents numerical differences when using
     multiple processors. (bmy, 3/24/04)
(5 ) Now use parallel DO-loop to zero ND44_TMP (bmy, 4/14/04)
(6 ) Now reference STT & TCVV from "tracer_mod.f".  Also remove reference
     to CMN, it's not needed anymore. (bmy, 7/20/04)
(7 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP from
     "pbl_mix_mod.f".  Also reference GET_PBL_MAX_L from "pbl_mix_mod.f"
     Vertical DO-loops can run up to PBL_MAX and not LLTROP. (bmy, 2/22/05)
(8 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(9 ) Rearrange error check to avoid SEG FAULTS (bmy, 5/23/06)
22 Dec 2011 - M. Payer    - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
31 Jul 2012 - R. Yantosca - Now loop from 1..LLPAR for GIGC compatibility
31 Jul 2012 - R. Yantosca - Declare temp drydep arrays w/ LLPAR (not LLTROP)
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
05 Mar 2013 - R. Yantosca - Now use Input_Opt%LNLPBL
13 Mar 2013 - R. Yantosca - Bug fix: make sure we pass values to the
                            SOIL_DRYDEP routine even when ND44 is off
                            (this happens when LNLPBL = F)
19 Mar 2013 - R. Yantosca - Now copy Input_Opt%TCVV(1:N_TRACERS) and
                            Input_Opt%XNUMOL(1:N_TRACERS) -- avoid OOB errs
25 Mar 2013 - M. Payer    - Now pass State_Chm object via the arg list
12 Sep 2013 - M. Sulprizio- Now include references to nitrate on dust
                            (tdf, 04/07/08)
23 Sep 2013 - M. Sulprizio- Bug fix: Skip stratospheric boxes to prevent
                            out-of-bounds error in PNIT_DUST
12 Jun 2015 - R. Yantosca - Now remove orphaned ND44 variables
12 Jun 2015 - R. Yantosca - Drydep is now handled in mixing_mod.F90,
                            so we can greatly collapse this code
23 Sep 2015 - R. Yantosca - Remove reference to DRYNIT, DRYNITs
24 Jun 2016 - R. Yantosca - Now return if id_NIT<0 or id_NITs<0 (not == 0)
```

```
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

8.5.24 sulfate_pbl_mix

Subroutine SULFATE_PBL_MIX partitions the total anthro sulfate emissions thru the entire boundary layer. Emissions above the PBL are not used, and left in their level, regardless of the mixing scheme. For non-local mixing scheme, all emissions within the PBL are put in the first level.

INTERFACE:

```
      SUBROUTINE SULFATE_PBL_MIX ( EMISS, SULFATE, FRAC_OF_PBL,
     $                             PBL_TOP, IS_LOCAL )
```

USES:

```
      USE ERROR_MOD,    ONLY : ERROR_STOP
      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      INTEGER,  INTENT(IN)    :: PBL_TOP ! Top level of boundary layer
      LOGICAL,  INTENT(IN)    :: IS_LOCAL ! mixing scheme
      REAL(fp), INTENT(IN)    :: FRAC_OF_PBL(:) !
      REAL(fp), INTENT(IN)    :: EMISS(:)
```

OUTPUT PARAMETERS:

```
      REAL(fp), INTENT(INOUT) :: SULFATE(:) ! partitioned emissions
```

REVISION HISTORY:

```
27 Oct 2009 - P. Le Sager - initial
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
```

8.5.25 get_oh

Function GET_OH returns OH from State_Chmcoupled runs) or monthly mean OH (for offline runs). Imposes a diurnal variation on OH for offline simulations. (bmy, 12/16/02, 7/20/04)

INTERFACE:

```
      FUNCTION GET_OH( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( OH_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: I, J, L     ! Lon, lat, level indices
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
      TYPE(ChmState), INTENT(IN) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDOH (bmy, 11/1/02)
(2 ) Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(3 ) Now reference ITS_A_FULLCHEM_SIM, ITS_AN_AEROSOL_SIM from
     "tracer_mod.f".  Also replace IJSURF w/ an analytic function.
     (bmy, 7/20/04)
22 Dec 2011 - M. Payer    - Added ProTeX headers
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
28 Nov 2012 - R. Yantosca - Add State_Met to argument list
04 Mar 2013 - R. Yantosca - Now pass Input_Opt%ITS_A_FULLCHEM_SIM and
                            Input_Opt%ITS_AN_AEROSOL_SIM
18 Sep 2014 - M. Sulprizio- Now get OH for offline aerosol sim from HEMCO
22 Dec 2015 - M. Sulprizio- Remove references to CSPEC and JLOOP. We now get
                            species concentrations from State_Chm%Species.
```

8.5.26 get_no3

Function GET_NO3 returns NO3 from State_Chmcoupled runs) or monthly mean OH (for offline runs). For offline runs, the concentration of NO3 is set to zero during the day. (rjp, bmy, 12/16/02)

INTERFACE:

```
      FUNCTION GET_NO3( I, J, L, Input_Opt, State_Chm, State_Met )
     &         RESULT( NO3_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_SIZE_MOD
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I, J, L     ! Lon, lat, vertical level
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
(1 ) Now references ERROR_STOP from "error_mod.f".  We also assume that
     SETTRACE has been called to define IDNO3.  Now also set NO3 to
     zero during the day. (rjp, bmy, 12/16/02)
(2 ) Now reference ITS_A_FULLCHEM_SIM and ITS_AN_AEROSOL_SIM from
     "tracer_mod.f".  Also remove reference to CMN.   Also replace
     IJSURF with an analytic function. (bmy, 7/20/04)
22 Dec 2011 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
04 Mar 2013 - R. Yantosca - Now pass Input_Opt%ITS_A_FULLCHEM_SIM and
                            Input_Opt%ITS_AN_AEROSOL_SIM
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
18 Sep 2014 - M. Sulprizio- Now get NO3 for offline aerosol sims from HEMCO
22 Dec 2015 - M. Sulprizio- Remove references to CSPEC and JLOOP. We now get
                            species concentrations from State_Chm%Species.
```

8.5.27 get_o3

Function GET_O3 returns monthly mean O3 for offline sulfate aerosol simulations. (bmy, 12/16/02, 10/25/05)

INTERFACE:

```
FUNCTION GET_O3( I, J, L, Input_Opt, State_Chm, State_Met )
&                RESULT( O3_VV )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I, J, L     ! Lon, lat, vertical level
TYPE(OptInput), INTENT(IN)  :: Input_Opt
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
(1 ) We assume SETTRACE has been called to define IDO3. (bmy, 12/16/02)
(2 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
(3 ) Now remove reference to CMN, it's obsolete.  (bmy, 8/22/05)
(4 ) Now references XNUMOLAIR from "tracer_mod.f" (bmy, 10/25/05)
22 Dec 2011 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
04 Mar 2013 - R. Yantosca - Now pass Input_Opt%ITS_A_FULLCHEM_SIM and
                            Input_Opt%ITS_AN_AEROSOL_SIM
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
24 Mar 2015 - E. Lundgren - Replace dependency on tracer_mod with
                            CMN_GTCM_MOD to get XNUMOLAIR.
22 Dec 2015 - M. Sulprizio- Remove references to CSPEC and JLOOP. We now get
                            species concentrations from State_Chm%Species.
```

8.5.28 ohno3time

Subroutine OHNO3TIME computes the sum of cosine of the solar zenith angle over a 24 hour day, as well as the total length of daylight. This is needed to scale the offline OH and NO3 concentrations. (rjp, bmy, 12/16/02, 3/30/04)

INTERFACE:

```
SUBROUTINE OHNO3TIME
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD, ONLY : GET_XMID,    GET_YMID_R
USE TIME_MOD,    ONLY : GET_NHMSb,   GET_ELAPSED_SEC
USE TIME_MOD,    ONLY : GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT
```

REVISION HISTORY:

```
(1 ) Copy code from COSSZA directly for now, so that we don't get NaN
     values.  Figure this out later (rjp, bmy, 1/10/03)
(2 ) Now replace XMID(I) with routine GET_XMID from "grid_mod.f".
     Now replace RLAT(J) with routine GET_YMID_R from "grid_mod.f".
     Removed NTIME, NHMSb from the arg list.  Now use GET_NHMSb,
     GET_ELAPSED_SEC, GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT from
     "time_mod.f". (bmy, 3/27/03)
(3 ) Now store the peak SUNCOS value for each surface grid box (I,J) in
     the COSZM array. (rjp, bmy, 3/30/04)
22 Dec 2011 - M. Payer    - Added ProTeX headers
16 May 2016 - M. Sulprizio- Remove IJLOOP and change SUNTMP array dimensions
                            from (MAXIJ) to (IIPAR,JJPAR)
```

8.5.29 get_alk

Subroutine GET_ALK returns the seasalt alkalinity emitted at each timestep to sulfate_mod.f for chemistry on seasalt aerosols. (bec, 12/7/04, 11/23/09)

INTERFACE:

```
      SUBROUTINE GET_ALK( am_I_Root, I,J,L, ALK1, ALK2, Kt1, Kt2,
     &                    Kt1N, Kt2N, Input_Opt, State_Met, State_Chm,
     &                    RC)
```

USES:

```
      USE CMN_SIZE_MOD,       ONLY : NDUST
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : IT_IS_NAN, ERROR_STOP
      USE HCO_INTERFACE_MOD,  ONLY : GetHcoVal
  (jas, 8/4/15) calculate kt using sea salt surface area concentration
      USE CMN_SIZE_MOD,       ONLY : NDUST
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_TOP_L
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Root CPU?
      INTEGER,        INTENT(IN)    :: I, J, L     ! Lon-lat-alt indices
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      REAL(fp),       INTENT(OUT)   :: ALK1, ALK2  ! [kg]
      REAL(fp),       INTENT(OUT)   :: Kt1, Kt2, Kt1N, Kt2N ! [s-1]
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(INOUT) :: RC
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
    (1 ) Becky Alexander says we can remove AREA1, AREA2 (bec, bmy, 9/5/06)
    (2 ) Bug fix to remove a double-substitution.  Replace code lines for
         TERM{123}A, TERM{123}B, TERM{123}AN, TERM{123}BN. (bec, bmy, 7/18/08)
    (3 ) Updated hygroscopic growth parameters (bec, bmy, 11/23/09)
    (4 ) Fixed bug when calculating rate constants for uptake of SO2 and HNO3
         (kt). The bug caused kt to be too small and prevented acidification
         of SSA. (jas, 8/4/15)
    22 Dec 2011 - M. Payer    - Added ProTeX headers
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
```

```
                            derived type object
25 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
25 Jun 2014 - R. Yantosca - Removed references to tracer_mod.F
02 Nov 2014 - C. Keller   - Now get alkalinity and number density from HEMCO
04 Nov 2014 - C. Keller   - Moved from seasalt_mod.F
12 Nov 2014 - C. Keller   - Now weight # dens. and alk. by fraction of PBL
12 May 2016 - M. Sulprizio- Remove 1D arrays that depend on JLOOP. ERADIUS,
                            TAREA, are now pointers that point to 3D fields
                            fields in State_Chm.
```

8.5.30 init_sulfate

Subroutine INIT_SULFATE initializes and zeros all allocatable arrays declared in "sulfate_mod.f" (bmy, 6/2/00, 10/15/09)

INTERFACE:

```
SUBROUTINE INIT_SULFATE( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : Alloc_Err
USE ERROR_MOD,          ONLY : Error_Stop
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

INPUT/OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
(1 ) Only allocate some arrays for the standalone simulation (NSRCX==10).
     Also reference NSRCX from "CMN".  Now eferences routine ALLOC_ERR
     from "error_mod.f" ((rjp, bdf, bmy, 10/15/02)
(2 ) Now also allocate the IJSURF array to keep the 1-D grid box indices
     for SUNCOS (for both coupled & offline runs).  Now allocate PH2O2m
     and O3m for offline runs.  Also allocate ESO2_bf (bmy, 1/16/03)
(3 ) Now allocate ENH3_na array (rjp, bmy, 3/23/03)
(4 ) Now allocate COSZM for offline runs (bmy, 3/30/04)
(5 ) Now allocate ESO2_sh array (bec, bmy, 5/20/04)
```

```
(6 ) Now allocates ITS_AN_AEROSOL_SIM from "tracer_mod.f".  Now remove
     IJSURF (bmy, 7/20/04)
(7 ) Now locate species in the DEPSAV array here instead of in CHEMSULFATE.
     Now reference LDRYD from "logical_mod.f".  Updated for AS, AHS, LET,
     SO4aq, NH4aq. (bmy, 1/6/06)
(8 ) Now allocates PSO4_ss, PNITs (bec, bmy, 4/13/05)
(9 ) Initialize drydep flags outside of IF block (bmy, 5/23/06)
(10) Now redimension EEV & NEV arrays for new SO2 volcanic emissions
     inventory.  Deleted obsolete arrays from older SO2 volcanic
     emissions inventory. (jaf, bmy, 10/15/09)
(11) Now alllocate PSO4_SO2AQ (win, 1/25/10)
22 Dec 2011 - M. Payer    - Added ProTeX headers
04 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC arguments
05 Mar 2013 - R. Yantosca - Now use Input_Opt%ITS_AN_AEROSOL_SIM
30 May 2013 - S. Farina   - Allocate PSO4_SO2AQ for TOMAS
12 Sep 2013 - M. Sulprizio- Add PSO4_dust and PNIT_dust for acid update on
                            dust aerosols (T.D. Fairlie)
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
22 May 2015 - R. Yantosca - Remove variables made obsolete by HEMCO
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
21 Jun 2016 - R. Yantosca - Reorder the Ind_ declaration statements a bit
24 Jun 2016 - R. Yantosca - Add error checks for dust uptake species
```

8.5.31 cleanup_sulfate

Subroutine CLEANUP_SULFATE deallocates all previously allocated arrays for sulfate emissions – call at the end of the run (bmy, 6/1/00, 10/15/09)

INTERFACE:

```
SUBROUTINE CLEANUP_SULFATE()
```

REVISION HISTORY:

```
(1 ) Now also deallocates IJSURF. (bmy, 11/12/02)
(2 ) Now also deallocates ENH3_na (rjp, bmy, 3/23/03)
(3 ) Now also deallocates COSZM (rjp, bmy, 3/30/04)
(4 ) Now also deallocates ESO4_sh (bec, bmy, 5/20/04)
(5 ) Now remove IJSURF (bmy, 7/20/04)
(6 ) Bug fix: now deallocate PSO4_ss, PNITs (bmy, 5/3/06)
(7 ) Deleted obsolete arrays from older SO2 volcanic emissions
     inventory (jaf, bmy, 10/15/09)
(8 ) Deallocate PSO4_SO2AQ (win, 1/25/10)
22 Dec 2011 - M. Payer    - Added ProTeX headers
30 May 2013 - S. Farina   - Deallocate PSO4_SO2AQ for TOMAS
04 Mar 2015 - R. Yantosca - Remove EEV, NEV.  Volcano eruptions are now
                            handled via HEMCO.
```

```
22 May 2015 - R. Yantosca - Remove variables made obsolete by HEMCO
```

8.6 Fortran: Module Interface isoropiaii_mod.F

Module ISOROPIAII_MOD contains the routines that provide the interface between ISORROPIA II and GEOS-Chem.

The actual ISORROPIA II code which performs Na-SO4-NH3-NO3-Cl-(Ca-K-Mg) aerosol thermodynamic equilibrium is in `isoropiaIIcode.f`.

INTERFACE:

```
MODULE ISOROPIAII_MOD
```

USES:

```
USE HCO_ERROR_MOD    ! For real precisions (hp)
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CLEANUP_ISOROPIAII
PUBLIC  :: DO_ISOROPIAII
PUBLIC  :: GET_GNO3
PUBLIC  :: GET_ISRINFO
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: GET_HNO3
PRIVATE :: INIT_ISOROPIAII
PRIVATE :: SAFELOG10
PRIVATE :: SET_HNO3
```

REMARKS:

```
Original Author:
*** COPYRIGHT 1996-2006, UNIVERSITY OF MIAMI, CARNEGIE MELLON UNIVERSITY,
*** GEORGIA INSTITUTE OF TECHNOLOGY
*** WRITTEN BY ATHANASIOS NENES
*** UPDATED BY CHRISTOS FOUNTOUKIS

Original v1.3 isoropia implementation into GEOS-Chem by
Becky Alexander and Bob Yantosca (bec, bmy, 4/12/05, 11/2/05)

For Ca,K,Mg = 0, ISOROPIA II performs exactly like ISOROPIAv1.7
Ca, K, Mg, Na from dust is not currently considered
```

```
To implement ISOROPIA II into GEOS-Chem:
  * cleanup_isoropiaII needs to be called from cleanup.f
  * DO_ISOROPIA needs to be replaced with DO_ISOROPIAII in chemistry_mod.f
  * Change ISOROPIA to ISOROPIAII in sulfate_mod.f
  * add isoropiaII_mod.f, isoropiaIIcode.f, and irspia.inc to Makefile

ISOROPIA II implementation notes by Havala O.T. Pye:
(1) The original isoropia code from T.Nenes is left as unmodified as
     possible. Original isoropia code can be found in isoropiaIIcode.f
     and common blocks can be found in isrpia.inc. For future upgrades
     to isoropia, replace isrpia.inc and isoropiaIIcode.f with the new
     version of isoropia and modify the call to ISOROPIA in this module.
     Please let the original author know of any changes made to ISOROPIA.
(2) As of Nov 2007, routines using non-zero Ca, K, and Mg do not always
     conserve mass. Ca, K, and Mg are set to zero.

NOTE: ISORROPIA is Greek for "equilibrium", in case you were wondering.
```

REVISION HISTORY:

```
06 Jul 2007 - H. O. T. Pye - Initial version
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
21 Apr 2010 - R. Yantosca  - Bug fix in DO_ISOROPIAII for offline aerosol
16 Feb 2011 - R. Yantosca  - Add modifications for APM from G. Luo
20 Aug 2013 - R. Yantosca  - Removed "define.h", this is now obsolete
23 Sep 2014 - M. Sulprizio - Get global HNO3 for offline aerosol simulation
                             from HEMCO
14 Nov 2014 - M. Yannetti  - Added PRECISION_MOD
23 Jun 2016 - R. Yantosca - Remove references to APM code; it is no longer
                            compatible with the FlexChem implementation
```

8.6.1 do_isoropiaii

Subroutine DO_ISOROPIAII is the interface between the GEOS-Chem model and the aerosol thermodynamical equilibrium routine ISORROPIA II.

INTERFACE:

```
  SUBROUTINE DO_ISOROPIAII( am_I_Root, Input_Opt,
 &                          State_Met, State_Chm, RC )
```

USES:

```
  USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRATMESO
  USE CMN_SIZE_MOD
  USE ErrCode_Mod
  USE ERROR_MOD,          ONLY : DEBUG_MSG
  USE ERROR_MOD,          ONLY : ERROR_STOP
```

```
USE ERROR_MOD,          ONLY : SAFE_DIV
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH
USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Original isoropia v1.3 implmentation: (rjp, bec, bmy, 12/17/01, 8/22/05)
```

REVISION HISTORY:

```
24 Aug 2007 - H. O. T. Pye - Initial version, in ISORROPIA II
18 Dec 2009 - H. O. T. Pye - Added division checks
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
21 Apr 2010 - E. Sofen     - Prevent out-of-bounds errors for offline
                             aerosol simulations where HNO3 is undefined
23 Jul 2010 - R. Yantosca  - Bug fix: corrected typo in ND42 diag section
30 Jul 2012 - R. Yantosca  - Now accept am_I_Root as an argument when
                             running with the traditional driver main.F
31 Jul 2012 - R. Yantosca  - Now loop from 1..LLPAR for GIGC compatibilit
14 Nov 2012 - R. Yantosca  - Add am_I_Root, Input_Opt, RC as arguments
15 Nov 2012 - M. Payer     - Replaced all met field arrays with State_Met
                             derived type object
25 Mar 2013 - M. Payer     - Now pass State_Chm object via the arg list
23 Sep 2014 - M. Sulprizio - Now get HNO3 for offline aerosol sim from HEMCO
16 Jun 2016 - K. Travis    - Now define species ID's with the Ind_ function
17 Jun 2016 - R. Yantosca  - Now only define species ID's on the first call;
                             we don't want to do it on each loop iteration
30 Jun 2016 - R. Yantosca  - Remove instances of STT.  Now get the advected
                             species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca  - Remove temporary tracer-removal code
```

8.6.2 safelog10

Calculates the LOG (base 10) of a number X. Returns a minimum value if X is too small, in order to avoid NaN or Infinity problems.

INTERFACE:

```
FUNCTION SAFELOG10( X ) RESULT ( SAFLOG )
```

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: X        ! Argument for LOG10 function
```

RETURN VALUE:

```
REAL(fp)             :: SAFLOG   ! LOG10 output --
```

REVISION HISTORY:

```
11 Aug 2009 - H. O. T. Pye - Initial version, in ISORROPIA II
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
```

8.6.3 get_isrinfo

Subroutine GET_ISRINFO returns information related to aerosol pH.

INTERFACE:

```
FUNCTION GET_ISRINFO( I, J, L, N ) RESULT ( RETURNVALUE )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I   ! GEOS-Chem longitude index
INTEGER, INTENT(IN) :: J   ! GEOS-Chem latitude index
INTEGER, INTENT(IN) :: L   ! GEOS-Chem level index
INTEGER, INTENT(IN) :: N   ! Flag for which information is desired
```

RETURN VALUE:

```
REAL(fp)              :: RETURNVALUE
```

REVISION HISTORY:

```
11 Aug 2009 - H. O. T. Pye - Initial version
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
```

8.6.4 get_hno3

Subroutine GET_HNO3 allows the HNO3 concentrations to evolve with time, but relaxes back to the monthly mean concentrations every 3 hours.

INTERFACE:

```
FUNCTION GET_HNO3( I, J, L, State_Met ) RESULT ( HNO3_UGM3 )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AIRMW
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_ELAPSED_MIN
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I           ! GEOS-Chem longitude index
INTEGER,        INTENT(IN)  :: J           ! GEOS-Chem latitude index
INTEGER,        INTENT(IN)  :: L           ! GEOS-Chem level index
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
16 Dec 2002 - R. Yantosca  - Initial version, in ISORROPIA I
24 Mar 2003 - R. Yantosca  - Now use function GET_ELAPSED_MIN() from the
                             new "time_mod.f" to get the elapsed minutes
                             since the start of run.
06 Jul 2007 - H. O. T. Pye - Initial version, in ISORROPIA II
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
23 Sep 2014 - M. Sulprizio - Now get HNO3 for offline aerosol sims from HEMCO
06 Jan 2016 - E. Lundgren  - Use global physical parameters
```

8.6.5 set_hno3

Subroutine SET_HNO3 stores the modified HNO3 value back into the HNO3_sav array for the next timestep.

INTERFACE:

```
SUBROUTINE SET_HNO3( I, J, L, HNO3_UGM3 )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: I           ! GEOS-Chem longitude index
INTEGER, INTENT(IN) :: J           ! GEOS-Chem longitude index
INTEGER, INTENT(IN) :: L           ! GEOS-Chem longitude index
REAL(f8),  INTENT(IN) :: HNO3_UGM3   ! HNO3 concentration [ug/m3]
```

REVISION HISTORY:

```
16 Dec 2002 - R. Yantosca  - Initial version, in ISORROPIA I
06 Jul 2007 - H. O. T. Pye - Initial version, in ISORROPIA II
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
11 Jan 2015 - M. Yannetti  - Some precision edits, for safety.
19 Sep 2016 - R. Yantosca  - Bug fix: #ifdef's should be lower case
19 Sep 2016 - R. Yantosca  - Bug fix: elif should be else
```

8.6.6 get_gno3

Function GET_GNO3 returns the gas-phase HNO3 [v/v] for calculation of sea-salt chemistry in sulfate_mod (SEASALT_CHEM).

INTERFACE:

```
SUBROUTINE GET_GNO3( I, J, L, HNO3_kg, State_Met )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: I          ! GEOS-Chem longitude index
INTEGER,        INTENT(IN)    :: J          ! GEOS-Chem latitude index
INTEGER,        INTENT(IN)    :: L          ! GEOS-Chem level index
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

OUTPUT PARAMETERS:

```
REAL(fp),          INTENT(OUT)  :: HNO3_kg    ! Gas-phase HNO3 [kg]
```

REVISION HISTORY:

```
15 Apr 2005 - B. Alexander - Initial version, in ISORROPIA I
06 Jul 2007 - H. O. T. Pye - Initial version, in ISORROPIA II
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
09 Nov 2012 - M. Payer     - Replaced all met field arrays with State_Met
                             derived type object
```

8.6.7 init_isoropiaII

Subroutine INIT_ISOROPIAII initializes all module arrays.

INTERFACE:

```
SUBROUTINE INIT_ISOROPIAII
```

USES:

```
USE CMN_SIZE_MOD      ! Size parameters
USE ERROR_MOD,   ONLY : ALLOC_ERR
```

REVISION HISTORY:

```
06 Jul 2007 - H. O. T. Pye - Initial version
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
31 Jul 2012 - R. Yantosca  - Declare diag arrays w/ LLPAR (not LLTROP)
```

8.6.8 cleanup_isoropiaII

Subroutine CLEANUP_ISOROPIAII deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_ISOROPIAII
```

REVISION HISTORY:

```
06 Jul 2007 - H. O. T. Pye - Initial version
29 Jan 2010 - R. Yantosca  - Added ProTeX headers
```

9 Meteorological field modules

These modules contain routines to read archived meteorology into GEOS-Chem.

9.1 Fortran: Module Interface dao_mod.F

Module DAO_MOD contains both arrays that hold DAO met fields, as well as subroutines that compute, interpolate, or otherwise process DAO met field data.

INTERFACE:

```
MODULE DAO_MOD
```

USES:

```
USE CMN_SIZE_MOD          ! Size parameters
USE PhysConstants         ! Physical constants
USE PRECISION_MOD         ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: AVGPOLE
PUBLIC  :: AIRQNT
PUBLIC  :: COPY_I3_I6_FIELDS
PUBLIC  :: GET_COSINE_SZA
PUBLIC  :: GET_OBK
PUBLIC  :: INTERP
PUBLIC  :: IS_LAND
PUBLIC  :: IS_WATER
PUBLIC  :: IS_ICE
PUBLIC  :: IS_NEAR
PUBLIC  :: SET_DRY_SURFACE_PRESSURE
```

REVISION HISTORY:

```
26 Jun 2010 - R. Yantosca - Initial version
(1 ) Added sea level pressure (SLP) met field for GEOS-3 (bmy, 10/10/00)
(2 ) Moved MAKE_QQ to "wetscav_mod.f" (bmy, 10/12/00)
(3 ) Now get LWI from ALBEDO for GEOS-3 in routines IS_LAND and
     IS_WATER (bmy, 4/4/01)
(4 ) Define OPTDEP allocatable array for GEOS-3 -- this is the grid
     box optical depth and is now stored as a met field (bmy, 8/15/01)
(5 ) Updated comments (bmy, 9/4/01)
(6 ) Now make AVGW an allocatable module array.  Also replace obsolete
     parameters {IJL}GCMPAR with IIPAR,JJPAR,LLPAR. (bmy, 9/27/01)
(7 ) Remove arguments LMAKEPW, PW, and LM from AIRQNT (bmy, 10/3/01)
(8 ) Remove obsolete code from 9/01 (bmy, 10/23/01)
(9 ) Bug fixes in IS_LAND and IS_WATER.  Also cosmetic changes and
     updated some comments. (mje, bmy, 1/9/02)
(10) Now add additional array PSC2 in order to pass to TPCORE, which will
     fix the mixing ratio bug.  Compute PSC2 in subroutine INTERP.
     Now bundle "convert_units.f" into "dao_mod.f".  Updated comments.
     (bmy, 3/27/02)
(11) Updated comments (bmy, 5/28/02)
(12) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
     to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(13) Eliminated PS, PSC arrays.  Now reference "pressure_mod.f".  Also
     updated AIRQNT for hybrid grid.  Added routine MAKE_RH to this
     module. (dsa, bdf, bmy, 8/27/02)
(14) Added arrays AD, BXHEIGHT, and T to "dao_mod.f".  Also removed
     obsolete code from 8/02 from several module routines.  Now
     references "error_mod.f".  Remove all references to QQ, it is now
     declared in "wetscav_mod.f".  (bmy, 11/8/02)
(15) Now references "grid_mod.f".  Also added PHIS field, which was
     formerly stored as PALTD in "CMN".  Added bug fix in routine
     AVGPOLE for 1x1 nested grid. (bmy, 3/11/03)
(16) Added SUNCOSB array for SMVGEAR II.  Also removed KZZ array, since
     that is now obsolete. (bmy, 4/28/03)
```

```
(17) Now moved MAKE_CLDFRC into "a6_read_mod.f".  Added HKBETA, HKETA,
     TSKIN, GWETTOP, ZMEU, ZMMD, ZMMU, PARDF, PARDR fields for
     GEOS-4/fvDAS. (bmy, 6/25/03)
(18) Added CLDFRC, RADSWG, RADLWG, SNOW arrays (bmy, 12/9/03)
(19) Added routine COPY_I6_FIELDS w/ parallel DO-loops (bmy, 4/13/04)
(20) Now also allocate AVGW for offline aerosol simulation (bmy, 9/28/04)
(21) AVGPOLE now uses NESTED_CH and NESTED_NA cpp switches (bmy, 12/1/04)
(22) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(23) Now allocate SNOW and GWET for GCAP (bmy, 8/17/05)
(24) Now also add TSKIN for GEOS-3 (tmf, bmy, 10/20/05)
(25) Modifications for near-land formulation (ltm, bmy, 5/16/06)
(26) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(27) Modified for variable tropopause (phs, bdf, 9/14/06)
(28) Add in extra fields for GEOS-5.  Updated COSSZA.  Now cap var trop
     at 200hPa near poles in INTERP (bmy, phs, 9/18/07)
(29) Bug fix in INIT_DAO for CMFMC array (bmy, jaf, 6/11/08)
(30) Add heat flux EFLUX for GEOS5. (lin, ccc, 5/29/09)
(31) Add fractions of land and water, FRLAND, FROCEAN, FRLANDIC, FRLAKE
     for methane (kjw, 8/18/09)
(32) Bug fix in AVGPOLE (bmy, 12/18/09)
(33) Remove obsolete SUNCOSB array (bmy, 4/28/10)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
18 Aug 2010 - R. Yantosca - Added modifications for MERRA data
18 Aug 2010 - R. Yantosca - Move CMN_SIZE, CMN_DIAG to top of module
25 Aug 2010 - R. Yantosca - Now read LWI (land/water/ice) for MERRA met
05 Oct 2011 - R. Yantosca - Add SUNCOS_30 array to hold the cos(SZA)
                            computed @ 30 mins after each GMT hour.
07 Oct 2011 - R. Yantosca - Rename SUNCOS30 to SUNCOS_MID, which is the
                            cos(SZA) at the midpt of the chemistry timestep
06 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x met fields
06 Feb 2012 - R. Yantosca - Split up INIT_DAO into several routines
07 Feb 2012 - M. Payer    - Add subroutine GET_COSINE_SZA to compute sun
                            angles at the current time and 5 hours prior to
                            the current time (for the PARANOX ship emissions
                            plume model) (R. Yantosca)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now references the new grid_mod.F90
06 Mar 2012 - R. Yantosca - Now allocate TO3 for all met fields
21 Nov 2012 - R. Yantosca - Removed met fields now contained in State_met
21 Nov 2012 - R. Yantosca - Remove functions INIT_DAO_GCAP, INIT_DAO_GEOS4,
                            INIT_DAO_GEOS5, INIT_DAO_GEOS57, INIT_DAO_MERRA
27 Nov 2012 - R. Yantosca - Removed obsolete AIRQNT_FULLGRID routine and
                            obsolete arrays AIRDEN_FULLGRID, T_FULLGRID
28 Nov 2012 - R. Yantosca - Removed SUNCOS, SUNCOS_MID, SUNCOS_MID_5hr
28 Nov 2012 - R. Yantosca - Removed routines INIT_DAO, INIT_DAO_DERIVED, and
                            CLEANUP_DAO; we have no more allocatable arrays
14 Mar 2013 - M. Payer    - Restored routines AIRQNT_FULLGRID, INIT_DAO,
                            CLEANUP_DAO and arrays AIRDEN_FULLGRID and
```

```
                            T_FULLGRID. They are required to correct vertical
                            regridding of OH for offline simulations.
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
07 Nov 2014 - M. Yannetti - Added PRECISION_MOD
23 Feb 2015 - E. Lundgren - Change AIRQNT and formulas to take into
                            account the presence of water vapor
26 Feb 2015 - E. Lundgren - Move calculations of RH and AVGW from MAKE_RH
                            and MAKE_AVGW to AIRQNT. Update algorithms
                            to account for the presence of water vapor
                            and to use [g water / kg moist air] for the
                            definition of specific humidity (SPHU).
16 Apr 2015 - R. Yantosca - Removed AIRQNT_FULLGRID, this was used to regrid
                            OH fields, but that is now done by HEMCO
16 Apr 2015 - R. Yantosca - Also remove INIT_DAO and CLEANUP_DAO, since
                            these allocated/deallocated the FULLGRID arrays
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

9.1.1 avgpole

Subroutine AVGPOLE computes average quantity near polar caps, defined by (J = 1, 2) and (J = JJPAR-1, JJPAR).

INTERFACE:

```
SUBROUTINE AVGPOLE( Z )
```

USES:

```
USE GC_GRID_MOD, ONLY : GET_AREA_M2
```

INPUT/OUTPUT PARAMETERS:

```
REAL(fp), INTENT(INOUT) :: Z(IIPAR,JJPAR)   ! Quantity to be averaged
                                            !  over the pole (usually PS)
```

REVISION HISTORY:

```
30 Jan 1998 - R. Yantosca - Initial version
(1 ) AVGPOLE is written in Fixed-Form Fortran 90.  Use F90 syntax
     for declarations, etc (bmy, 4/14/99)
(2 ) MAIN now passes the Harvard CTM variable for surface area of
     a gridbox, DXYP(JJPAR), to AVGPOLE.  Use window offset
     J+J0 when accessing DXYP.  Add JJPAR to the parameter list.
(3 ) Added this routine to "dao_mod.f" (bmy, 6/27/00)
(4 ) Updated comments (bmy, 4/4/01)
(5 ) Now replaced DXYP(J) with routine GET_AREA_M2 of "grid_mod.f"
     Now also return immediately if GRID1x1 is selected. (bmy, 3/11/03)
(6 ) Now use cpp switches NESTED_CH and NESTED_NA to denote nested
```

```
      grids...GRID1x1 can now also denote a global grid (bmy, 12/1/04)
(7 ) Also need to RETURN for 0.5 x 0.666 nested grid simulations
      (mpb, bmy, 12/18/09)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
26 Sep 2013 - R. Yantosca - Remove SEAC4RS C-preprocessor switch
```

9.1.2 airqnt

Subroutine AIRQNT sets several members of State_Met, the meteorology object of derived type MetState, and optionally updates the tracer concentrations to conserve tracer mass when air quantities change.

INTERFACE:

```
      SUBROUTINE AIRQNT( am_I_Root, Input_Opt, State_Met, State_Chm,
     &                   RC, update_mixing_ratio )
```

USES:

```
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,          ONLY : GET_AREA_M2
      USE Input_Opt_Mod,        ONLY : OptInput
      USE State_Met_Mod,        ONLY : MetState
      USE State_Chm_Mod,        ONLY : ChmState
      USE PRESSURE_MOD

      ! Temporary fix for calculating air density (mps, 12/23/15)
      USE PhysConstants,        ONLY : AIRMW, AVO
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)           :: am_I_Root  ! On the root CPU?
      TYPE(OptInput), INTENT(IN)           :: Input_Opt  ! Input options
      LOGICAL,        INTENT(IN), OPTIONAL :: update_mixing_ratio
                                                         ! Update mixing ratio?
                                                         ! Default is yes
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Obj for met fields
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
DAO met fields updated by AIRQNT:
=============================================================================
(1)  PEDGE     (REAL(fp)) : Moist air pressure at grid box bottom      [hPa]
(2)  PEDGE_DRY (REAL(fp)) : Dry air partial pressure at box bottom     [hPa]
(3)  PMID      (REAL(fp)) : Moist air pressure at grid box centroid    [hPa]
(4)  PMID_DRY  (REAL(fp)) : Dry air partial pressure at box centroid   [hPa]
(5)  PMEAN     (REAL(fp)) : Altitude-weighted mean moist air pressure  [hPa]
(6)  PMEAN_DRY (REAL(fp)) : Alt-weighted mean dry air partial pressure [hPa]
(7)  DELP      (REAL(fp)) : Delta-P extent of grid box                 [hPa]
                            (Same for both moist and dry air since we
                            assume constant water vapor pressure
                            across box)
(8)  AIRDEN    (REAL(fp)) : Mean grid box dry air density           [kg/m^3]
                            (defined as total dry air mass/box vol)
(9)  MAIRDEN   (REAL(fp)) : Mean grid box moist air density        [kg/m^3]
                            (defined as total moist air mass/box vol)
(10) AD        (REAL(fp)) : Total dry air mass in grid box            [kg]
(11) ADMOIST   (REAL(fp)) : Total moist air mass in grid box          [kg]
(12) BXHEIGHT  (REAL(fp)) : Vertical height of grid box               [m]
(13) AIRVOL    (REAL(fp)) : Volume of grid box                        [m^3]
(14) MOISTMW   (REAL(fp)) : Molecular weight of moist air in box     [g/mol]
(15) DELP_PREV (REAL(fp)) : Prev delta-P for trcr mixing ratio update  [hPa]
```

REVISION HISTORY:

```
30 Jan 1998 - R. Yantosca - Initial version
(1 ) AIRQNT is written in Fixed-Form Fortran 90.  Use F90 syntax
     for declarations etc. (bmy, 4/14/99)
(2 ) AIRQNT can now compute PW from PS (if LMAKEPW=T) or PS from PW.
(3 ) AIRQNT should also be called after TPCORE, since TPCORE changes
     the PW values.  AIRQNT must then be called to compute the post-TPCORE
     values of AD, BXHEIGHT, AIRVOL, and AIRDEN.
(4 ) The AIRDEN and DELP arrays are now dimensioned as (LLPAR,IIPAR,JJPAR)
     for better efficiency when processing a whole (I,J) column layer by
     layer.  In FORTRAN, the best efficiency is obtained when the leftmost
     array index corresponds to the innermost loop.
(5 ) Remove PTOP from the arg list.  PTOP is now a parameter in
    "CMN_SIZE".  Also updated comments. (bmy, 2/22/00)
(6 ) Replace IM, JM, LM with IIPAR, JJPAR, LLPAR as loop boundaries.
     This ensures that all quantities get defined up to the top of
     the atmosphere. (bmy, 6/15/00)
(7 ) Added to "dao_mod.f" (bmy, 6/26/00)
(8 ) Updated comments (bmy, 4/4/01)
(9 ) P(IREF,JREF) is now P(I,J).  T(IREF,JREF,L) is now T(I,J,L).  Also
     removed LM from the arg list, it is obsolete.  Also updated
     comments. (bmy, 9/26/01)
(10) Remove PW -- it is now obsolete.  Also make PW a local variable,
     we need to preserve the way it computes P so as to avoid numerical
     drift. (bmy, 10/4/01)
```

```
(11) Removed obsolete code from 9/01 and 10/01 (bmy, 10/23/01)
(12) Removed LMAKEPW from arg list.  Added parallel DO loops (bmy, 11/15/01)
(13) Removed obsolete code from 11/01 (bmy, 1/9/02)
(14) Now rename G_SIGE to SIGE, and dimension it (1:LLPAR+1).  Updated
     comments, cosmetic changes. (bmy, 4/4/02)
(15) Removed obsolete, commented-out code (bmy, 6/25/02)
(16) Removed PS, P, SIGE from the arg list for hybrid grid.  Now reference
     routines GET_PEDGE and GET_BP from "pressure_mod.f".  Removed
     obsolete, commented-out code. (dsa, bdf, bmy, 8/27/02)
(17) Now only pass DXYP via the arg list -- the other arguments are actually
     are already contained within "dao_mod.f" (bmy, 11/15/02)
(18) Now replace DXYP(JREF) with routine GET_AREA_M2 of "grid_mod.f".
     (bmy, 3/11/03)
(19) Now move computation of DELP into main loop.  Also remove P, LOGP,
     JREF, DSIG variables -- these are obsolete for fvDAS.  (bmy, 6/19/03)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
22 Oct 2012 - R. Yantosca - Now reference gigc_state_met_mod.F90
22 Oct 2012 - R. Yantosca - Renamed LOCAL_MET argument to State_Met
09 Nov 2012 - M. Payer    - Copy met field arrays to the State_Met derived
                            type object
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%DELP(I,J,L)
07 Jan 2015 - E. Lundgren - Add new Met field MAIRDEN (moist air density)
13 Feb 2015 - E. Lundgren - Incorporate water vapor in calculations of
                            densities. Calculate dry air pressures.
23 Feb 2015 - E. Lundgren - Change box height formula to include water vapor
24 Feb 2015 - E. Lundgren - Add calculation of RH to subroutine. Use new
                            formulate for H20 saturation pressure.
03 Mar 2015 - E. Lundgren - Set State_Met%TV (virtual temperature)
16 Apr 2015 - E. Lundgren - Add new State_Met variables PMEAN, PMEAN_DRY,
                            MOISTMW, and ADMOIST
28 Oct 2015 - E. Lundgren - Pass update_mixing_ratio flag, Input_Opt, and
                            State_Chm to optionally update tracer units
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
15 Aug 2016 - E. Lundgren - Update conc w/ RH for all species
```

9.1.3 interp

Subroutine INTERP linearly interpolates GEOS-Chem I6 and I3 fields (winds, surface pressure, temperature, surface albedo, specific humidity etc.) to the current dynamic timestep.

INTERFACE:

```
SUBROUTINE INTERP( NTIME0, NTIME1, NTDT, Input_Opt, State_Met )
```

USES:

```
      USE GC_GRID_MOD,        ONLY : GET_YEDGE
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: NTIME0     ! Elapsed time [s] at
                                                  !  start of outer time step
      INTEGER,        INTENT(IN)    :: NTIME1     ! Elapsed time [s] at
                                                  !  current time
      INTEGER,        INTENT(IN)    :: NTDT       ! Dynamic timestep [s]
      TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
    Different met fields are archived at I6 (instantaneous 6-hr) and
    I3 (instantaneous 3-hr) time resolution depending on the specific product.
    For example, relative humidity is an instantaneous 6hr field in MERRA and
    a 6-hr time averaged field in GEOS-5.
```

REVISION HISTORY:

```
    30 Jan 1998 - R. Yantosca - Initial version
    (1 ) INTERP is written in Fixed-Form Fortran 90.
    (2 ) Subtract PINT from PSC since the only subroutine that uses PSC
         is TPCORE.  This prevents having to subtract and add PINT to PSC
         before and after each call of TPCORE.
    (3 ) Pass the Harvard CTM temperature variable T(IGCMPAR,JGCMPAR,LGCMPAR)
         to INTERP via the argument list (instead of including file CMN).
         It is computationally inefficient to keep two large arrays for
         the same quantity.  Use the proper window offsets with T.
    (4 ) Added to "dao_mod.f" (bmy, 6/26/00)
    (5 ) Updated comments (bmy, 4/4/01)
    (6 ) Replaced {IJL}GCMPAR w/ IIPAR,JJPAR,LLPAR.  Also now use parallel
         DO-loop for interpolation.  Updated comments. (bmy, 9/26/01)
    (7 ) Removed obsolete code from 9/01 (bmy, 10/23/01)
    (8 ) Add PSC2 as the surface pressure at the end of the dynamic timestep.
         This needs to be passed to TPCORE and AIRQNT so that the mixing ratio
         can be converted to mass properly.  Removed PINT from the arg list,
         since we don't need it anymore.  Also updated comments and made
         some cosmetic changes.  (bmy, 3/27/02)
    (9 ) Removed obsolete, commented-out code (bmy, 6/25/02)
    (10) Eliminated PS, PSC from the arg list, for floating-pressure fix.
         (dsa, bdf, bmy, 8/27/02)
    (11) Met field arrays are module variables, so we don't need to pass them
         as arguments. (bmy, 11/20/02)
```

```
(12) Removed NDT from the arg list since that is always 21600.  For GEOS-4
     met fields, only interpolate PSC2; the other fields are 6-h averages.
     Eliminate TC variable, it's obsolete.  Now use double precision to
     compute TM and TC2 values.  Renamed NTIME to NTIME1 and NTIME1 to
     NTIME0.  Updated comments. (bmy, 6/19/03)
(13) Now modified for GEOS-5 and GCAP met fields. (swu, bmy, 5/25/05)
(14) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(15) Now interpolate TROPP, only if variable tropopause is used
     (phs, 9/12/06)
(16) Don't interpolate TROPP for GEOS-5 (bmy, 1/17/07)
(17) Now limit tropopause pressure to 200 mbar at latitudes above 60deg
     (phs, 9/18/07)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
18 Aug 2010 - R. Yantosca - Rewrite #if block logic for clarity
06 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x met fields
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now use GET_YEDGE(I,J,L) from new grid_mod.F90
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
29 Oct 2013 - R. Yantosca - Now interpolate T_FULLGRID field for GEOS-FP met
12 May 2015 - E. Lundgren - Fix I3 interpolation bug where time fraction
                            spans from 1 to 2, not 0 to 1, for hrs 3 to 6
11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS-FP
28 Oct 2015 - E. Lundgren - Set previous SPHU to current SPHU before update
04 May 2016 - E. Lundgren - Now also interpolate dry pressure calculated
                            in SET_DRY_SURFACE_PRESSURE using GMAO wet P
```

9.1.4 set_dry_surface_pressure

Subroutine SET_DRY_SURFACE_PRESSURE sets the dry surface pressures PS1_DRY or PS2_DRY by removing the water vapor from the column constructed with MET pressure fields PS1_WET or PS2_WET.

INTERFACE:

```
SUBROUTINE SET_DRY_SURFACE_PRESSURE( State_Met, PS_ID )
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD,            ONLY : CHECK_VALUE
USE State_Met_Mod,        ONLY : MetState
USE PRESSURE_MOD,         ONLY : GET_AP, GET_BP
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)     :: PS_ID       ! 1 = PS1, 2 = PS2
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT)  :: State_Met   ! Object for met fields
```

REVISION HISTORY:

```
03 May 2002 - E. Lundgren - Initial version (M. Lee, JPL)
```

REMARKS:

```
This subroutine is an adaptation of the GEOS-Chem moisture fix
implemented by Meemong Lee (JPL) in the adjoint model. Like PS1_WET
and PS2_WET, from which PS1_DRY and PS2_DRY are derived, these values
are interpolated within routine INTERP to derive instantaneous PSC2_DRY.
Note that PSC2_WET and PSC2_DRY are not used to fetch pressures and
calculate air quantities until after advection. Also note that the
dry surface pressure calculated in this routine may be used to
calculate delta dry pressures across a level by utilitizing GMAO
parameters Ap and Bp but should not be used to extract dry pressure
edge values as a height proxy.
```

9.1.5 is_land

Function IS_LAND returns TRUE if surface grid box (I,J) is a land box.

INTERFACE:

```
FUNCTION IS_LAND( I, J, State_Met ) RESULT ( LAND )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I           ! Longitude index of grid box
INTEGER,        INTENT(IN)  :: J           ! Latitude  index of grid box
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
LOGICAL                     :: LAND        ! =T if it is a land box
```

REVISION HISTORY:

```
26 Jun 2000 - R. Yantosca - Initial version
(1 ) Now use ALBEDO field to determine land or land ice boxes for GEOS-3.
     (bmy, 4/4/01)
(2 ) For 4x5 data, regridded albedo field can cause small inaccuracies
```

```
      near the poles (bmy, 4/4/01)
(3 ) Add references to CMN_SIZE and CMN, so that we can use the JYEAR
      variable to get the current year.  Also, for 1998, we need to compute
      if is a land box or not from the surface albedo, since for this
      year the LWI/SURFTYPE field is not given.  For other years than 1998,
      we use LWI(I,J) < 50 as our land box criterion.  Deleted obsolete
      code and updated comments.(mje, bmy, 1/9/02)
(4 ) Deleted GEOS-2 #ifdef statement.  GEOS-2 met fields never really
      materialized, we use GEOS-3 instead. (bmy, 9/18/02)
(5 ) Now uses function GET_YEAR from "time_mod.f".  Removed reference
      to CMN header file. (bmy, 3/11/03)
(6 ) Added code to determine land boxes for GEOS-4 (bmy, 6/18/03)
(7 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(8 ) Now return TRUE only for land boxes (w/ no ice) (bmy, 8/10/05)
(9 ) Now use NINT to round LWI for GEOS-4/GEOS-5 (ltm, bmy, 5/9/06)
(10) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
06 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA/GEOS-5
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

9.1.6 is_water

Function IS_WATER returns TRUE if surface grid box (I,J) is an ocean or an ocean-ice box.

INTERFACE:

```
FUNCTION IS_WATER( I, J, State_Met ) RESULT ( WATER )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
INTEGER,         INTENT(IN) :: I           ! Longitude index of grid box
INTEGER,         INTENT(IN) :: J           ! Latitude  index of grid box
TYPE(MetState),  INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
LOGICAL                     :: WATER       ! =T if this is a water box
```

REVISION HISTORY:

```
30 Jan 1998 - R. Yantosca - Initial version
(1 ) Now use ALBEDO field to determine water or water ice boxes for GEOS-3.
     (bmy, 4/4/01)
(2 ) For 4x5 data, regridded albedo field can cause small inaccuracies
     near the poles (bmy, 4/4/01)
(3 ) Add references to CMN_SIZE and CMN, so that we can use the JYEAR
     variable to get the current year.  Also, for 1998, we need to compute
     if is an ocean box or not from the surface albedo, since for this
     year the LWI/SURFTYPE field is not given.  For other years than 1998,
     we use LWI(I,J) >= 50 as our ocean box criterion.  Deleted obsolete
     code and updated comments. (mje, bmy, 1/9/02)
(4 ) Deleted GEOS-2 #ifdef statement.  GEOS-2 met fields never really
     materialized, we use GEOS-3 instead. (bmy, 9/18/02)
(5 ) Now uses function GET_YEAR from "time_mod.f".  Removed reference
     to CMN header file. (bmy, 3/11/03)
(6 ) Added code to determine water boxes for GEOS-4 (bmy, 6/18/03)
(7 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(8 ) Now remove test for sea ice (bmy, 8/10/05)
(9 ) Now use NINT to round LWI for GEOS-4/GEOS-5 (ltm, bmy, 5/9/06)
(10) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06
16 Aug 2010 - R. Yantosca - Added ProTeX headers
25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
06 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA/GEOS-5
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

9.1.7 is_ice

Function IS_ICE returns TRUE if surface grid box (I,J) contains either land-ice or sea-ice.

INTERFACE:

```
FUNCTION IS_ICE( I, J, State_Met ) RESULT ( ICE )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
INTEGER,         INTENT(IN) :: I           ! Longitude index of grid box
INTEGER,         INTENT(IN) :: J           ! Latitude  index of grid box
TYPE(MetState),  INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
LOGICAL                     :: ICE         ! =T if this is an ice box
```

REVISION HISTORY:

```
09 Aug 2005 - R. Yantosca - Initial version
(1 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
06 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA/GEOS-5
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
```

9.1.8 is_near

Function IS_NEAR returns TRUE if surface grid box (I,J) contains any land above a certain threshold (THRESH) or any of the adjacent boxes up to NEIGHBOR boxes away contain land.

INTERFACE:

```
      FUNCTION IS_NEAR( I, J, THRESH, NEIGHBOR, State_Met )
     &   RESULT ( NEAR )
```

USES:

```
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      ! Arguments
      INTEGER,        INTENT(IN) :: I, J       ! Lon & lat grid box indices
      INTEGER,        INTENT(IN) :: NEIGHBOR   ! # of neighbor boxes to consider
      REAL(fp),         INTENT(IN) :: THRESH     ! LWI threshold for near-land
      TYPE(MetState), INTENT(IN) :: State_Met  ! Meteorology State object
```

RETURN VALUE:

```
      LOGICAL                    :: NEAR       ! # of near land boxes
```

REMARKS:

```
   Typical values for:
      GCAP   : THRESH =  0.2, NEIGHBOR = 1
      GEOS-3 : THRESH = 80.0, NEIGHBOR = 1
      GEOS-4 : THRESH =  0.2, NEIGHBOR = 1
      GEOS-5 : THRESH =  0.2, NEIGHBOR = 1

   NOTE: This routine is mostly obsolete now.
```

REVISION HISTORY:

```
09 May 2006 - R. Yantosca - Initial version
(1 ) Modified for GCAP and GEOS-3 met fields (bmy, 5/16/06)
(2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
19 Aug 2010 - R. Yantosca - Rewrote logic of #if block for clarity
25 Aug 2010 - R. Yantosca - Treat MERRA in same way as GEOS-5
06 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA/GEOS-5
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

9.1.9 get_obk

Function GET_OBK returns the Monin-Obhukov length at a grid box (I,J).

INTERFACE:

```
FUNCTION GET_OBK( I, J, State_Met ) RESULT( OBK )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,         INTENT(IN) :: I           ! Longitude index
INTEGER,         INTENT(IN) :: J           ! Latitude  index
TYPE(MetState),  INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: OBK         ! Monin-Obhukhov length
```

REMARKS:

REVISION HISTORY:

```
25 May 2005 - R. Yantosca - Initial version
16 Aug 2010 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
```

9.1.10 get_cosine_sza

Routine GET_COSINE_SZA is a driver for calling the COSSZA routine from dao_mod.F. This routine calls COSSZA twice. The first call computes the sun angles at the current time and midpoint of the current chemistry time step. The second call computes the sun angles 5 hours prior to the current time (for the PARANOX ship emissions plume model).

INTERFACE:

```
      SUBROUTINE GET_COSINE_SZA( am_I_Root, Input_Opt, State_Met, RC  )
  USES:
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE JULDAY_MOD,         ONLY : JULDAY
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_DAY_OF_YEAR
      USE TIME_MOD,           ONLY : GET_DAY
      USE TIME_MOD,           ONLY : GET_GMT
      USE TIME_MOD,           ONLY : GET_HOUR
      USE TIME_MOD,           ONLY : GET_MINUTE
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : GET_YEAR
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
    07 Feb 2012 - R. Yantosca - Initial version
    27 Nov 2012 - R. Yantosca - Add am_I_root, Input_Opt, State_Met, RC args
    27 Nov 2012 - R. Yantosca - Now pass State_Met to COSSZA so that the
                                SUNCOS fields may be updated
    28 Nov 2012 - R. Yantosca - Removed references to 1-D SUNCOS arrays
    04 Dec 2014 - M. Yannetti - REAL*8 needs to stay *8 due to JULDAY
```

9.1.11 cossza

COSSZA computes the cosine of the solar zenith angle, given the day of the year and GMT hour. The cosine of the solar zenith angle is returned at both the current time and at the midpoint of the chemistry timestep (i.e. for the centralized chemistry timestep option).

INTERFACE:

```
      SUBROUTINE COSSZA( DOY, GMT_HOUR, DO_5hr_AGO, State_Met )
```

USES:

```
      USE GC_GRID_MOD,        ONLY : GET_YMID_R
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MINUTE
      USE TIME_MOD,           ONLY : GET_LOCALTIME
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: DOY          ! Day of the year
INTEGER,        INTENT(IN)    :: GMT_HOUR     ! Hour of day
LOGICAL,        INTENT(IN)    :: DO_5hr_AGO   ! Compute 5h ago?
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met    ! Meteorology State
```

REMARKS:

Hour angle (AHR) is a function of longitude. AHR is zero at solar noon, and increases by 15 deg for every hour before or after solar noon. Hour angle can be thought of as the time in hours since the sun last passed the meridian (i.e. the time since the last local noon).

.

The cosine of the solar zenith angle (SZA) is given by:

.

```
cos(SZA) = sin(LAT)*sin(DEC) + cos(LAT)*cos(DEC)*cos(AHR)
```

.

where LAT = the latitude angle,
DEC = the solar declination angle,
AHR = the hour angle, all in radians.

.

If SUNCOS < 0, then the sun is below the horizon, and therefore does not contribute to any solar heating.

REVISION HISTORY:

21 Jan 1998 - R. Yantosca - Initial version
(1) COSSZA is written in Fixed-Form Fortran 90.
(2) Use IMPLICIT NONE
(3) Use C-preprocessor #include statement to include CMN_SIZE, which has IIPAR, JJPAR, LLPAR, IIPAR, JJPAR, LGLOB.
(4) Use IM and JM (in CMN_SIZE) as loop limits.
(5) Include Harvard CTM common blocks and rename variables where needed.
(6) Use SUNCOS(MAXIJ) instead of a 2D array, in order for compatibility with the Harvard CTM subroutines. SUNCOS loops over J, then I.
(7) Added DO WHILE loops to reduce TIMLOC into the range 0h - 24h.
(8) Cosmetic changes. Also use F90 declaration statements (bmy, 6/5/00)
(9) Added to "dao_mod.f". Also updated comments. (bmy, 9/27/01)
(10) Replaced all instances of IM with IIPAR and JM with JJPAR, in order to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(11) Deleted obsolete code from 6/02 (bmy, 8/21/02)
(12) Removed RLAT and XLON from the arg list. Now compute these using functions from "grid_mod.f" (bmy, 2/3/03)
(13) Now uses GET_LOCALTIME from "time_mod.f" to get the local time. Added parallel DO loop. Removed NHMSb, NSEC arguments. (bmy, 2/13/07)
(14) Now compute SUNCOS at the midpoint of the relevant time interval (i.e. the chemistry timestep). Also make the A and B coefficients

```
      parameters instead of variables. (bmy, 4/27/10)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
05 Oct 2011 - R. Yantosca - Now also return the cosine of the solar
                            zenith angle at 30m after the GMT hour.
07 Oct 2011 - R. Yantosca - Now return SUNCOS_MID, the cos(SZA) at the
                            midpt of the chem step (not always at 00:30).
07 Feb 2012 - R. Yantosca - Now add GMT_HOUR as a new argument, which !
                            will facilitate computing sun angles 5h ago
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_LOCALTIME(I,J,L) from time_mod.F90
27 Nov 2012 - R. Yantosca - Update SUNCOS fields of the State_Met object
```

9.1.12 copy_i3_i6_fields

Subroutine COPY_I3_I6_FIELDS copies the I-6 fields at the end of a 6-hr timestep. The I-6 fields at the end of a given 6-hr timestep become the fields at the beginning of the next 6-hr timestep.

INTERFACE:

```
SUBROUTINE COPY_I3_I6_FIELDS( State_Met )
```

USES:

```
USE State_Met_Mod,        ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
13 Apr 2004 - R. Yantosca - Initial version
(1 ) Added parallel DO-loops (bmy, 4/13/04)
(2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(3 ) Added TROPP (phs 11/10/06)
(4 ) Don't copy TROPP2 to TROPP1 for GEOS-5 (bmy, 1/17/07)
16 Aug 2010 - R. Yantosca - Added ProTeX headers
20 Aug 2010 - R. Yantosca - Rewrite #if block for clarity
20 Aug 2010 - R. Yantosca - Added #if block for MERRA met fields
06 Feb 2012 - R. Yantosca - Added #if block for GEOS-5.7.x met fields
07 Feb 2012 - R. Yantosca - Renamed to COPY_I3_I6_FIELDS
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
11 Aug 2015 - R. Yantosca - MERRA2 behaves in the same way as GEOS-FP
03 May 2016 - E. Lundgren - Add PS1_DRY update
```

9.2 Fortran: Module Interface merra2_read_mod.F90

Module MERRA2_READ_MOD contains subroutines for reading the MERRA2 data from disk (in netCDF format).

INTERFACE:

```
MODULE Merra2_Read_Mod
```

USES:

```
  ! NcdfUtil modules for netCDF I/O
  USE m_netcdf_io_open                    ! netCDF open
  USE m_netcdf_io_get_dimlen              ! netCDF dimension queries
  USE m_netcdf_io_read                    ! netCDF data reads
  USE m_netcdf_io_close                   ! netCDF close

  ! GEOS-Chem modules
  USE CMN_SIZE_MOD                        ! Size parameters
#if defined( BPCH_DIAG )
  USE CMN_DIAG_MOD                        ! Diagnostic arrays & counters
  USE DIAG_MOD,      ONLY : AD21          ! Array for ND21 diagnostic
  USE DIAG_MOD,      ONLY : AD66          ! Array for ND66 diagnostic
  USE DIAG_MOD,      ONLY : AD67          ! Array for ND67 diagnostic
#endif
  USE ERROR_MOD,     ONLY : ERROR_STOP    ! Stop w/ error message
  USE PhysConstants                       ! Physical constants
  USE Precision_Mod                       ! Flexible precision definitions
  USE TIME_MOD                            ! Date & time routines
  USE TRANSFER_MOD                        ! Routines for casting

  IMPLICIT NONE
  PRIVATE

# include "netcdf.inc"                    ! Include file for netCDF library
```

PRIVATE MEMBER FUNCTIONS:

```
  PRIVATE :: Check_Dimensions
  PRIVATE :: Merra2_Read_A3cld
  PRIVATE :: Merra2_Read_A3dyn
  PRIVATE :: Merra2_Read_A3mstC
  PRIVATE :: Merra2_Read_A3mstE
  PRIVATE :: Get_Resolution_String
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: Merra2_Read_CN
  PUBLIC  :: Merra2_Read_A1
  PUBLIC  :: Merra2_Read_A3
  PUBLIC  :: Merra2_Read_I3_1
```

```
PUBLIC  :: Merra2_Read_I3_2
PUBLIC  :: Cleanup_Merra2_Read
```

REMARKS:

```
Assumes that you have a netCDF library (either v3 or v4) installed on
your system.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Add file ID's as module variables
03 Dec 2015 - R. Yantosca - Add CLEANUP_MERRA2_READ to close any open
                            netCDF files left at the end of a simulation
02 Feb 2016 - E. Lundgren - Block of diagnostics with if defined BPCH
```

9.2.1 Get_Resolution_String

Function Get_Resolution_String returns the proper filename extension for the GEOS-Chem horizontal grid resolution. This is used to construct the various file names.

INTERFACE:

```
FUNCTION Get_Resolution_String() RESULT( resString )
```

RETURN VALUE:

```
 CHARACTER(LEN=255) :: resString
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
13 Aug 2015 - R. Yantosca - MERRA2 data is now storead as netCDF4 (.nc4)
```

9.2.2 Check_Dimensions

Subroutine CHECK_DIMENSIONS checks to see if dimensions read from the netCDF file match the defined GEOS-Chem dimensions. If not, then it will stop the GEOS-Chem simulation with an error message.

INTERFACE:

```
SUBROUTINE Check_Dimensions( lon, lat, lev, time, time_expected, caller )
```

INPUT PARAMETERS:

```
 INTEGER,          OPTIONAL, INTENT(IN)  :: lon           ! Lon dimension
 INTEGER,          OPTIONAL, INTENT(IN)  :: lat           ! Lat dimension
 INTEGER,          OPTIONAL, INTENT(IN)  :: lev           ! Alt dimension
```

```
INTEGER,          OPTIONAL, INTENT(IN)  :: time           ! Time dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: time_expected  ! Expected # of
                                                          !  time slots
CHARACTER(LEN=*), OPTIONAL, INTENT(IN)  :: caller         ! Name of caller
                                                          !  routine
```

REMARKS:

```
Call this routine with keyword arguments, e.g
   CALL CHECK_DIMENSION( lon=X,  lat=Y,           lev=Z,         &
                         time=T, time_expected=8, caller=caller )
```

REVISION HISTORY:

```
02 Feb 2012 - R. Yantosca - Initial version
03 Feb 2012 - R. Yantosca - Now pass the caller routine name as an argument
```

9.2.3 Merra2_Read_cn

Routine to read variables and attributes from a MERRA2 met fields file containing constant (CN) data.

INTERFACE:

```
SUBROUTINE Merra2_Read_CN( Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
13 Aug 2015 - R. Yantosca - Bug fix: change CN date to 2015/01/01
```

9.2.4 Merra2_Read_a1

Routine to read variables and attributes from a MERRA2 met fields file containing 1-hr time-averaged (A1) data.

INTERFACE:

```
SUBROUTINE Merra2_Read_A1( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.

                                                                             .
Special handling for surface precipitation fields:
-----------------------------------------------------------------------------
In MERRA2 (and in MERRA), the PRECTOT etc. surface precipitation
met fields fields have units of [kg/m2/s].  In all other GEOS
versions, PREACC and PRECON have units of [mm/day].

                                                                             .
Therefore, for backwards compatibility with existing code, apply
the following unit conversion to the GEOS-5 PRECTOT and PRECCON
fields:

                                                                             .
    kg  |    m3    | 86400 s | 1000 mm
  ------+----------+---------+--------- = 86400
   m2 s |  1000 kg |  day    |   m
             ^
             |
      1 / density of water
```

REMARKS:

```
MERRA2 pressure quantities are stored on disk with units of Pa.  For now
we will convert to hPa for compatibility with GEOS-Chem.  But in the near
future we will probably recode GEOS-Chem to use the native units, which
facilitate GEOS-Chem HP development.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
23 Sep 2015 - E. Lundgren - Now assign SWGDN to State_Met SWGDN not RADSWG
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.2.5 Merra2_Read_a3

Convenience wrapper for the following routines which read 3-hour time averaged data from disk:

- Merra2_Read_A3cld
- Merra2_Read_A3dyn
- Merra2_Read_A3mstC
- Merra2_Read_A3mstE

INTERFACE:

```
SUBROUTINE Merra2_Read_A3( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
```

9.2.6 Merra2_Read_a3cld

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr time-averaged (A3) data (cloud fields).

INTERFACE:

```
SUBROUTINE Merra2_Read_A3cld( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
17 Mar 2016 - M. Sulprizio- Read optical depth into State_Met%OPTD instead of
                            State_Met%OPTDEP (obsolete).
```

9.2.7 Merra2_Read_a3dyn

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr time-averaged (A3) data (dynamics fields).

INTERFACE:

```
SUBROUTINE Merra2_Read_A3dyn( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.2.8 Merra2_Read_a3mstc

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr time-averaged (A3) data (moist fields, saved on level centers).

INTERFACE:

```
SUBROUTINE Merra2_Read_A3mstC( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.2.9 Merra2_Read_a3mste

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr time-averaged (A3) data (moist fields, saved on level edges).

INTERFACE:

```
SUBROUTINE Merra2_read_A3mstE( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.2.10 Merra2_Read_I3_1

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr instantaneous (I3) data.

INTERFACE:

```
SUBROUTINE Merra2_Read_I3_1( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
MERRA2 pressure quantities are stored on disk with units of Pa.  For now
we will convert to hPa for compatibility with GEOS-Chem.  But in the near
future we will probably recode GEOS-Chem to use the native units, which
facilitate GEOS-Chem HP development.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.2.11 Merra2_Read_I3_2

Routine to read variables and attributes from a MERRA2 met fields file containing 3-hr instantaneous (I3) data.

INTERFACE:

```
SUBROUTINE Merra2_Read_I3_2( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
Even though the netCDF file is self-describing, the MERRA2 data,
dimensions, and units are pre-specified according to the GMAO MERRA2
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
MERRA2 pressure quantities are stored on disk with units of Pa.  For now
we will convert to hPa for compatibility with GEOS-Chem.  But in the near
future we will probably recode GEOS-Chem to use the native units, which
facilitate GEOS-Chem HP development.
```

REVISION HISTORY:

```
12 Aug 2015 - R. Yantosca - Initial version, based on geosfp_read_mod.F90
03 Dec 2015 - R. Yantosca - Now open file only once per day
20 Sep 2016 - R. Yantosca - Bug fix: FIRST must be declared as LOGICAL
```

9.2.12 Cleanup_Merra2_Read

Closes any open netCDF files at the end of a simulation. This can occur if the simulation ends at a time other than 00:00 GMT.

INTERFACE:

```
SUBROUTINE Cleanup_Merra2_Read()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
```

9.3 Fortran: Module Interface geosfp_read_mod.F90

Module GEOSFP_READ_MOD contains subroutines for reading the GEOS-FP data from disk (in netCDF format).

INTERFACE:

```
MODULE GeosFp_Read_Mod
```

USES:

```
! NcdfUtil modules for netCDF I/O
USE m_netcdf_io_open                    ! netCDF open
USE m_netcdf_io_get_dimlen              ! netCDF dimension queries
USE m_netcdf_io_read                    ! netCDF data reads
USE m_netcdf_io_close                   ! netCDF close

! GEOS-Chem modules
USE CMN_SIZE_MOD                        ! Size parameters
```

```
#if defined( BPCH_DIAG )
  USE CMN_DIAG_MOD                          ! Diagnostic arrays & counters
  USE DIAG_MOD,      ONLY : AD21            ! Array for ND21 diagnostic
  USE DIAG_MOD,      ONLY : AD66            ! Array for ND66 diagnostic
  USE DIAG_MOD,      ONLY : AD67            ! Array for ND67 diagnostic
#endif
  USE ERROR_MOD,     ONLY : ERROR_STOP      ! Stop w/ error message
  USE PhysConstants                         ! Physical constants
  USE TIME_MOD                              ! Date & time routines
  USE TRANSFER_MOD                          ! Routines for casting

  IMPLICIT NONE
  PRIVATE

# include "netcdf.inc"                      ! Include file for netCDF library
```

PRIVATE MEMBER FUNCTIONS:

```
  PRIVATE :: Check_Dimensions
  PRIVATE :: GeosFp_Read_A3cld
  PRIVATE :: GeosFp_Read_A3dyn
  PRIVATE :: GeosFp_Read_A3mstC
  PRIVATE :: GeosFp_Read_A3mstE
  PRIVATE :: Get_Resolution_String
```

PUBLIC MEMBER FUNCTIONS:

```
  PUBLIC  :: GeosFp_Read_CN
  PUBLIC  :: GeosFp_Read_A1
  PUBLIC  :: GeosFp_Read_A3
  PUBLIC  :: GeosFp_Read_I3_1
  PUBLIC  :: GeosFp_Read_I3_2
  PUBLIC  :: Cleanup_GeosFp_Read
```

REMARKS:

```
  Assumes that you have a netCDF library (either v3 or v4) installed on
  your system.
```

REVISION HISTORY:

```
  30 Jan 2012 - R. Yantosca - Initial version
  03 Feb 2012 - R. Yantosca - Add Geos57_Read_A3 wrapper function
  07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
  10 Feb 2012 - R. Yantosca - Add function Get_Resolution_String
  05 Apr 2012 - R. Yantosca - Convert units for specific humidity properly
  15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
  11 Apr 2013 - R. Yantosca - Now pass directory fields via Input_Opt
  26 Sep 2013 - R. Yantosca - Renamed to geosfp_read_mod.F90
  14 Jan 2014 - R. Yantosca - Remove "define GEOS572_FILES #ifdef blocks
  14 Aug 2014 - R. Yantosca - Compute CLDTOPS field in GeosFp_Read_A3mstE
```

```
03 Dec 2015 - R. Yantosca - Add file ID's as module variables
03 Dec 2015 - R. Yantosca - Add CLEANUP_GEOSFP_READ to close any open
                            netCDF files left at the end of a simulation
02 Feb 2016 - E. Lundgren - Block of diagnostics with if defined BPCH
```

9.3.1 Get_Resolution_String

Function Get_Resolution_String returns the proper filename extension for the GEOS-Chem horizontal grid resolution. This is used to construct the various file names.

INTERFACE:

```
FUNCTION Get_Resolution_String() RESULT( resString )
```

RETURN VALUE:

```
CHARACTER(LEN=255) :: resString
```

REVISION HISTORY:

```
10 Feb 2012 - R. Yantosca - Initial version
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Remove SEAC4RS C-preprocssor switch
```

9.3.2 Check_Dimensions

Subroutine CHECK_DIMENSIONS checks to see if dimensions read from the netCDF file match the defined GEOS-Chem dimensions. If not, then it will stop the GEOS-Chem simulation with an error message.

INTERFACE:

```
SUBROUTINE Check_Dimensions( lon, lat, lev, time, time_expected, caller )
```

INPUT PARAMETERS:

```
INTEGER,          OPTIONAL, INTENT(IN)  :: lon           ! Lon dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: lat           ! Lat dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: lev           ! Alt dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: time          ! Time dimension
INTEGER,          OPTIONAL, INTENT(IN)  :: time_expected ! Expected # of
                                                         !  time slots
CHARACTER(LEN=*), OPTIONAL, INTENT(IN)  :: caller        ! Name of caller
                                                         !  routine
```

REMARKS:

```
Call this routine with keyword arguments, e.g
   CALL CHECK_DIMENSION( lon=X,  lat=Y,           lev=Z,         &
                         time=T, time_expected=8, caller=caller )
```

REVISION HISTORY:

```
02 Feb 2012 - R. Yantosca - Initial version
03 Feb 2012 - R. Yantosca - Now pass the caller routine name as an argument
```

9.3.3 GeosFp_Read_cn

Routine to read variables and attributes from a GEOS-FP met fields file containing constant (CN) data.

INTERFACE:

```
SUBROUTINE GeosFp_Read_CN( Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_CN
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
```

9.3.4 GeosFp_Read_a1

Routine to read variables and attributes from a GEOS-FP met fields file containing 1-hr time-averaged (A1) data.

INTERFACE:

```
SUBROUTINE GeosFp_Read_A1( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

.

Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.

.

Special handling for surface precipitation fields:
-------------------------------------------------------------------------
In GEOS-FP (and in MERRA), the PRECTOT etc. surface precipitation
met fields fields have units of [kg/m2/s].  In all other GEOS
versions, PREACC and PRECON have units of [mm/day].

.

Therefore, for backwards compatibility with existing code, apply
the following unit conversion to the GEOS-5 PRECTOT and PRECCON
fields:

.

    kg  |    m3    | 86400 s | 1000 mm
  ------+----------+---------+--------- = 86400
   m2 s |  1000 kg |  day    |   m
             ^
             |
      1 / density of water
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
04 Jan 2013 - M. Payer    - Bug fix: Use State_Met%TSKIN for ND67 surface
                            skin temperature diagnostic, not State_MET%TS
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
02 Dec 2013 - S. Philip   - Correction for GEOS-FP boundary layer height
04 Dec 2013 - R. Yantosca - Now comment out GEOS-FP BL height correction
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
23 Sep 2015 - E. Lundgren - Now assign SWGDN to State_Met SWGDN not RADSWG
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.3.5 GeosFp_Read_a3

Convenience wrapper for the following routines which read 3-hour time averaged data from disk:

- GeosFp_Read_A3cld
- GeosFp_Read_A3dyn
- GeosFp_Read_A3mstC
- GeosFp_Read_A3mstE

INTERFACE:

```
SUBROUTINE GeosFp_Read_A3( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_A3
```

9.3.6 GeosFp_Read_a3cld

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr time-averaged (A3) data (cloud fields).

INTERFACE:

```
SUBROUTINE GeosFp_Read_A3cld( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

                                                                        .
Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
05 Apr 2012 - R. Yantosca - Fixed bug: TAUCLI was overwritten w/ TAUCLW
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_A3Cld
06 Nov 2014 - R. Yantosca - Replace TRANSFER_A6 with TRANSFER_3D
03 Dec 2015 - R. Yantosca - Now open file only once per day
17 Mar 2016 - M. Sulprizio- Read optical depth into State_Met%OPTD instead of
                            State_Met%OPTDEP (obsolete).
```

9.3.7 GeosFp_Read_a3dyn

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr time-averaged (A3) data (dynamics fields).

INTERFACE:

```
SUBROUTINE GeosFp_Read_A3dyn( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

                                                                             .
Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directories with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_A3dyn
15 Nov 2013 - R. Yantosca - Now convert RH from [1] to [%], in order
                            to be consistent with GEOS-Chem convention
14 Aug 2014 - R. Yantosca - Now compute CLDTOPS in GeosFP_Read_A3mstE
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.3.8 GeosFp_Read_a3mstc

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr time-averaged (A3) data (moist fields, saved on level centers).

INTERFACE:

```
SUBROUTINE GeosFp_Read_A3mstC( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

                                                                             .
Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_A3mstC
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.3.9 GeosFp_Read_a3mste

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr time-averaged (A3) data (moist fields, saved on level edges).

INTERFACE:

```
SUBROUTINE GeosFp_Read_A3mstE( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

                                                                             .
Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_A3mstE
26 Sep 2013 - R. Yantosca - Now read CMFMC from GEOSFP*.nc files
14 Aug 2014 - R. Yantosca - Now compute CLDTOPS here; it depends on CMFMC
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.3.10 GeosFp_Read_I3_1

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr instantaneous (I3) data.

INTERFACE:

```
SUBROUTINE GeosFp_Read_I3_1( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

                                                                        .
Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
05 Apr 2012 - R. Yantosca - Now convert QV1 from [kg/kg] to [g/kg]
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
06 Sep 2013 - R. Yantosca - Bug fix: we need to initialize State_Met%T
                            with State_Met%TMPU1 to avoid errors.  The
                            State_Met%T field will be set again in INTERP.
26 Sep 2013 - R. Yantosca - Renamed to GeosFp_Read_I3_1
29 Oct 2013 - R. Yantosca - Now read T_FULLGRID_1 for offline simulations
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
16 Apr 2015 - R. Yantosca - Remove reference to T_FULLGRID; it's obsolete
12 Jun 2015 - E. Lundgren - Initialize State_MET%SPHU with State_Met%SPHU1
03 Dec 2015 - R. Yantosca - Now open file only once per day
```

9.3.11 GeosFp_Read_I3_2

Routine to read variables and attributes from a GEOS-FP met fields file containing 3-hr instantaneous (I3) data.

INTERFACE:

```
SUBROUTINE GeosFp_Read_I3_2( YYYYMMDD, HHMMSS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: YYYYMMDD   ! GMT date in YYYY/MM/DD format
INTEGER,        INTENT(IN)    :: HHMMSS     ! GMT time in hh:mm:ss   format
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REMARKS:

```
This routine was automatically generated by the Perl script ncCodeRead,
and was subsequently hand-edited for compatibility with GEOS-Chem.

.

Even though the netCDF file is self-describing, the GEOS-FP data,
dimensions, and units are pre-specified according to the GMAO GEOS-FP
file specification.  Therefore we can "cheat" a little bit and not have
to read netCDF attributes to find what these values are.
```

REVISION HISTORY:

```
30 Jan 2012 - R. Yantosca - Initial version
07 Feb 2012 - R. Yantosca - Now echo info after reading fields from disk
10 Feb 2012 - R. Yantosca - Now get a string for the model resolution
05 Apr 2012 - R. Yantosca - Now convert QV2 from [kg/kg] to [g/kg]
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
26 Sep 2013 - R. Yantosca - Rename to GeosFp_Read_I3_2
29 Oct 2013 - R. Yantosca - Now read T_FULLGRID_2 for offline simulations
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
03 Dec 2015 - R. Yantosca - Now open file only once per day
20 Sep 2016 - R. Yantosca - Bug fix: FIRST must be declared as LOGICAL
```

9.3.12 Cleanup_GeosFp_Read

Closes any open netCDF files at the end of a simulation. This can occur if the simulation ends at a time other than 00:00 GMT.

INTERFACE:

```
SUBROUTINE Cleanup_GeosFp_Read()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
```

9.4 Fortran: Module Interface merra_a1_mod.F90

Module MERRA_A1_MOD contains subroutines for reading the 1-hour time averaged (aka "A1") fields from the MERRA data archive.

INTERFACE:

```
MODULE MERRA_A1_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: GET_MERRA_A1_FIELDS
PUBLIC  :: OPEN_MERRA_A1_FIELDS
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: A1_CHECK
PRIVATE :: DO_OPEN_A1
PRIVATE :: READ_A1
```

REMARKS:

```
Don't bother with the file unzipping anymore.
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
03 Aug 2012 - R. Yantosca - Now make IU_A1 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.4.1 do_open_a1

Function DO_OPEN_A1 returns TRUE if is time to open the A1 met field file or FALSE otherwise. This prevents us from opening a file which has already been opened.

INTERFACE:

```
FUNCTION DO_OPEN_A1( NYMD, NHMS, RESET ) RESULT( DO_OPEN )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)           :: NYMD     ! YYYYMMDD and hhmmss to test
INTEGER, INTENT(IN)           :: NHMS     !  if it's time to open file
LOGICAL, INTENT(IN), OPTIONAL :: RESET    ! Reset the
```

RETURN VALUE:

```
      LOGICAL                       :: DO_OPEN  ! =T if it's time to open file
```

REVISION HISTORY:

```
    19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
    21 Sep 2010 - R. Yantosca - Add RESET via the argument list to reset
                                the FIRST flag if so desired.
```

9.4.2 open_merra_a1_fields

Subroutine OPEN_MERRA_A1_FIELDS opens the A1 met fields file for date NYMD and time NHMS.

INTERFACE:

```
      SUBROUTINE OPEN_MERRA_A1_FIELDS( NYMD,  NHMS, Input_Opt,
     &                                 RESET, IUNIT            )
```

USES:

```
      USE BPCH2_MOD,          ONLY : GET_RES_EXT
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE FILE_MOD,           ONLY : FILE_EXISTS
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)            :: NYMD      ! YYYYMMDD date
      INTEGER,        INTENT(IN)            :: NHMS      ! hhmmss time
      TYPE(OptInput), INTENT(IN)            :: Input_Opt ! Input Options
      LOGICAL,        INTENT(IN),  OPTIONAL :: RESET     ! Reset first A1 flag?
```

INPUT/OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT), OPTIONAL :: IUNIT     ! Returns IU_A1
```

REVISION HISTORY:

```
    19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
    03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_A1 locally
    06 Aug 2012 - R. Yantosca - Add optional IUNIT to pass LUN to calling routine
    07 Aug 2012 - R. Yantosca - Now print LUN used to open file
    11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
```

9.4.3 get_merra_a1_fields

Subroutine GET_MERRA_A1_FIELDS is a wrapper for routine READ_A1.

INTERFACE:

```
SUBROUTINE GET_MERRA_A1_FIELDS( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE CMN_SIZE_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD        ! YYYYMMDD and
INTEGER,        INTENT(IN)    :: NHMS        !  hhmmss of data to read
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
25 Aug 2010 - R. Yantosca - Now pass LWI down to READ_A1
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Remove reference to dao_mod.F module arrays
22 Sep 2015 - E. Lundgren - Now also read SWGDN
```

9.4.4 read_a1

Subroutine READ_A1 reads MERRA 1-hour time averaged ("A1") met fields from disk.

INTERFACE:

```
 SUBROUTINE READ_A1( NYMD,     NHMS,     Input_Opt,
&                    ALBEDO,   CLDTOT,   EFLUX,    EVAP,
&                    FRSEAICE, FRSNO,    GRN,      GWETROOT,
&                    GWETTOP,  HFLUX,    LAI,      LWGNT,
&                    LWI,      PARDF,    PARDR,    PBLH,
&                    PRECANV,  PRECTOT,  PRECCON,  PRECLSC,
&                    PRECSNO,  SEAICE00, SEAICE10, SEAICE20,
&                    SEAICE30, SEAICE40, SEAICE50, SEAICE60,
&                    SEAICE70, SEAICE80, SEAICE90, SLP,
&                    SNODP,    SNOMAS,   SWGDN,    SWGNT,
&                    TROPPT,   T2M,      TS,       U10M,
&                    USTAR,    V10M,     Z0M               )
```

USES:

```
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_CT_A1
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: NYMD            ! YYYYMMDD and hhmmss
      INTEGER,        INTENT(IN)  :: NHMS            !  of data to read
      TYPE(OptInput), INTENT(IN)  :: Input_Opt       ! Input Options object
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT) :: ALBEDO  (IIPAR,JJPAR)  ! Sfc albedo [unitless]
      REAL(fp),  INTENT(OUT) :: CLDTOT  (IIPAR,JJPAR)  ! Column cld fraction
      REAL(fp),  INTENT(OUT) :: EFLUX   (IIPAR,JJPAR)  ! Latent heat flux [W/m2]
      REAL(fp),  INTENT(OUT) :: EVAP    (IIPAR,JJPAR)  ! Surface evap [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: FRSEAICE(IIPAR,JJPAR)  ! Sfc sea ice fraction
      REAL(fp),  INTENT(OUT) :: FRSNO   (IIPAR,JJPAR)  ! Sfc snow fraction
      REAL(fp),  INTENT(OUT) :: GRN     (IIPAR,JJPAR)  ! Greenness fraction
      REAL(fp),  INTENT(OUT) :: GWETROOT(IIPAR,JJPAR)  ! Root soil wetness [frac]
      REAL(fp),  INTENT(OUT) :: GWETTOP (IIPAR,JJPAR)  ! Topsoil wetness [frac]
      REAL(fp),  INTENT(OUT) :: HFLUX   (IIPAR,JJPAR)  ! Sensible H-flux [W/m2]
      REAL(fp),  INTENT(OUT) :: LAI     (IIPAR,JJPAR)  ! Leaf area index [m2/m2]
      REAL(fp),  INTENT(OUT) :: LWI     (IIPAR,JJPAR)  ! Leaf area index [m2/m2]
      REAL(fp),  INTENT(OUT) :: LWGNT   (IIPAR,JJPAR)  ! Net LW rad @ sfc [W/m2]
      REAL(fp),  INTENT(OUT) :: PARDF   (IIPAR,JJPAR)  ! Diffuse PAR [W/m2]
      REAL(fp),  INTENT(OUT) :: PARDR   (IIPAR,JJPAR)  ! Direct PAR [W/m2]
      REAL(fp),  INTENT(OUT) :: PBLH    (IIPAR,JJPAR)  ! PBL height [m]
      REAL(fp),  INTENT(OUT) :: PRECANV (IIPAR,JJPAR)  ! Anv prec @ sfc [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: PRECTOT (IIPAR,JJPAR)  ! Tot prec @ sfc [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: PRECCON (IIPAR,JJPAR)  ! CV prec @ sfc [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: PRECLSC (IIPAR,JJPAR)  ! LS prec @ sfc [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: PRECSNO (IIPAR,JJPAR)  ! Snow precip [kg/m2/s]
      REAL(fp),  INTENT(OUT) :: SEAICE00(IIPAR,JJPAR)  ! Sea ice coverage 00-10%
      REAL(fp),  INTENT(OUT) :: SEAICE10(IIPAR,JJPAR)  ! Sea ice coverage 10-20%
      REAL(fp),  INTENT(OUT) :: SEAICE20(IIPAR,JJPAR)  ! Sea ice coverage 20-30%
      REAL(fp),  INTENT(OUT) :: SEAICE30(IIPAR,JJPAR)  ! Sea ice coverage 30-40%
      REAL(fp),  INTENT(OUT) :: SEAICE40(IIPAR,JJPAR)  ! Sea ice coverage 40-50%
      REAL(fp),  INTENT(OUT) :: SEAICE50(IIPAR,JJPAR)  ! Sea ice coverage 50-60%
      REAL(fp),  INTENT(OUT) :: SEAICE60(IIPAR,JJPAR)  ! Sea ice coverage 60-70%
      REAL(fp),  INTENT(OUT) :: SEAICE70(IIPAR,JJPAR)  ! Sea ice coverage 70-80%
      REAL(fp),  INTENT(OUT) :: SEAICE80(IIPAR,JJPAR)  ! Sea ice coverage 80-90%
```

```
REAL(fp),  INTENT(OUT) :: SEAICE90(IIPAR,JJPAR)  ! Sea ice coverage 90-100%
REAL(fp),  INTENT(OUT) :: SLP     (IIPAR,JJPAR)  ! Sea level pressure [hPa]
REAL(fp),  INTENT(OUT) :: SNODP   (IIPAR,JJPAR)  ! Snow depth [m]
REAL(fp),  INTENT(OUT) :: SNOMAS  (IIPAR,JJPAR)  ! Snow mass [kg/m2]
REAL(fp),  INTENT(OUT) :: SWGDN   (IIPAR,JJPAR)  ! Incident SW rad @ sfc
                                                 ! [W/m2]
REAL(fp),  INTENT(OUT) :: SWGNT   (IIPAR,JJPAR)  ! Net SW rad @ sfc [W/m2]
REAL(fp),  INTENT(OUT) :: TROPPT  (IIPAR,JJPAR)  ! T'pause pressure [hPa]
REAL(fp),  INTENT(OUT) :: T2M     (IIPAR,JJPAR)  ! T @ 2m height [K]
REAL(fp),  INTENT(OUT) :: TS      (IIPAR,JJPAR)  ! Sfc skin T [K]
REAL(fp),  INTENT(OUT) :: U10M    (IIPAR,JJPAR)  ! U-wind @ 10m [m/s]
REAL(fp),  INTENT(OUT) :: USTAR   (IIPAR,JJPAR)  ! Friction velocity [m/s]
REAL(fp),  INTENT(OUT) :: V10M    (IIPAR,JJPAR)  ! V-wind @ 10m [m/s]
REAL(fp),  INTENT(OUT) :: Z0M     (IIPAR,JJPAR)  ! Roughness height [m]
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
25 Aug 2010 - R. Yantosca - Now read LWI (land/water/ice) from disk
15 Aug 2011 - R. Yantosca - Now save SWGDN in 2nd slot of ND67 diagnostic
25 Mar 2011 - R. Yantosca - Bug fix: make local SWGDN array for ND67 diag
08 Jun 2012 - S. Philip   - Correction for MERRA boundary layer height
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_A1 file LUN
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
22 Sep 2015 - E. Lundgren - Now save SWGDN globally
02 Feb 2016 - E. Lundgren - Block off bpch diagnostics with if defined bpch
```

9.4.5 a1_check

Subroutine A1_CHECK prints an error message if not all of the A-3 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE A1_CHECK( NFOUND, N_A1 )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! Number of met fields read in from disk
INTEGER, INTENT(IN) :: N_A1     ! Number of expected met fields
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
```

9.5 Fortran: Module Interface merra_a3_mod.F90

Module MERRA_A3_MOD contains subroutines for reading the 3-hour time averaged (aka "A3") fields from the MERRA data archive.

INTERFACE:

```
MODULE MERRA_A3_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: GET_MERRA_A3_FIELDS
PUBLIC  :: OPEN_MERRA_A3_FIELDS
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: A3_CHECK
PRIVATE :: DO_OPEN_A3
PRIVATE :: READ_A3
```

REMARKS:

```
Don't bother with the file unzipping anymore.
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
03 Aug 2012 - R. Yantosca - Now make IU_A3 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.5.1 do_open_a3

unction DO_OPEN_A3 returns TRUE if is time to open the A3 met field file or FALSE otherwise. This prevents us from opening a file which has already been opened.

INTERFACE:

```
FUNCTION DO_OPEN_A3( NYMD, NHMS ) RESULT( DO_OPEN )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NYMD      ! YYYYMMDD and hhmmss to be tested
INTEGER, INTENT(IN) :: NHMS      !  to see if it's time to open A3 file
```

RETURN VALUE:

```
LOGICAL             :: DO_OPEN   ! = T if it is time to open the file
```

REVISION HISTORY:

```
20 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
```

9.5.2 open_merra_a3_fields

Subroutine OPEN_MERRA_A3_FIELDS opens the A3 met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_MERRA_A3_FIELDS( NYMD, NHMS, Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : FILE_EXISTS
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: NYMD        ! YYYYMMDD and hhmmss
INTEGER,        INTENT(IN) :: NHMS        !  to test for A3 file open
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
```

REVISION HISTORY:

```
20 Aug 2010 - R. Yantosca - Initial version, based on a6_read_mod.f
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_A3 locally
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass fields with Input_Opt
```

9.5.3 get_merra_a3_fields

Subroutine GET_MERRA_A3_FIELDS is a wrapper for routine READ_A3.

INTERFACE:

```
SUBROUTINE GET_MERRA_A3_FIELDS( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
      USE CMN_SIZE_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: NYMD        ! YYYYMMDD and
      INTEGER,        INTENT(IN)    :: NHMS        !  hhmmss of desired data
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
   20 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
   09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                               object
   15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_met
   23 Oct 2013 - R. Yantosca - Now accept Input_Opt as an argument
   23 Oct 2013 - R. Yantosca - Now read T_FULLGRID for specialty (offline) sims
   16 Apr 2015 - R. Yantosca - Remove reference to T_FULLGRID; it's obsolete
   17 Mar 2016 - M. Sulprizio- Read optical depth into State_Met%OPTD instead of
                               State_Met%OPTDEP (obsolete).
```

9.5.4 read_a3

Subroutine READ_A3 reads the MERRA 3-hour time-averaged (aka "A3") met fields from disk.

INTERFACE:

```
      SUBROUTINE READ_A3( NYMD,     NHMS,      Input_Opt,
     &                    CLOUD,    CLDTOPS,   CMFMC,    DQRCU,
     &                    DQRLSAN,  DQIDTMST,  DQLDTMST, DQVDTMST,
     &                    DTRAIN,   MOISTQ,    OPTDEPTH, PFICU,
     &                    PFILSAN,  PFLCU,     PFLLSAN,  QI,
     &                    QL,       QV,        REEVAPCN, REEVAPLS,
     &                    T,        TAUCLI,    TAUCLW,   U,
     &                    V                                      )
```

USES:

```
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD
```

```
      USE DIAG_MOD,           ONLY : AD21
      USE DIAG_MOD,           ONLY : AD66
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_CT_A3
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D_Lp1
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D
      USE TRANSFER_MOD,       ONLY : TRANSFER_G5_PLE
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN) :: NYMD        ! YYYYMMDD & hhmmss
      INTEGER,        INTENT(IN) :: NHMS        !  of desired data
      TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      ! Fields dimensioed as (I,J)
      INTEGER, INTENT(OUT) :: CLDTOPS   (IIPAR,JJPAR       )

      ! Fields dimensioned as (I,J,L)
      REAL(fp),  INTENT(OUT) :: CMFMC     (IIPAR,JJPAR,LLPAR+1)
      REAL(fp),  INTENT(OUT) :: DQRCU     (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: DQRLSAN   (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: DQIDTMST  (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: DQLDTMST  (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: DQVDTMST  (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: DTRAIN    (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: PFICU     (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: PFILSAN   (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: PFLCU     (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: PFLLSAN   (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: QI        (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: QL        (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: QV        (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: REEVAPCN  (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: REEVAPLS  (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: T         (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: TAUCLI    (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: TAUCLW    (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: U         (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: V         (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: CLOUD     (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: MOISTQ    (IIPAR,JJPAR,LLPAR  )
      REAL(fp),  INTENT(OUT) :: OPTDEPTH  (IIPAR,JJPAR,LLPAR  )
```

REVISION HISTORY:

```
20 Aug 2010 - R. Yantosca - Initial version, based on a3_read_mod.f
20 Aug 2010 - R. Yantosca - Now save CLDTOPS to ND67 diagnostic
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_A3 file LUN
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
05 Sep 2013 - R. Yantosca - Set negatives in QI, QL to zero
28 Oct 2013 - R. Yantosca - Add optional T_FULLGRID argument for the
                            offline "specialty" simulations
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
06 Nov 2014 - R. Yantosca - All input arguments are declared as (I,J,L)
06 Nov 2014 - R. Yantosca - Replace TRANSFER_A6 with TRANSFER_3D
16 Apr 2015 - R. Yantosca - Remove reference to T_FULLGRID; it's obsolete
02 Feb 2016 - E. Lundgren - Block of diagnostics with if defined BPCH
```

9.5.5 a3_check

Subroutine A3_CHECK prints an error message if not all of the A-6 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE A3_CHECK( NFOUND, N_A3 )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! # of fields found in file
INTEGER, INTENT(IN) :: N_A3     ! # of expected fields
```

REVISION HISTORY:

```
20 Aug 2010 - R. Yantosca - Initial version, based on a6_read_mod.f
```

9.6 Fortran: Module Interface merra_cn_mod.F90

Module MERRA_CN_MOD contains subroutines for reading the constant (aka "CN") fields from the MERRA data archive.

INTERFACE:

```
MODULE MERRA_CN_MOD
```

USES:

```
USE CMN_SIZE_MOD                       ! Size parameters
USE CMN_DIAG_MOD                       ! NDxx flags
USE inquireMod,    ONLY : findFreeLUN  ! Routine to find free LUNs
USE PhysConstants                      ! g0
USE PRECISION_MOD                      ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: GET_MERRA_CN_FIELDS
PUBLIC  :: OPEN_MERRA_CN_FIELDS
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: CN_CHECK
PRIVATE :: READ_CN
```

REMARKS:

Don't bother with the file unzipping anymore.

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
20 Aug 2010 - R. Yantosca - Moved include files to top of module
03 Aug 2012 - R. Yantosca - Now make IU_A3 a private module variable
09 Nov 2012 - R. Yantosca - Now get met fields from State_Met object
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.6.1 open_merra_cn_fields

Subroutine OPEN_MERRA_CN_FIELDS opens the MERRA "CN" met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_MERRA_CN_FIELDS( NYMD, NHMS, Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : FILE_EXISTS
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: NYMD   ! YYYYMMDD date
INTEGER,        INTENT(IN) :: NHMS   ! hhmmss time
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_CN locally
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass directory fields via Input_Opt
```

9.6.2 get_merra_cn_fields

Subroutine GET_MERRA_CN_FIELDS is a wrapper for routine READ_CN.

INTERFACE:

```
SUBROUTINE GET_MERRA_CN_FIELDS( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD        ! YYYYMMDD date and
INTEGER,        INTENT(IN)    :: NHMS        ! hhmmss time of data
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
```

9.6.3 read_cn

Subroutine READ_CN reads the MERRA CN (constant) fields from disk.

INTERFACE:

```
SUBROUTINE READ_CN( NYMD,   NHMS,   Input_Opt,
&                   FRLAKE, FRLAND, FRLANDIC, FROCEAN, PHIS )
```

USES:

```
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: NYMD       ! YYYYMMDD and
      INTEGER,        INTENT(IN)  :: NHMS       !  hhmmss time of desired data
      TYPE(OptInput), INTENT(IN)  :: Input_Opt  ! Input Options object
```

OUTPUT PARAMETERS:

```
      ! Fraction of grid box covered by lakes [unitless]
      REAL(fp),         INTENT(OUT) :: FRLAKE  (IIPAR,JJPAR)

      ! Fraction of grid box covered by land ice [unitless]
      REAL(fp),         INTENT(OUT) :: FRLAND  (IIPAR,JJPAR)

      ! Fraction of grid box covered by land ice [unitless]
      REAL(fp),         INTENT(OUT) :: FRLANDIC(IIPAR,JJPAR)

      ! Fraction of grid box covered by ocean [unitless]
      REAL(fp),         INTENT(OUT) :: FROCEAN (IIPAR,JJPAR)

      ! Surface geopotential height [m2/s2]
      REAL(fp),         INTENT(OUT) :: PHIS    (IIPAR,JJPAR)
```

REVISION HISTORY:

```
   19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
   03 Aug 2012 - R. Yantosca - Now use locally-defined IU_CN file LUN
   07 Aug 2012 - R. Yantosca - Now print LUN used to open file
   06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
   02 Feb 2015 - E. Lundgren - Block off bpch diagnostics with if defined bpch
```

9.6.4 cn_check

Subroutine CN_CHECK prints an error message if not all of the CN met fields are found. The run is also terminated.

INTERFACE:

```
      SUBROUTINE CN_CHECK( NFOUND, N_CN )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! Number of met fields read in from disk
INTEGER, INTENT(IN) :: N_CN     ! Number of expected met fields
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
```

9.7 Fortran: Module Interface merra_i6_mod.F90

Module MERRA_I6_MOD contains subroutines for reading the 6-hour instantaneous (aka "I6") fields from the MERRA data archive.

INTERFACE:

```
MODULE MERRA_I6_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: GET_MERRA_I6_FIELDS_1
PUBLIC  :: GET_MERRA_I6_FIELDS_2
PUBLIC  :: OPEN_MERRA_I6_FIELDS
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: I6_CHECK
PRIVATE :: READ_I6
```

REMARKS:

```
Don't bother with the file unzipping anymore.
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
03 Aug 2012 - R. Yantosca - Now make IU_I6 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.7.1 open_merra_i6_fields

Subroutine OPEN_MERRA_I6_FIELDS opens the MERRA "I6" met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_MERRA_I6_FIELDS( NYMD, NHMS, Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : FILE_EXISTS
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: NYMD        ! YYYYMMDD date
INTEGER,        INTENT(IN) :: NHMS        ! hhmmss time
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_I6 locally
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
```

9.7.2 get_merra_i6_fields_1

Subroutine GET_MERRA_I6_FIELDS_1 is a wrapper for routine READ_I6. It reads the initial data at the start of a GEOS-Chem simulation.

INTERFACE:

```
SUBROUTINE GET_MERRA_I6_FIELDS_1( NYMD,      NHMS,
&                                 Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD   ! YYYYMMDD date
INTEGER,        INTENT(IN)    :: NHMS   ! hhmmss time of desired data
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
```

9.7.3 get_merra_i6_fields_2

Subroutine GET_MERRA_I6_FIELDS_2 is a wrapper for routine READ_I6. It reads the data every 6 hours during a GEOS-Chem simulation.

INTERFACE:

```
SUBROUTINE GET_MERRA_I6_FIELDS_2( NYMD,      NHMS,
&                                 Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD   ! YYYYMMDD date
INTEGER,        INTENT(IN)    :: NHMS   ! hhmmss time of desired data
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
```

9.7.4 read_i6

Subroutine READ_I6 reads GEOS-Chem I-6 (instantaneous 6-hour) met fields from disk.

INTERFACE:

```
SUBROUTINE READ_I6( NYMD, NHMS, Input_Opt, PS, RH )
```

USES:

```
USE CMN_SIZE_MOD
USE CMN_DIAG_MOD
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : SET_CT_I6
USE TIME_MOD,           ONLY : TIMESTAMP_STRING
USE TRANSFER_MOD,       ONLY : TRANSFER_3D
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: NYMD           ! YYYYMMDD and hhmmss
INTEGER,        INTENT(IN)  :: NHMS           !  time of desired data
TYPE(OptInput), INTENT(IN)  :: Input_Opt      ! Input Options object
```

OUTPUT PARAMETERS:

```
REAL(fp),  INTENT(OUT) :: PS(IIPAR,JJPAR      )  ! Surface pressure [hPa]
REAL(fp),  INTENT(OUT) :: RH(IIPAR,JJPAR,LLPAR)  ! Rel. humidity    [1]
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_I6 file LUN
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
15 Nov 2013 - R. Yantosca - Now convert RH from [1] to [%], in order
                            to be consistent with GEOS-Chem convention
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
```

9.7.5 i6_check

Subroutine I6_CHECK prints an error message if not all of the I6 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE I6_CHECK( NFOUND, N_I6 )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! Number of met fields read in from disk
INTEGER, INTENT(IN) :: N_I6     ! Number of expected met fields
```

REVISION HISTORY:

```
19 Aug 2010 - R. Yantosca - Initial version, based on i6_read_mod.f
```

9.8 Fortran: Module Interface a3_read_mod.F

Module A3_READ_MOD contains routines that unzip, open, and read the GEOS-Chem A3 (avg 3-hour) met fields from disk.

INTERFACE:

```
      MODULE A3_READ_MOD
```

USES:

```
      USE inquireMod,    ONLY : findFreeLUN
      USE PRECISION_MOD

      IMPLICIT NONE
      PRIVATE
```

PUBLIC DATA MEMBERS:

```
      PUBLIC  :: GET_A3_FIELDS
      PUBLIC  :: OPEN_A3_FIELDS
      PUBLIC  :: UNZIP_A3_FIELDS
  !PRIVATE DATA MEMBERS:
      PRIVATE :: A3_CHECK
      PRIVATE :: CHECK_TIME
      PRIVATE :: DO_OPEN_A3
      PRIVATE :: GET_N_A3
      PRIVATE :: READ_A3
```

REMARKS:

```
   This module reads GEOS-4, GEOS-5, and GCAP met fields
   MERRA met fields are read in routines merra_*_mod.F
   GEOS-FP met fields are read in geosfp_read_mod.F
```

REVISION HISTORY:

```
   23 Jun 2003 - R. Yantosca - Initial version
   (1 ) Adapted from "dao_read_mod.f" (bmy, 6/23/03)
   (2 ) Now can read from either zipped or unzipped files. (bmy, 12/11/03)
   (3 ) Now skips past the GEOS-4 met field ident string (bmy, 12/12/03)
   (4 ) Now references "unix_cmds_mod.f", "directory_mod.f", and
        "logical_mod.f" (bmy, 7/20/04)
   (5 ) Now references FILE_EXISTS from "file_mod.f" (bmy, 3/23/05)
   (6 ) Now modified for GEOS-5 and GCAP met fields (bmy, 5/25/05)
   (7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
   (8 ) Fixed typos for GCAP fields and ND67 diagnostics (bmy, 2/9/06)
   (9 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
   (10) Now read PARDF, PARDR for GCAP met fields (swu, bmy, 10/4/06)
   (11) Extra modifications for GEOS-5 met fields (bmy, 1/17/07)
   (12) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
   (13) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
```

```
21 Sep 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
03 Aug 2012 - R. Yantosca - Now make IU_A3 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
05 Nov 2014 - M. Yannetti - Added PRECISION_MOD
12 May 2016 - M. Sulprizio- Remove routine ARCHIVE_ND67_1D. It is obsolete
                            and it not called from any other routine.
```

9.8.1 unzip_a3_fields

Subroutine UNZIP_A3_FIELDS invokes a FORTRAN system call to uncompress GEOS-Chem A3 met field files and store the uncompressed data in a temporary directory, where GEOS-CHEM can read them. The original data files are not disturbed.

INTERFACE:

```
SUBROUTINE UNZIP_A3_FIELDS( Input_Opt, OPTION, NYMD )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*),  INTENT(IN) :: OPTION    ! Unzip option
INTEGER, OPTIONAL, INTENT(IN) :: NYMD      ! YYYY/MM/DD of file to unzip
TYPE(OptInput),    INTENT(IN) :: Input_Opt ! Input Options object
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from UNZIP_MET_FIELDS of "dao_read_mod.f" (bmy, 6/23/03)
(2 ) Directory information YYYY/MM or YYYYMM is now contained w/in
     GEOS_1_DIR, GEOS_S_DIR, GEOS_3_DIR, GEOS_4_DIR (bmy, 12/11/03)
(3 ) Now reference "directory_mod.f" and "unix_cmds_mod.f". Now prevent
     EXPAND_DATE from overwriting directory paths with Y/M/D tokens in
     them (bmy, 7/20/04)
(4 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(5 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(6 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
```

9.8.2 do_open_a3

Function DO_OPEN_A3 returns TRUE if is time to open the A3 met field file or FALSE otherwise. This prevents us from opening a file which has already been opened.

INTERFACE:

```
FUNCTION DO_OPEN_A3( NYMD, NHMS, RESET ) RESULT( DO_OPEN )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)            :: NYMD    ! YYYY/MM/DD date
INTEGER, INTENT(IN)            :: NHMS    ! hh:mm:ss time
LOGICAL, INTENT(IN),  OPTIONAL :: RESET   ! Reset first-time flag?
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Sep 2010 - R. Yantosca - Bug fix: If we are using MEGAN (which reads many
                            days of A3 data @ start of run), then reset the
                            first-time flag.  This will prevent an error if
                            if the start time is not 00 GMT.
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
```

9.8.3 open_a3_fields

Subroutine OPEN_A3_FIELDS opens the A3 met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_A3_FIELDS( NYMD, NHMS, Input_Opt, RESET, IUNIT )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD                         ! Size parameters
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR,    FILE_EXISTS
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)            :: Input_Opt  ! Input_Options
INTEGER,        INTENT(IN)            :: NYMD       ! YYYY/MM/dd and
INTEGER,        INTENT(IN)            :: NHMS       !  hh:mm:ss of data
LOGICAL,        INTENT(IN),  OPTIONAL :: RESET      ! Reset first flag?
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT), OPTIONAL :: IUNIT      ! Returns IU_A1
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from OPEN_MET_FIELDS of "dao_read_mod.f" (bmy, 6/13/03)
(2 ) Now opens either zipped or unzipped files (bmy, 12/11/03)
(3 ) Now skips past the GEOS-4 ident string (bmy, 12/12/03)
(4 ) Now references "directory_mod.f" instead of CMN_SETUP.  Also now
     references LUNZIP from "logical_mod.f".  Also now prevents EXPAND_DATE
     from overwriting Y/M/D tokens in directory paths. (bmy, 7/20/04)
(5 ) Now use FILE_EXISTS from "file_mod.f" to determine if file unit IU_A3
     refers to a valid file on disk (bmy, 3/23/05)
(6 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(9 ) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
21 Sep 2010 - R. Yantosca - Now pass RESET flag to DO_OPEN_A3
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_A3 locally
06 Aug 2012 - R. Yantosca - Add IUNIT to pass IU_A3 to calling routine
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass Input_Opt object
```

9.8.4 get_a3_fields

Subroutine GET_A3_FIELDS is a wrapper for routine READ_A3. GET_A3_FIELDS calls READ_A3 properly for reading GEOS-3, GEOS-4, GEOS-5, or GCAP met data sets.

INTERFACE:

```
SUBROUTINE GET_A3_FIELDS( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE CMN_SIZE_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD      ! YYYY/MM/DD
INTEGER,        INTENT(IN)    :: NHMS      !  and hh:mm:ss of desired data
TYPE(OptInput), INTENT(IN)    :: Input_Opt ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(MetState), INTENT(INOUT) :: State_Met ! Meteorology State object
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Now save RADSWG to the RADSWG array (instead of RADIAT).  Now save
     CLDFRC to the CLDFRC array (instead of CFRAC).  Now get RADLWG,
     SNOW arrays.  Also updated comments. (bmy, 12/9/03)
(2 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(3 ) Bug fix: replace RADSWG in call to READ_A3 for GCAP met fields.
     (bmy, 2/9/06)
(4 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(5 ) Now read PARDF, PARDR for GCAP met fields (swu, bmy, 10/4/06)
(6 ) Now read SNOW and GETWETTOP for GCAP met fields (swu, phs, 11/15/06)
(7 ) Now read extra fields for GEOS-5 (bmy, 1/17/07)
(8 ) Now read EFLUX field for non-local PBL scheme (only GEOS5).
     (ccc, 5/14/09)
(9 ) Now read FRLAND, FROCEAN, FRLANDIC and FRLAKE for methane
     (kjw, 8/18/09)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
02 Jul 2013 - R. Yantosca - For GCAP, PBL is now State_Met%PBLH (similarly
                            for State_Met%PRECCON and State_Met%PRECTOT)
13 Aug 2013 - R. Yantosca - For GEOS-4, PBL is now State_Met%PBLH (similarly
                            for State_Met%PRECCON and State_Met%PRECTOT)
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
```

9.8.5 get_n_a3

Function GET_N_A3 returns the number of A3 fields per met data set.

INTERFACE:

```
      FUNCTION GET_N_A3( NYMD ) RESULT( N_A3 )
```

USES:

```
      USE CMN_SIZE_MOD              ! Size parameters
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: NYMD   ! YYYY/MM/DD date
```

RETURN VALUE:

```
      INTEGER             :: N_A3   ! Number of A3 fields in file
```

REMARKS:

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) GEOS-4/fvDAS now has 19 A-3 fields; we added LAI, RADLWG, SNOW.
      (bmy, 12/9/03)
(2 ) Now modified for GEOS-5 and GCAP met fields (bmy, 5/25/05)
(3 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(4 ) Increase # of fields for GCAP from 12 to 16 (swu, bmy, 10/4/06)
(5 ) Increase # of fields for GEOS-5 to 25 (bmy, 1/17/07)
(6 ) Increase # of fields for GEOS-5 to 26 (EFLUX) (ccc, 5/21/09)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
```

9.8.6 check_time

Function CHECK_TIME checks to see if the timestamp of the A3 field just read from disk matches the current time. If so, then it's time to return the A3 field to the calling program.

INTERFACE:

```
FUNCTION CHECK_TIME( XYMD, XHMS, NYMD, NHMS ) RESULT( ITS_TIME )
```

USES:

```
USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: XYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: XHMS       !  timestamp of A3 data in file
INTEGER, INTENT(IN) :: NYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: NHMS       !  timestamp for desired data
```

RETURN VALUE:

```
LOGICAL             :: ITS_TIME   ! =T if XYMD & XHMS match NYMD & NHMS
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
```

9.8.7 read_a3

Subroutine READ_A3 reads GEOS A-3 (3-hr avg) fields from disk.

INTERFACE:

```
      SUBROUTINE READ_A3( NYMD,    NHMS,   Input_Opt,
     &                    ALBEDO,  CLDFRC, EVAP,   GRN,      GWETROOT,
     &                    GWETTOP, HFLUX,  LAI,    MOLENGTH, OICE,
     &                    PARDF,   PARDR,  PBL,    PREACC,   PRECON,
     &                    PRECSNO, RADLWG, RADSWG, RADSWT,   SNICE,
     &                    SNODP,   SNOMAS, SNOW,   TROPP,    TS,
     &                    TSKIN,   U10M,   USTAR,  V10M,     Z0,
     &                    EFLUX,   FRLAND, FRLAKE, FROCEAN,  FRLANDIC )
```

USES:

```
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput!
      USE TIME_MOD,           ONLY : SET_CT_A3
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)     :: NYMD      ! YYYYMMDD
      INTEGER,        INTENT(IN)     :: NHMS      ! and hhmmss of desired data
      TYPE(OptInput), INTENT(IN)     :: Input_Opt ! Input Options object
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT), OPTIONAL :: ALBEDO  (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: CLDFRC  (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: EVAP    (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: GRN     (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: GWETROOT(IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: GWETTOP (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: HFLUX   (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: LAI     (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: MOLENGTH(IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: OICE    (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: PARDF   (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: PARDR   (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: PBL     (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: PREACC  (IIPAR,JJPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: PRECON  (IIPAR,JJPAR)
```

```
REAL(fp),  INTENT(OUT), OPTIONAL :: PRECSNO (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: RADLWG  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: RADSWG  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: RADSWT  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: SNICE   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: SNODP   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: SNOMAS  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: SNOW    (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: TROPP   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: TS      (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: TSKIN   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: U10M    (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: USTAR   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: V10M    (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: Z0      (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: EFLUX   (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: FRLAND  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: FRLAKE  (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: FROCEAN (IIPAR,JJPAR)
REAL(fp),  INTENT(OUT), OPTIONAL :: FRLANDIC(IIPAR,JJPAR)
```

REMARKS:

```
(1 ) ALBEDO   : (2-D) GMAO surface albedo at 10 m            [unitless]
(2 ) CLDFRC   : (2-D) GMAO column cloud fraction @ ground    [unitless]
(3 ) EVAP     : (2-D) GMAO evapotranspiration flux
(4 ) GRN      : (2-D) GMAO greenness index
(5 ) GWETROOT : (2-D) GMAO root soil wetness                 [unitless]
(6 ) GWETTOP  : (2-D) GMAO topsoil wetness                   [unitless]
(7 ) HFLUX    : (2-D) GMAO sensible heat flux                [W/m2]
(8 ) LAI      : (2-D) GMAO leaf area index                   [m2/m2]
(9 ) MOLENGTH : (2-D) GCAP Monin-Obhukov length              [m]
(10) OICE     : (2-D) GCAP fraction of ocean ice             [unitless]
(11) PARDF    : (2-D) GMAO photosyn active diffuse radiation [W/m2]
(12) PARDR    : (2-D) GMAO photosyn active direct radiation  [W/m2]
(13) PBL      : (2-D) GMAO planetary boundary layer depth    [mb]
(14) PREACC   : (2-D) GMAO accumulated precip @ ground       [mm H2O/day]
(15) PRECON   : (2-D) GMAO convective  precip @ ground       [mm H2O/day]
(16) PRECSNO  : (2-D) GMAO "snow" precip @ ground
(17) RADLWG   : (2-D) GMAO upward LW flux @ ground           [W/m2]
(18) RADSWG   : (2-D) GMAO downward SW flux @ ground         [W/m2]
(19) RADSWT   : (2-D) GMAO downward SW flux @ atm top        [W/m2]
(20) SNICE    : (2-D) GCAP fraction of snow/ice              [unitless]
(21) SNODP    : (2-D) GMAO GEOS-5 geometric snow depth       [m]
(22) SNOMAS   : (2-D) GMAO GEOS-5 H2O equiv snow depth       [m]
(23) SNOW     : (2-D) GMAO snow depth (H2O equivalent)       [mm H2O]
(24) TROPP    : (2-D) GMAO tropopause pressure               [hPa]
(25) TS       : (2-D) GMAO surface air temperature           [K]
(26) TSKIN    : (2-D) GMAO radiance temperature              [K]
```

```
(27) USTAR    : (2-D) GMAO friction velocity                [m/s]
(28) U10M     : (2-D) GMAO U-wind at 10 m                   [m/s]
(29) V10M     : (2-D) GMAO V-wind at 10 m                   [m/s]
(30) Z0       : (2-D) GMAO roughness height                 [m]
(31) EFLUX    : (2-D) GMAO latent heat flux                 [W/m2]
(32) FRLAND   : (2-D) GMAO fraction of land                 [unitless]
(33) FROCEAN  : (2-D) GMAO fraction of ocean                [unitless]
(34) FRLANDIC : (2-D) GMAO fraction of land ice             [unitless]
(35) FRLAKE   : (2-D) GMAO fraction of lake water           [unitless]
```

REVISION HISTORY:

```
08 May 1998 - R. Yantosca - Initial version
(1 ) Now use function TIMESTAMP_STRING from "time_mod.f" for formatted
     date/time output. (bmy, 10/28/03)
(2 ) RADSWG, CLDFRC, USTAR, and Z0. are now 2-D arrays.  Also added RADLWG
     and SNOW arrays via the arg list.  Now skip over LAI. (bmy, 12/9/03)
(3 ) Now modified for GEOS-5 and GCAP met fields.  Added GCAP MOLENGTH,
     SNICE, OICE optional arguments. (swu, bmy, 5/25/05)
(4 ) Fixed typo in the ND67 diagnostic for RADSWG (swu, bmy, 2/9/06)
(5 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(6 ) Add "PARDIF", "PARDIR" to case statement for GCAP (swu, bmy, 10/4/06)
(7 ) Add EVAP, GRN, GWETROOT, LAI, PRECSNO, SNODP, SNOMAS, and TROPP as
     optional arguments.  Also update the CASE statement accordingly for
     GEOS-5 fields.  Convert GEOS-5 PRECTOT and PRECCON fields from
     [kg/m2/s] to [mm/day] for backwards compatibility. (bmy, 1/17/07)
(8 ) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
(9 ) Now read EFLUX for non-local PBL scheme for GEOS5 (ccc, 5/14/09)
(10) Now read FRLAND, FROCEAN, FRLANDIC, FRLAKE for methane (kjw, 8/18/09)
(11) Remove reference to IN_CLOUD_OD (bmy, 10/15/09)
21 Sep 2010 - R. Yantosca - Added ProTeX headers
08 Jun 2012 - S. Philip   - Correction for GEOS_5 boundary layer height
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_A3 file LUN
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
05 Nov 2014 - M. Yannetti - Changed REAL*8 to REAL(fp)
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
02 Feb 2016 - E. Lundgren - Block off bpch diagnostics with if defined bpch
```

9.8.8 a3_check

Subroutine A3_CHECK prints an error message if not all of the A-3 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE A3_CHECK( NFOUND, N_A3 )
```

USES:

```
      USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: NFOUND   ! Number of A3 fields found in file
      INTEGER, INTENT(IN) :: N_A3     ! Expected number of A3 fields
```

REVISION HISTORY:

```
    27 Oct 2000 - R. Yantosca - Initial version
    (1 ) Adapted from DAO_CHECK from "dao_read_mod.f" (bmy, 6/23/03)
    21 Sep 2010 - R. Yantosca - Added ProTeX headers
```

9.9 Fortran: Module Interface a6_read_mod.F

Module A6_READ_MOD contains subroutines that unzip, open, and read GEOS-CHEM A-6 (avg 6-hour) met fields from disk.

INTERFACE:

```
      MODULE A6_READ_MOD
```

USES:

```
      USE inquireMod,    ONLY : findFreeLUN
      USE PRECISION_MOD

      IMPLICIT NONE
      PRIVATE
```

PUBLIC DATA MEMBERS:

```
      PUBLIC :: GET_A6_FIELDS
      PUBLIC :: OPEN_A6_FIELDS
      PUBLIC :: UNZIP_A6_FIELDS
```

REMARKS:

```
    This module reads GEOS-4, GEOS-5, and GCAP met fields
    MERRA met fields are read in routines merra_*_mod.F
    GEOS-FP met fields are read in geosfp_read_mod.F
```

REVISION HISTORY:

```
    19 Jun 2003 - R. Yantosca - Initial version
    (1 ) Adapted from "dao_read_mod.f" (bmy, 6/19/03)
    (2 ) Now use TIMESTAMP_STRING for formatted output (bmy, 10/28/03)
    (3 ) CLDFRC is now a 2-D array in MAKE_CLDFRC< GET_A6_FIELDS.  Also now
         read from either zipped or unzipped files. (bmy, 12/9/03)
    (4 ) Now skips past the GEOS-4 ident string (bmy, 12/12/03)
```

```
(5 ) Bug fix: need to determine CLDTOPS for GEOS-4.  (bmy, 3/4/04)
(6 ) Now modified for GEOS-4 "a_llk_03" and "a_llk_04" data (bmy, 3/4/04)
(7 ) Now references "unix_cmds_mod.f", "directory_mod.f" and
     "logical_mod.f" (bmy, 7/20/04)
(8 ) Now references FILE_EXISTS from "file_mod.f" (bmy, 3/23/05)
(9 ) Now modified for GEOS-5 and GCAP met fields.  Added MAKE_GCAP_CLDFRC
     routine. (swu, bmy, 5/25/05)
(10) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(11) Bug fix in ND66 diagnostic for ZMMU (bmy, 2/1/06)
(12) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(13) Now set negative Q (i.e. SPHU)to a small positive # (bmy, 9/8/06)
(14) Now read extra fields for GEOS-5.  Bug fix: we must convert RH from
     unitless to % to be compatible w/ present drydep etc. algorithms.
     (phs, bmy, 3/28/08)
(15) Now get the # of A-6 fields from the file ident string (bmy, 10/7/08)
(16) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Now make IU_A6 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
05 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.9.1 unzip_a6_fields

Subroutine UNZIP_A6_FIELDS invokes a FORTRAN system call to uncompress GEOS-Chem A6 met field files and store the uncompressed data in a temporary directory, where GEOS-CHEM can read them. The original data files are not disturbed.

INTERFACE:

```
SUBROUTINE UNZIP_A6_FIELDS( Input_Opt, OPTION, NYMD )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*),  INTENT(IN) :: OPTION    ! Unzip option
INTEGER, OPTIONAL, INTENT(IN) :: NYMD      ! YYYY/MM/DD of file to unzip
TYPE(OptInput),    INTENT(IN) :: Input_Opt ! Input Options object
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from UNZIP_MET_FIELDS of "dao_read_mod.f" (bmy, 6/19/03)
(2 ) Directory information YYYY/MM or YYYYMM is now contained w/in
     GEOS_1_DIR, GEOS_S_DIR, GEOS_3_DIR, GEOS_4_DIR (bmy, 12/11/03)
(3 ) Now reference "directory_mod.f" and "unix_cmds_mod.f". Now prevent
     EXPAND_DATE from overwriting directory paths with Y/M/D tokens in
     them (bmy, 7/20/04)
(4 ) Removed code for GEOS-4 a_llk_03 data.  Also modified for GEOS-5
     and GCAP met fields. (bmy, 5/25/05)
(5 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(6 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
11 Apr 2013 - R. Yantosca - Now replace directory_mod.F and unix_cmds_mod.F
                            with the Input_Opt derived type object
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.9.2 do_open_a6

Function DO_OPEN_A6 returns TRUE if is time to open the A6 met field file or FALSE otherwise. This prevents us from opening a file which has already been opened.

INTERFACE:

```
FUNCTION DO_OPEN_A6( NYMD, NHMS ) RESULT( DO_OPEN )
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NYMD    ! YYYY/MM/DD date
INTEGER, INTENT(IN) :: NHMS     ! hh:mm:ss time
```

REVISION HISTORY:

```
19 Jun 2003 - R. Yantosca - Initial version
(1 ) Now modified for GEOS-4 "a_llk_03" or "a_llk_04" data (bmy, 3/22/04)
(2 ) Remove code for obsolete GEOS-4 a_llk_03 data.  Also modified for
     GEOS-5 and GCAP met fields. (swu, bmy, 5/25/05)
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.9.3 open_a6_fields

Subroutine OPEN_A6_FIELDS opens the A6 met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_A6_FIELDS( NYMD, NHMS, Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR, FILE_EXISTS
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN) :: Input_Opt  ! Input_Options
INTEGER,        INTENT(IN) :: NYMD       ! YYYY/MM/dd and
INTEGER,        INTENT(IN) :: NHMS       !  hh:mm:ss of data
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from OPEN_MET_FIELDS of "dao_read_mod.f" (bmy, 6/19/03)
(2 ) Now opens either zipped or unzipped files (bmy, 12/11/03)
(3 ) Now skips past the GEOS-4 ident string (bmy, 12/12/03)
(4 ) Now references "directory_mod.f" instead of CMN_SETUP.  Also now
     references LUNZIP from "logical_mod.f".  Also now prevents EXPAND_DATE
     from overwriting Y/M/D tokens in directory paths. (bmy, 7/20/04)
(5 ) Now use FILE_EXISTS from "file_mod.f" to determine if file unit IU_A6
     refers to a valid file on disk (bmy, 3/23/05)
(6 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(9 ) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
(10) Set N_A6_FIELDS=21 for GEOS-5 and IN_CLOUD_OD (jmao, bmy, 2/12/09)
(11) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_A6 locally
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass directory fields with Input_Opt
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.9.4 get_a6_fields

Subroutine GET_A6_FIELDS is a wrapper for routine READ_A6. GET_A6_FIELDS calls READ_A6 properly for reading A-6 fields from GEOS-1, GEOS-STRAT, GEOS-3, GEO b S-4, GEOS-5, or GCAP met data sets.

INTERFACE:

```
SUBROUTINE GET_A6_FIELDS( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE CMN_SIZE_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
! Arguments
INTEGER,        INTENT(IN)    :: NYMD      ! YYYY/MM/DD
INTEGER,        INTENT(IN)    :: NHMS      !  and hh:mm:ss of desired data
TYPE(OptInput), INTENT(IN)    :: Input_Opt ! Input_Options
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met ! Meteorology State object
```

REVISION HISTORY:

```
19 Jun 2003 - R. Yantosca - Initial version
(1 ) CFRAC has been removed from CMN_DEP.  Now use CLDFRC(I,J) from
     "dao_mod.f" (bmy, 12/9/03)
(2 ) Now pass CLDTOPS to READ_A6 for GEOS-4 (bmy, 3/4/04)
(3 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(4 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(5 ) Now read CMFMC, DQIDTMST, DQLDTMST, DQRCON, DQRLSC, DQVDTMST, MFXC,
     MFYC, MFZ, PV, QI, QL, RH, TAUCLI, TAUCLW for GEOS-5
     (bmy, 10/30/07)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
19 Oct 2012 - R. Yantosca - Now reference gigc_state_met_mod.F90
23 Oct 2012 - R. Yantosca - Add QI, QL to the State_Met object
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
14 Mar 2013 - M. Payer    - Now read T_FULLGRID for vertical regridding of
                            OH for offline simulations (C. Holmes)
02 Jul 2013 - R. Yantosca - Now use State_Met%U and State_Met%V to hold
                            the GCAP U and V wind fields
02 Jul 2013 - R. Yantosca - Now use State_Met%U and State_Met%V to hold
                            the GEOS-4 U and V wind fields
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
16 Apr 2015 - R. Yantosca - Remove reference to T_FULLGRID; it's obsolete
17 Mar 2016 - M. Sulprizio- Read optical depth into State_Met%OPTD instead of
                            State_Met%OPTDEP (obsolete).
```

9.9.5 make_gcap_cldfrc

Subroutine MAKE_CLDFRC constructs the GCAP CLDFRC field from the 3-D cloud fraction field.

INTERFACE:

```
      SUBROUTINE MAKE_GCAP_CLDFRC( CLDF, CLDFRC )
```

USES:

```
      USE CMN_SIZE_MOD   ! Size parameters
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD   ! ND67
      USE DIAG_MOD, ONLY : AD67
#endif
```

INPUT PARAMETERS:

```
      ! GCAP 3-D cloud fraction field [unitless]
      REAL(fp), INTENT(IN)  :: CLDF(IIPAR,JJPAR,LLPAR)
```

OUTPUT PARAMETERS:

```
      ! GCAP column cloud fraction field [unitless]
      REAL(fp), INTENT(OUT) :: CLDFRC(IIPAR,JJPAR)
```

REVISION HISTORY:

```
   25 May 2005 - R. Yantosca - Initial version
   25 Feb 2014 - M. Sulprizio- Added ProTeX headers
   06 Nov 2014 - R. Yantosca - Now use CLDF(I,J,L)
```

9.9.6 get_n_a6

Function GET_N_A6 returns the number of A6 fields per met data set.

INTERFACE:

```
      FUNCTION GET_N_A6() RESULT( N_A6 )
```

USES:

```
      USE CMN_SIZE_MOD
```

RETURN VALUE:

```
      INTEGER :: N_A6
```

REVISION HISTORY:

```
   19 Jun 2003 - R. Yantosca - Initial version
   (1 ) Now modified for GCAP and GEOS-5 met fields (swu, bmy, 5/25/05)
   (2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
   (3 ) Increase number of A-6 fields for GEOS-5 to 21 (bmy, 5/15/07)
   28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
   25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.9.7 check_time

Function CHECK_TIME checks to see if the timestamp of the A6 field just read from disk matches the current time. If so, then it's time to return the A6 field to the calling program.

INTERFACE:

```
FUNCTION CHECK_TIME( XYMD, XHMS, NYMD, NHMS ) RESULT( ITS_TIME )
```

USES:

```
USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: XYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: XHMS       !  timestamp of A6 data in file
INTEGER, INTENT(IN) :: NYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: NHMS       !  timestamp for desired data
```

RETURN VALUE:

```
LOGICAL             :: ITS_TIME   ! =T if XYMD & XHMS match NYMD & NHMS
```

REVISION HISTORY:

```
19 Jun 2003 - R. Yantosca - Initial version
(1 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.9.8 read_a6

Subroutine READ_A6 reads GEOS A-6 (6-hr avg) fields from disk.

INTERFACE:

```
 SUBROUTINE READ_A6( NYMD,      NHMS,      Input_Opt,
&                    CLDF,      CLDMAS,    CLDTOPS,   CMFMC,
&                    DETRAINE,  DETRAINN,  DNDE,      DNDN,
&                    DQIDTMST,  DQLDTMST,  DQRCON,    DQRLSC,
&                    DQVDTMST,  DTRAIN,    ENTRAIN,   HKBETA,
&                    HKETA,     MFXC,      MFYC,      MFZ,
&                    MOISTQ,    OPTDEPTH,  PLE,       PV,
&                    Q,         QI,        QL,        RH,
&                    T,         TAUCLI,    TAUCLW,    U,
&                    UPDE,      UPDN,      V,         ZMEU,
&                    ZMMD,      ZMMU )
```

USES:

```
      USE CMN_SIZE_MOD
      USE PhysConstants
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD
      USE DIAG_MOD,           ONLY : AD21
      USE DIAG_MOD,           ONLY : AD66
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_CT_A6
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D_Lp1
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D
      USE TRANSFER_MOD,       ONLY : TRANSFER_G5_PLE
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: NYMD      ! YYYYMMDD
      INTEGER,        INTENT(IN)    :: NHMS      !  and hhmmss of desired data
      TYPE(OptInput), INTENT(IN)    :: Input_Opt ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,  INTENT(OUT), OPTIONAL :: CLDTOPS(IIPAR,JJPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: CLDF(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: CLDMAS(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: CMFMC(IIPAR,JJPAR,LLPAR+1)
      REAL(fp), INTENT(OUT), OPTIONAL :: DETRAINE(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DETRAINN(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DNDE(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DNDN(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DQIDTMST(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DQLDTMST(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DQRCON(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DQRLSC(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DQVDTMST(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: DTRAIN(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: ENTRAIN(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: HKBETA(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: HKETA(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: MFXC(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: MFYC(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: MFZ(IIPAR,JJPAR,LLPAR+1)
      REAL(fp), INTENT(OUT), OPTIONAL :: MOISTQ(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: OPTDEPTH(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: PLE(IIPAR,JJPAR,LLPAR+1)
      REAL(fp), INTENT(OUT), OPTIONAL :: PV(IIPAR,JJPAR,LLPAR)
      REAL(fp), INTENT(OUT), OPTIONAL :: Q(IIPAR,JJPAR,LLPAR)
```

```
REAL(fp), INTENT(OUT), OPTIONAL :: QI(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: QL(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: RH(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: T(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: TAUCLI(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: TAUCLW(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: U(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: UPDE(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: UPDN(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: V(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: ZMEU(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: ZMMD(IIPAR,JJPAR,LLPAR)
REAL(fp), INTENT(OUT), OPTIONAL :: ZMMU(IIPAR,JJPAR,LLPAR)
```

REMARKS:

```
(3 ) CLDF     : (3-D) Total cloud fractions                [unitless]
(4 ) CLDMAS   : (3-D) Cloud mass flux field                [kg/m2/600s]
(5 ) CLDTOPS  : (2-D) CTM Level in which cloud top occurs  [unitless]
(6 ) CMFMC    : (3-D) GEOS-5 cloud mass flux               [kg/m2/s]
(7 ) DETRAINE : (3-D) GCAP detrainment (entraining plume)  [kg/m2/s]
(8 ) DETRAINN : (3-D) GCAP detrainment (non-entr'n plume)
(9 ) DNDE     : (3-D) GCAP downdraft   (entraining plume)
(10) DNDN     : (3-D) GCAP downdraft   (non-entr'n plume)
(11) DQIDTMST : (3-D) GEOS-5 ice tendency in moist proc    [kg/kg/s]
(12) DQLDTMST : (3-D) GEOS-5 liquid tendency in moist proc [kg/kg/s]
(13) DQRCON   : (3-D) GEOS-5 precip formation rate / conv
(14) DQRLSC   : (3-D) GEOS-5 precip formation rate / lg scl
(15) DQVDTMST : (3-D) GEOS-5 vapor tendency in moist proc  [kg/kg/s]
(16) DTRAIN   : (3-D) Detrainment field                    [kg/m2/s]
(17) ENTRAIN  : (3-D) GCAP entrainment
(18) HKBETA   : (3-D) Hack overshoot parameter             [unitless]
(19) HKETA    : (3-D) Hack convective mass flux            [kg/m2/s]
(20) MFXC     : (3-D) GEOS-5 E-W mass flux                 [Pa*m2/s]
(21) MFYC     : (3-D) GEOS-5 N-S mass flux                 [Pa*m2/s]
(22) MFZ      : (3-D) GEOS-5 up/down mass flux             [kg/m2/s]
(23) MOISTQ   : (3-D) DAO water vapor tendency d           [g/kg/day]
(24) OPTDEPTH : (3-D) GEOS grid box optical depth          [unitless]
(25) PLE      : (3-D) GEOS-5 pressure edges                [hPa]
(26) PV       : (3-D) GEOS-5 potential vorticity           [kg*m2/kg/s]
(27) Q        : (3-D) Specific humidity                    [g H2O/kg air]
(28) T        : (3-D) Temperature                          [K]
(29) TAUCLI   : (3-D) GEOS ice path optical depth          [unitless]
(30) TAUCLW   : (3-D) GEOS water path optical depth        [unitless]
(31) U        : (3-D) Zonal winds                          [m/s]
(32) UPDE     : (3-D) GCAP updraft (entraining plume)
(33) UPDN     : (3-D) GCAP updraft (non-entr'n plume)
(34) V        : (3-D) Meridional winds                     [m/s]
(35) ZMEU     : (3-D) Zhang/McFarlane updraft entrainment  [Pa/s]
```

```
(36) ZMMD     : (3-D) Zhang/McFarlane downdraft mass flux   [Pa/s]
(37) ZMMU     : (3-D) Zhang/McFarlane updraft mass flux     [Pa/s]
```

REVISION HISTORY:

```
05 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from READ_A6 of "dao_read_mod.f" (bmy, 6/19/03)
(2 ) Now use function TIMESTAMP_STRING from "time_mod.f" for formatted
     date/time output. (bmy, 10/28/03)
(3 ) Now compute CLDTOPS using ZMMU for GEOS-4 (bmy, 3/4/04)
(4 ) Now modified for GEOS-5 and GCAP fields.  Added DETRAINE,
     DETRAINN, DNDE, DNDN, ENTRAIN, UPDE, UPDN as optional arguments.
     Now references "CMN_DIAG". (swu, bmy, 5/25/05)
(5 ) Bug fix in ND66 diagnostic for GEOS-4 (bmy, 2/1/06)
(6 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(7 ) Now set negative SPHU to a small positive # (1d-32) instead of zero,
     so as not to blow up logarithms (bmy, 9/8/06)
(8 ) Add CMFMC, DQIDTMST, DQLDTMST, DQRCON, DQRLSC, DQVDTMST, MFXC, MFYC,
     MFZ, PLE, PV, RH, TAUCLI, and TAUCLW as optional arguments.  Also
     update the CASE statement accordingly for GEOS-5 met fields.
     Now reference TRANSFER_3D_Lp1 from "transfer_mod.f".  Now convert
     GEOS-5 specific humidity from [kg/kg] to [g/kg] for compatibility
     with existing routines.  Also recognize EPV, which is an alternate
     name for PV.  Bug fix: convert GEOS-5 RH from unitless to %.
     (phs, bmy, 3/28/08)
(8 ) Now get the # of A-6 fields from the file ident string (bmy, 10/7/08)
(9 ) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_A3 file LUN
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
14 Mar 2013 - M. Payer    - Added T_FULLGRID as optional argument
29 Oct 2013 - R. Yantosca - Remove reference to TRANSFER_3D_NOLUMP
07 Nov 2013 - R. Yantosca - Now replace any NaN's in the MOISTQ field
                            with zeroes.  NaN's have occured near t-pause.
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
05 Nov 2014 - M. Yannetti - Changed REAL*8 to REAL(fp)
06 Nov 2014 - R. Yantosca - All input arguments are now declared as (I,J,L)
06 Nov 2014 - R. Yantosca - Replace TRANSFER_A6 with TRANSFER_3D
16 Apr 2015 - R. Yantosca - Remove reference to T_FULLGRID; it's obsolete
02 Feb 2016 - E. Lundgren - Block of diagnostics with if defined BPCH
```

9.9.9 a6_check

Subroutine A6_CHECK prints an error message if not all of the A-6 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE A6_CHECK( NFOUND, N_A6 )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! Number of A6 fields found in file
INTEGER, INTENT(IN) :: N_A6     ! Expected number of A6 fields
```

REVISION HISTORY:

```
27 Oct 2000 - R. Yantosca - Initial version
(1 ) Adapted from DAO_CHECK from "dao_read_mod.f" (bmy, 6/19/03)
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10 Fortran: Module Interface i6_read_mod.F

Module I6_READ_MOD contains routines that unzip, open, and read the GEOS-Chem I6 (instantaneous 6-hour) met fields from disk.

INTERFACE:

```
MODULE I6_READ_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC DATA MEMBERS:

```
PUBLIC :: GET_I6_FIELDS_1
PUBLIC :: GET_I6_FIELDS_2
PUBLIC :: OPEN_I6_FIELDS
PUBLIC :: UNZIP_I6_FIELDS
```

REMARKS:

```
This module reads GEOS-4, GEOS-5, and GCAP met fields
MERRA met fields are read in routines merra_*_mod.F
GEOS-FP met fields are read in geosfp_read_mod.F
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Adapted from "dao_read_mod.f" (bmy, 6/23/03)
(2 ) Now use TIMESTAMP_STRING for formatted date/time output (bmy, 10/28/03)
(3 ) Now reads either zipped or unzipped files (bmy, 12/11/03)
(4 ) Now skips past the GEOS-4 ident string (bmy, 12/12/03)
(5 ) Now references "directory_mod.f", "unix_cmds_mod.f", and
     "logical_mod.f" (bmy, 7/20/04)
(6 ) Now references FILE_EXISTS from "file_mod.f" (bmy, 3/23/05)
(7 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(8 ) Now account for GEOS-4 coastal boxes in LWI properly (bmy, 8/10/05)
(9 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(10) Now make LWI REAL(fp) for near-land formulation (ltm, bmy, 5/9/06)
(11) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(12) Now set negative SPHU to a very small positive # (bmy, 9/8/06)
(13) Now read TROPP files for GEOS-4, and check tropopause level
     in case of a variable tropopause (phs, bmy, bdf, 9/14/06)
(14) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
(15) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Now make IU_I6 a private module variable
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
14 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.10.1 unzip_i6_fields

Subroutine UNZIP_I6_FIELDS invokes a FORTRAN system call to uncompress GEOS-Chem I-6 met field files and store the uncompressed data in a temporary directory, where GEOS-CHEM can read them. The original data files are not disturbed.

INTERFACE:

```
SUBROUTINE UNZIP_I6_FIELDS( Input_Opt, OPTION, NYMD )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*),  INTENT(IN) :: OPTION    ! Unzip option
INTEGER, OPTIONAL, INTENT(IN) :: NYMD      ! YYYY/MM/DD of file to unzip
TYPE(OptInput),    INTENT(IN) :: Input_Opt ! Input Options object
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from UNZIP_MET_FIELDS of "dao_read_mod.f" (bmy, 6/23/03)
(2 ) Directory information YYYY/MM or YYYYMM is now contained w/in
     GEOS_1_DIR, GEOS_S_DIR, GEOS_3_DIR, GEOS_4_DIR (bmy, 12/11/03)
(3 ) Now reference "directory_mod.f" and "unix_cmds_mod.f". Now prevent
     EXPAND_DATE from overwriting directory paths with Y/M/D tokens in
     them (bmy, 7/20/04)
(4 ) Now modified for GEOS-5 and GCAP met fields
(5 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(6 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
11 Apr 2013 - R. Yantosca - Now pass fields via Input_Opt
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10.2 open_i6_fields

Subroutine OPEN_I6_FIELDS opens the I-6 met fields file for date NYMD and time NHMS.

INTERFACE:

```
SUBROUTINE OPEN_I6_FIELDS( NYMD, NHMS, Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR, FILE_EXISTS
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input Options object
INTEGER,        INTENT(IN) :: NYMD        ! YYYY/MM/dd and
INTEGER,        INTENT(IN) :: NHMS        !  hh:mm:ss of data
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from OPEN_MET_FIELDS of "dao_read_mod.f" (bmy, 6/13/03)
(2 ) Now opens either zipped or unzipped files (bmy, 12/11/03)
(3 ) Now skips past the GEOS-4 ident string (bmy, 12/12/03)
(4 ) Now references "directory_mod.f" instead of CMN_SETUP.  Also now
     references LUNZIP from "logical_mod.f".  Also now prevents EXPAND_DATE
     from overwriting Y/M/D tokens in directory paths. (bmy, 7/20/04)
(5 ) Now use FILE_EXISTS from "file_mod.f" to determine if file unit IU_I6
```

```
      refers to a valid file on disk (bmy, 3/23/05
(6 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(9 ) Updated for variable tropopause (phs, bmy, 9/14/06)
(10) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
03 Aug 2012 - R. Yantosca - Now use findFreeLUN to define IU_I6 locally
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
11 Apr 2013 - R. Yantosca - Now pass fields via Input_Opt
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10.3 get_i6_fields_1

Subroutine GET_I6_FIELDS_1 is a wrapper for routine READ_I6. This routine calls READ_I6 properly for reading I-6 fields from GEOS-3, GEOS-4, GEOS-5, or GCAP met data sets at the START of a GEOS-CHEM run.

INTERFACE:

```
SUBROUTINE GET_I6_FIELDS_1( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD       ! YYYY/MM/DD
INTEGER,        INTENT(IN)    :: NHMS       !  and hh:mm:ss of data
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
(2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(3 ) Now also read TO3 and TTO3 for GEOS-5 (bmy, 1/16/07)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
24 Jun 2014 - R. Yantosca - Now pass Input_Opt to READ_I6
```

9.10.4 get_i6_fields_2

Subroutine GET_I6_FIELDS_2 is a wrapper for routine READ_I6. This routine calls READ_I6 properly for reading I-6 fields from GEOS-3, GEOS-4, GEOS-5, or GCAP met data sets every 6 hours during a GEOS-CHEM run.

INTERFACE:

```
SUBROUTINE GET_I6_FIELDS_2( NYMD, NHMS, Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: NYMD       ! YYYY/MM/DD
INTEGER,        INTENT(IN)    :: NHMS       !  and hh:mm:ss of data
TYPE(OptInput), INTENT(IN)    :: Input_Opt  ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met  ! Meteorology State object
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Now modified for GEOS-5 and GCAP met fields
(2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(3 ) Now read TO3 and TTO3 for GEOS-5 (bmy, 1/16/07)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
15 Nov 2012 - R. Yantosca - Now replace dao_mod.F arrays with State_Met
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10.5 get_n_i6

Function GET_N_I6 returns the number of I-6 fields per met data set.

INTERFACE:

```
FUNCTION GET_N_I6( NYMD ) RESULT( N_I6 )
```

USES:

```
USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NYMD   ! YYYY/MM/DD date
```

RETURN VALUE:

```
INTEGER             :: N_I6   ! Number of I-6 fields in file
```

REVISION HISTORY:

```
(1 ) Now modified for GCAP and GEOS-5 met fields (swu, bmy, 5/25/05)
(2 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(3 ) Increase # of I-6 fields to 5 for GEOS-5 (bmy, 1/17/06)
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10.6 check_time

Function CHECK_TIME checks to see if the timestamp of the I6 field just read from disk matches the current time. If so, then it's time to return the I6 field to the calling program.

INTERFACE:

```
FUNCTION CHECK_TIME( XYMD, XHMS, NYMD, NHMS ) RESULT( ITS_TIME )
```

USES:

```
USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: XYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: XHMS       !  timestamp of I6 data in file
INTEGER, INTENT(IN) :: NYMD       ! YYYY/MM/DD and hh:mm:ss
INTEGER, INTENT(IN) :: NHMS       !  timestamp for desired data
```

RETURN VALUE:

```
LOGICAL             :: ITS_TIME   ! =T if XYMD & XHMS match NYMD & NHMS
```

REVISION HISTORY:

```
23 Jun 2003 - R. Yantosca - Initial version
(1 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.10.7 read_i6

Subroutine READ_I6 reads GEOS I-6 (inst. 6-hr) met fields from disk.

INTERFACE:

```
      SUBROUTINE READ_I6( NYMD, NHMS,  Input_Opt,
     &                    ALBD, LWI,   PS,   SLP,  SPHU, TMPU,
     &                    TO3,  TROPP, TTO3, UWND, VWND         )
```

USES:

```
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD
      USE DIAG_MOD,           ONLY : AD66
      USE DIAG_MOD,           ONLY : AD67
#endif
      USE FILE_MOD,           ONLY : IOERROR
      USE Input_Opt_Mod,      ONLY : OptInput
      USE TIME_MOD,           ONLY : SET_CT_I6
      USE TIME_MOD,           ONLY : TIMESTAMP_STRING
      USE TRANSFER_MOD,       ONLY : TRANSFER_3D
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)     :: NYMD      ! YYYYMMDD
      INTEGER,        INTENT(IN)     :: NHMS      ! and hhmmss of desired data
      TYPE(OptInput), INTENT(IN)     :: Input_Opt ! Input Options object
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT), OPTIONAL :: ALBD (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: LWI  (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: PS   (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: SLP  (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: SPHU (IIPAR,JJPAR,LLPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: TMPU (IIPAR,JJPAR,LLPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: TO3  (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: TROPP(IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: TTO3 (IIPAR,JJPAR      )
      REAL(fp),  INTENT(OUT), OPTIONAL :: UWND (IIPAR,JJPAR,LLPAR)
      REAL(fp),  INTENT(OUT), OPTIONAL :: VWND (IIPAR,JJPAR,LLPAR)
```

REMARKS:

```
   (3 ) ALBD  : (2-D) GMAO Surface albedo            [unitless]
   (4 ) LWI   : (2-D) GMAO Land-water indices        [unitless]
   (5 ) PS    : (2-D) GMAO Surface pressure          [hPa]
   (6 ) SLP   : (2-D) GMAO Sea-level pressures       [hPa]
   (7 ) SPHU  : (3-D) GMAO Specific humidity field   [g H2O/kg air]
   (8 ) TMPU  : (3-D) GMAO Temperature field         [K]
```

```
(9 ) TO3   : (2-D) GMAO GEOS-5 column ozone       [DU]
(10) TROPP : (2-D) GMAO tropopause pressure pressures     [hPa]
(11) TTO3  : (2-D) GMAO GEOS-5 trop column ozone  [DU]
(12) UWND  : (3-D) GMAO U-wind (zonal wind)       [m/s]
(13) VWND  : (3-D) GMAO V-wind (meridional wind)  [m/s]
```

REVISION HISTORY:

```
08 May 1998 - R. Yantosca - Initial version
(1 ) Adapted from "READ_I6" of "dao_read_mod.f" (bmy, 6/23/03)
(2 ) Now use function TIMESTAMP_STRING from "time_mod.f" for formatted
     date/time output. (bmy, 10/28/03)
(3 ) Round up to account for GEOS-4 coastal boxes properly (bmy, 8/10/05)
(4 ) For near-land formulation: (a) make LWI a REAL(fp) and (b) do not round
     up LWI for GEOS-4 meteorology (ltm, bmy, 5/9/06)
(5 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(6 ) Now set negative SPHU to a small positive number (1d-32) instead of
     zero, so as not to blow up logarithms (bmy, 9/8/06)
(7 ) Now read TROPP files for GEOS-4 (phs, bmy, bdf, 9/12/06)
(8 ) Now read TO3 and TTO3 for GEOS-5 (bmy, 1/16/07)
(9 ) Now get the # of A-3 fields from the file ident string (bmy, 10/7/08)
(10) Remove references to IN_CLOUD_OD (bmy, 10/15/09)
03 Aug 2012 - R. Yantosca - Now use locally-defined IU_I6, IU_TP file LUNs
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
24 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
03 Dec 2014 - R. Yantosca - Bug fix: remove TRANSFER_2D from GEOS-4 block
02 Feb 2016 - E. Lundgren - Block of diagnostics with if defined BPCH
```

9.10.8 i6_check

Subroutine I6_CHECK prints an error message if not all of the I-6 met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE I6_CHECK( NFOUND, N_I6 )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! Number of I-6 fields found in file
INTEGER, INTENT(IN) :: N_I6     ! Expected number of I-6 fields
```

REVISION HISTORY:

```
27 Oct 2000 - R. Yantosca - Initial version
(1 ) Adapted from DAO_CHECK from "dao_read_mod.f" (bmy, 6/23/03)
25 Feb 2014 - M. Sulprizio- Added ProTeX headers
```

9.11 Fortran: Module Interface gcap_read_mod.f

Module GCAP_READ_MOD contains file unit numbers, as well as file I/O routines for GEOS-Chem. FILE_MOD keeps all of the I/O unit numbers in a single location for convenient access.

INTERFACE:

```
MODULE GCAP_READ_MOD
```

USES:

```
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: CHECK_TIME
PRIVATE :: READ_GCAP
PRIVATE :: GCAP_CHECK
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: GET_GCAP_FIELDS
PUBLIC :: OPEN_GCAP_FIELDS
PUBLIC :: UNZIP_GCAP_FIELDS
```

REVISION HISTORY:

```
(1 ) Adapted from the obsolete "phis_read_mod.f" (bmy, 2/1/06)
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
06 Aug 2012 - R. Yantosca - Now make IU_PH a local variable
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
13 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

9.11.1 unzip_gcap_fields

Subroutine UNZIP_GCAP_FIELDS invokes a FORTRAN system call to uncompress GCAP PHIS met field files and store the uncompressed data in a temporary directory, where GEOS-CHEM can read them. The original data files are not disturbed.

INTERFACE:

```
SUBROUTINE UNZIP_GCAP_FIELDS( Input_Opt, OPTION )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
TYPE(OptInput),    INTENT(IN) :: Input_Opt   ! Input Options object
CHARACTER(LEN=*),  INTENT(IN) :: OPTION      ! Unzipping option
```

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from UNZIP_MET_FIELDS of "dao_read_mod.f" (bmy, 6/16/03)
(2 ) Directory information YYYY/MM or YYYYMM is now contained w/in
     GEOS_1_DIR, GEOS_S_DIR, GEOS_3_DIR, GEOS_4_DIR (bmy, 12/11/03)
(3 ) Now reference "directory_mod.f" and "unix_cmds_mod.f". Now prevent
     EXPAND_DATE from overwriting directory paths with Y/M/D tokens in
     them (bmy, 7/20/04)
(4 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
06 Aug 2012 - R. Yantosca - Added ProTeX headers
11 Apr 2013 - R. Yantosca - Now pass fields via Input_Opt
```

9.11.2 open_gcap_fields

Subroutine OPEN_GCAP_FIELDS opens the PHIS and LWI met fields file.

INTERFACE:

```
SUBROUTINE OPEN_GCAP_FIELDS( Input_Opt )
```

USES:

```
USE CMN_SIZE_MOD
USE BPCH2_MOD,          ONLY : GET_RES_EXT
USE ERROR_MOD,          ONLY : ERROR_STOP
USE FILE_MOD,           ONLY : IOERROR, FILE_EXISTS
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

REVISION HISTORY:

```
01 Feb 2006 - S. Wu        - Initial version
(1 ) Adapted from OPEN_MET_FIELDS of "dao_read_mod.f" (bmy, 6/13/03)
(2 ) Now opens either zipped or unzipped files (bmy, 12/11/03)
(3 ) Now skips past the GEOS-4 ident string (bmy, 12/12/04)
(4 ) Now references "directory_mod.f" instead of CMN_SETUP.  Also now
      references LUNZIP from "logical_mod.f".  Also now prevents EXPAND_DATE
      from overwriting Y/M/D tokens in directory paths. (bmy, 7/20/04)
(5 ) Now use FILE_EXISTS from "file_mod.f" to determine if file unit IU_PH
      refers to a valid file on disk (bmy, 3/23/05)
(6 ) Now modified for GEOS-5 and GCAP met fields (swu, bmy, 5/25/05)
06 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
06 Aug 2012 - R. Yantosca - Added ProTeX headers
```

9.11.3 get_gcap_fields

Subroutine GET_GCAP_FIELDS calls READ_GCAP to read GCAP fields from disk at the start of a GEOS-Chem run.

INTERFACE:

```
SUBROUTINE GET_GCAP_FIELDS( Input_Opt, State_Met )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(MetState), INTENT(INOUT) :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
01 Feb 2006 - S. Wu       - Initial version
(1 ) Now also read LWI_GISS for GCAP met fields (swu, bmy, 5/25/05)
06 Aug 2012 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Copy all met fields to the State_Met derived type
                            object
```

9.11.4 check_time

Function CHECK_TIME checks to see if the timestamp of the GCAP field just read from disk matches the current time. If so, then it's time to return the GCAP field to the calling program. (bmy, 6/16/03)

INTERFACE:

```
      FUNCTION CHECK_TIME( XYMD, XHMS, NYMD, NHMS ) RESULT( ITS_TIME )
```

USES:

```
      USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: XYMD       ! Date stamp in file (YYYYMMDD)
      INTEGER, INTENT(IN) :: XHMS       ! Time stamp in file (hhmmss)
      INTEGER, INTENT(IN) :: NYMD       ! Current model date (YYYYMMDD)
      INTEGER, INTENT(IN) :: NHMS       ! Current model time (hhmmss)
```

RETURN VALUE:

```
      ! Function value
      LOGICAL             :: ITS_TIME   ! = T is time to return fields
```

REVISION HISTORY:

```
    16 Jun 2003 - R. Yantosca - Initial version
    06 Aug 2012 - R. Yantosca - Added ProTeX headers
```

9.11.5 read_gcap

Subroutine READ_GCAP reads the PHIS (surface geopotential heights) field from disk. PHIS is an I-6 field, but is time-independent. Thus READ_GCAP only needs to be called once at the beginning of the model run.

INTERFACE:

```
      SUBROUTINE READ_GCAP( NYMD, NHMS, PHIS, LWI )
```

USES:

```
 #if defined( BPCH_DIAG )
      USE CMN_DIAG_MOD       ! ND67
      USE DIAG_MOD,     ONLY : AD67
 #endif
      USE CMN_SIZE_MOD
      USE FILE_MOD,     ONLY : IOERROR
      USE PhysConstants      ! g0
      USE TIME_MOD,     ONLY : TIMESTAMP_STRING
```

INPUT PARAMETERS:

```
      INTEGER,   INTENT(IN)            :: NYMD               ! YYYYMMDD date
      INTEGER,   INTENT(IN)            :: NHMS               ! hhmmss time
```

OUTPUT PARAMETERS:

```
REAL(fp),  INTENT(OUT)          :: PHIS(IIPAR,JJPAR)  ! PHIS [m2/s2]
REAL(fp),  INTENT(OUT), OPTIONAL :: LWI(IIPAR,JJPAR)   ! LWI flags
```

REVISION HISTORY:

```
01 Feb 2006 - S. Wu       - Initial version
(1 ) Adapted from READ_PHIS from "dao_read_mod.f" (bmy, 6/16/03)
(2 ) Now use function TIMESTAMP_STRING from "time_mod.f" for formatted
     date/time output. (bmy, 10/28/03)
(3 ) Now also read LWI_GISS for GCAP met fields.  Added optional variable
     LWI to the arg list. (swu, bmy, 5/25/05)
06 Aug 2012 - R. Yantosca - Added ProTeX headers
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
02 Feb 2015 - E. Lundgren - Block out bpch diagnostics with if defined bpch
```

9.11.6 gcap_check

Subroutine GCAP_CHECK prints an error message if not all of the GCAP met fields are found. The run is also terminated.

INTERFACE:

```
SUBROUTINE GCAP_CHECK( NFOUND, N_PHIS )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NFOUND   ! # of fields read from disk
INTEGER, INTENT(IN) :: N_PHIS   ! # of of fields expected to be found
```

REMARKS:

REVISION HISTORY:

```
15 Jun 1998 - R. Yantosca - Initial version
(1 ) Adapted from DAO_CHECK from "dao_read_mod.f" (bmy, 6/16/03)
06 Aug 2012 - R. Yantosca - Added ProTeX headers
```

10 Specialty simulation modules

These modules contain routines used by the GEOS-Chem "specialty" simulations.

10.1 Fortran: Module Interface c2h6_mod.F

Module C2H6_MOD contains variables and routines used for the tagged C2H6 (ethane) simulation. (xyp, qli, bmy, 7/28/01, 4/5/06)

INTERFACE:

```
      MODULE C2H6_MOD
```

USES:

```
      USE PRECISION_MOD
      USE PhysConstants, ONLY : AVO

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: GET_C2H6_ANTHRO
      PUBLIC  :: CHEMC2H6
      PUBLIC  :: CLEANUP_C2H6
      PUBLIC  :: INIT_C2H6
  PRIVATE DATA MEMBERS:
      PRIVATE :: NGASC2H6
      PRIVATE :: FMOL_C2H6
      PRIVATE :: XNUMOL_C2H6
```

REMARKS:

```
   Setting LSPLIT = T in "input.geos" will run with the following tracers:
      (1) Total C2H6
      (2) C2H6 from biomass burning
      (3) C2H6 from biofuel burning
      (4) C2H6 from natural gas leaking/venting (e.g. "anthro" C2H6)

   Setting LSPLIT = F in "input.geos" will run w/ the following tracers:
      (1) Total C2H6
```

REVISION HISTORY:

```
   (1 ) Eliminated obsolete code from 1/02 (bmy, 2/27/02)
   (2 ) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
        MODULE ROUTINES sections.  Updated comments (bmy, 5/28/02)
   (3 ) Now reference BXHEIGHT and T from "dao_mod.f".  Also references
        "error_mod.f".  Removed obsolete code.  Now references F90 module
        tracerid_mod.f". (bmy, 11/15/02)
   (4 ) Now references "grid_mod.f" and the new "time_mod.f" (bmy, 2/11/03)
   (5 ) Now references "directory_mod.f", "logical_mod.f", and "tracer_mod.f".
        (bmy, 7/20/04)
   (6 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
   (7 ) Now modified
```

```
22 Mar 2012 - M. Payer    - Add function GET_C2H6_ANTHRO
22 Mar 2012 - M. Payer    - Added ProTeX headers
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
11 Apr 2014 - R. Yantosca - Now declare INIT_C2H6 public, so that it can
                            be called from input_mod.F
20 Jun 2014 - R. Yantosca - Remove obsolete code now replaced by HEMCO
06 Nov 2014 - M. Yannetti - Added PRECISION_MOD
06 Jan 2016 - E. Lundgren - Use global physical params
```

10.1.1 chemc2h6

Subroutine CHEMC2H6 performs C2H6 chemistry. Loss of C2H6 is via reaction with OH. (xyp, qli, bmy, 10/19/99, 7/20/04)

INTERFACE:

```
SUBROUTINE CHEMC2H6( am_I_Root, Input_Opt,
&                    State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE Error_Mod,          ONLY : Error_Stop
USE HCO_Interface_Mod,  ONLY : HcoState
USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH, GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
(1 ) Now do chemistry all the way to the model top.
(2 ) Use monthly mean OH fields for oxidation -- reference the monthly
     mean OH array and the routine which reads it from disk in
    "global_oh_mod.f" (bmy, 1/25/02)
(3 ) Now reference T from "dao_mod.f".  Also make FIRSTCHEM a local SAVEd
     variable. (bmy, 11/15/02)
(4 ) Now use functions GET_MONTH and GET_TS_CHEM from "time_mod.f".
(5 ) Now reference STT & N_TRACERS from "tracer_mod.f".  Now reference
     LSPLIT from "logical_mod.f" (bmy, 7/20/04)
22 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
06 Nov 2014 - M. Yannetti - Converted REAL*8 to REAL(fp)
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Removed temporary tracer-removal code
```

10.1.2 get_c2h6_anthro

Function GET_C2H6_ANTHRO returns the monthly average anthropogenic C2H6 emissions at GEOS-Chem grid box (I,J). Data will be returned in units of [atoms C/cm2/s].

INTERFACE:

```
FUNCTION GET_C2H6_ANTHRO( I, J, N ) RESULT( C2H6_ANTHRO )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Chm_Mod,      ONLY :  Ind_
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)   :: I   ! GEOS-Chem longitude index
INTEGER, INTENT(IN)   :: J   ! GEOS-Chem latitude index
INTEGER, INTENT(IN)   :: N   ! GEOS-Chem tracer index
```

RETURN VALUE:

```
REAL(fp)              :: C2H6_ANTHRO
```

REVISION HISTORY:

```
22 Mar 2012 - M. Payer    - Initial version adapted from GET_RETRO_ANTHRO
```

10.1.3 init_c2h6

Subroutine INIT_C2H6 allocates and zeroes the NGASC2H6 array, which holds global monthly mean natural gas C2H6 emissions.

INTERFACE:

```
SUBROUTINE INIT_C2H6( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?!
```

REMARKS:

```
This routine is now called from GC_INIT_EXTRA (in GeosCore/input_mod.F).
```

REVISION HISTORY:

```
(1 ) Now references ALLOC_ERR from "error_mod.f" (bmy, 10/15/02)
22 Mar 2012 - M. Payer    - Added ProTeX headers
11 Apr 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC arguments
```

10.1.4 cleanup_c2h6

Subroutine CLEANUP_C2H6 deallocates the natural gas C2H6 emission array.

INTERFACE:

```
SUBROUTINE CLEANUP_C2H6
```

REVISION HISTORY:

```
22 Mar 2012 - M. Payer    - Added ProTeX headers
```

10.2 Fortran: Module Interface co2_mod.F

Module CO2_MOD contains variables and routines used for the CO2 simulation. A tagged CO2 simulation capability has now been added.

References:

- Andres, R.J, G. Marland, I. Fung, and E. Matthews, *A 1x1 distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture*, Glob. Biogeochem. Cycles, **10**, 419-429, 1996.
- Corbett and Koehler (2003) *Updated emissions from ocean shipping*, J. Geophys. Res., **108**, D20, 4650.
- Corbett and Koehler (2004) *Considering alternative input parameters in an activity-based ship fuel consumption and emissions model: Reply ...* J. Geophys. Res., D23303.
- Endresen et al. (2007) *A historical reconstruction of ships fuel consumption and emissions*, J. Geophys. Res. **112**, D12301.
- Kim et al. (2005) *System for assessing Aviation's Global Emissions (SAGE) Version 1.5 global Aviation Emissions Inventories for 2000-2004*
- Kim et al. (2007) *System for assessing Aviation's Global Emissions (SAGE) Part 1: Model description and inventory results*
- LeQuere et al. (2009) *Trends in the sources and sinks of carbon dioxide*, Nature Geoscience, doi:10.1038/ngeo689.
- Olsen and Randerson (2004), *Differences between surface and column atmospheric CO2 and implications for carbon cycle research*, J. Geophys. Res., **109**, D02301,
- Potter et al. (1993), *Terrestrial Ecosystem Production: A process model based on global satellite and surface data*, Glob. Biogeochem. Cycles, **7**(4), 811-841.
- Randerson, J.T, M.V. Thompson, T.J.Conway, I.Y. Fung, and C.B. Field, *The contribution of terrestrial sources and sinks to trends in the seasonal cycle of atmospheric carbon dioxide*, Glob. Biogeochem. Cycles,**11**, 535-560, 1997.
- Suntharalingam et al. (2005) *Infulence of reduced carbon emissions and oxidation on the distribution of atmospheric CO2: Implications for inversion analysis*, BGC, 19, GB4003.
- Takahashi, T, R. Feely, R. Weiss, R. Wanninkof, D. Chipman, S. Sutherland, and T. Takahashi (1997), *Global air-sea flux of CO2: An estimate based on measurements of sea-air pCO2 difference*, Proceedings of the National Academy of Sciences, **94**, 8292-8299.
- Takahashi, T, et al. (2009), *Climatological mean and decadal change in surface ocean pCO2, and net sea-air CO2 flux over the global oceans*, **Deep-Sea Research II**, doi:10.1016/jdsr2/2008.12.009.

- Yevich, R. and J. A. Logan, *An assesment of biofuel use and burning of agricultural waste in the developing world*, Glob. Biogeochem. Cycles, **17**, 1095, doi:10.1029/2002GB001952, 2003.
- Sausen, R. and Schumann, U. "Estimates of the Climate Response to Aircraft CO2 and NOx Emissions Scenarios", Climate Change, 44: 27-58, 2000
- Wilkersen, J.T. et al. *Analysis of emission data from global commercial Aviation: 2004 and 2006*, Atmos. chem. Phys. Disc., **10**, 2945-2983, 2010.

INTERFACE:

```
MODULE CO2_MOD
```

USES:

```
USE PhysConstants       ! Physical constants
USE inquireMod,    ONLY : findFreeLUN
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CLEANUP_CO2
PUBLIC  :: INIT_CO2
PUBLIC  :: EMISSCO2
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: DEF_BIOSPH_CO2_REGIONS_F
PRIVATE :: DEF_OCEAN_CO2_REGIONS_F
PRIVATE :: DEF_FOSSIL_CO2_REGIONS_F
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  WARNING! Tagged CO2 simulation only work for 2 x 2.5 grid! %%%
%%%  Someone will have to make this more general later on...    %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

.

REVISION HISTORY:

```
16 Aug 2005 - P. Suntharalingam - Initial version
(1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(2 ) Now references biomass_mod.f (bmy, 9/27/06)
(3 ) Tagged CO2 capability developed (dbj)
(4 ) Implemented monthly and annual fossil fuel inventories
```

```
      (R.Nassar 2009-03-10)
(5 ) Implemented CO2 emissions from shipping and aviation (R.Nassar 2010)
(6 ) Implemented monthly CO2 chemical production and surface correction
      (R.Nassar 2010)
25 Feb 2011 - R. Nassar  - Now read updated CDIAC CO2 emissions data
07 Sep 2011 - P. Kasibhatla - Modified to include GFED3
01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
20 Jun 2014 - R. Yantosca - Remove obsolete emissions code; we now use HEMCO
07 Nov 2014 - M. Yannetti - Added PRECISION_MOD
```

10.2.1 emissco2

Subroutine EMISSCO2 is the driver routine for CO2 emissions.

INTERFACE:

```
      SUBROUTINE EMISSCO2( am_I_Root, Input_Opt,
     &                     State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE DIAG04_MOD,         ONLY : AD04, ND04
      USE DIAG04_MOD,         ONLY : AD04_plane,    AD04_chem
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
      USE HCO_STATE_MOD,      ONLY : HCO_GetHcoID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
The initial condition for CO2 has to be at least 50 ppm or higher or else
the balanced biosphere fluxes will make STT negative. (pns, bmy, 8/16/05)
```

REVISION HISTORY:

```
16 Aug 2005 - P. Suntharalingam - Initial version
(1 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(2 ) We now get CO2 biomass emissions from biomass_mod.f.  This allows us
     to use either GFED2 or default Duncan et al biomass emissions.
     (bmy, 9/27/06)
(3 ) Tagged tracer capability added. This requires the editable region
     files Regions_land.dat and Regions_ocean.dat in the run directory
     (rnassar,dbj, 2009)
(4 ) New tracers for emissions from international and domestic shipping,
     international and domestic aviation, and the chemical CO2 source
     from the oxidation of CO, CH4, and other organics (rnassar,dbj, 2009)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
27 Aug 2014 - C. Keller   - Now interface with HEMCO.
13 Apr 2015 - R. Nassar   - Some bug fixes for HEMCO implementation,
                            e.g. unit fixes for aviation and chem source
11 Sep 2015 - E. Lundgren - Tracer units are now kg/kg dry air (prev kg)
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.2.2 def_biosph_co2_regions_f

Subroutine DEF_BIOSPH_CO2_REGIONS defines the land biospheric and ocean CO2 exchange regions.

INTERFACE:

```
SUBROUTINE DEF_BIOSPH_CO2_REGIONS_F( REGION )
```

USES:

```
USE CMN_SIZE_MOD        ! Size parameters
USE FILE_MOD,      ONLY : IOERROR
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT)   :: REGION(IIPAR,JJPAR)
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  WARNING! Tagged CO2 simulation only work for 2 x 2.5 grid!  %%%
%%%  Someone will have to make this more general later on...     %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
18 May 2010 - R. Nassar, D. Jones - Initial version
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
13 Apr 2013 - R. Nassar - minor fixes to region boundary indices
```

10.2.3 def_ocean_co2_regions_f

Subroutine DEF_OCEAN_CO2_REGIONS defines CO2 regions for ocean exchange.

INTERFACE:

```
SUBROUTINE DEF_OCEAN_CO2_REGIONS_F( REGION )
```

USES:

```
USE CMN_SIZE_MOD        ! Size parameters
USE FILE_MOD,      ONLY : IOERROR
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT)  :: REGION(IIPAR,JJPAR)
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  WARNING! Tagged CO2 simulation only work for 2 x 2.5 grid!  %%%
%%%  Someone will have to make this more general later on...     %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
18 May 2010 - R. Nassar, D. Jones - Initial version
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
```

10.2.4 def_fossil_co2_regions_f

Subroutine DEF_FOSSIL_CO2_REGIONS defines CO2 regions for anthropogenic emissions

INTERFACE:

```
SUBROUTINE DEF_FOSSIL_CO2_REGIONS_F( REGION )
```

USES:

```
USE CMN_SIZE_MOD        ! Size parameters
USE FILE_MOD,      ONLY : IOERROR
```

OUTPUT PARAMETERS:

```
INTEGER, INTENT(OUT)   :: REGION(IIPAR,JJPAR)
```

REMARKS:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  WARNING! Tagged CO2 simulation only work for 2 x 2.5 grid!  %%%
%%%  Someone will have to make this more general later on...     %%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

REVISION HISTORY:

```
18 May 2010 - R. Nassar, D. Jones - Initial version
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
```

10.2.5 init_co2

Subroutine INIT_CO2 allocates memory to module arrays and reads in annual mean emissions.

INTERFACE:

```
SUBROUTINE INIT_CO2( am_I_Root, Input_Opt, RC )
```

USES:

```
! References to F90 modules
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
16 Aug 2005 - P. Suntharalingam   - Initial version
18 May 2010 - R. Nassar, D. Jones - Updated
25 Mar 2013 - R. Yantosca - Now use logical fields from Input_Opt
```

10.2.6 cleanup_co2

Subroutine CLEANUP_CO2 deallocates all module arrays.

INTERFACE:

```
      SUBROUTINE CLEANUP_CO2
```

REVISION HISTORY:

```
   16 Aug 2005 - P. Suntharalingam   - Initial version
   18 May 2010 - R. Nassar, D. Jones - Updated
```

10.3 Fortran: Module Interface exchange_mod.F90

Module EXCHANGE_MOD contains variables and routines which are used to exchange data between two or more runs (Global Domain and Nested Domains), thus to combine them into TWO-WAY nested run. (yanyy, 6/18/14)

INTERFACE:

```
      MODULE EXCHANGE_MOD
```

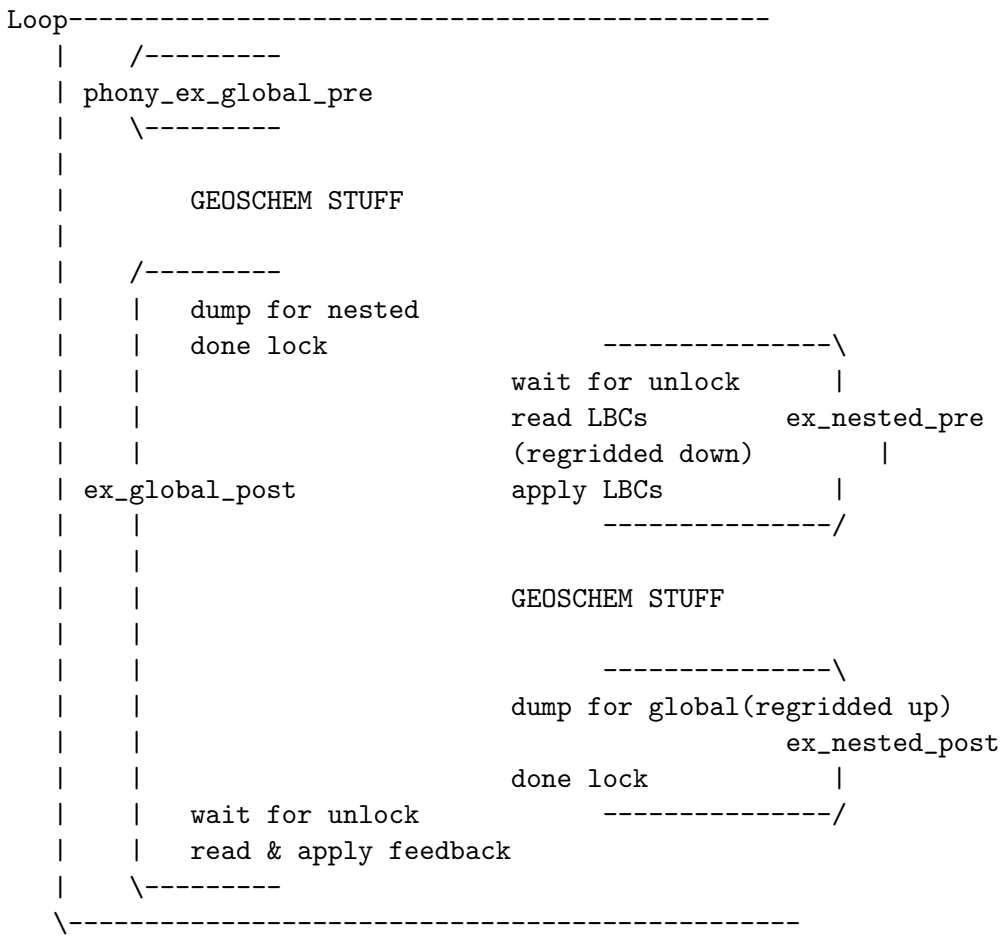
USES:

```
      IMPLICIT NONE
      PRIVATE
  !PUBLIC MEMBER FUNCTIONS
      PUBLIC   :: EXCHANGE_GLOBAL_INIT
      PUBLIC   :: EXCHANGE_NESTED_INIT
      PUBLIC   :: EXCHANGE_GLOBAL_POST
      PUBLIC   :: EXCHANGE_NESTED_PRE
      PUBLIC   :: EXCHANGE_NESTED_POST
      PUBLIC   :: ITS_TIME_FOR_EXCHANGE
      PUBLIC   :: INIT_EXCHANGE
      PUBLIC   :: CLEANUP_EXCHANGE
```

PRIVATE MEMBER FUNCTIONS:

REMARKS:

```
   Diagram:
                 Global            Nested
   Init-----------------------------------------------
      |
      |        wait for unlock      wait for unlock
      |
      \-----------------------------------------------
```



REVISION HISTORY:

```
30 Mar 2014 - Y.Y. Yan - Initial Version
(1) Establish the frame of the data exchange between models
     (kuangye,yanyy, 6/10/12)
(2) Now update for version 9-02 (yanyy, 6/21/14)
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.1 exchange_global_init

Global initialization for exchange

INTERFACE:

```
SUBROUTINE EXCHANGE_GLOBAL_INIT()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.2 exchange_nested_init

Nested initialization for exchange

INTERFACE:

```
SUBROUTINE EXCHANGE_NESTED_INIT()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.3 exchange_global_post

Carry out the process to communicate the nested simulated results back to global model.

INTERFACE:

```
SUBROUTINE EXCHANGE_GLOBAL_POST( am_I_Root, Input_Opt,
&                                State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE DAO_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GC_Error
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TPCORE_BC_MOD
USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root
TYPE(OptInput), INTENT(IN)    :: Input_Opt
TYPE(MetState), INTENT(IN)    :: State_Met
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC
```

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
13 Aut 2015 - E. Lundgren - Now input tracer conc in kg/kg not v/v.
```

10.3.4 exchange_nested_pre

Before nested grid exchange

INTERFACE:

```
SUBROUTINE EXCHANGE_NESTED_PRE()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.5 exchange_nested_post

After nested-grid exchange

INTERFACE:

```
SUBROUTINE EXCHANGE_NESTED_POST( am_I_Root, Input_Opt,
&                                State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD          ! Size parameters
USE DAO_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : GC_Error
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE UnitConv_Mod
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root
TYPE(OptInput), INTENT(IN)    :: Input_Opt
TYPE(MetState), INTENT(IN)    :: State_Met
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC
```

RETURN VALUE:

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
13 Aug 2015 - E. Lundgren - Input tracer conc in kg/kg not v/v
```

10.3.6 its_time_for_exchange

Returns TRUE if it's time to do the 2-way exchange of data.

INTERFACE:

```
FUNCTION ITS_TIME_FOR_EXCHANGE()
```

USES:

```
USE TIME_MOD, ONLY : ITS_TIME_FOR_EXCH
```

RETURN VALUE:

```
LOGICAL :: ITS_TIME_FOR_EXCHANGE
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.7 init_exchange

Initialization routine.

INTERFACE:

```
SUBROUTINE INIT_EXCHANGE( am_I_Root )
```

USES:

```
USE CMN_SIZE_MOD          ! Size parameters
USE ERROR_MOD
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)       :: am_I_Root
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Now only print output on the root CPU
06 Jan 2015 - R. Yantosca - Added ProTeX headers
24 Mar 2015 - E. Lundgren - Remove tracer_mod dependency since unused
```

10.3.8 cleanup_exchange

Cleanup routine.

INTERFACE:

```
SUBROUTINE CLEANUP_EXCHANGE( am_I_Root )
```

INPUT PARAMETERS:

```
      LOGICAL, INTENT(IN) :: am_I_Root
```

REVISION HISTORY:

```
    06 Jan 2015 - R. Yantosca - Now only write output on the root CPU
    06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.9 ex_dump_for_global

?

INTERFACE:

```
      SUBROUTINE EX_DUMP_FOR_GLOBAL( am_I_Root, Input_Opt,
     &                               State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root
      TYPE(OptInput), INTENT(IN)    :: Input_Opt
      TYPE(MetState), INTENT(IN)    :: State_Met
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC
```

REVISION HISTORY:

```
    06 Jan 2015 - R. Yantosca - Added ProTeX headers
    06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies
    15 Aug 2016 - E. Lundgren - Replace tracers with species
```

10.3.10 ex_read_and_apply_feedback

?

INTERFACE:

```
      SUBROUTINE EX_READ_AND_APPLY_FEEDBACK( am_I_Root, Input_Opt,
     &                         State_Met, State_Chm, RC, DOMAIN )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE ERROR_MOD
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root
      TYPE(OptInput), INTENT(IN)    :: Input_Opt
      TYPE(MetState), INTENT(IN)    :: State_Met
      INTEGER,        INTENT(IN)    :: DOMAIN
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC
```

REVISION HISTORY:

```
    06 Jan 2015 - R. Yantosca - Now get LPRT from Input_Opt
    06 Jan 2015 - R. Yantosca - Added ProTeX headers
    24 Mar 2015 - E. Lundgren - Remove tracer_mod dependency since not used
    06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies
    15 Aug 2016 - E. Lundgren - Replace tracers with species
```

10.3.11 ex_regrid_up

This subroutine will be called within EX_DUMP_FOR_GLOBAL, Using module's global vars: REGRID_MAT_L, REGRID_MAT_R

INTERFACE:

```
      SUBROUTINE EX_REGRID_UP( NX_ORIG, NY_ORIG, NX_NEW, NY_NEW,
     &                         NZ, ORIG_ARRAY, NEW_ARRAY )
```

REVISION HISTORY:

```
    06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.12 ex_convert_units_cspec

Converts molec/cm3/box to fakemass (e.g. convert cspecfull to a masslike unit)

INTERFACE:

```
SUBROUTINE EX_CONVERT_UNITS_CSPEC( am_I_Root, Input_Opt,
&                 State_Met, State_Chm, RC, FLAG, NX, NY, NZ )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE DAO_MOD
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root
TYPE(OptInput), INTENT(IN)    :: Input_Opt
TYPE(MetState), INTENT(IN)    :: State_Met
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC
```

RETURN VALUE:

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
06 Jun 2016 - M. Sulprizio- Replace NTSPEC with State_Chm%nSpecies
```

10.3.13 wait_for_unlock

Waits for MPI unlock.

INTERFACE:

```
SUBROUTINE WAIT_FOR_UNLOCK()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.14 done_lock_me_up

?

INTERFACE:

```
SUBROUTINE DONE_LOCK_ME_UP()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.15 no_more_lock

?

INTERFACE:

```
SUBROUTINE NO_MORE_LOCK()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.16 alert_for_kill_command

Stops if there is a kill command issued.

INTERFACE:

```
SUBROUTINE ALERT_FOR_KILL_COMMAND()
```

USES:

```
USE ERROR_MOD
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.17 touch_file

Touches a file (i.e. updates the timestamp on disk).

INTERFACE:

```
SUBROUTINE TOUCH_FILE( FNAME )
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN)     :: FNAME
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.18 open_bin_file_for_read

Opens a binary file for reading.

INTERFACE:

```
SUBROUTINE OPEN_BIN_FILE_FOR_READ( FNAME )
```

USES:

```
USE FILE_MOD
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.19 open_bin_file_for_write

Opens a binary file for writing.

INTERFACE:

```
SUBROUTINE OPEN_BIN_FILE_FOR_WRITE( FNAME )
```

USES:

```
USE FILE_MOD
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN)     :: FNAME
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.20 open_bin_file_for_append

Opens a binary file for appending.

INTERFACE:

```
SUBROUTINE OPEN_BIN_FILE_FOR_APPEND( FNAME )
```

USES:

```
USE FILE_MOD
```

INPUT PARAMETERS:

```
CHARACTER(LEN=*), INTENT(IN)     :: FNAME
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.21 close_bin_file

Closes a binary file.

INTERFACE:

```
SUBROUTINE CLOSE_BIN_FILE()
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.22 write_3d_real8_array

Writes data to a 3-D REAL*8 array.

INTERFACE:

```
SUBROUTINE WRITE_3D_REAL8_ARRAY( NI, NJ, NK, ARRAY )
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN)     :: NI, NJ, NK
REAL*8,           INTENT(IN)     :: ARRAY(NI,NJ,NK)
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.23 read_3d_real8_array

Reads data from 3-D REAL*8 array.

INTERFACE:

```
SUBROUTINE READ_3D_REAL8_ARRAY( NI, NJ, NK, ARRAY )
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN)     :: NI, NJ, NK
```

OUTPUT PARAMETERS:

```
REAL*8,           INTENT(OUT)    :: ARRAY(NI,NJ,NK)
```

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.3.24 gen_regrid_mat

Regridding utility.

INTERFACE:

```
SUBROUTINE GEN_REGRID_MAT( N1, N2, RATIO, OFFSET, RES )
```

INPUT PARAMETERS:

```
INTEGER,          INTENT(IN)     :: N1, N2
REAL*8,           INTENT(IN)     :: RATIO, OFFSET
```

OUTPUT PARAMETERS:

```
REAL*8,           INTENT(OUT)    :: RES(N1, N2)
```

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Added ProTeX headers
```

10.4 Fortran: Module Interface global_ch4_mod.F

Module GLOBAL_CH4_MOD contains variables and routines for simulating CH4 chemistry in the troposphere.

INTERFACE:

```
MODULE GLOBAL_CH4_MOD
```

USES:

```
USE HCO_ERROR_MOD       ! For HEMCO error reporting
USE PhysConstants, ONLY : AVO, AIRMW
USE PRECISION_MOD       ! For GEOS-Chem Precision (fp, f4, f8)

IMPLICIT NONE
PRIVATE

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Normally we will not save out the CH4_BUDGET diagnostics (esp. when
%%% using the nested grid simulations) in order to save memory.  If you
%%% want to use CH4_BUDGET, then uncomment the following line of code:
%%% (kjw, bmy, 2/12/14)
#define USE_CH4_BUDGET_DIAG 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC :: CH4_AVGTP
      PUBLIC :: EMISSCH4
      PUBLIC :: CHEMCH4
      PUBLIC :: INIT_GLOBAL_CH4
      PUBLIC :: CLEANUP_GLOBAL_CH4
```

PUBLIC DATA MEMBERS:

```
      REAL(fp), PARAMETER,   PUBLIC :: XNUMOL_CH4 = AVO / 16d-3 ! hard-coded MW

#if defined( USE_CH4_BUDGET_DIAG )
      REAL(fp), ALLOCATABLE, PUBLIC :: TCH4(:,:,:,:)
#endif

      ! Make CH4_EMIS now public so that it can be used by vdiff_mod.F90
      ! Methane emissions units are [kg/m2/s]
      REAL(fp),  ALLOCATABLE, PUBLIC :: CH4_EMIS(:,:,:)
```

REVISION HISTORY:

```
   17 Jan 2001- J. Wang, B. Duncan, R. Yantosca -- Initial version
   (1 ) Merged routines from jsw's CH4 code  into "global_ch4_mod.f"
        (bmy, 1/16/01)
   (2 ) XNUMOL_CH4 and TCH4 have to be public - all other variables can
        be made private, so as not to conflict with other common-block
        definitions (bmy, 1/17/01)
   (3 ) Minor fixes from jsw added (jsw, bmy, 2/17/01)
   (4 ) Removed some F90 module references from EMISSCH4 (bmy, 3/20/01)
   (5 ) Eliminate obsolete commented-out code (bmy, 4/20/01)
   (6 ) Updated comments (bmy, 9/4/01)
   (7 ) Fixes for binary punch file in READ_COPROD (bmy, 9/26/01)
   (8 ) Removed obsolete code from READ_COPROD (bmy, 10/24/01)
   (9 ) Minor bug fixes for compilation on ALPHA (bmy, 11/15/01)
   (10) Eliminate obsolete code from 11/01 (bmy, 2/27/02)
   (11) Now eliminate PS from the arg list to CH4_AVGTP (4/11/02)
   (12) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
        MODULE ROUTINES sections.  Updated comments (bmy, 5/28/02)
   (13) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
        to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
   (14) Now reference "file_mod.f".  Also removed obsolete code. (bmy, 6/27/02)
   (15) Now references "pressure_mod.f" (bmy, 8/21/02)
   (16) Now reference AD and T from "dao_mod.f".  Now reference "error_mod.f".
        Remove obsolete code from various routines.  Remove reference to
        header file "comtrid.h" -- it's not used. (bmy, 11/6/02)
   (17) Minor bug fix in FORMAT statements (bmy, 3/23/03)
   (18) Now references "grid_mod.f" and "time_mod.f" (bmy, 3/27/03)
   (19) Updates to GET_GLOBAL_CH4 (bmy, 7/1/03)
   (20) Now references "directory_mod.f", "tracer_mod.f", and "diag_oh_mod.f"
```

```
       (bmy, 7/20/04)
  (21) Now can read data for both GEOS and GCAP grids (bmy, 8/16/05)
  (22) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
  (23) Updated CH4 simulation (kjw, cph, ccarouge, 10/1/09)
  (24) Added modifications for MERRA (bmy, 8/13/10)
  08 Feb 2012 - R. Yantosca - Added modifications for GEOS-5.7.x
  01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
  07 Mar 2012 - M. Payer    - Added ProTeX headers
  01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
  03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
  20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
  12 Feb 2014 - K. Wecht    - Add modifications for 0.25 x 0.3125 NA grid
  12 Feb 2014 - K. Wecht    - Disable CH4 budget diagnostic (bracket the
                              code out with #ifdef blocks so it can be used)
  20 Jun 2014 - R. Yantosca - Remove obsolete emissions code; we now use HEMCO
  09 Sep 2014 - C. Keller   - Implemented HEMCO for emissions.
  16 Sep 2014 - C. Keller   - Now also get chemical fields (OH and CH4 prod)
                              through HEMCO. Removed READ_COPROD and
                              READ_CH4LOSS (now obsolete)
  16 Sep 2014 - C. Keller   - Removed all references to Clarisa's OH clima-
                              tology (not used anywhere)
  14 Nov 2014 - M. Yannetti - Added PRECISION_MOD
  04 Mar 2015 - R. Yantosca - Now use REAL(f4) for HCO_GetPtr pointer args
  06 Jan 2016 - E. Lundgren - Use global physical parameters
  16 Jun 2016 - M. Sulprizio- Now define IDTCH4 locally
  20 Jun 2016 - R. Yantosca - Rename IDTCH4 to id_CH4 for consistency
  29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
!------------------------------------------------------------------------------
BOC
```

DEFINED PARAMETERS:

```
!=============================================================================
! Module Variables:
! N_CH4      : Number of budget items in TCH4
! BAIRDENS   : Array for air density                      [molec/cm3]
! BOH        : Array for OH values                        [kg/m3]
! COPROD     : Array for zonal mean P(CO)                 [v/v/s]
! CH4LOSS    : Array for monthly average CH4 loss freq    [1/s]
! PAVG       : Array for 24-h avg surface pressure        [mb]
! TAVG       : Array for 24-h avg temperature             [K]
! TCH4       : Array for CH4 budget (N_CH4 items)         [molec/box]
! FMOL_CH4   : Molecular weight of CH4                    [kg/mole]
! XNUMOL_CH4 : Molecules CH4 / kg CH4                     [molec/kg]
! CH4_EMIS   : Array for CH4 Emissions                    [kg/m2/s]
!=============================================================================

! Number of CH4 budget types
```

```
       INTEGER,  PARAMETER   :: N_CH4     = 12

       REAL(fp), PARAMETER   :: XNUMOL_OH = AVO / 17e-3_fp  ! molec OH / kg OH
                                                            ! hard-coded MW
       REAL(fp), PARAMETER   :: CM3PERM3  = 1.e+6_fp
```

LOCAL VARIABLES:

```
       ! Species ID flag
       INTEGER               :: id_CH4

       ! Various arrays
       REAL(fp), ALLOCATABLE :: BAIRDENS(:,:,:)
       REAL(fp), ALLOCATABLE :: PAVG(:,:,:)
       REAL(fp), ALLOCATABLE :: TAVG(:,:,:)

       ! Pointers to fields in the HEMCO data structure.
       ! These need to be declared as REAL(f4), aka REAL*4.
       ! NOTE: These are globally SAVEd variables so we can
       ! nullify these in the declaration statement (bmy, 4/29/16)
       REAL(f4), POINTER     :: BOH    (:,:,:) => NULL()
       REAL(f4), POINTER     :: CH4LOSS(:,:,:) => NULL()

       ! Online CH4 only
       REAL(fp), ALLOCATABLE :: SUMANTHRO(:,:)
       REAL(fp), ALLOCATABLE :: SUMBIOG(:,:)

       REAL(fp)              :: TROPOCH4

       CONTAINS
  EOC
  ------------------------------------------------------------------------------
                   GEOS-Chem Global Chemical Transport Model                  !
  ------------------------------------------------------------------------------
%//////////////////////////////////////////////////////////

\mbox{}\hrulefill\


  \subsubsection [ch4\_avgtp] {ch4\_avgtp}


  Subroutine CH4\_AVGTP gets the 24-h average surface pressure
    and temperature needed for the CH4 simulation. (jsw, bnd, bmy, 1/16/01,
    7/20/04)
  \\
  \\{\bf INTERFACE:}
\begin{verbatim}       SUBROUTINE CH4_AVGTP( State_Met )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_DYN, GET_TS_CHEM
      USE TIME_MOD,           ONLY : GET_ELAPSED_MIN
```

INPUT PARAMETERS:

```
      TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry and
     placed into module "global_ch4_mod.f" by Bob Yantosca. (bmy, 1/16/01)
(2 ) CH4_AVGTP is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
     (bmy, 1/16/01)
(3 ) Removed duplicate definition for NTDT, NMIN (bmy, 11/15/01)
(4 ) Removed PS from argument list.  Now use P(I,J)+PTOP instead of
     PS, this ensures that we have consistency between P and AD.
     (bmy, 4/11/02)
(5 ) Removed obsolete code (bmy, 6/27/02)
(6 ) Now uses GET_PCENTER from "pressure_mod.f" to return the pressure
     at the midpoint of the box (I,J,L).  Also added parallel DO-loops.
     Updated comments. (dsa, bdf, bmy, 8/21/02)
(7 ) Now reference T from "dao_mod.f".  Now reference GEOS_CHEM_STOP from
     "error_mod.f" (bmy, 10/15/02)
(8 ) Removed NTDT, NMIN from the arg list.  Now uses functions GET_TS_DYN,
     GET_TS_CHEM, and GET_ELAPSED_MIN from "time_mod.f" (bmy, 3/27/03)
(9 ) Remove reference to CMN, it's not needed (bmy, 7/20/04)
07 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
17 Sep 2014 - C. Keller   - Removed legacy code (unused variables).
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID and
                            remove dependency on pressure_mod
01 Apr 2015 - E. Lundgren - Change State_Met%PMID to State_Met%PMID_DRY
```

10.4.1 emissch4

Subroutine EMISSCH4 places emissions of CH4 [kg] into the chemical species array.

INTERFACE:

```
      SUBROUTINE EMISSCH4( am_I_Root, Input_Opt,
     &                     State_Met, RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD58
      USE HCO_INTERFACE_MOD,  ONLY : HcoState, GetHcoDiagn
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE GC_GRID_MOD,        ONLY : GET_XOFFSET, GET_YOFFSET
      USE HCO_STATE_MOD,      ONLY : HCO_STATE
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    WARNING: Soil absorption has to be the 11th field in CH4_EMIS
```

REVISION HISTORY:

```
    (1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
         James Wang (7/00).  Inserted into module "global_ch4_mod.f"
         by Bob Yantosca. (bmy, 1/16/01)
    (2 ) EMISSCH4 is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
         (bmy, 1/16/01)
    (3 ) GLOBASEAEMIS, GLOBSEAEMIS are diagnostics by jsw.
    (4 ) Do not multiply CO emissions by 1.28 anymore (jsw, bmy, 2/12/01)
    (5 ) Renamed input files to CH4_monthly.geos.{RES} and
         CH4_aseasonal.geos.{RES}. (bmy, 2/12/01)
    (6 ) Add reference to "CMN_SETUP" for the DATA_DIR variable (bmy, 2/13/01)
    (7 ) Removed references to "biofuel_mod.f" and "biomass_mod.f"; these
         weren't necessary (bmy, 3/20/01)
    (8 ) Now reference IU_FILE and IOERROR from "file_mod.f".  Now use IU_FILE
         instead of IUNIT as the file unit #. (bmy, 6/27/02)
    (9 ) Now reference BXHEIGHT and SUNCOS from "dao_mod.f".  Remove reference
         to header file "comtrid.h" -- it's not used.  Make FIRSTEMISS a local
         SAVEd variable.  Also use MONTH from "CMN" instead of the variable
         LMN. (bmy, 11/15/02)
    (10) Now replace DXYP(JREF)*1d4 with routine GET_AREA_CM2 of "grid_mod.f".
         Now use function GET_MONTH and GET_TS_EMIS from "time_mod.f".
         Now use functions GET_XOFFSET and GET_YOFFSET from "grid_mod.f".
         I0 and J0 are now local variables. (bmy, 3/27/03)
```

```
(11) Now reference STT from "tracer_mod.f".  Now reference DATA_DIR from
     "directory_mod.f". (bmy, 7/20/04)
(12) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(13) Add non-local PBL capability (ccc, 8/31/09)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
07 Mar 2012 - M. Payer    - Added ProTeX headers
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
11 Apr 2014 - R. Yantosca - Remove call to INIT_GLOBAL_CH4
09 Sep 2014 - C. Keller   - Implemented HEMCO
11 Sep 2015 - E. Lundgren - Remove area-dependency (except for global mass
                            sums) by outputting diagnostics as kg/m2 not kg
11 Sep 2015 - E. Lundgren - Remove State_Chm from arg list since not used
```

10.4.2 chemch4

Subroutine CHEMCH4 computes the chemical loss of CH4 (sources - sinks). (jsw, bnd, bmy, 6/8/00, 10/3/05)

INTERFACE:

```
      SUBROUTINE CHEMCH4( am_I_Root, Input_Opt,
     &                    State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD43
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP, ERROR_STOP
      USE ERROR_MOD,          ONLY : IT_IS_NAN, IT_IS_FINITE
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_DAY,   GET_MONTH
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
CH4 SOURCES
============================================================================
(1 ) Oxidation of methane, isoprene and monoterpenes (SRCO_fromHCs).
(2 ) Direct emissions of CO from fossil fuel combustion, biomass
      burning and wood (for fuel) burning (SR SETEMIS).
(3 ) Emissions.
                                                                            .
CH4 SINKS:
============================================================================
(1 ) Removal of CO by OH (SR OHparam & CO_decay).
(2 ) CO uptake by soils (neglected).
(3 ) Transport of CO to stratosphere from troposphere
      (in dynamical subroutines).
(4 ) Removal by OH (Clarissa's OH--climatol_OH.f and CO_decay.f)
(5 ) Transport of CH4 between troposphere and stratosphere, and
      destruction in strat (CH4_strat.f).
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
      James Wang (6/8/00).  Inserted into module "global_ch4_mod.f"
      by Bob Yantosca. (bmy, 1/16/01)
(2 ) CHEMCH4 is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
      (bmy, 1/16/01)
(3 ) Updated comments (jsw, bmy, 2/12/01)
(4 ) LD43 is already declared in CMN_DIAG; don't redefine it (bmy, 11/15/01)
(5 ) Replaced all instances of IM with IIPAR and JM with JJPAR, in order
      to prevent namespace confusion for the new TPCORE (bmy, 6/25/02)
(6 ) Now reference AD from "dao_mod.f".  Now reference GEOS_CHEM_STOP from
      "error_mod.f"  Now make FIRSTCHEM a local SAVEd variable.  Now
      reference ALBD from "dao_mod.f".  Now use MONTH and JDATE from "CMN"
      instead of LMN and LDY. (bmy, 11/15/02)
(7 ) Remove NYMDb, NYMDe from the arg list.  Now use functions GET_MONTH,
      GET_NYMDb, GET_NYMDe, GET_MONTH, GET_DAY from the new "time_mod.f"
      (bmy, 3/27/03)
(8 ) Now reference DATA_DIR from "directory_mod.f" (bmy, 7/20/04)
(9 ) Remove reference to BPCH2_MOD, it's not needed (bmy, 10/3/05)
07 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
12 Feb 2014 - K. Wecht    - Disable CH4 budget diagnostic (bracket the
```

```
                            code out with #ifdef blocks so it can be used)
23 Jul 2014 - R. Yantosca - Remove reference to obsolete CMN_mod.F
23 Jul 2014 - R. Yantosca - Reference ITS_IN_THE_CHEMGRID (chemgrid_mod.F)
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
17 Sep 2014 - C. Keller   - Now use HEMCO to get CH4 loss and OH conc. field.
06 Jan 2016 - E. Lundgren - Use global physical parameters
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

10.4.3 ch4_decay

Subroutine CH4_DECAY calculates the decay rate of CH4 by OH. OH is the only sink for CH4 considered here. (jsw, bnd, bmy, 1/16/01, 7/20/04)

INTERFACE:

```
SUBROUTINE CH4_DECAY( State_Met, State_Chm )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE DIAG_MOD,           ONLY : AD19
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM, ITS_A_NEW_YEAR
USE TIME_MOD,           ONLY : GET_MONTH
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REMARKS:

```
We now use function ITS_IN_THE_CHEMGRID from chemgrid_mod.F to diagnose
if box (I,J,L) is in the troposphere or stratosphere.

Monthly loss of CH4 is summed in TCH4(3)
   TCH4(3)  = CH4 sink by OH
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
     James Wang (7/00).  Inserted into module "global_ch4_mod.f"
     by Bob Yantosca. (bmy, 1/16/01)
(2 ) CH4_DECAY is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
     (bmy, 1/16/01)
(3 ) Now use function GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(4 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
07 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
12 Feb 2014 - K. Wecht    - Disable CH4 budget diagnostic (bracket the
                            code out with #ifdef blocks so it can be used)
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.4.4 ch4_ohsave

Subroutine CH4_OHSAVE archives the CH3CCl3 lifetime from the OH used in the CH4 simulation. (bnd, jsw, bmy, 1/16/01, 7/20/04)

INTERFACE:

```
SUBROUTINE CH4_OHSAVE( State_Met, State_Chm )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_CHEMGRID
USE CMN_SIZE_MOD
USE DIAG_OH_MOD,        ONLY : DO_DIAG_OH_CH4
USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REMARKS:

```
We now use function ITS_IN_THE_CHEMGRID from chemgrid_mod.F to diagnose
if box (I,J,L) is in the troposphere or stratosphere.
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
     James Wang (7/00).  Inserted into module "global_ch4_mod.f"
     by Bob Yantosca. (bmy, 1/16/01)
(2 ) CH4_OHSAVE is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
     (bmy, 1/16/01)
(3 ) Now call DO_DIAG_OH_CH4 to pass OH diagnostic info to the
     "diag_oh_mod.f" (bmy, 7/20/04)
07 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.4.5 ch4_strat

Subroutine CH4_STRAT calculates uses production rates for CH4 to calculate loss of CH4 in above the tropopause. (jsw, bnd, bmy, 1/16/01, 7/20/04)

INTERFACE:

```
SUBROUTINE CH4_STRAT( am_I_Root, Input_Opt,
&                     State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE CHEMGRID_MOD,       ONLY : GET_MIN_TPAUSE_LEVEL
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_NOCHEMGRID
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : CHECK_SPC
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH, GET_TS_CHEM
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input options
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
Production (mixing ratio/sec) rate provided by Dylan Jones.
Only production by CH4 + OH is considered.

We now use function ITS_IN_THE_CHEMGRID from chemgrid_mod.F to diagnose
if box (I,J,L) is in the troposphere or stratosphere.
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
     James Wang (7/00).  Inserted into module "global_ch4_mod.f"
     by Bob Yantosca. (bmy, 1/16/01)
(2 ) CH4_STRAT is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
     (bmy, 1/16/01)
(3 ) Removed LMN from the arg list and made it a local variable.  Now use
     functions GET_MONTH and GET_TS_CHEM from "time_mod.f" (bmy, 3/27/03)
(4 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
07 Mar 2012 - M. Payer    - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
23 Jun 2014 - R. Yantosca - Now accept am_I_Root and RC
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
24 Mar 2015 - E. Lundgren - Now pass Input_Opt to Check_STT
06 Jan 2016 - E. Lundgren - Use global physical parameters
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.4.6 ch4_budget

Subroutine CH4_BUDGET calculates the budget of CH4. This SR only works for monthly averages, so be sure to start on the first of the month and run to another first of the month! (jsw, bnd, bmy, 1/16/01, 10/3/05)
Disable CH4 Budget for SEAC4RS code to save memory kjw, 2/3/2014

INTERFACE:

```
SUBROUTINE CH4_BUDGET( State_Chm )
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD,        ONLY : GET_XOFFSET, GET_YOFFSET
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_MONTH,   GET_YEAR
USE TIME_MOD,           ONLY : GET_DIAGb,   GET_CT_DYN
```

INPUT PARAMETERS:

```
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

REMARKS:

```
Store the sources/sinks of CH4 in TCH4 in total molecules
         ( 1) = Initial burden
         ( 2) = Final burden
SINKS
         ( 3) = Tropospheric CH4 sink by OH
SOURCES
         ( 4) = Total Sources
         ( 5) = Industrial  ( Gas + Oil + Mine )
         ( 6) = Agriculture ( Enteric fermentation + Manure + Rice + Waste
                            + Waste water )
         ( 7) = Biomass burning
         ( 8) = Termites
         ( 9) = Wetland
         (10) = Soil absorption
         (11) = Interhemispheric Exchange (+ = northward)
```

REVISION HISTORY:

```
(1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
      James Wang (7/00).  Inserted into module "global_ch4_mod.f"
      by Bob Yantosca. (bmy, 1/16/01)
(2 ) CH4_BUDGET is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
      (bmy, 1/16/01)
(3 ) Updated comments (jsw, bmy, 2/13/01)
(4 ) Renamed XLABEL to LABEL so as not to conflict w/ "CMN"
(5 ) Now use functions GET_MONTH, GET_YEAR, GET_DIAGb, and GET_CT_DYN from
      "time_mod.f".  Removed LMN from the arg list and made it a local
      variable.  Use functions GET_XOFFSET and GET_YOFFSET from
      "grid_mod.f".  (bmy, 3/27/03)
(6 ) Now references STT from "tracer_mod.f" (bmy, 7/20/04)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Modified for the run with new emissions (j drevet, 03/06)
07 Mar 2012 - M. Payer    - Added ProTeX headers
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

10.4.7 sum_ch4

Function SUM_CH4 sums a section of the TCH4 array bounded by the input variables I1, I2, J1, J2, L1, L2, K1, K2. SUM_CH4 is called by module subroutine CH4_BUDGET. (jsw, bnd, bmy, 1/16/01)
Disable CH4 Budget for SEAC4RS code to save memory kjw, 2/3/2014

INTERFACE:

```
      REAL(fp) FUNCTION SUM_CH4( I1, I2, J1, J2, L1, L2, K1, K2, UPDOWN,
     &                           State_Met )
```

USES:

```
      USE CHEMGRID_MOD,      ONLY : ITS_IN_THE_CHEMGRID
      USE CHEMGRID_MOD,      ONLY : ITS_IN_THE_NOCHEMGRID
      USE CMN_SIZE_MOD
      USE State_Met_Mod,     ONLY : State_Met
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN) :: I1, I2 ! Min/max longitude indices of TCH4 to sum
      INTEGER, INTENT(IN) :: J1, J2 ! Min/max latitude  indices of TCH4 to sum
      INTEGER, INTENT(IN) :: L1, L2 ! Min/max altitude  indices of TCH4 to sum
      INTEGER, INTENT(IN) :: K1, K2 ! Min/max species   indices of TCH4 to sum
      INTEGER, INTENT(IN) :: UPDOWN ! Sum in trop (=1) or in strat (=0)

      ! Also need to pass the State_Met for the CHEMGRID functons
      TYPE(MetState), INTENT(IN) :: State_Met
```

REMARKS:

```
    Store the sources/sinks of CH4 in TCH4 in total molecules
             ( 1) = Initial burden
             ( 2) = Final burden
    SINKS
             ( 3) = Tropospheric CH4 sink by OH
    SOURCES
             ( 4) = Total Source
             ( 5) = Industral
             ( 6) = Agriculture
             ( 7) = Biomass Burning
             ( 8) = Termites
             ( 9) = Wetland
             (10) = Soil absorption
             (11) = Interhemispheric Exchange (+ = northward)
             (12) = ...
                                                                            .
    Levels            1 <= L <= LPAUSE(I,J) - 1 are tropospheric
           LPAUSE(I,J) <= L <= LLPAR            are stratospheric (bmy, 4/17/00)
```

REVISION HISTORY:

```
    (1 ) Created by Bryan Duncan (1/99).  Adapted for CH4 chemistry by
         James Wang (7/00).  Inserted into module "global_ch4_mod.f"
         by Bob Yantosca. (bmy, 1/16/01)
    (2 ) CH4_BUDGET is independent of "CMN_OH", "CMN_CO", and "CMN_CO_BUDGET".
         (bmy, 1/16/01)
    (3 ) Updated comments (jsw, bmy, 2/12/01)
    07 Mar 2012 - M. Payer    - Added ProTeX headers
    23 Jul 2014 - R. Yantosca - Now pass the State_Met for chemgrid functions
```

10.4.8 ch4_distrib

Subroutine CH4_DISTRIB allocates the chemistry sink to different emission species. (ccc, 10/2/09)

INTERFACE:

```
SUBROUTINE CH4_DISTRIB( PREVCH4, Input_Opt, State_Chm )
```

USES:

```
USE CMN_SIZE_MOD
USE ERROR_MOD,          ONLY : SAFE_DIV
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState

IMPLICIT NONE
```

INPUT PARAMETERS:

```
REAL(fp)                        :: PREVCH4(IIPAR,JJPAR,LLPAR)! CH4 bef chem
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
07 Mar 2012 - M. Payer    - Added ProTeX headers
25 Mar 2013 - R. Yantosca - Now accept Input_Opt, State_Chm args
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.4.9 get_ch4_anthro

Function GET_CH4_ANTHRO returns the monthly average CH4 emissions at GEOS-Chem grid box (I,J). Data will be returned in units of [atoms C/cm2/s].

INTERFACE:

```
FUNCTION GET_CH4_ANTHRO( I, J, N, Input_Opt ) RESULT( CH4_ANTHRO )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! GEOS-Chem longitude index
INTEGER,        INTENT(IN) :: J           ! GEOS-Chem latitude index
INTEGER,        INTENT(IN) :: N           ! GEOS-Chem species index
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input options!
```

RETURN VALUE:

```
REAL(fp) :: CH4_ANTHRO   ! Anthro CH4 emissions [molec/cm2/s]
```

REVISION HISTORY:

```
24 Jan 2012 - M. Payer    - Initial version adapted from GET_RETRO_ANTHRO
25 Mar 2013 - S.D. Eastham- Adapted for unified simulations
```

10.4.10 get_ch4_biog

Function GET_CH4_BIOG returns annual average biogenic CH4 emissions at GEOS-Chem grid-box (I,J). Data will be returned in units of [atoms C/cm2/s].

INTERFACE:

```
FUNCTION GET_CH4_BIOG( I, J, N, Input_Opt ) RESULT( CH4_BIOG )
```

USES:

```
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! GEOS-Chem longitude index
INTEGER,        INTENT(IN) :: J           ! GEOS-Chem latitude index
INTEGER,        INTENT(IN) :: N           ! GEOS-Chem species index
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input options!
```

RETURN VALUE:

```
REAL(fp)  :: CH4_BIOG   ! Biogenic CH4 emissions [molec/cm2/s]
```

REVISION HISTORY:

```
24 Jan 2012 - M. Payer    - Initial version adapted from GET_RETRO_ANTHRO
25 Mar 2013 - S.D. Eastham- Adapted for unified simulations
```

10.4.11 init_global_ch4

Subroutine INIT_GLOBAL_CH4 allocates and zeroes module arrays.

INTERFACE:

```
SUBROUTINE INIT_GLOBAL_CH4( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE CMN_DIAG_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
This routine is called from GC_INIT_EXTRA (in GeosCore/input_mod.f)
```

REVISION HISTORY:

```
(1 ) Now references ALLOC_ERR from "error_mod.f" (bmy, 10/15/02)
07 Mar 2012 - M. Payer    - Added ProTeX headers
12 Feb 2014 - K. Wecht    - Disable CH4 budget diagnostic (bracket the
                            code out with #ifdef blocks so it can be used
11 Apr 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC arguments
16 Jun 2016 - M. Sulprizio- Now define IDT_CH4 locally
20 Jun 2016 - R. Yantosca - Rename IDTCH4 to id_CH4 for consistency
20 Jun 2016 - R. Yantosca - Now stop run if id_CH4 is undefined
```

10.4.12 cleanup_global_ch4

Subroutine CLEANUP_GLOBAL_CH4 deallocates module arrays. (bmy, 1/16/01)

INTERFACE:

```
SUBROUTINE CLEANUP_GLOBAL_CH4
```

REVISION HISTORY:

```
(1 ) Now references ALLOC_ERR from "error_mod.f" (bmy, 10/15/02)
07 Mar 2012 - M. Payer    - Added ProTeX headers
12 Feb 2014 - K. Wecht    - Disable CH4 budget diagnostic (bracket the
                            code out with #ifdef blocks so it can be used)
```

10.5 Fortran: Module Interface mercury_mod.F

Module MERCURY_MOD contains variables and routines for the GEOS-CHEM mercury simulation. Many choices of reaction mechanism and model processes can be selected with logical switches located in INIT_MERCURY.

INTERFACE:

```
MODULE MERCURY_MOD
```

USES:

```
USE DEPO_MERCURY_MOD,  ONLY : ADD_HG2_SNOWPACK
USE DEPO_MERCURY_MOD,  ONLY : LHGSNOW
USE OCEAN_MERCURY_MOD, ONLY : LDYNSEASALT
USE OCEAN_MERCURY_MOD, ONLY : LGCAPEMIS
USE OCEAN_MERCURY_MOD, ONLY : LPOLARBR
USE OCEAN_MERCURY_MOD, ONLY : LGEIA05
USE OCEAN_MERCURY_MOD, ONLY : LVEGEMIS
USE OCEAN_MERCURY_MOD, ONLY : LBRCHEM
USE OCEAN_MERCURY_MOD, ONLY : LRED_JNO2
USE OCEAN_MERCURY_MOD, ONLY : LHg2HalfAerosol
USE OCEAN_MERCURY_MOD, ONLY : STRAT_BR_FACTOR
USE OCEAN_MERCURY_MOD, ONLY : LAnthroHgOnly
USE OCEAN_MERCURY_MOD, ONLY : LOHO3CHEM
USE OCEAN_MERCURY_MOD, ONLY : LGCBROMINE
USE OCEAN_MERCURY_MOD, ONLY : LnoUSAemis
USE OCEAN_MERCURY_MOD, ONLY : LBROCHEM
USE OCEAN_MERCURY_MOD, ONLY : LNEI2005
USE OCEAN_MERCURY_MOD, ONLY : LInPlume
USE OCEAN_MERCURY_MOD, ONLY : LOCEANCOEF
USE PhysConstants           ! Physical constants
USE PRECISION_MOD           ! For GEOS-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CHEMMERCURY
PUBLIC  :: CLEANUP_MERCURY
PUBLIC  :: INIT_MERCURY
PUBLIC  :: EMISSMERCURY
PUBLIC  :: PARTITIONHG2
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: EMITHG
PRIVATE :: SRCHg0
PRIVATE :: SRCHg2
PRIVATE :: SRCHgP
```

```
   PRIVATE :: MERCURY_READYR
   PRIVATE :: OHNO3TIME
   PRIVATE :: CALC_HG2_SEASALT_LOSSRATE
   PRIVATE :: RED_INPLUME_GRID
   PRIVATE :: DO_RED_INPLUME
   PRIVATE :: GET_HGBR_RATE
   PRIVATE :: GET_LWC
   PRIVATE :: GET_VCLDF
   PRIVATE :: GET_O3
   PRIVATE :: GET_OH
   PRIVATE :: GET_BR
   PRIVATE :: GET_JNO2
```

REMARKS:

```
Nomenclature:
============================================================================
(1 ) Hg(0)  a.k.a. Hg0  : Elemental   mercury
(2 ) Hg(II) a.k.a. Hg2  : Divalent    mercury
(3 ) HgP                : Particulate mercury
                                                                            .
Mercury Species (1-3 are always defined; 4-87 are defined for tagged runs)
============================================================================
(1 ) Hg(0)              : Hg(0)  - total species
(2 ) Hg(II)             : Hg(II) - total species
(3 ) HgP                : HgP    - total species
------------------------+---------------------------------------------------
(4 ) Hg0_can            : Hg(0) - Canadian Anthropogenic
(5 ) Hg0_usa            : Hg(0) - USA Anthropogenic
(6 ) Hg0_cam            : Hg(0) - Central American  Anthropogenic
(7 ) Hg0_sam            : Hg(0) - South American Anthropogenic
(8 ) Hg0_waf            : Hg(0) - West African Anthropogenic
(9 ) Hg0_eaf            : Hg(0) - East African Anthropogenic
(10) Hg0_saf            : Hg(0) - South African Anthropogenic
(11) Hg0_naf            : Hg(0) - North African Anthropogenic
(12) Hg0_eur            : Hg(0) - OECD European Anthropogenic
(13) Hg0_eeu            : Hg(0) - Eastern European Anthropogenic
(14) Hg0_sov            : Hg(0) - Former USSR Anthropogenic
(15) Hg0_mde            : Hg(0) - Middle Eastern Anthropogenic
(16) Hg0_sas            : Hg(0) - South Asian Anthropogenic
(17) Hg0_eas            : Hg(0) - East Asian Anthropogenic
(18) Hg0_sea            : Hg(0) - Southeast Asian Anthropogenic
(19) Hg0_jpn            : Hg(0) - Japanese Anthropogenic
(20) Hg0_ocn            : Hg(0) - Oceanian Anthropogenic
(21) Hg0_so             : Hg(0) - Organic Soils
(22) Hg0_bb             : Hg(0) - Biomass Burning
(23) Hg0_geo            : Hg(0) - Geogenic
(24) Hg0_atl            : Hg(0) - Middle Atlantic Subsurface Waters
(25) Hg0_nat            : Hg(0) - North Atlantic Subsurface Waters
```

```
(26) Hg0_sat            : Hg(0) - South Atlantic Subsurface Waters
(27) Hg0_npa            : Hg(0) - North Pacific Subsurface Waters
(28) Hg0_arc            : Hg(0) - Arctic Subsurface Waters
(29) Hg0_ant            : Hg(0) - Antarctic Subsurface Waters
(30) Hg0_oce            : Hg(0) - Indo-Pacific Subsurface Waters
(31) Hg0_str            : Hg(0) - Stratospheric Hg from Intial Conditions
(32-59) Same as (4-31) but for Hg(II)
(60-87) Same as (4-31) but for Hg(P)
                                                                              .
References:
================================================================================
```


(1) Hall, B. (1995). "The gas phase oxidation of elemental mercury by ozone.", Water, Air, and Soil Pollution 80: 301-315.

(2) Sommar, J., et al. (2001). "A kinetic study of the gas-phase reaction between the hydroxyl radical and atomic mercury." Atmospheric Environment 35: 3049-3054.

(3) Selin, N., et al. (2007). "Chemical cycling and deposition of atmospheric mercury: Global constraints from observations." J. Geophys. Res. 112.

(4) Selin, N., et al. (2008). "Global 3-D land-ocean-atmospehre model for mercury: present-day versus preindustrial cycles and anthropogenic enrichment factors for deposition." Global Biogeochemical Cycles 22: GB2011.

(5) Allison, J.D. and T.L. Allison (2005) "Partition coefficients for metals in surface water, soil and waste." Rep. EPA/600/R-05/074, US EPA, Office of Research and Development, Washington, D.C.

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(7) Soerensen, A. et al. (2010), An improved global model for air-sea exchange of mercury: High concentrations over the North Atlantic, Environ. Sci. Technol., 44, 8574-8580.

(8) Corbitt, E.S. et al. (2011), Global source-receptor relationships for mercury deposition under present-day and 2050 emissions scenarios, Environ. Sci. Technol., 45, 10477-10484.

(9) Street, D.G. et al. (2009), Projections of global mercury emissions in 2050, Environ. Sci. Technol., 43, 2983-2988.

(10) Holmes, C.D., et al. (2010) Global atmospheric model for mercury including oxidation by bromine atoms, AC&P, 10, 12,037-12,057.

(11) Parrella, J. et al. (2012), Tropospheric bromine chemistry: implications for present and pre-industrial ozone and mercury, ACP.

(12) Pohler, D. et al. (2010), Observation of halogen species in the Amundsen Gulf, Arctic, by active long-path differential optical absorption spectroscopy, Proc. Natl. Acad. Sci, 107(15): 6528-6587.

(13) Prados-Roman, C. et al. (2011), Airborne DOAS limb measurements of tropospheric trace gas profiles: case studies on the profile retrieval of O4 and BrO, Atmos. Meas. Tech., 4: 1241-1260.

REVISION HISTORY:

```
(1 ) Updated for reduction rxn and online Hg0 ocean flux.  Now use
     diagnostic arrays from "diag03_mod.f".  (eck, sas, bmy, 1/21/05)
(2 ) Now references "pbl_mix_mod.f".  Remove FEMIS array and routine
     COMPUTE_FEMIS. (bmy, 2/15/05)
(3 ) Now can read data for both GEOS and GCAP grids (bmy, 8/16/05)
(4 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(5 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(6 ) Various updates added for tagged Hg sim. (eck, sas, cdh, bmy, 4/6/06)
(7 ) Now includes LPREINDHG logical switch for preindustrial simulation
     (eds 7/30/08)
13 Aug 2010 - R. Yantosca - Add modifications for MERRA (treat like GEOS-5)
01 Apr 2011 - H. Amos     - added LVEGEMIS, distinct from LGCAPEMIS
27 Sep 2011 - H. Amos     - Remove LHg_WETDasHNO3 logical, it's obsolete
01 Nov 2011 - Y. Zhang    - Add subroutines to do in plume reduction of Hg
07 Feb 2012 - E. Corbitt  - Imported tagged tracers; renamed nt to geo.
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x met
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
01 Mar 2012 - R. Yantosca - Use updated GET_LOCALTIME from time_mod.F
19 Apr 2012 - E. Corbitt  - Added LGCBROMINE to use GEOS-Chem bromine.
03 Jun 2013 - C. Holmes   - Extensively rewritten for simplicity
03 Jun 2013 - R. Yantosca - Added ProTeX headers
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
12 Mar 2015 - R. Yantosca - Now get JNO2 from the HEMCO data structure
12 Mar 2015 - R. Yantosca - Remove GET_GLOBAL_JNO2 routine
10 Aug 2015 - J. Fisher   - Updated treatment of polar BrO chemistry
                            (orig. 29/11/11)
05 Jan 2016 - E. Lundgren - Now use global dry air gas and Henry's Law consts
31 May 2016 - E. Lundgren - Replace Input_Opt%XNUMOL with AVO / (emMW_g*1e-3)
                            where emMW_g is emitted MW from species database
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.5.1 chemmercury

Subroutine CHEMMERCURY is the driver routine for mercury chemistry in the GEOS-CHEM module.

INTERFACE:

```
  SUBROUTINE CHEMMERCURY( am_I_Root, Input_Opt,
 &                        State_Met, State_Chm, RC )
```

USES:

```
  USE CMN_SIZE_MOD
  USE CMN_DIAG_MOD
```

```
      USE DAO_MOD,            ONLY : IS_ICE
      USE DAO_MOD,            ONLY : IS_LAND
      USE DAO_MOD,            ONLY : IS_WATER
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HG2_DD
      USE DEPO_MERCURY_MOD,   ONLY : ADD_HgP_DD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
      USE DIAG03_MOD,         ONLY : AD03_Hg2_Hg0, AD03_Hg2_O3
      USE DIAG03_MOD,         ONLY : AD03_Hg2_Br,  AD03_Hg2_OH
      USE DIAG03_MOD,         ONLY : AD03_Hg2_SS,  LD03
      USE DIAG03_MOD,         ONLY : AD03_Hg2_SSR, ND03
      USE DIAG03_MOD,         ONLY : AD03_Br
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE ERROR_MOD,          ONLY : SAFE_DIV
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
      USE GLOBAL_BR_MOD,      ONLY : GET_GLOBAL_BR
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
      USE Species_Mod,        ONLY : Species
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH
      USE TIME_MOD,           ONLY : GET_TS_CHEM
      USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH
      USE TIME_MOD,           ONLY : ITS_TIME_FOR_A3
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    Description of the chemistry mechanism:
    ========================================================================
    The comments and code below refer to 3 mercury species:
       1. Hg0  or Hg(0)     : gaseous elemental mercury
```

```
   2. Hg2g or Hg(II)g   : gaseous Hg(II) (comparable to RGM observations)
   3. Hg2p or Hg(II)p   : particle-bound Hg(II) (comparable to PBM
      observations)

Following Amos et al. (2012), the Hg(II) partitioning between
Hg2g and Hg2p is based on temperature and aerosol surface area.
There is no refractory particulate Hg.
In some legacy code below Hg2p is called HgP and Hg2g is called Hg2.

The differential equations for oxidation, reduction and deposition are:

   d[Hg0]/dt = -(k_Ox + k_Dep0) [Hg0] + k_Red_Hg2g [Hg2g]
                                      + k_Red_Hg2p [Hg2p]

   d[Hg2g]/dt =  k_Ox [Hg0] - (k_Red_Hg2g + k_Dep_Hg2g) [Hg2g]

   d[Hg2p]/dt =  -(k_Red_Hg2p + k_Dep_Hg2p) [Hg2p]

The chemical mechanism currently assumes that the product of Hg(0)
oxidation is in the gas phase. This can be easily changed.

Equilibrium partitioning between Hg2g and Hg2p is established at
the beginning and end of CHEMMERCURY.

Notes on chemistry and deposition:
================================================================================

(1 ) Oxidation: Hg(0) --> Hg(II):
   Oxidation by Br, BrO, OH, and O3 can be selectively enabled or disabled
   with switches (LBRCHEM, LBROCHEM, LOHO3CHEM) in INIT_MERCURY.

   Hg(0)(g) + Br(g) --> + Br/OH --> Hg(II)g, rates are selected with
      METHOD keyword below. Recommded kinetics are 'DonohoueYBBalabanov'
      which use rates from Donohoue et al. (2006), Goodsite et al. (2004)
      and Balabanov et al. (2005)

   Hg(0)(g)+ O3(g) --> Hg(II) ,  k  = 3.0e-20 cm3 molec-1 s-1
                                      Source: Hall, 1995

   Hg(0)(g)+ OH(g) --> Hg(II) ,  k  = 8.7e-14 cm3 s-1
                                      Source: Sommar et al. 2001

(2 ) Reduction:
   Reduction rates can be scaled to NO2 photolysis rates or OH
   concentrations with the switch LRED_JNO2.  In either case,
   aqueous-phase photochemical reduction of Hg(II) is included based
   on estimate of rate constant and scaled to NO2 photolysis or [OH].
   The rate is tuned to match the global Hg(0) concentration and
```

```
   seasonal cycle.

(3 ) Hg(0) dry deposition:
   The dry deposition frequency is calculated by drydep_mod. If the
   non-local PBL mixing scheme is used, however, all dry deposition is
   done elsewhere.  The ocean module separately cacluates Hg(0) dry
   deposition over ocean, so CHEMMERCURY only includes Hg(0) dry
   deposition over land.

(4 ) Hg(II)g and Hg(II)p dry deposition:
   The dry deposition frequencies are calculated by drydep_mod. If the
   non-local PBL mixing scheme is used, however, all dry deposition is
   done elsewhere.

(5 ) Sea-salt uptake of Hg(II)g
   Hg(II)g is taken up into sea-salt aerosol and deposited to the ocean
   surface at a rate based on wind speed and relative humidity. Hg(II)p
   uptake into sea-salt aerosol may also occur at a slower rate, but is
   not yet treated here.
```

REVISION HISTORY:

```
01 Oct 1995 - R. Yantosca - Initial version
08 Dec 2009 - R. Yantosca - Added ProTeX headers
06 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Now references routine GET_PBL_MAX_L from "pbl_mix_mod.f".  Now
     references AD44 from "diag_mod.f".  Now sum the levels from T44 into
     the AD44 array.  Now references N_TRACERS from "tracer_mod.f".
     (bmy, 2/24/05)
(2 ) Bug fix: Set T44 to 0e0 for single precision.  Now allow for zero
     dry deposition velocity.  Now call INIT_MERCURY from "input_mod.f"
     (bmy, 4/6/06)
02 Apr 2013 - C. Holmes - CHEMMERCURY rewritten for clarity and easier
     maintainability. The chemistry and deposition for particle-bound
     mercury is now solved simultaneously with Hg(0) and gaseous Hg(II).
     The subroutine now uses a 4th-order Runge-Kutta method to solve
     the coupled chemistry. The subroutines CHEM_HG0_HG2 and CHEM_HGP
     are now obsolete.
04 Apr 2013 - C. Holmes   - Use State_Met for met fields.
03 Jun 2013 - R. Yantosca - Now use fields from Input_OPt instead of from
                            logical_mod.F and tracer_mod.F
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
06 Nov 2014 - R. Yantosca - Now use State_Met%AIRDEN(I,J,L)
06 Nov 2014 - R. Yantosca - Now use State_Met%CLDF(I,J,L)
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID_DRY.
                            Remove dependency on pressure_mod.
12 Aug 2015 - R. Yantosca - Added support for MERRA2 meteorology
05 Jan 2016 - E. Lundgren - Use Henry's constant from species database and
```

```
                           calculate dry air gas constant from global params
25 Apr 2016 - R. Yantosca - Now pass Hg category # to ADD_Hg2_* routines
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                           species ID from State_Chm%Map_Advect.
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
11 Oct 2016 - R. Yantosca - Pass additional args to SET_OPTIONS_FROM_HEMCO
```

10.5.2 get_hgbr_rate

Function GET_HGBR_RATE computes the effective 1st order conversion rate of Hg(0) to Hg(II) via two-step recombination with Br and OH.

INTERFACE:

```
FUNCTION GET_HGBR_RATE( BR, T, P, OH, METHOD ) RESULT( K_HGBR )
```

INPUT PARAMETERS:

```
! BR     : Concentration of atomic Br [molec/cm3]
! T      : Temperature [K]
! P      : Pressure [hPa]
! OH     : Concentration of OH [molec/cm3]
! METHOD : Set of rate constants to use in calculation
REAL(fp),         INTENT(IN)  :: BR, OH, T, P
CHARACTER(LEN=*), INTENT(IN)  :: METHOD
```

RETURN VALUE:

```
! K_HgBr : Effective 1st order loss rate of Hg(0) [1/s]
REAL(fp)                       :: K_HGBR
```

REMARKS:

```
=============================================================================
This subroutine calculates the net rate of Hg(0) oxidation to Hg(II) through
   the following reactions. All are gas phase.
                                                                             .
   (1  )  Hg(0) + Br -> HgBr
   (2  )  HgBr + M -> Hg(0) + Br
   (2a )  HgBr     -> Hg(0) + Br
   (3Br)  HgBr + Br -> HgBr2
   (3OH)  HgBr + OH -> HgBrOH
                                                                             .
References:
=============================================================================
1. Ariya, P. A., A. Khalizov, and A. Gidas (2002), Reaction of gaseous
   mercury with atomic and molecular halogens: kinetics, product studies,
   and atmospheric implications, Journal of Physical Chemistry A, 106,
```

7310-7320.

.

2. Balabanov, N. B., B. C. Shepler, and K. A. Peterson (2005), Accurate global potential energy surface and reaction dynamics for the ground state of HgBr2, Journal of Physical Chemistry A, 109(39), 8765-8773.

.

3. Donohoue, D. L., D. Bauer, B. Cossairt, and A. J. Hynes (2006), Temperature and Pressure Dependent Rate Coefficients for the Reaction of Hg with Br and the Reaction of Br with Br: A Pulsed Laser Photolysis-Pulsed Laser Induced Fluorescence Study, Journal of Physical Chemistry A, 110, 6623-6632.

.

4. Goodsite, M. E., J. M. C. Plane, and H. Skov (2004), A theoretical study of the oxidation of Hg-0 to HgBr2 in the troposphere, Environmental Science & Technology, 38(6), 1772-1776.

.

5. Holmes, C. D., et al. (2006), Global lifetime of elemental mercury against oxidation by atomic bromine in the free troposphere, Geophys. Res. Lett., 33(20).

.

6. Khalizov, A. F., B. Viswanathan, P. Larregaray, and P. A. Ariya (2003), A theoretical study on the reactions of Hg with halogens: Atmospheric implications, Journal of Physical Chemistry A, 107(33), 6360-6365.

REVISION HISTORY:

```
06 Jul 2006 - C. Holmes   - Initial version
05 Jan 2016 - E. Lundgren - Use global physical parameters
```

10.5.3 emissmercury

Subroutine EMISSMERCURY is the driver routine for mercury emissions.

NOTE/TODO: The mercury simulation is the only GEOS-Chem emission code that is not yet fully compatible with HEMCO. So far, only the anthropogenic emissions are included in HEMCO. For all other sources, the original mercury code is used.

For the non-local PBL mixing, all emissions are written into module array HG_EMIS (in kg m-2 s-1). These values are then used by vdiff_mod.F90. This is just a workaround to ensure backwards compatibility of the mercury code. Once we have added all mercury emissions to HEMCO, HG_EMIS is not used any more (ckeller, 10/21/2014).

INTERFACE:

```
      SUBROUTINE EMISSMERCURY( am_I_Root, Input_Opt,
     &                         State_Met, State_Chm, RC )
```

USES:

```
      USE CMN_SIZE_MOD
      USE DEPO_MERCURY_MOD,   ONLY : RESET_HG_DEP_ARRAYS
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,        ONLY : GET_XMID, GET_YMID
      USE Input_Opt_Mod,      ONLY : OptInput
      USE LAND_MERCURY_MOD,   ONLY : LAND_MERCURY_FLUX, VEGEMIS
      USE LAND_MERCURY_MOD,   ONLY : SOILEMIS, BIOMASSHG
      USE LAND_MERCURY_MOD,   ONLY : SNOWPACK_MERCURY_FLUX
      USE OCEAN_MERCURY_MOD,  ONLY : OCEAN_MERCURY_FLUX
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_MONTH, ITS_A_NEW_MONTH
      USE UnitConv_Mod

      ! Added for GTMM (ccc, 11/19/09)
      USE LAND_MERCURY_MOD,   ONLY : GTMM_DR
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

REVISION HISTORY:

```
    03 Jun 2013 - N. (Eckley) Selin - Initial version
    (1 ) Now call OCEAN_MERCURY_FLUX from "ocean_mercury_mod.f" to compute
         the emissions of Hg0 from the ocean instead of reading it from disk.
         (sas, bmy, 1/20/05)
    (2 ) Now no longer call COMPUTE_FEMIS, since we can get the same information
         from routine GET_FRAC_OF_PBL in "pbl_mix_mod.f" (bmy, 2/22/05)
    (3 ) Now modified for new ocean mercury module. (cdh, sas, bmy, 4/6/06)
    01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
    01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
    25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
    08 Dec 2009 - R. Yantosca - Added ProTeX headers
    20 Jun 2014 - R. Yantosca - Now pass Input_Opt to VEGEMIS
    23 Jun 2014 - R. Yantosca - Now pass am_I_Root to OCEAN_MERCURY_FLUX
    05 Oct 2015 - E. Lundgren - Now convert tracer units to kg locally
```

10.5.4 emithg

Subroutine EMITHG directs emission either to the chemical species array (State_Chmnon-local PBL mixing. This is a programming convenience.

INTERFACE:

```
SUBROUTINE EMITHG( I, J, L, ID, E_HG, Input_Opt, State_Chm )
```

USES:

```
USE ErrCode_Mod
USE GC_GRID_MOD,        ONLY : GET_AREA_M2
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)    :: I, J, L, ID ! Grid boxes + species #
REAL(fp),       INTENT(IN)    :: E_Hg        ! Hg emissions
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

REVISION HISTORY:

```
27 Aug 2009 - C. Holmes   - Initial version
25 Mar 2013 - R. Yantosca - Now accept Input_Opt, State_Chm, arguments
```

10.5.5 srcHg0

Subroutine SRCHg0 is the subroutine for Hg(0) emissions. Emissions of Hg(0) will be distributed throughout the boundary layer. (eck, cdh, bmy, 1/21/05, 4/6/06)

INTERFACE:

```
SUBROUTINE SRCHg0( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DIAG03_MOD,         ONLY : AD03, ND03, AD03_nat
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_MAX_L
USE State_Chm_Mod,      ONLY : ChmState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
21 Jan 2005 - N. (Eckley) Selin, C. Holmes - Initial version
(1 ) Now use diagnostic arrays from "diag03_mod.f" (bmy, 1/21/05)
(2 ) Now references GET_FRAC_OF_PBL and GET_PBL_MAX_L from "pbl_mix_mod.f".
     Remove reference to FEMIS. (bmy, 2/22/05)
(3 ) EHg0_an is now a 2-D array.  Modified for new ocean mercury module.
     Now use ID_Hg0 index array from "tracerid_mod.f".  Now make sure
     STT does not underflow. (cdh, bmy, 4/6/06)
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.5.6 srcHg2

Subroutine SRCHg2 is the subroutine for Hg(II) emissions. Emissions of Hg(II) will be distributed throughout the boundary layer.

INTERFACE:

```
SUBROUTINE SRCHg2( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DIAG03_MOD,         ONLY : AD03, ND03
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_MAX_L
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
07 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Now use diagnostic arrays from "diag03_mod.f" (bmy, 1/21/05)
(2 ) Now references GET_FRAC_OF_PBL and GET_PBL_MAX_L from "pbl_mix_mod.f".
     Remove reference to FEMIS. (bmy, 2/22/05)
(3 ) EHg2_an is now a 2-D array.  Now use ID_Hg2 index array from
     "tracerid_mod.f".  Now make sure STT does not underflow.
     (eck, cdh, bmy, 4/6/06)
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
```

10.5.7 srcHgp

Subroutine SRCHgP is the subroutine for HgP emissions. Emissions of HgP will be distributed throughout the boundary layer.

INTERFACE:

```
SUBROUTINE SRCHgP( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DIAG03_MOD,         ONLY : AD03, ND03
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE PBL_MIX_MOD,        ONLY : GET_FRAC_OF_PBL, GET_PBL_MAX_L
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
07 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Now use diagnostic arrays from "diag03_mod.f" (bmy, 1/21/05)
(2 ) Now references GET_FRAC_OF_PBL and GET_PBL_MAX_L from "pbl_mix_mod.f".
     Remove reference to FEMIS. (bmy, 2/22/05)
(3 ) EHgP_an is now a 2-D array.  Now use ID_HgP index array from
     "tracerid_mod.f".  Now make sure STT does not underflow.
     (eck, cdh, bmy, 4/6/06)
```

10.5.8 mercury_readyr

Subroutine MERCURY_READYR reads the year-invariant emissions for Mercury from anthropogenic, ocean, and land sources.

INTERFACE:

```
SUBROUTINE MERCURY_READYR( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_ERROR_MOD
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
USE HCO_INTERFACE_MOD,  ONLY : GetHcoDiagn
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
06 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Now read data from mercury_200501 subdirectory.  Now compute oceanic
     Hg(0) emissions w/ ocean flux module instead of reading them from
     disk.  Now use 1985 TAU values. (sas, bmy, 1/20/05)
(2 ) Now can read data for both GEOS and GCAP grids (bmy, 8/16/05)
(3 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(4 ) Now read anthro emissions on GEOS 1x1 grid in DATA_1x1_DIR.  Also
```

```
      keep 2x25 and 4x5 files together in DATA_1x1_DIR.  Also now use new
      land re-emissions files from Noelle Selin. (eck, bmy, 4/6/06)
(5 ) Now reads anthro emissions for 17 world regions from David Streets
     for use in tagged simulations. (eds 2/7/12)
(6 ) Bug fix: emissions are read on GENERIC grid (jaf, 2/8/12)
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
13 Mar 2012 - M. Cooper   - Changed regrid algorithm to map_a2a
24 May 2012 - R. Yantosca - Fixed minor bugs in map_a2a algorithm
24 May 2012 - H. Amos     - updated file paths for soil Hg files
28 Jun 2012 - S. Kim      - Bug fix: you need to provide a location
                            in the call to ERROR_STOP
24 Aug 2012 - R. Yantosca - DO_REGRID_A2A now reads netCDF input file
03 Jan 2013 - M. Payer    - Renamed PERAREA to IS_MASS in DO_REGRID_A2A
13 Jan 2013 - M. Payer    - Update soil Hg files for v9-02c (Y. Zhang)
06 Jun 2013 - R. Yantosca - Get ANTHRO_Hg_YEAR, Hg_SCENARIO from Input_Opt
06 Sep 2013 - R. Yantosca - Kludge: use MERRA soil file for GEOS-FP testing
                            and debugging.  Worry about this later.
06 Sep 2013 - R. Yantosca - Kludge: use GEOS-5 soil file for GEOS-4 testing
                            and debugging.  Worry about this later.
24 Sep 2014 - C. Keller   - HEMCO update
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

10.5.9 get_lwc

Function GET_LWC returns the cloud liquid water content [m3 H2O/m3 air] at a GEOS-CHEM grid box as a function of temperature.

INTERFACE:

```
FUNCTION GET_LWC( T ) RESULT( LWC )
```

USES:

INPUT PARAMETERS:

```
REAL(fp), INTENT(IN) :: T     ! Temperature [K]
```

RETURN VALUE:

```
REAL(fp)             :: LWC   ! Liquid water content [m3 H2O/m3 air]
```

REVISION HISTORY:

```
31 Oct 2002 - R. Park     - Initial version
18 Jan 2011 - R. Yantosca - Updated comments
```

10.5.10 get_vcldf

Subroutine GET_VCLDF computes the volume cloud fraction for Hg0 and Hg2 chemistry.

INTERFACE:

```
FUNCTION GET_VCLDF( I, J, L, State_Met ) RESULT( VCLDF )
```

USES:

```
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I           ! Longitude index
INTEGER,        INTENT(IN)  :: J           ! Latitude index
INTEGER,        INTENT(IN)  :: L           ! Level index
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                     :: VCLDF       ! Volume cloud fraction
```

REMARKS:

```
References:
============================================================================
(1  ) Sundqvist et al. [1989]
```

REVISION HISTORY:

```
06 Dec 2004 - N. (Eckley) Selin - Copied from "sulfate_mod.f" but was made
                                  into a function since we are already
                                  looping over (I,J,L) in CHEM_Hg0_Hg2
09 Nov 2012 - M. Payer          - Replaced all met field arrays with
                                  State_Met derived type object
26 Feb 2015 - E. Lundgren       - Replace GET_PCENTER and GET_PEDGE with
                                  State_Met%PMID and State_Met%PEDGE.
                                  Remove dependency on pressure_mod.
```

10.5.11 get_o3

Function GET_O3 returns monthly mean O3 for the mercury simulation.

INTERFACE:

```
FUNCTION GET_O3( I, J, L, State_Met ) RESULT( O3_MOLEC_CM3 )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I             ! Longitude index
INTEGER,        INTENT(IN)  :: J             ! Latitude index
INTEGER,        INTENT(IN)  :: L             ! Level index
TYPE(MetState), INTENT(IN)  :: State_Met     ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: O3_MOLEC_CM3   ! O3 conc [molec/cm3]
```

REVISION HISTORY:

```
06 Dec 2002 - R. Yantosca - Initial version
(1 ) We assume SETTRACE has been called to define IDO3. (bmy, 12/16/02)
(2 ) Now reference inquiry functions from "tracer_mod.f" (bmy, 7/20/04)
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
11 Mar 2015 - R. Yantosca - Remove reference to GLOBAL_O3_MOD
```

10.5.12 get_oh

Function GET_OH returns monthly mean OH and imposes a diurnal variation.

INTERFACE:

```
FUNCTION GET_OH( I, J, L, State_Met ) RESULT( OH_MOLEC_CM3 )
```

USES:

```
USE CMN_SIZE_MOD
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN)  :: I             ! Longitude index
INTEGER,        INTENT(IN)  :: J             ! Latitude index
INTEGER,        INTENT(IN)  :: L             ! Level index
TYPE(MetState), INTENT(IN)  :: State_Met     ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: OH_MOLEC_CM3   ! OH conc [molec/cm3]
```

REVISION HISTORY:

```
07 Dec 2004 - N. (Eckley) Selin - Initial version
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
28 Nov 2012 - R. Yantosca - Now pass State_Met via the argument list
11 Mar 2015 - R. Yantosca - Remove reference to GLOBAL_OH_MOD
```

10.5.13 get_Br

Function GET_BR returns instantaneous Br concentration calculated from the monthly mean and an imposed diurnal variation.

INTERFACE:

```
      FUNCTION GET_BR( I, J, L, BRO_MOLEC_CM3, State_Met )
     &   RESULT( BR_MOLEC_CM3 )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRAT
      USE CMN_SIZE_MOD
      USE DAO_MOD,            ONLY : GET_OBK
      USE DAO_MOD,            ONLY : IS_WATER
      USE DIAG03_MOD,         ONLY : AD03_Br,   LD03,     ND03
      USE ERROR_MOD,          ONLY : SAFE_DIV
      USE GLOBAL_BR_MOD,      ONLY : BR_MERGE,  BR_TROP
      USE GLOBAL_BR_MOD,      ONLY : BR_STRAT,  J_BRO
      USE GLOBAL_BR_MOD,      ONLY : BRO_MERGE, BRO_TROP, BRO_STRAT
      USE GC_GRID_MOD,        ONLY : GET_YMID
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_LOCALTIME
      USE TIME_MOD,           ONLY : ITS_A_NEW_DAY
      USE TIME_MOD,           ONLY : GET_MONTH
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)  :: I              ! Longitude index
      INTEGER,        INTENT(IN)  :: J              ! Latitude index
      INTEGER,        INTENT(IN)  :: L              ! Level index
      REAL(fp),       INTENT(OUT) :: BrO_MOLEC_CM3  ! BrO conc [molec/cm3]
      TYPE(MetState), INTENT(IN)  :: State_Met      ! Meteorology State object
```

RETURN VALUE:

```
      REAL(fp)                    :: BR_MOLEC_CM3   ! Br conc [molec/cm3]
```

REVISION HISTORY:

```
    06 Jul 2006 - C. Holmes   - Initial version
    01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
    01 Mar 2012 - R. Yantosca - Now use GET_LOCALTIME(I,J,L) from time_mod.F90
    09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                                derived type object
    28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
    24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
    26 Feb 2015 - E. Lundgren - Remove dependency on pressure_mod (not used)
    10 Aug 2015 - J. Fisher - implement variable polar BrO concentrations based
```

```
                          on temperature and incoming solar radiation
10 Aug 2015 - J. Fisher - only apply diurnal cycle to BrO from pTOMCAT
                          daily means, NOT to polar BrO which represents
                          instantaneous values
10 Aug 2015 - J. Fisher - add upper ice threshold to MERRA conditions for
                          polar BrO release
```

10.5.14 ohno3time

Subroutine OHNO3TIME computes the sum of cosine of the solar zenith angle over a 24 hour day, as well as the total length of daylight. This is needed to scale the offline OH and NO3 concentrations.

INTERFACE:

```
SUBROUTINE OHNO3TIME
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD, ONLY : GET_XMID,    GET_YMID_R
USE TIME_MOD,    ONLY : GET_NHMSb,   GET_ELAPSED_SEC
USE TIME_MOD,    ONLY : GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT
```

REVISION HISTORY:

```
16 Dec 2002 - R. Park & R. Yantosca - Initial version
(1 ) Copy code from COSSZA directly for now, so that we don't get NaN
     values.  Figure this out later (rjp, bmy, 1/10/03)
(2 ) Now replace XMID(I) with routine GET_XMID from "grid_mod.f".
     Now replace RLAT(J) with routine GET_YMID_R from "grid_mod.f".
     Removed NTIME, NHMSb from the arg list.  Now use GET_NHMSb,
     GET_ELAPSED_SEC, GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT from
     "time_mod.f". (bmy, 3/27/03)
(3 ) Now store the peak SUNCOS value for each surface grid box (I,J) in
     the COSZM array. (rjp, bmy, 3/30/04)
(4 ) Also added parallel loop over grid boxes (eck, bmy, 12/8/04)
01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R(I,J,L) from grid_mod.F90
16 May 2016 - M. Sulprizio- Remove IJLOOP and change SUNTMP array dimensions
                            from (MAXIJ) to (IIPAR,JJPAR)
```

10.5.15 calc_hg2_seasalt_lossrate

Subroutine CALC_HG2_SEASALT_LOSSRATE calculates the loss rate of RGM (/s) by uptake of RGM into sea salt aerosol for each model grid. Return value is a loss frequency

(/s)

INTERFACE:

```
SUBROUTINE CALC_HG2_SEASALT_LOSSRATE( State_Met )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE DAO_MOD,            ONLY : IS_WATER
USE PBL_MIX_MOD,        ONLY : GET_PBL_TOP_M
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REMARKS:

```
The formula used here is a least-squares fit to the full-physics model of
sea-salt aerosol emissions, hydroscopic growth, mass-transport limited
uptake of Hg(II), and aerosol deposition presented by Holmes et al. (2009)
See Holmes et al. 2010 for evaluation of this parameterization.
(cdh, 11/25/09)
```

REVISION HISTORY:

```
25 Nov 2009 - C. Holmes   - Initial version
25 Jul 2014 - R. Yantosca - Remove reference to function SFCWINDSQR
04 Dec 2014 - M. Yannetti - Remove reference to RNPBE_MOD
```

10.5.16 get_jno2

Function GET_JNO2 returns monthly mean JNO2 and imposes a diurnal variation.

INTERFACE:

```
FUNCTION GET_JNO2( I, J, L, State_Met ) RESULT( JNO2_NOW )
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD,        ONLY : GET_YMID_R
USE PhysConstants
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM, GET_DAY_OF_YEAR
```

INPUT PARAMETERS:

```
INTEGER,        INTENT(IN) :: I           ! Longitude index
INTEGER,        INTENT(IN) :: J           ! Latitude index
INTEGER,        INTENT(IN) :: L           ! Level index
TYPE(MetState), INTENT(IN) :: State_Met   ! Meteorology State object
```

RETURN VALUE:

```
REAL(fp)                    :: JNO2_NOW    ! J(NO2) value [s-1]
```

REMARKS:

```
Impose the diurnal variation of JNO2 found by Parrish et al. (1983) under
clear skies. J-NO2 ~ exp( -0.360 * sec(SZA) )
```

REVISION HISTORY:

```
01 Mar 2012 - R. Yantosca - Now use GET_YMID_R(I,J,L) from grid_mod.F90
28 Nov 2012 - R. Yantosca - Now pass State_Met via the argument list
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
```

10.5.17 partitionhg2

Subroutine PARTITIONHG2 splits Hg(II) into gas and aerosol portions according to the thermodynamic equilibrium determined by temperature and aerosol surface area.

INTERFACE:

```
SUBROUTINE PARTITIONHG2( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : SAFE_DIV  , GEOS_CHEM_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE OCEAN_MERCURY_MOD,  ONLY : Fg
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
12-Jul-2010 - H. Amos     - Add option to partition Hg2 according to Fg/Fp
02-Jan-2011 - H. Amos     - Add/clean up comments
04 Jan 2012 - H. Amos     - modify algorithms to reflect the fact that
                            anthropogenic Hg(p) is now emitted as Hg(II)
                            (i.e. it's no longer considered refractory).
28-Mar-2013 - C. Holmes   - Since we now assume that all HgP and Hg2
                            actively partition between gas and aerosol,
                            we no longer need to 'reverse' partition.
03 Jun 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
18 Nov 2014 - M. Yannetti - Took out OCEAN_MERCURY_MOD calling Fp
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.5.18 red_inplume_grid

Subroutine RED_INPLUME_GRID conducts in plume reduction of Hg2 for selected grids

INTERFACE:

```
SUBROUTINE RED_INPLUME_GRID( I, J, E_plant )
```

INPUT PARAMETERS:

```
INTEGER,INTENT(IN) :: I, J
REAL(fp), INTENT(IN) :: E_plant
```

REVISION HISTORY:

```
11 Jan 2011 - Y. Zhang    - Initial version
```

10.5.19 do_red_inplume

Subroutine DO_RED_INPLUME conducts in plume reduction of Hg2 for selected grids.

INTERFACE:

```
SUBROUTINE DO_RED_INPLUME( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE GC_GRID_MOD,        ONLY : GET_AREA_M2
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : EXPAND_DATE

IMPLICIT NONE
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
11 Jan 2011 - Y. Zhang    - Initial version
23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
06 Nov 2014 - R. Yantosca - Replace TRANSFER_2D with direct casts
17 Dec 2014 - R. Yantosca - Leave time/date variables as 8-byte
05 Mar 2015 - R. Yantosca - Add Input_Opt%RES_DIR to data path'
16 Mar 2015 - R. Yantosca - Remove bpch input
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

10.5.20 init_mercury

Subroutine INIT_MERCURY allocates and zeroes all module arrays.

INTERFACE:

```
SUBROUTINE INIT_MERCURY( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR, ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE Species_Mod,        ONLY : Species
USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)    :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
02 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Removed reference to FEMIS array.  Now also allocates and zeroes
     the T44 array.  Added reference to CMN_DIAG.  Now references
     N_TRACERS from "tracer_mod.f". (bmy, 2/24/05)
(2 ) EHg0_an, EHg2_an, EHgP_an are now 2-D arrays.  Now modified for
     updated ocean mercury module. (eck, cdh, sas, bmy, 4/6/06)
27 Sep 2011 - H. Amos - remove LHg_WETDasHNO3 logical, it's obsolete
11 Apr 2012 - R. Yantosca - Now retire lai_mod.F; remove call to INIT_LAI
11 Apr 2012 - R. Yantosca - Now move LAI initialization to main.F
03 Jun 2013 - R. Yantosca - Now use fields from Input_Opt
12 Mar 2015 - R. Yantosca - Now test if HEMCO_Collections are defined
25 Apr 2016 - R. Yantosca - Now use species database for tagHg indexing
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
```

10.5.21 set_options_from_hemco

Overrides some of the Hg simulation settings depending on the inputs that are specified in the HEMCO configuration file.

INTERFACE:

```
SUBROUTINE SET_OPTIONS_FROM_HEMCO( am_I_Root, Input_Opt, RC )
```

USES:

```
USE ERROR_MOD,         ONLY : ERROR_STOP
USE HCO_ERROR_MOD
USE HCO_INTERFACE_MOD, ONLY : HcoState
USE HCO_ExtList_Mod,   ONLY : GetExtOpt
USE Input_Opt_Mod,     ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root
TYPE(OptInput), INTENT(IN)  :: Input_Opt
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC   ! Success or failure?
```

REMARKS:

REVISION HISTORY:

```
06 Jan 2015 - R. Yantosca - Initial version
11 Oct 2016 - R. Yantosca - Move call to DO_RED_INPLUME here
```

10.5.22 cleanup_mercury

Subroutine CLEANUP_MERCURY deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_MERCURY
```

REVISION HISTORY:

```
06 Dec 2004 - N. (Eckley) Selin - Initial version
(1 ) Now deallocate MLD, NPP, RAD (sas, bmy, 1/18/05)
(2 ) Now deallocate T44 (bmy, 2/24/05)
```

10.6 Fortran: Module Interface depo_mercury_mod.F

Module DEPO_MERCURY_MOD contains routines to handle deposition fluxes for mercury.
INTERFACE:

```
MODULE DEPO_MERCURY_MOD
```

USES:

```
USE PRECISION_MOD   ! For Geos-Chem Precision (fp)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: ADD_Hg2_DD
PUBLIC :: ADD_Hg2_WD
PUBLIC :: ADD_HgP_DD
PUBLIC :: ADD_HgP_WD
PUBLIC :: ADD_HG2_SNOWPACK
PUBLIC :: RESET_HG_DEP_ARRAYS
PUBLIC :: CHECK_DIMENSIONS
PUBLIC :: READ_GTMM_RESTART
PUBLIC :: MAKE_GTMM_RESTART
PUBLIC :: UPDATE_DEP
PUBLIC :: INIT_DEPO_MERCURY
PUBLIC :: CLEANUP_DEPO_MERCURY
```

PUBLIC DATA MEMBERS:

```
PUBLIC :: DD_HG2, DD_HGP, WD_HG2, WD_HGP
PUBLIC :: HG2mth_wd, HG0mth_dd, HG2mth_dd
PUBLIC :: SNOW_HG_OC
PUBLIC :: SNOW_HG_LN
PUBLIC :: SNOW_HG_STORED_OC
```

```
      PUBLIC :: SNOW_HG_STORED_LN
      PUBLIC :: LHGSNOW

      REAL(fp),  ALLOCATABLE :: DD_Hg2(:,:,:)
      REAL(fp),  ALLOCATABLE :: DD_HgP(:,:,:)
      REAL(fp),  ALLOCATABLE :: WD_Hg2(:,:,:)
      REAL(fp),  ALLOCATABLE :: WD_HgP(:,:,:)
      REAL(fp),  ALLOCATABLE :: HG0mth_dd(:,:)
      REAL(fp),  ALLOCATABLE :: HG2mth_dd(:,:)
      REAL(fp),  ALLOCATABLE :: HG2mth_wd(:,:)
      REAL(fp),  ALLOCATABLE :: SNOW_HG_OC(:,:,:)
      REAL(fp),  ALLOCATABLE :: SNOW_HG_LN(:,:,:)
      REAL(fp),  ALLOCATABLE :: SNOW_HG_STORED_OC(:,:,:)
      REAL(fp),  ALLOCATABLE :: SNOW_HG_STORED_LN(:,:,:)
      REAL(fp),  ALLOCATABLE :: Hg0dryGEOS(:,:), HgIIdryGEOS(:,:),
     &                          HgIIwetGEOS(:,:)
  !PRIVATE DATA MEMBERS:
      CHARACTER(LEN=255)   :: GTMM_RST_FILE
      LOGICAL              :: LHGSNOW
```

REVISION HISTORY:

```
23 Apr 2010 - C. Carouge  - Initial version
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.x met
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
07 Nov 2014 - M. Yannetti - Added PRECISION_MOD
30 May 2013 - J. Fisher   - Add land snow Hg reservoirs
06 Aug 2015 - J. Fisher   - Add stored snow Hg reservoirs (orig.
                            29/11/11)
26 Apr 2016 - R. Yantosca - Make N_Hg_CATS IDTHg0, IDTHg2 module variables
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.6.1 add_Hg2_dd

Subroutine ADD_Hg2_DD computes the amount of Hg(II) dry deposited out of the atmosphere into the column array DD_Hg2.

INTERFACE:

```
      SUBROUTINE ADD_Hg2_DD( I, J, HG_CAT, DRY_Hg2 )
```

INPUT PARAMETERS:

```
      INTEGER,  INTENT(IN) :: I, J      ! Grid box lon & lat indices
      INTEGER,  INTENT(IN) :: Hg_Cat    ! Hg category number
      REAL(fp), INTENT(IN) :: DRY_Hg2   ! Hg(II) dry deposited out of the
                                        !  atmosphere [kg]
```

REVISION HISTORY:

```
19 Jan 2005 - S. Strode, C. Holmes - Initial version
(1 ) DD_Hg2 is now a 3-D array.  Also pass N via the argument list. Now
      call GET_Hg2_CAT to return the Hg category #. (cdh, bmy, 3/28/06)
23 Apr 2010 - C. Carouge  - Moved from ocean_mercury_mod.f to
                            depo_mercury_mod.f
25 Apr 2016 - R. Yantosca - Remove reference to GET_HG2_CAT, we now pass
                            this in as an argument.  Rename NN to Hg2_Cat.
```

10.6.2 add_Hg2_wd

Subroutine ADD_Hg2_WD computes the amount of Hg(II) wet scavenged out of the atmosphere into the column array WD_Hg2.

INTERFACE:

```
SUBROUTINE ADD_Hg2_WD( I, J, Hg_Cat, WET_Hg2 )
```

INPUT PARAMETERS:

```
INTEGER,   INTENT(IN) :: I, J      ! Grid box lon & lat indices
INTEGER,   INTENT(IN) :: Hg_Cat    ! Hg category number
REAL(fp),  INTENT(IN) :: WET_Hg2   ! Hg(II) scavenged out of the
                                   !  atmosphere [kg]
```

REVISION HISTORY:

```
19 Jan 2005 - S. Strode, C. Holmes - Initial version
(1 ) WD_Hg2 is now a 3-D array.  Also pass N via the argument list. Now
      call GET_Hg2_CAT to return the Hg category #. (cdh, bmy, 3/28/06)
23 Apr 2010 - C. Carouge  - Moved from ocean_mercury_mod.f to
                            depo_mercury_mod.f
25 Apr 2016 - R. Yantosca - Remove reference to GET_HG2_CAT, we now pass
                            this in as an argument.  Rename NN to Hg2_Cat.
```

10.6.3 add_HgP_dd

Subroutine ADD_HgP_DD computes the amount of HgP dry deposited out of the atmosphere into the column array DD_HgP.

INTERFACE:

```
SUBROUTINE ADD_HgP_DD( I, J, Hg_Cat, DRY_HgP )
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: I, J      ! Grid box lon & lat indices
INTEGER,  INTENT(IN) :: Hg_Cat    ! Hg category number
REAL(fp), INTENT(IN) :: DRY_HgP   ! HgP dry deposited out of the
                                  !  atmosphere [kg]
```

REVISION HISTORY:

```
19 Jan 2005 - S. Strode, C. Holmes - Initial version
(1 ) DD_HgP is now a 3-D array.  Also pass N via the argument list. Now
      call GET_HgP_CAT to return the Hg category #. (cdh, bmy, 3/28/06)
23 Apr 2010 - C. Carouge  - Moved from ocean_mercury_mod.f to
                            depo_mercury_mod.f
25 Apr 2016 - R. Yantosca - Remove reference to GET_HGP_CAT, we now pass
                            this in as an argument.  Rename NN to HgP_Cat.
```

10.6.4 add_HgP_wd

Subroutine ADD_HgP_WD computes the amount of HgP wet scavenged out of the atmosphere into the column array WD_HgP.

INTERFACE:

```
SUBROUTINE ADD_HgP_WD( I, J, Hg_Cat, WET_HgP )
```

INPUT PARAMETERS:

```
INTEGER,  INTENT(IN) :: I, J      ! Grid box lon & lat indices
INTEGER,  INTENT(IN) :: Hg_Cat    ! Hg category number
REAL(fp), INTENT(IN) :: WET_HgP   ! HgP scavenged out of the
                                  !  atmosphere [kg]
```

REVISION HISTORY:

```
19 Jan 2005 - S. Strode, C. Holmes - Initial version
(1 ) WD_HgP is now a 3-D array.  Also pass N via the argument list. Now
      call GET_HgP_CAT to return the Hg category #. (cdh, bmy, 3/28/06)
23 Apr 2010 - C. Carouge  - Moved from ocean_mercury_mod.f to
                            depo_mercury_mod.f
25 Apr 2016 - R. Yantosca - Remove reference to GET_HGP_CAT, we now pass
                            this in as an argument.  Rename NN to HgP_Cat.
```

10.6.5 add_hg2_snowpack

Subroutine ADD_Hg2_SNOWPACKS adds Hg2 deposition to snowpack.

INTERFACE:

```
SUBROUTINE ADD_HG2_SNOWPACK( I, J, Hg_Cat, DEP_Hg2, State_Met )
```

USES:

```
USE DAO_MOD,            ONLY : IS_ICE, IS_LAND
USE DIAG03_MOD,         ONLY : AD03, ND03
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
! Arguments as input
INTEGER,        INTENT(IN)  :: I, J        ! Grid box lon & lat indices
INTEGER,        INTENT(IN)  :: Hg_Cat      ! Hg category number
REAL(fp),       INTENT(IN)  :: Dep_Hg2     ! Hg2 (or HgP) deposited
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REVISION HISTORY:

```
02 Sep 2008 - C. Holmes   - Initial version
23 Apr 2010 - C. Carouge  - Moved from mercury_mod.f to depo_mercury_mod.f
25 Aug 2010 - R. Yantosca - Treat MERRA in the same way as GEOS-5
26 Apr 2011 - J. Fisher   - Use MERRA land fraction information
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
13 Apr 2011 - R. Yantosca - Bug fix: reference IS_LAND from dao_mod.f
 8 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
30 May 2013 - J. Fisher   - Add land snow Hg reservoirs
06 Aug 2015 - J. Fisher   - Store reservoir of non-reducible Hg in snowpack
                            (orig. 29/11/11)
11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS_FP
25 Apr 2016 - R. Yantosca - Remove reference to routines GET_HG2_CAT and
                            GET_HGP_CAT, these are now passed in as the
                            Hg_Cat argument.
```

10.6.6 reset_hg_dep_arrays

Subroutine RESET_Hg_DEP_ARRAYS resets the wet and dry deposition arrays for Hg(II) and Hg(p) to zero. This allows us to call OCEAN_MERCURY_FLUX and LAND_MERCURY_FLUX in any order in MERCURY_MOD.

INTERFACE:

```
SUBROUTINE RESET_HG_DEP_ARRAYS
```

REVISION HISTORY:

```
02 Sep 2008 - C. Holmes   - Initial version
23 Apr 2010 - C. Carouge  - Moved from ocean_mercury_mod.f to
                            depo_mercury_mod.f
```

10.6.7 make_gtmm_restart

MAKE_GTMM_RESTART writes a GTMM restart file with deposition fluxes and store deposition fluxes for continuous runs.

INTERFACE:

```
 SUBROUTINE MAKE_GTMM_RESTART( am_I_Root, Input_Opt, NYMD,
&                              NHMS,      TAU,       RC    )
```

USES:

```
 USE BPCH2_MOD
 USE CMN_SIZE_MOD              ! Size parameters
 USE ErrCode_Mod
 USE GC_GRID_MOD,         ONLY : GET_XOFFSET, GET_YOFFSET
 USE Input_Opt_Mod,       ONLY : OptInput
 USE inquireMod,          ONLY : findFreeLUN
 USE TIME_MOD,            ONLY : EXPAND_DATE
 USE TIME_MOD,            ONLY : GET_CT_DYN, GET_CT_CHEM
```

INPUT PARAMETERS:

```
 INTEGER,         INTENT(IN)   :: NYMD        ! Year-Month-Date
 INTEGER,         INTENT(IN)   :: NHMS        ! and Hour-Min-Sec
 REAL(f8),        INTENT(IN)   :: TAU         ! TAU value: hrs since 1/1/85
 LOGICAL,         INTENT(IN)   :: am_I_Root   ! Are we on the root CPU?
 TYPE(OptInput), INTENT(IN)   :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
 INTEGER,         INTENT(OUT)  :: RC          ! Success or failure?
```

REVISION HISTORY:

```
15 Sep 2009 - C. Carouge  - Initial version
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
07 Aug 2012 - R. Yantosca - Now print LUN used to open file
20 Jun 2014 - R. Yantosca - Remove reference to directory_mod.F
```

10.6.8 read_gtmm_restart

Subroutine READ_GTMM_RESTART reads dry and wet deposition for mercury from GTMM restart.

INTERFACE:

```
 SUBROUTINE READ_GTMM_RESTART( am_I_Root,   Input_Opt,
&                              YYYYMMDD,    HHMMSS,
```

```
     &                              Hg0dryGEOS,  HgIIdryGEOS,
     &                              HgIIwetGEOS, RC )
```

USES:

```
      USE BPCH2_MOD,           ONLY : OPEN_BPCH2_FOR_READ
      USE CMN_SIZE_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,           ONLY : DEBUG_MSG
      USE FILE_MOD,            ONLY : IOERROR
      USE Input_Opt_Mod,       ONLY : OptInput
      USE inquireMod,          ONLY : findFreeLun
      USE State_Chm_Mod,       ONLY : ChmState
      USE TIME_MOD,            ONLY : EXPAND_DATE
```

INPUT PARAMETERS:

```
      INTEGER,        INTENT(IN)    :: YYYYMMDD, HHMMSS
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?!
      REAL(fp), DIMENSION(IIPAR, JJPAR)   :: Hg0dryGEOS
      REAL(fp), DIMENSION(IIPAR, JJPAR)   :: HgIIdryGEOS
      REAL(fp), DIMENSION(IIPAR, JJPAR)   :: HgIIwetGEOS
```

REVISION HISTORY:

```
   15 Sep 2009 - C. Carouge  - Initial version
   25 Jun 2014 - R. Yantosca - Remove references to tracer_mod.F
   29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

10.6.9 update_dep

Subroutine UPDATE_DEP update the monthly average for wet and dry deposition of Hg0 and Hg2 for mercury from GTMM restart.

INTERFACE:

```
      SUBROUTINE UPDATE_DEP( NN )
```

USES:

```
 #if defined( BPCH_DIAG )
      USE DIAG_MOD,     ONLY : AD38,   AD39
      USE DIAG_MOD,     ONLY : AD44
 #endif
      USE TIME_MOD,     ONLY : GET_CT_DYN,  GET_CT_CHEM
```

INPUT PARAMETERS:

```
INTEGER :: NN    ! Hg2 ID for wet deposition
```

REVISION HISTORY:

```
04 June 2010  - C. Carouge  - Initial version
```

10.6.10 check_dimensions

Subroutine CHECK_DIMENSIONS makes sure that the dimensions of the Hg restart file extend to cover the entire grid.

INTERFACE:

```
SUBROUTINE CHECK_DIMENSIONS( NI, NJ, NL )
```

USES:

```
USE ERROR_MOD, ONLY : GEOS_CHEM_STOP
USE CMN_SIZE_MOD
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN) :: NI, NJ, NL
```

REVISION HISTORY:

```
30 Aug 2010 - S. Strode, C. Holmes - Initial version
```

10.6.11 init_depo_mercury

Subroutine INIT_DEPO_MERCURY initialize deposition arrays for mercury.

INTERFACE:

```
SUBROUTINE INIT_DEPO_MERCURY( am_I_Root, Input_Opt,
&                             State_Chm, RC         )
!USES
    USE CMN_SIZE_MOD
    USE ErrCode_Mod
    USE ERROR_MOD,          ONLY : ALLOC_ERR
    USE Input_Opt_Mod,      ONLY : OptInput
    USE Species_Mod,        ONLY : Species
    USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
23 Apr 2010 - C. Carouge  - Moved arrays allocation from ocean_mercury_mod.f
23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
30 May 2013 - J. Fisher   - Add land snow Hg reservoirs
06 Aug 2015 - J. Fisher   - Add stored snow Hg reservoirs (orig. 29/11/11)
25 Apr 2016 - R. Yantosca - Now handle all Hg indexing locally
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
01 Jul 2016 - R. Yantosca - Now rename species DB object ThisSpc to SpcInfo
```

10.6.12 cleanup_depo_mercury

Subroutine CLEANUP_DEPO_MERCURY deallocate all arrays

INTERFACE:

```
SUBROUTINE CLEANUP_DEPO_MERCURY
```

REVISION HISTORY:

```
23 Apr 2010 - C. Carouge - Moved from ocean_mercury_mod.f
30 May 2013 - J. Fisher   - Add land snow Hg reservoirs
06 Aug 2015 - J. Fisher   - Add stored snow Hg reservoirs (orig. 29/11/11)
```

10.7 Fortran: Module Interface land_mercury_mod.F

Module LAND_MERCURY_MOD contains variables and routines for the land emissions for the GEOS-Chem mercury simulation.

INTERFACE:

```
MODULE LAND_MERCURY_MOD
```

USES:

```
USE HCO_ERROR_MOD    ! For real precisions (hp)
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp, f4, f8)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: BIOMASSHG
PUBLIC :: VEGEMIS
PUBLIC :: SOILEMIS
PUBLIC :: LAND_MERCURY_FLUX
PUBLIC :: GTMM_DR
PUBLIC :: SNOWPACK_MERCURY_FLUX
PUBLIC :: INIT_LAND_MERCURY
PUBLIC :: CLEANUP_LAND_MERCURY
```

REVISION HISTORY:

```
02 Jun 2010 - N. E. Selin, C. Carouge - Initial version
02 Jun 2010 - C. Carouge  - Group all land emissions routine for mercury
                            into this new module.
13 Aug 2010 - R. Yantosca - Added modifications for MERRA
25 Aug 2010 - R. Yantosca - Treat MERRA in same way as GEOS-5
30 Aug 2010 - R. Yantosca - Added more ProTeX headers
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
11 Apr 2012 - R. Yantosca - Now reference new modis_lai_mod.F90
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
17 Nov 2014 - M. Yannetti - Added PRECISION_MOD
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.7.1 land_mercury_flux

Subroutine LAND_MERCURY_FLUX calculates emissions of Hg(0) from prompt recycling of previously deposited mercury to land, in [kg/s].

INTERFACE:

```
SUBROUTINE LAND_MERCURY_FLUX( LFLUX, LHGSNOW, State_Met )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE DAO_MOD,            ONLY : IS_ICE, IS_LAND
USE DEPO_MERCURY_MOD,   ONLY : WD_HGP, WD_HG2, DD_HGP, DD_HG2
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: LHGSNOW     ! Use Hg0 from snow?
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
REAL(fp),       INTENT(OUT) :: LFLUX(IIPAR,JJPAR,N_Hg_CATS) ! Hg0 flux
                                                            !  [kg/s]
```

REVISION HISTORY:

```
30 Aug 2010 - N. E. Selin, C. Holmes, B. Corbitt - Initial version
(1 ) Now uses SNOWMAS from DAO_MOD for compatibility with GEOS-5.
     (eds 7/30/08)
(2 ) Now includes REEMFRAC in parallelization; previous versions may have
     overwritten variable. (cdh, eds 7/30/08)
(3 ) Now also reemit Hg(0) from ice surfaces, including sea ice
     (cdh, 8/19/08)
13 Aug 2010 - R. Yantosca - Add modifications for MERRA
25 Aug 2010 - R. Yantosca - Treat MERRA in same way as GEOS-5
26 Apr 2011 - J. Fisher   - Use MERRA land fraction information
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
```

10.7.2 biomasshg

Subroutine BIOMASSHG is the subroutine for Hg(0) emissions from biomass burning. These emissions are active only for present day simulations and not for preindustrial simulations.

INTERFACE:

```
SUBROUTINE BIOMASSHG( am_I_Root, Input_Opt, EHg0_bb, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE CMN_DIAG_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_ERROR_MOD
USE HCO_STATE_MOD,      ONLY : HCO_STATE
USE HCO_INTERFACE_MOD,  ONLY : GetHcoDiagn
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,                INTENT(IN)  :: am_I_Root   ! Root CPU
TYPE(OptInput),         INTENT(IN)  :: Input_Opt   ! Input Options
```

OUTPUT PARAMETERS:

```
REAL(fp),  DIMENSION(:,:),INTENT(OUT) :: EHg0_bb
INTEGER,                INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
Emissions are based on an inventory of CO emissions from biomass burning
(Duncan et al. J Geophys Res 2003), multiplied by a Hg/CO ratio in BB
plumes from Franz Slemr (Poster, EGU 2006).

Slemr surveyed emission factors from measurements worldwide. Although his
best estimate was 1.5e-7 mol Hg/ mol CO, we chose the highest value
(2.1e-7 mol Hg/ mol CO) in the range because the simulations shown in
Selin et al. (GBC 2008) required large Hg(0) emissions to sustain
reasonable atmospheric Hg(0) concentrations. (eck, 11/13/2008)
```

REVISION HISTORY:

```
30 Jul 2008 - N. E. Selin, C. Holmes, B. Corbitt - Initial version
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
15 Aug 2014 - R. Yantosca - Removed reference to IDBCO; now obsolete
23 Sep 2014 - C. Keller   - Now use HEMCO diagnostics
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
```

10.7.3 vegemis

Subroutine VEGEMIS is the subroutine for Hg(0) emissions from vegetation by evapotranspiration.

INTERFACE:

```
! Bug fix: VEGEMIS shouldn't be tied to GCAP emissions
! (jaf, eds, 4/1/11)
SUBROUTINE VEGEMIS( am_I_Root, Input_Opt, State_Met,
&                   LVEGEMIS,  EHg0_dist, EHg0_vg,   RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DAO_MOD,            ONLY : IS_LAND
USE ErrCode_Mod
USE GC_GRID_MOD,        ONLY : GET_AREA_M2
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH, ITS_A_NEW_MONTH
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,                INTENT(IN)  :: am_I_Root   ! Are we on root CPU?
TYPE(OptInput),         INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(MetState),         INTENT(IN)  :: State_Met   ! Met State object
LOGICAL,                INTENT(IN)  :: LVEGEMIS    !
REAL(fp), DIMENSION(:,:), INTENT(IN)  :: EHg0_dist   !
```

OUTPUT PARAMETERS:

```
      REAL(fp), DIMENSION(:,:), INTENT(OUT) :: EHg0_vg
      INTEGER,                  INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
    Vegetation emissions are proportional to the evapotranspiration rate and the
    soil water mercury content. We assume a constant concentration of mercury
    in soil matter, based on the preindustrial and present-day simulations
    described in Selin et al. (GBC 2008) and in SOILEMIS subroutine. From the
    soil matter Hg concentration, we calculate a soil water Hg concentration in
    equilibrium (Allison and Allison, 2005).
    NASA provides a climatology of evapotranspiration based on a water budget
    model (Mintz and Walker, 1993).
  Calculate vegetation emissions following Xu et al (1999)
     Fc = Ec Cw
     Fc is Hg0 flux (ng m-2 s-1)
     Ec is canopy transpiration (m s-1)
     Cw is conc of Hg0 in surface soil water (ng m-3)
  Calculate Cw from the Allison and Allison (2005) equilibrium formula
     Cw = Cs / Kd
     Cs is the concentration of Hg is surface soil solids, ng/g
     Kd is the equilibrium constant = [sorbed]/[dissolved]
        log Kd = 3.8 L/kg -> Kd = 6310 L /kg = 6.31D-3 m3/g
  We assume a global mean Cs = 45 ng/g for the preindustrial period. In
  iterative simulations we redistribute this according to the deposition
  pattern while maintining the global mean. The scaling factor, EHg0_dist,
  also accounts for the anthropogenic enhancement of soil Hg in the present
  day.
```

REVISION HISTORY:

```
    30 Aug 2010 - N. Eckley, C. Holmes, B. Corbitt - Initial version
    01 Mar 2012 - R. Yantosca - Now use GET_AREA_M2(I,J,L) from grid_mod.F90
    20 Jun 2014 - R. Yantosca - Now accept Input_Opt via the arg list
```

10.7.4 soilemis

Subroutine SOILEMIS is the subroutine for Hg(0) emissions from soils.

INTERFACE:

```
      SUBROUTINE SOILEMIS( EHg0_dist, EHg0_so, State_Met )
```

USES:

```
      USE CMN_SIZE_MOD             ! Size parameters
      USE DAO_MOD,            ONLY : IS_LAND
```

```
USE GC_GRID_MOD,        ONLY : GET_AREA_M2
USE MODIS_LAI_MOD,      ONLY : ISOLAI  => GC_LAI
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_MONTH, ITS_A_NEW_MONTH
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
REAL(fp), DIMENSION(:,:), INTENT(IN)  :: EHg0_dist
TYPE(MetState),         INTENT(IN)  :: State_Met   ! Met State object
```

OUTPUT PARAMETERS:

```
REAL(fp), DIMENSION(:,:), INTENT(OUT) :: EHg0_so
```

REMARKS:

```
Soil emissions are a function of solar radiation at ground level
(accounting for attenuation by leaf canopy) and surface temperature.
The radiation dependence from Zhang et al. (2000) is multiplied by the
temperature dependence from Poissant and Casimir (1998).
Finally, this emission factor is multiplied by the soil mercury
concentration and scaled to meet the global emission total.
Comments on soil Hg concentration:
---------------------------------
We chose the preindustrial value of 45 ng Hg /g dry soil as the mean of
the range quoted in Selin et al. (GBC 2008): 20-70 ng/g (Andersson, 1967;
Shacklette et al., 1971; Richardson et al., 2003; Frescholtz and Gustin,
2004). Present-day soil concentrations are thought to be 15% greater than
preindustrial (Mason and Sheu 2002), but such a difference is much less
than the range of concentrations found today, so not well constrained.
We calculate the present-day soil Hg distribution by adding a global mean
6.75 ng/g (=0.15 * 45 ng/g) according to present-day Hg deposition.
(eck, 11/13/08)
```

REVISION HISTORY:

```
30 Aug 2010 - N. Eckley, B. Corbitt - Initial version
(1 ) Added comments. (cdh, eds, 7/30/08)
(2 ) Now include light attenuation by the canopy after sunset. Emissions
     change by < 1% in high-emission areas  (cdh, 8/13/2008)
(3 ) Removed FRCLND for consistency with other Hg emissions (cdh, 8/19/08)
2 June 2010 - C. Carouge  - Solve
13 Aug 2010 - R. Yantosca - Added modifications for MERRA
25 Aug 2010 - R. Yantosca - Treat MERRA in same way as GEOS-5
26 Apr 2011 - J. Fisher   - Use MERRA land fraction information
12 Apr 2011 - J. Fisher   - Bug fixes, add missing code from Holmes 2010
08 Feb 2012 - R. Yantosca - Treat GEOS-5.7.x in the same way as MERRA
10 Feb 2012 - R. Yantosca - Extend #if statement for SOIL_EMIS_FAC in order
                            to get the code to compile w/o error.
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
```

```
11 Apr 2012 - R. Yantosca - Replace lai_mod.F with modis_lai_mod.F90
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
12 Aug 2015 - R. Yantosca - Add support for MERRA2 meteorology
```

10.7.5 snowpack_mercury_flux

Subroutine SNOWPACK_MERCURY_FLUX calculates emission of Hg(0) from snow and ice.

INTERFACE:

```
SUBROUTINE SNOWPACK_MERCURY_FLUX( FLUX, LHGSNOW, State_Met )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE DEPO_MERCURY_MOD,   ONLY : SNOW_HG_OC, SNOW_HG_LN
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_EMIS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: LHGSNOW     ! Use Hg from snow?
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
REAL(fp),       INTENT(OUT) :: FLUX(IIPAR,JJPAR,N_Hg_CATS)  ! Hg0 flux
                                                            !  [kg/s]
```

REMARKS:

```
Emissions are a linear function of Hg mass stored in the snowpack. The
Hg lifetime in snow is assumed to be 180 d when T< 270K and 7 d when T>270K
   E = k * SNOW_HG     : k = 6D-8 if T<270K, 1.6D-6 otherwise
These time constants reflect the time scales of emission observed in the
Arctic and in field studies. Holmes et al 2010

Formulation from Holmes et al. 2010 is now obsolete. Instead, emissions
from snow are tied to solar radiation, not temperature. Effective rate
constant is in the mid-range of values estimated by Durnford and Dastoor
(2011) and consistent with surface air Hg0 observations, as described in
Fisher et al. (2011, in review).
Note that only MERRA provides incident shortwave radiation; other met
fields only provide *net* shortwave radiation. The parameterization was
designed and tested using MERRA, and therefore may not work as well with
other met fields
```

REVISION HISTORY:

```
15 Sep 2009 - C. Holmes, S. Carouge - Initial version
30 Aug 2010 - R. Yantosca - Added ProTex headers
12 Apr 2011 - J. Fisher   - Add missing code from Holmes 2010
18 Nov 2011 - J. Fisher   - Update to radiation-dependent formulation
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
28 Nov 2012 - R. Yantosca - Replace SUNCOS with State_Met%SUNCOS
30 Mar 2015 - R. Yantosca - Remove obsolete variables
```

10.7.6 gtmm_dr

GTMM_DR is a driver to call GTMM from GEOS-Chem.

INTERFACE:

```
SUBROUTINE GTMM_DR( am_I_Root, Input_Opt, State_Met, Hg0gtm, RC )
```

USES:

```
USE BPCH2_MOD
USE CMN_SIZE_MOD             ! Size parameters
USE DAO_MOD,            ONLY : IS_LAND
USE DEPO_MERCURY_MOD,   ONLY : CHECK_DIMENSIONS
USE DEPO_MERCURY_MOD,   ONLY : WD_Hg2, WD_HgP, DD_HgP, DD_Hg2
USE DEPO_MERCURY_MOD,   ONLY : READ_GTMM_RESTART
USE ErrCode_Mod
USE FILE_MOD,           ONLY : IOERROR
USE Input_Opt_Mod,      ONLY : OptInput
USE inquireMod,         ONLY : findFreeLun
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : EXPAND_DATE, YMD_EXTRACT
USE TIME_MOD,           ONLY : GET_NYMD, GET_NHMS
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

OUTPUT PARAMETERS:

```
! Emission of Hg0 calculated by GTMM for the month [kg/s]
REAL(fp),         INTENT(OUT) :: Hg0gtm(IIPAR, JJPAR)

! Success or failure?
INTEGER,        INTENT(OUT) :: RC
```

REMARKS:

```
#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (05 Mar 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
15 Sep 2009 - C. Carouge  - Initial version
03 Aug 2012 - R. Yantosca - Move calls to findFreeLUN out of DEVEL block
05 Mar 2015 - R. Yantosca - Now add Input_Opt%RES_DIR to data path
```

10.7.7 init_land_mercury

Subroutine INIT_LAND_MERCURY allocates and zeroes all module arrays.

INTERFACE:

```
  SUBROUTINE INIT_LAND_MERCURY( am_I_Root, Input_Opt,
 &                              State_Chm, RC         )
```

USES:

```
  USE CMN_SIZE_MOD
  USE ErrCode_Mod
  USE ERROR_MOD,          ONLY : ALLOC_ERR
  USE Input_Opt_Mod,      ONLY : OptInput
  USE State_Chm_Mod,      ONLY : ChmState
```

INPUT PARAMETERS:

```
  LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
  TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

INPUT/OUTPUT PARAMETERS:

```
  TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
  INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
14 Sep 2009 - C. Carouge  - Initial version
23 Jun 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC
```

10.7.8 cleanup_land_mercury

Subroutine CLEANUP_LAND_MERCURY deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_LAND_MERCURY
```

REVISION HISTORY:

```
14 Sep 2009 - C. Carouge  - Initial version
```

10.8 Fortran: Module Interface pops_mod.F

Module POPS_MOD contains variables and routines for the GEOS-Chem peristent organic pollutants (POPs) simulation.

INTERFACE:

```
MODULE POPS_MOD
```

USES:

```
USE PhysConstants    ! For physical constants
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp, f4, f8)

IMPLICIT NONE
PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC :: CHEMPOPS
PUBLIC :: INIT_POPS
```

REMARKS:

```
POPs Tracers
=============================================================================
(1 ) POPG   : Gaseous POP - total tracer
(2 ) POPPOC : OC-sorbed POP  - total tracer
(3 ) POPPBC : BC-sorbed POP  - total tracer
```

REVISION HISTORY:

```
20 Sep 2010 - N.E. Selin    - Initial Version
04 Jan 2011 - C.L. Friedman - Expansion on initial version
21 Aug 2014 - M. Sulprizio  - Removed emissions routines now handled by HEMCO
04 Mar 2015 - R. Yantosca   - Use REAL(f4) for pointer args to HCO_GetPtr
23 Dec 2015 - E. Lundgren   - Use global physical constants
22 Jun 2016 - R. Yantosca   - Rename species ID flags from IDT* to id_*
22 Jun 2016 - R. Yantosca   - Rename species drydep flags from DRY* to dd_*
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.8.1 chempops

Subroutine CHEMPOPS is the driver routine for POPs chemistry (eck, 9/20/10)

INTERFACE:

```
SUBROUTINE CHEMPOPS( am_I_Root, Input_Opt,
&                    State_Met, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE DRYDEP_MOD,         ONLY : DEPSAV
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE ERROR_MOD,          ONLY : ERROR_STOP
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
20 September 2010 - N.E. Selin - Initial Version based on CHEMMERCURY
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
10 Sep 2014 - M. Sulprizio- Remove calls to GET_GLOBAL_OH and GET_GLOBAL_O3,
                            these fields are now read in HEMCO
10 Sep 2014 - M. Sulprizio- Now get global concentrations of OH, O3, OC, and
                            BC from HEMCO
03 Mar 2015 - C. Keller   - Now do dry-deposition always outside of chempops
```

10.8.2 chem_popgp

Subroutine CHEM_POPGP is the chemistry subroutine for the oxidation, gas-particle partitioning, and deposition of POPs. (eck, clf, 1/4/2011)

INTERFACE:

```
      SUBROUTINE CHEM_POPGP ( V_DEP_G,
     &                        V_DEP_P_OCPO, V_DEP_P_OCPI,
     &                        V_DEP_P_BCPO, V_DEP_P_BCPI,
     &                        am_I_Root,    Input_Opt,
     &                        State_Met,    State_Chm,
     7                        RC )
```

USES:

```
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD44
#endif
      USE DIAG53_MOD
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : DEBUG_MSG
      USE ERROR_MOD,          ONLY : SAFE_DIV
      USE GC_GRID_MOD,        ONLY : GET_AREA_CM2
      USE Input_Opt_Mod,      ONLY : OptInput
      USE PBL_MIX_MOD,        ONLY : GET_FRAC_UNDER_PBLTOP
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      ! Dry deposition frequencies [/s]
      REAL(fp),       INTENT(IN)    :: V_DEP_G(IIPAR,JJPAR)
      REAL(fp),       INTENT(IN)    :: V_DEP_P_OCPO(IIPAR,JJPAR)
      REAL(fp),       INTENT(IN)    :: V_DEP_P_BCPO(IIPAR,JJPAR)
      REAL(fp),       INTENT(IN)    :: V_DEP_P_OCPI(IIPAR,JJPAR)
      REAL(fp),       INTENT(IN)    :: V_DEP_P_BCPI(IIPAR,JJPAR)

      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Is this the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REMARKS:

```
    References:
    ============================================================================
    (1 ) For OH rate constant: Brubaker & Hites. 1998. OH reaction kinetics of
    PAHs and PCDD/Fs. J. Phys. Chem. A. 102:915-921.
```

REVISION HISTORY:

```
20 Sep 2010 - N.E. Selin  - Initial Version based on CHEM_HG0_HG2
29 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
14 Apr 2014 - R. Yantosca - Now prevent div-by-zero in computations below
17 Sep 2014 - C. Keller   - Renamed EmisList_GetDataArr to HCO_GetPtr
31 May 2016 - E. Lundgren - Replace Input_Opt%XNUMOL with AVO/(emMW_g*1e-3)
                            where emMW_g is emitted MW from species database
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Removed temporary tracer-removal code
06 Oct 2016 - R. Yantosca - Now zero C_NO3 to avoid floating-point error
```

10.8.3 rxn_ox_nodep

Subroutine RXN_OX_NODEP calculates new mass of POPG for given oxidation rates, without any deposition. This is for the free troposphere, or simulations with deposition turned off. (clf, 1/27/11, based on RXN_REDOX_NODEP in mercury_mod.f).

INTERFACE:

```
      SUBROUTINE RXN_OX_NODEP( OLD_POPG, K_OX, E_KOX_T,
     &                         NEW_POPG, GROSS_OX )
```

INPUT PARAMETERS:

```
      REAL(fp),  INTENT(IN)  :: OLD_POPG
      REAL(fp),  INTENT(IN)  :: K_OX
      REAL(fp),  INTENT(IN)  :: E_KOX_T
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT) :: NEW_POPG
      REAL(fp),  INTENT(OUT) :: GROSS_OX
```

REVISION HISTORY:

```
27 January 2011 - CL Friedman - Initial Version
```

10.8.4 rxn_ox_withdep

Subroutine RXN_OX_WITHDEP calculates new mass of POPG for given rates of oxidation and deposition. This is for the boundary layer. (clf, 1/27/11, based on RXN_REDOX_NODEP in mercury_mod.f).

INTERFACE:

```
      SUBROUTINE RXN_OX_WITHDEP( OLD_POPG, K_OX, K_DEPG, DT, E_KOX_T,
     &                           NEW_POPG, GROSS_OX, DEP_POPG )
  USES:
      USE ERROR_MOD,    ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      REAL(fp),  INTENT(IN)  :: OLD_POPG
      REAL(fp),  INTENT(IN)  :: DT
      REAL(fp),  INTENT(IN)  :: K_OX
      REAL(fp),  INTENT(IN)  :: K_DEPG
      REAL(fp),  INTENT(IN)  :: E_KOX_T
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT) :: NEW_POPG
      REAL(fp),  INTENT(OUT) :: GROSS_OX
      REAL(fp),  INTENT(OUT) :: DEP_POPG
```

REVISION HISTORY:

```
    27 January 2011 - CL Friedman - Initial Version
```

10.8.5 no_rxn_withdep

Subroutine NO_RXN_WITHDEP calculates new mass of POPP for given rate of deposition. No oxidation of POPP. This is for the boundary layer. (clf, 2/9/11)

INTERFACE:

```
      SUBROUTINE NO_RXN_WITHDEP( OLD_POPP, K_DEPP, DT,
     &                           NEW_POPP, DEP_POPP )
```

USES:

```
      USE ERROR_MOD,    ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
      REAL(fp),  INTENT(IN)  :: OLD_POPP
      REAL(fp),  INTENT(IN)  :: K_DEPP
      REAL(fp),  INTENT(IN)  :: DT
```

OUTPUT PARAMETERS:

```
      REAL(fp),  INTENT(OUT) :: NEW_POPP
      REAL(fp),  INTENT(OUT) :: DEP_POPP
```

REVISION HISTORY:

```
    9 February 2011 - CL Friedman - Initial Version
```

10.8.6 get_oh

Function GET_OH returns monthly mean OH and imposes a diurnal variation.

INTERFACE:

```
FUNCTION GET_OH( I, J, L, State_Met ) RESULT( OH_MOLEC_CM3 )
```

USES:

```
USE CMN_SIZE_MOD             ! Size parameters
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
INTEGER, INTENT(IN)         :: I, J, L

TYPE(MetState), INTENT(IN)  :: State_Met   ! Meteorology State object
```

REMARKS:

```
Copied GET_OH function from mercury_mod.f - CLF
```

REVISION HISTORY:

```
03 Feb 2011 - CL Friedman - Initial Version
29 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
23 Sep 2014 - M. Sulprizio- Now get OH for offline aerosol sim from HEMCO
```

10.8.7 ohno3time

Subroutine OHNO3TIME computes the sum of cosine of the solar zenith angle over a 24 hour day, as well as the total length of daylight. This is needed to scale the offline OH and NO3 concentrations. (rjp, bmy, 12/16/02, 12/8/04)

INTERFACE:

```
SUBROUTINE OHNO3TIME
```

USES:

```
USE CMN_SIZE_MOD      ! Size parameters
USE GC_GRID_MOD, ONLY : GET_XMID,    GET_YMID_R
USE TIME_MOD,    ONLY : GET_NHMSb,   GET_ELAPSED_SEC
USE TIME_MOD,    ONLY : GET_TS_CHEM, GET_DAY_OF_YEAR, GET_GMT
```

REVISION HISTORY:

```
20 Sep 2010 - N.E. Selin  - Initial Version for POPS_MOD
16 May 2016 - M. Sulprizio- Remove IJLOOP and change SUNTMP array dimensions
                            from (MAXIJ) to (IIPAR,JJPAR)
```

10.8.8 init_pops

Subroutine INIT_POPS allocates and zeroes all module arrays.

INTERFACE:

```
SUBROUTINE INIT_POPS( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : DEBUG_MSG
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REVISION HISTORY:

```
20 Sep 2010 - N.E. Selin  - Initial Version based on INIT_MERCURY
25 Mar 2013 - R. Yantosca - Now accept Input_Opt argument
25 Aug 2014 - M. Sulprizio- Now accept am_I_Root and RC arguments
10 Sep 2014 - M. Sulprizio- Remove calls to GET_GLOBAL_OC and GET_GLOBAL_BC,
                            these fields are now read in HEMCO
10 Mar 2015 - R. Yantosca - Now always allocate ZERO_DVEL
21 Sep 2015 - R. Yantosca - Now takes State_Chm as an argument, so that
                            we can take advantage of the species database
02 May 2016 - R. Yantosca - Now make id_POP* flags as module variables
                            instead of getting them from tracerid_mod.F
22 Jun 2016 - R. Yantosca - Now use Ind_() to define species & drydep ID's
22 Jun 2016 - R. Yantosca - Rename IDT* flags to id* and DRY* to dd_*
```

10.8.9 cleanup_pops

Subroutine CLEANUP_POPS deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_POPS
```

REVISION HISTORY:

```
20 September 2010 - N.E. Selin - Initial Version
```

10.9 Fortran: Module Interface RnPbBe_mod.F

Module RnPbBe_MOD contains variables and routines used for the 222Rn-210Pb-7Be simulation. (hyl, swu, bmy, 6/14/01, 8/4/06)

INTERFACE:

```
      MODULE RnPbBe_MOD
```

USES:

```
      USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PRIVATE
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CHEMRnPbBe
```

PRIVATE MEMBER FUNCTIONS:

```
#if defined( NC_DIAG )
      PRIVATE :: Diagn_RnPbBe_Update
#endif

      ! NOTE: WE NEED TO KEEP THIS HERE FOR NOW SINCE IT IS USED
      ! BY CODE IN mercury_mod.F.  REMOVE IT LATER. (bmy, 7/7/14)
      ! Removed. (mdy, 12/4/14)
       PUBLIC  :: SLQ
```

REMARKS:

```
   References:
   ============================================================================
   (1 ) Liu,H., D.Jacob, I.Bey, and R.M.Yantosca, Constraints from 210Pb
        and 7Be on wet deposition and transport in a global three-dimensional
        chemical tracer model driven by assimilated meteorological fields,
        JGR, 106, D11, 12,109-12,128, 2001.
   (2 ) Jacob et al.,Evaluation and intercomparison of global atmospheric
        transport models using Rn-222 and other short-lived tracers,
        JGR, 1997 (102):5953-5970
   (3 ) Dorothy Koch, JGR 101, D13, 18651, 1996.
   (4 ) Lal, D., and B. Peters, Cosmic ray produced radioactivity on the
        Earth. Handbuch der Physik, 46/2, 551-612, edited by K. Sitte,
        Springer-Verlag, New York, 1967.
```

REVISION HISTORY:

```
   14 Jun 2001 - H. Liu      - Initial version
   (1 ) Added existing routines to this module (bmy, 6/14/01)
```

```
(2 ) Updated comments (bmy, 9/4/01)
(3 ) Eliminate AVGF; redimensioned XTRA2 (bmy, 9/25/01)
(4 ) Replace references to PW(I,J) with P(I,J) (bmy, 10/3/01)
(5 ) Remove obsolete code from 9/01 and 10/01 (bmy, 10/23/01)
(6 ) Removed duplicate variable declarations (bmy, 11/15/01)
(7 ) Now read files from DATA_DIR/RnPbBe_200203/ directory.
     Also updated comments. (bmy, 3/29/02)
(8 ) Incorporated latest changes from Hongyu Liu.  Also split off the
     code to read in the 7Be emissions into a separate routine.
     Add parallel DO-loops in several places.  Cleaned up DRYFLXRnPbBe,
     and now make sure ND44 accurately represents the drydep fluxes
     of 210Pb and 7Be. (hyl, bmy, 8/7/02)
(9 ) Now reference AD from "dao_mod.f".  Now references "error_mod.f".
     Moved routine DRYFLXRnPbBe into "drydep_mod.f".  (bmy, 1/27/03)
(10) Now references the new "time_mod.f" (bmy, 2/11/03)
(11) Bug fix in EMISSRnPbBe -- take abs( lat) for 7Be emiss. (bmy, 6/10/03)
(12) Bug fix in EMISSRnPbBe -- shut off 222Rn emissions in polar regions
     (swu, bmy, 10/28/03)
(13) Now references "directory_mod.f", "logical_mod.f", and "tracer_mod.f"
     (bmy, 7/20/04)
(14) Now modified for GCAP and GEOS-5 met fields (swu, bmy, 5/24/05)
(15) Now references "tropopause_mod.f"
(16) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
19 Nov 2010 - R. Yantosca - Added ProTeX headers
08 Nov 2011 - R. Yantosca - Prevent out-of-bounds errors in diagnostics
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now use routines from the new grid_mod.F90
01 Aug 2012 - R. Yantosca - Add reference to findFreeLUN from inqure_mod.F90
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
07 Jul 2014 - R. Yantosca - Removed routines now orphaned by HEMCO
22 Aug 2014 - R. Yantosca - Removed LATSOU, PRESOU, BESOU arrays, these
                            are now defined in the HEMCO code.
22 Aug 2014 - R. Yantosca - Remove XNUMOL_* parameters; these are obsolete
04 Nov 2014 - M. Yannetti - Added PRECISION_MOD
30 Jan 2015 - E. Lundgren - Add new diagnostics stuctures for netCDF output.
02 May 2016 - R. Yantosca - Now define IDTRn, IDTPb, IDTBe locally
```

10.9.1 chemRnPbBe

Subroutine CHEMRnPbBe performs loss chemistry on 222Rn, 210Pb, and 7Be.

INTERFACE:

```
  SUBROUTINE CHEMRnPbBe( am_I_Root, Input_Opt,
 &                       State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRATMESO
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
#if defined( BPCH_DIAG )
      USE DIAG_MOD,           ONLY : AD01
      USE DIAG_MOD,           ONLY : AD02
#endif
      USE ErrCode_Mod
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Chm_Mod,      ONLY : Ind_
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
   31 Oct 1999 - H. Liu - Initial version
   (1 ) Now use F90 syntax (bmy, hyl, 3/22/99)
   (2 ) Add FIRSTCHEM as an argument.  Only compute the exponential terms
        when FIRSTCHEM = .TRUE., and save the values for later use
        (bmy, 3/24/99)
   (3 ) Cosmetic changes (bmy, 10/13/99)
   (4 ) Eliminate obsolete code and ND63 diagnostic (bmy, 4/12/00)
   (5 ) Cosmetic changes (bmy, 7/12/00)
   (6 ) Added to module "RnPbBe_mod.f".  Also updated comments
        and made cosmetic changes. (bmy, 6/14/01)
   (7 ) Add diagnostics for Rn/Be emissions.  Also cleaned up some old code
        and added parallel DO-loops.  Updated comments. (hyl, 8/6/02)
   (8 ) Now make FIRSTCHEM a local SAVEd variable.  (bmy, 1/27/03)
   (9 ) Now use function GET_TS_CHEM from "time_mod.f" (bmy, 2/11/03)
   (10) Now references STT and N_TRACERS from "tracer_mod.f" (bmy, 7/20/04)
   (11) Remove reference to CMN; it's obsolete.  Now use inquiry functions
        from "tropopause_mod.f" to diagnose strat boxes. (bmy, 8/15/05)
   08 Dec 2009 - R. Yantosca - Added ProTeX headers
   08 Nov 2011 - R. Yantosca - Prevent out-of-bounds errors in diagnostics
   09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
```

```
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
22 Aug 2014 - R. Yantosca - Copy emissions above the PBL to tracer array
22 Aug 2014 - R. Yantosca - Cosmetic changes, for clarity
04 Sep 2014 - R. Yantosca - Add minor changes for efficiency
04 Nov 2014 - M. Yannetti - Changed REAL*8 to REAL(fp)
12 Dec 2014 - M. Yannetti - Changed Hemco REAL*8 to REAL(hp)
 2 May 2016 - R. Yantosca - Now define IDTRn, IDTPb, IDTBe locally
22 Jun 2016 - R. Yantosca - Now use Ind_() to define species ID's
22 Jun 2016 - R. Yantosca - Rename species ID's to id_Rn, id_Pb, id_Be7
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
10 Aug 2016 - R. Yantosca - Remove temporary tracer-removal code
```

10.9.2 diagn_rnpbbe_update

Subroutine DIAGN_RNPBBE_UPDATE updates the Rn/Pb/Be7 diagnostics ND01 (emissions) and ND02 (loss due to decay) that are written to netCDF. ND01 Rn and Be7 emissions diagnostics are included in HEMCO emissions and are therefore not updated in this subroutine.

INTERFACE:

```
SUBROUTINE Diagn_RnPbBe_Update( am_I_Root, NDxx, SpeciesName,
&                               DiagArray, ColNo )
```

USES:

```
USE HCO_INTERFACE_MOD,  ONLY : HcoState
USE HCO_DIAGN_MOD,      ONLY : Diagn_Update
USE HCO_Error_Mod
USE Error_Mod
```

INPUT PARAMETERS:

```
LOGICAL,            INTENT(IN)  :: am_I_Root    ! Are we on the root CPU?
CHARACTER(LEN=4),   INTENT(IN)  :: NDxx         ! Diagnostic id
CHARACTER(LEN=*),   INTENT(IN)  :: SpeciesName  ! Species name
REAL(fp), TARGET,   INTENT(IN)  :: DiagArray(:,:,:)
INTEGER,            INTENT(IN)  :: ColNo        ! Diag collection #
```

REVISION HISTORY:

```
30 Jan 2015 - E. Lundgren   - Initial version
```

REMARKS:

10.10 Fortran: Module Interface rrtmg_rad_transfer_mod.F

Module RRTMG_RAD_TRANSFER_MOD contains arrays and routines for performing online radiative transfer in GEOS-Chem.

INTERFACE:

```
      MODULE RRTMG_RAD_TRANSFER_MOD
```

USES:

```
      USE CMN_FJX_MOD,  ONLY : RTODAER, RTSSAER, RTASYMAER,
     &                         WVAA, SPECMASK, LSPECRADMENU,
     &                         NSPECRADMENU
      USE CMN_SIZE_MOD, ONLY : IIPAR,JJPAR,LLPAR, NDUST, NAER
      USE DIAG_MOD,     ONLY : AD72 !RAD OUTPUT DIAGNOSTIC ARRAY
      USE OMP_LIB
      USE PARRRTM,      ONLY : NBNDLW
      USE PARRRSW,      ONLY : NBNDSW

      IMPLICIT NONE
       PRIVATE
  !PUBLIC MEMBER FUNCTIONS
      PUBLIC  :: CLEANUP_SURFACE_RAD
      PUBLIC  :: INIT_SURFACE_RAD
      PUBLIC  :: READ_SURFACE_RAD
      PUBLIC  :: CLEANUP_MCICA_CLOUDS
      PUBLIC  :: INIT_MCICA_CLOUDS
```

PUBLIC DATA MEMBERS:

```
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: ALBDIR(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: ALBDIF(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: EMISS (:,:,:)

      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CH4CLIM(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: N2OCLIM(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CFC11CLIM(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CFC12CLIM(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CCL4CLIM(:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CFC22CLIM(:,:,:)

      !MCICA cloud variables now stored for reuse
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CLDFMCL_LW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CIWPMCL_LW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CLWPMCL_LW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: TAUCMCL_LW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CLDFMCL_SW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CIWPMCL_SW(:,:,:,:)
      REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: CLWPMCL_SW(:,:,:,:)
```

```
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: TAUCMCL_SW(:,:,:,:)
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: SSACMCL(:,:,:,:)
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: ASMCMCL(:,:,:,:)
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: FSFCMCL(:,:,:,:)
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: REICMCL(:,:,:)
REAL*8,  ALLOCATABLE, PUBLIC, TARGET :: RELQMCL(:,:,:)
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
17 May 2016 - M. Sulprizio- Add extra dimension to MCICA cloud arrays to
                            allow for change from IIPAR*JJPAR to IIPAR,JJPAR
27 Jun 2016 - R. Yantosca - Now save species ID's in module variables
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.10.1 do_rrtmg_rad_transfer

INTERNAL SUBROUTINE

INTERFACE:

```
SUBROUTINE DO_RRTMG_RAD_TRANSFER( am_I_Root, THISDAY,   THISMONTH,
&                                 ICLD,      ISPECMENU, ISEED,
&                                 Input_Opt, State_Met, State_Chm,
&                                 RC  )
```

USES:

```
!-----------------------------------------------------------------
! Modules from GeosRad
!-----------------------------------------------------------------
USE MCICA_SUBCOL_GEN_LW, ONLY : MCICA_SUBCOL_LW
USE MCICA_SUBCOL_GEN_SW, ONLY : MCICA_SUBCOL_SW
USE PARKIND,             ONLY : IM=>KIND_IM, RB=>KIND_RB
USE RRLW_CON,            ONLY : GASCON, AVOGAD
USE PARRRTM,             ONLY : NBNDLW, NGPTLW
USE PARRRSW,             ONLY : NBNDSW, NGPTSW,NAEREC
USE RRTMG_LW_RAD,        ONLY : RRTMG_LW
USE RRTMG_SW_RAD,        ONLY : RRTMG_SW

!-----------------------------------------------------------------
! GEOS-Chem modules
!-----------------------------------------------------------------
USE CHEMGRID_MOD,        ONLY : ITS_IN_THE_TROP
USE CHEMGRID_MOD,        ONLY : GET_CHEMGRID_LEVEL
USE CMN_FJX_MOD,         ONLY : NSPECRAD  ! NUMBER OF SPECIES FOR RT
USE CMN_FJX_MOD,         ONLY : NASPECRAD ! NUMBER OF AEROSOL SPECIES
```

```
      USE CMN_FJX_MOD,         ONLY : SPECMASK,   IRTWVSELECT
      USE CMN_FJX_MOD,         ONLY : NWVSELECT,  WVSELECT
      USE CMN_FJX_MOD,         ONLY : ACOEF_RTWV, BCOEF_RTWV, CCOEF_RTWV
      USE CMN_FJX_MOD,         ONLY : WVAA,       NWVAA
      USE CMN_FJX_MOD,         ONLY : NWVAA0
      USE DIAG_MOD,            ONLY : AD72
      USE ErrCode_Mod
      USE ERROR_MOD
      USE GC_GRID_MOD,         ONLY : GET_YMID
      USE Input_Opt_Mod,       ONLY : OptInput
      USE PhysConstants,       ONLY : AIRMW, PI, AVO
      USE PRESSURE_MOD,        ONLY : GET_PCENTER,      GET_PEDGE
      USE State_Chm_Mod,       ONLY : ChmState
      USE State_Chm_Mod,       ONLY : Ind_
      USE State_Met_Mod,       ONLY : MetState
      USE TIME_MOD,            ONLY : GET_DAY_OF_YEAR, GET_HOUR
      USE TOMS_MOD,            ONLY : GET_OVERHEAD_O3
      USE UnitConv_Mod
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! root CPU?
      INTEGER,        INTENT(IN)    :: THISDAY     ! CURRENT DAY
      INTEGER,        INTENT(IN)    :: THISMONTH   ! CURRENT MONTH
      INTEGER,        INTENT(IN)    :: ISPECMENU   ! THE SPECIES BEING INCLUDED
                                                   ! NEEDED FOR OUTPUT PURPOSES
      INTEGER,        INTENT(IN)    :: ISEED
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
      INTEGER,        INTENT(INOUT) :: ICLD        ! CLOUD FLAG FOR RRTMG
                                                   ! 0-NOCLOUD, 1-GREY CLOUD
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Failure or success
```

REMARKS:

```
    THIS ROUTINE PASSES INPUTS TO THE RRTMG DRIVER ROUTINE "RAD_DRIVER"
    VIA THE ARGUMENT LIST.  THIS PREVENTS CIRCULAR REFERENCES.
```

REVISION HISTORY:

```
    17 AUG 2012 - R. YANTOSCA - INITIAL VERSION
    15 Dec 2014 - M. Sulprizio- Moved radiation diagnostic from ND71 to ND72 to
                                avoid conflicts with hourly max ppbv diagnostic.
    15 Jan 2015 - M. Sulprizio- Added T_CTM and P_CTM arrays and calculate them
                                in the same manner that we do in fast_jx_mod.F.
```

```
                            Also moved and fixed calculation of O3_CTM.
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
13 Apr 2015 - R. Yantosca - Fixed inefficient loop ordering (should be J,I)
13 Apr 2015 - R. Yantosca - Add error check for JLOOP > 0 in a few places
23 Apr 2015 - R. Yantosca - Bug fix: YLAT was undefined; now corrected
23 Apr 2015 - R. Yantosca - Bug fix: all members of State_Met now use
                            (I,J,L) ordering.  This is for the NASA GCM.
02 Jun 2015 - R. Yantosca - Bug fix: Add missing variables to OMP PRIVATE
03 Jun 2015 - R. Yantosca - Now use pointers to avoid array temporaries
12 Aug 2015 - E. Lundgren - Incoming tracer units are now [kg/kg] and
                            are converted to [kg] for RRTMG
12 Aug 2015 - E. Lundgren - Now accept am_I_Root and RC as arguments
21 Dec 2015 - M. Sulprizio- Get air density directly from State_Met object
22 Dec 2015 - M. Sulprizio- Replace CSPEC with State_Chm%Species
19 Jan 2016 - E. Lundgren - Use global physical constants from physconstants
                            rather than comode_loop_mod
17 May 2016 - M. Sulprizio- Remove NCOL, IJLOOP and change dimensions of
                            arrays from IIPAR*JJPAR to IIPAR,JJPAR
31 May 2016 - E. Lundgren - Replace Input_Opt%TRACER_MW_G with emMW_g from
                            species database (emitted species g/mol)
16 Jun 2016 - K. Yu       - Now define species ID's with the Ind_ function
17 Jun 2016 - R. Yantosca - Only define species ID's on the first call
27 Jun 2016 - R. Yantosca - Bug fix: replace a couple of leftover IDO3
                            variables with the new id_O3 species ID
30 Jun 2016 - M. Sulprizio- Replace ICH4 with id_CH4 to remove dependence
                            on comode_loop_mod.F
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.10.2 set_specmask

Subroutine SET_SPECMASK converts the species switches in the input.mod radiation section into the list of species that should be passed through to RRTMG. This must be done in a subtractive way, e.g. If we require the DRE of sulfate then the baseline will contain all species and the sulfate run will contain everything but sulfate, this way the contribution of sulfate can be inferred. Therefore, all species are initially set to 1 and their inclusion results in SPECMASK for the particular species being set to zero. (dar 10/2013)

INTERFACE:

```
      SUBROUTINE SET_SPECMASK(ISPECRADMENU)
```

USES:

```
      USE CMN_FJX_MOD,   ONLY :  SPECMASK,NSPECRAD,NASPECRAD,
     &                           LSPECRADMENU,NSPECRADMENU
```

INPUT PARAMETERS:

```
      INTEGER, INTENT(IN)    :: ISPECRADMENU
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
26 Jun 2015 - E. Lundgren - Fix typo in NXTRA definition
```

10.10.3 read_surface_rad

Subroutine READ_SURFACE_RAD gets the surface albedo and emissivity from data files processed from MODIS MCD43C3.5 and MOD11C2. Albedo is direct (black sky) and diffuse (white sky) and interpolated to the first 21 wavelengths of GADS, used in the RRTMG code. Emissivity has been interpolated to last 40 wavelengths of GADS.! This routine is called from main.F when ITS_TIME_FOR_SURFACE_RAD() is true (every 8 days) DAR (10/2012)

INTERFACE:

```
      SUBROUTINE READ_SURFACE_RAD( Input_Opt, FORCEREAD )
```

USES:

```
      USE BPCH2_MOD,          ONLY : GET_NAME_EXT_2D, GET_RES_EXT
      USE BPCH2_MOD,          ONLY : GET_TAU0,        READ_BPCH2
      USE CMN_FJX_MOD
      USE CMN_SIZE_MOD             ! SIZE PARAMETERS
      USE Input_Opt_Mod,      ONLY : OptInput
      USE JULDAY_MOD,         ONLY : JULDAY, CALDATE
      USE TIME_MOD,           ONLY : GET_YEAR, GET_MONTH
      USE TIME_MOD,           ONLY : GET_DAY,  GET_DAY_OF_YEAR
      USE TIME_MOD,           ONLY : YMD_EXTRACT
```

INPUT PARAMETERS:

```
      TYPE(OptInput), INTENT(IN)           :: Input_Opt ! Input options
      LOGICAL,        INTENT(IN), OPTIONAL :: FORCEREAD ! Reset first-time flag?
```

REMARKS:

```
#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (05 Mar 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
10 Apr 2015 - R. Yantosca - Read from ExtData/CHEM_INPUTS/modis_surf_201210
```

10.10.4 read_strat_clim

Subroutine READ_STRAT_CLIM gets the stored N2O and CH4 profiles created based on TES climatology. These are global July mean profiles from TES that are interpolated to the 3D GEOS-Chem grid as a simple solution to account for stratospheric contribution of these species to radiative balance. This routine is called from main.F once at the start of the model run. DAR (12/2012)

INTERFACE:

```
SUBROUTINE READ_STRAT_CLIM( Input_Opt )
```

USES:

```
USE BPCH2_MOD,          ONLY : GET_NAME_EXT_2D, GET_RES_EXT
USE BPCH2_MOD,          ONLY : GET_TAU0,        READ_BPCH2
USE CMN_FJX_MOD
USE CMN_SIZE_MOD             ! SIZE PARAMETERS
USE Input_Opt_Mod,      ONLY : OptInput
USE TIME_MOD,           ONLY : GET_YEAR, GET_MONTH
USE TIME_MOD,           ONLY : GET_DAY,  GET_DAY_OF_YEAR
USE TRANSFER_MOD,       ONLY : TRANSFER_3D
```

INPUT PARAMETERS:

```
TYPE(OptInput), INTENT(IN) :: Input_Opt   ! Input options
```

REMARKS:

```
#############################################################################
#####    NOTE: BINARY PUNCH INPUT IS BEING PHASED OUT.  THIS DATA    #####
#####    WILL EVENTUALLY BE READ IN FROM netCDF FILES VIA HEMCO!     #####
#####       -- Bob Yantosca (10 Apr 2015)                            #####
#############################################################################
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
10 Apr 2015 - R. Yantosca - Now read from ExtData/CHEM_INPUTS/RRTMG_201104/
```

10.10.5 init_surface_rad

Subroutine INIT_SURFACE_RAD initializes all allocatable module arrays.

INTERFACE:

```
SUBROUTINE INIT_SURFACE_RAD()
```

USES:

```
USE CMN_FJX_MOD
USE CMN_SIZE_MOD
USE ERROR_MOD,    ONLY : ALLOC_ERR
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
```

10.10.6 init_strat_clim

Subroutine INIT_STRAT_CLIM initializes all allocatable module arrays.

INTERFACE:

```
SUBROUTINE INIT_STRAT_CLIM
```

USES:

```
USE CMN_FJX_MOD
USE CMN_SIZE_MOD
USE ERROR_MOD,    ONLY : ALLOC_ERR
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
```

10.10.7 init_mcica_clouds

Subroutine INIT_MCICA_CLOUDS initializes all allocatable module arrays.

INTERFACE:

```
SUBROUTINE INIT_MCICA_CLOUDS()
```

USES:

```
USE CMN_FJX_MOD
USE CMN_SIZE_MOD
USE ERROR_MOD,    ONLY : ALLOC_ERR
USE PARRRTM,      ONLY : NGPTLW
USE PARRRSW,      ONLY : NGPTSW
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
17 May 2016 - M. Sulprizio- Change array dimensions from IIPAR*JJPAR to
                            IIPAR,JJPAR
```

10.10.8 cleanup_surface_rad

Subroutine CLEANUP_SURFACE_RAD deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_SURFACE_RAD
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
```

10.10.9 cleanup_strat_clim

Subroutine CLEANUP_STRAT_CLIM deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_STRAT_CLIM
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
```

10.10.10 cleanup_mcica_clouds

Subroutine CLEANUP_MCICA_CLOUDS deallocates all module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_MCICA_CLOUDS
```

REVISION HISTORY:

```
18 Jun 2013 - D.A. Ridley - Initial version
15 Jan 2015 - M. Sulprizio- Added ProTeX headers
```

10.11 Fortran: Module Interface tagged_co_mod.F

Module TAGGED_CO_MOD contains variables and routines used for the geographically tagged CO simulation.

INTERFACE:

```
MODULE TAGGED_CO_MOD
```

USES:

```
      USE PhysConstants
      USE PRECISION_MOD    ! For GEOS-Chem Precision (fp)

      IMPLICIT NONE
      PRIVATE
```

PRIVATE MEMBER FUNCTIONS:

```
      PRIVATE :: CALC_DIURNAL
```

PUBLIC MEMBER FUNCTIONS:

```
      PUBLIC  :: CHEM_TAGGED_CO
      PUBLIC  :: GET_ALPHA_ISOP
      PUBLIC  :: INIT_TAGGED_CO
      PUBLIC  :: CLEANUP_TAGGED_CO
```

REMARKS:

```
    Tagged CO Species (you can modify these as needs be!)
    ============================================================================
    (1 ) Total CO
    (2 ) CO from North American fossil fuel
    (3 ) CO from European fossil fuel
    (4 ) CO from Asian fossil fuel
    (5 ) CO from fossil fuel from everywhere else
    (6 ) CO from South American biomass burning
    (7 ) CO from African biomass burning
    (8 ) CO from Southeast Asian biomass burning
    (9 ) CO from Oceania biomass burning
    (10) CO from European biomass burning
    (11) CO from North American biomass burning
    (12) CO chemically produced from Methane
    (13) CO from Biofuel burning (whole world)
    (14) CO chemically produced from Isoprene
    (15) CO chemically produced from Monoterpenes
    (16) CO chemically produced from Methanol (CH3OH)
    (17) CO chemically produced from Acetone
```

REVISION HISTORY:

```
    28 Jul 2000- R. Yantosca - Initial version
    (1 ) Removed obsolete code from CHEM_TAGGED_CO (bmy, 12/21/00)
    (2 ) Added CO sources from oxidation of biofuel VOC's, biomass burning
         VOC's, fossil fuel VOC's, and natural VOC's (bnd, bmy, 1/2/01)
    (3 ) Added chemical P(CO) from CH3OH and MONOTERPENES (bnd, bmy, 1/2/01)
    (4 ) Now cap SCALEYEAR at 1997 in "emiss_tagged_co" (bnd, bmy, 4/6/01)
    (5 ) Removed obsolete commented-out code (bmy, 4/23/01)
    (6 ) Added new module variables SUMACETCO, EMACET, CO_PRODS, CO_LOSSS,
         ISOP96, MONO96, and MEOH96.  Also added new module routines
         GET_ALPHA_ISOP, READ_PCO_LCO_STRAT, GET_PCO_LCO_STRAT,
```

```
      READ_ACETONE, and READ_BIOG_FOR_GEOS3. (bnd, bmy, 6/14/01)
(7 ) Now read files from DATA_DIR/tagged_CO_200106/ (bmy, 6/19/01)
(8 ) Removed ISOP96, MONO96, and CH3OH96 since we now use the new GEOS-3
      fields and no longer have to correct for the surface temperature.
      (bmy, 8/21/01)
(9 ) Bug fix: don't call GLOBAL_NOX_MOD in routine CHEM_TAGGED_CO
      unless a logical switch is set (bmy, 8/28/01)
(10) Updated comments (bmy, 9/6/01)
(11) Deleted obsolete code for 1998 GEOS-3 fix.  Also now archive ND46
      diagnostic as [atoms C/cm2/s] (bmy, 9/13/01)
(12) Bug fix in CHEM_TAGGED_CO: now save CO sources/sinks into the
      Total CO tracer (N=1). (qli, bmy, 9/21/01)
(13) Resize arrays of (IIPAR,JJPAR) to (IIPAR,JJPAR) (bmy, 9/28/01)
(14) Removed obsolete code from 9/28/01 (bmy, 10/23/01)
(15) Updated comments (bmy, 2/15/02)
(16) Removed double definition of SUMCH3OHCO (bmy, 3/20/02)
(17) Now use P(I,J) + PTOP instead of PS(I,J) (bmy, 4/11/02)
(18) Now divide module header into MODULE PRIVATE, MODULE VARIABLES, and
      MODULE ROUTINES sections.  Updated comments (bmy, 5/28/02)
(19) Now references "pressure_mod.f" (dsa, bdf, bmy, 8/21/02)
(20) Now reference AD, BXHEIGHT, T and SUNCOS from "dao_mod.f".  Also
      removed obsolete code from various routines.  Now references
      ERROR_STOP from "error_mod.f". (bmy, 10/15/02)
(21) Now references "grid_mod.f" and the new "time_mod.f". (bmy, 2/3/03)
(22) Bug fix for NTAU in EMISS_TAGGED_CO.  Bug fix for FILENAME in routine
      READ_PCO_LCO_STRAT. (ave, bnd, bmy, 6/3/03)
(23) Updated arg list in call to EMISOP in EMISS_TAGGED_CO (bmy, 12/9/03)
(24) Now references "directory_mod.f", "logical_mod.f", "tracer_mod.f".
      Now remove IJLOOP_CO. (bmy, 7/20/04)
(25) Fixed bug in CHEM_TAGGED_CO (bmy, 3/7/05)
(26) Now reads data from both GEOS and GCAP grids.  Now also references
      "tropopause_mod.f". (bmy, 8/16/05)
(27) Now modified for new "biomass_mod.f" (bmy, 4/5/06)
(28) BIOMASS(:,:,IDBCO) from "biomass_mod.f" is now in units of
      [molec CO/cm2/s].  Adjust unit conversion accordingly. (bmy, 9/27/06)
(29) Routines GET_ALPHA_ISOP, GET_PCO_LCO_STRAT, READ_PCO_LCO_STRAT,
      READ_ACETONE and INIT_TAGGED_CO are public now. Variable
      EMACET is public now.  (phs, 9/18/07)
13 Aug 2010 - R. Yantosca - Add modifications for MERRA (treat like GEOS-5)
08 Feb 2012 - R. Yantosca - Add modifications for GEOS-5.7.2 met
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
23 Oct 2012 - R. Yantosca - Update prod/loss for new GMI strat chem
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
10 Apr 2014 - R. Yantosca - Now change CO_PRODS and CO_LOSSS to REAL*4
11 Jun 2014 - J.A. Fisher - Replace SUNCOS with SUNCOSmid for MEGAN
11 Jun 2014 - J.A. Fisher - Treat monoterpenes as in full chemistry
12 Jun 2014 - J.A. Fisher - Add option for non-local PBL mixing
10 Jul 2014 - J.A. Fisher - Add diurnal cycle for OH
```

```
10 Jul 2014 - J.A. Fisher - Change FIRSTEMISS to FIRSTTIME to allow
                            initialisation when emissions are off
20 Nov 2014 - M. Yannetti - Added PRECISION_MOD
11 Mar 2015 - R. Yantosca - Add OH pointer for HEMCO data input
06 Jan 2016 - E. Lundgren - Use global physical parameters
21 Mar 2016 - R. Yantosca - Removed CO_PRODS and CO_LOSSS, we now get
                            GMI strat P(CO) and L(CO) directly from HEMCO
21 Mar 2016 - R. Yantosca - Removed GET_PCO_LCO_STRAT, it was obsolete
21 Mar 2016 - R. Yantosca - Get rid of READ_PCO_LCO_STRAT, it's obsolete
28 Jun 2016 - R. Yantosca - Add extra error checks; remove EMACET array\
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.11.1 chem_tagged_co

Subroutine CHEM_TAGGED_CO performs CO chemistry on geographically "tagged" CO species. Loss is via reaction with OH.

INTERFACE:

```
SUBROUTINE CHEM_TAGGED_CO( am_I_Root, Input_Opt,
&                          State_Met, State_Chm, RC )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_STRAT
USE CMN_SIZE_MOD
USE CMN_DIAG_MOD
USE DIAG_MOD,           ONLY : AD65
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : CHECK_VALUE
USE ERROR_MOD,          ONLY : ERROR_STOP
USE GC_GRID_MOD,        ONLY : GET_YMID
USE HCO_EmisList_Mod,   ONLY : HCO_GetPtr
USE HCO_Error_Mod
USE HCO_Interface_Mod,  ONLY : HcoState, GetHcoID
USE Input_Opt_Mod,      ONLY : OptInput
USE PhysConstants,      ONLY : AVO
USE State_Chm_Mod,      ONLY : ChmState
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM,     GET_TS_EMIS
USE TIME_MOD,           ONLY : GET_MONTH,       GET_YEAR
USE TIME_MOD,           ONLY : ITS_A_NEW_MONTH, ITS_A_NEW_YEAR
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
19 Oct 1999 - Q. Li, B. Duncan, B. Field - Initial version
(1 ) Now do chemistry all the way to the model top.
(2 ) Use monthly mean OH fields for oxidation.
(3 ) Now reference the monthly mean OH array and the routine which reads
     it from disk in "global_oh_mod.f" (bmy, 7/28/00)
(4 ) Removed obsolete code from 10/6/00 (bmy, 12/21/00)
(5 ) Added P(CO) from CH3OH and MONOTERPENES.  Also account for the
     variation of CH4 conc. w/ latitude and year (bnd, bmy, 1/2/01)
(6 ) Removed obsolete commented-out code (bmy, 4/23/01)
(7 ) Updated with new stuff from bnd.  Also references module routines
     & arrays from "global_nox_mod.f" and "error_mod.f".  Removed
     THISMONTH as an argument since we can use the MONTH value
     from the "CMN" include file. (bmy, 6/14/01)
(8 ) Remove GEOS-3 fix for biogenic fields (ISOP96, MONO96, CH3OH96),
     since we now use updated met fields w/o the surface temperature
     problem (bmy, 8/21/01)
(9 ) Now only call GLOBAL_NOX_MOD to define the BNOX array, if switch
     ALPHA_ISOP_FROM_NOX is set.  The NOx concentrations used to compute
     the CO yield from isoprene are currently only at 4x5 (bmy, 8/28/01)
(10) Bug fix: now make sure to add CO production and loss into the
     STT(:,:,:,1), which is the Total CO tracer. (qli, bmy, 9/21/01)
(11) Updated comments.  Bug fix: multiply CO_OH (after using it to update
     tagged tracers) by GCO (the initial value of STT in molec/cm3) to
     convert it to an amount of CO lost by OH [molec/cm3]. (bmy, 2/19/02)
(12) Removed PS as an argument; use P(I,J) + PTOP instead of PS, in order
     to ensure that we use P and AD computed from the same preesure
     by AIRQNT. (bmy, 4/11/02)
(13) Now use GET_PCENTER from "pressure_mod.f" to compute the pressure
     at the midpoint of box (I,J,L).  Also deleted obsolete, commented-out
     code. (dsa, bdf, bmy, 8/21/02)
(14) Now reference AD and T from "dao_mod.f".  Now make FIRSTCHEM a local
     SAVEd variable. (bmy, 11/15/02)
(15) Now replace YLMID(J) with routine GET_YMID of "grid_mod.f".  Now
     uses functions GET_TS_CHEM, GET_MONTH, GET_YEAR from the new
     "time_mod.f".  (bmy, 2/10/03)
(16) Now reference STT & N_TRACERS from "tracer_mod.f".  Now references
     LSPLIT from "logical_mod.f".  Now references AD65 from
     "diag_pl_mod.f".  Updated comments. (bmy, 7/20/04)
(17) Bug fix: re-insert ELSE between (1a-1) and (1a-2); it appears to have
```

```
      been mistakenly deleted. (bmy, 3/7/05)
(18) Now references ITS_IN_THE_STRAT from "tropopause_mod.f".  Now remove
      reference to "CMN", it's obsolete. (bmy, 8/22/05)
(19) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(20) Remove reference to "global_ch4_mod.f" (bmy, 5/31/06)
(21) Use newest JPL 2006 rate constant for CO+OH (jaf, jmao, 3/4/09)
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
22 Oct 2012 - R. Yantosca - Now pass am_I_Root=.TRUE. to GET_GLOBAL_CH4
23 Oct 2012 - R. Yantosca - Added ProTeX headers
09 Nov 2012 - M. Payer    - Replaced all met field arrays with State_Met
                            derived type object
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
11 Apr 2013 - R. Yantosca - Now pass Input_Opt to GET_GLOBAL_NOX
10 Jun 2013 - R. Yantosca - Avoid array temporaries in CHECK_VALUE
23 Oct 2013 - R. Yantosca - Now pass objects to GET_GLOBAL_OH routine
10 Apr 2014 - R. Yantosca - Now use pointers to fields in State_Met
10 Apr 2014 - R. Yantosca - Bug fix: DTSRCE should be DTCHEM
10 Jul 2014 - J.A. Fisher - Add diurnal cycle for OH
10 Jul 2014 - J.A. Fisher - Restore assignment of DTCHEM
10 Jul 2014 - J.A. Fisher - Remove unused DTSRCE, PCO, and AREA_CM2
10 Jul 2014 - J.A. Fisher - Moved ALPHA definitions out of code
27 Aug 2014 - R. Yantosca - Bug fix: pass Input_Opt to GET_GLOBAL_CH4
21 Oct 2014 - C. Keller   - Now use GetHcoVal instead ot Trac_Tend array
26 Feb 2015 - E. Lundgren - Replace GET_PCENTER with State_Met%PMID.
11 Mar 2015 - R. Yantosca - Remove references to global_nox_mod.F
11 Mar 2015 - R. Yantosca - Now get OH via the HEMCO data structure
06 Jan 2016 - E. Lundgren - Use global physical parameters
21 Mar 2016 - R. Yantosca - Now define FMOL_CO from the species database
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
28 Jun 2016 - R. Yantosca - Add error traps to make sure that the ISOP,
                            ACET, MONX non-advected species are all found
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
11 Oct 2016 - R. Yantosca - If emissions are turned off, do not update
                            the SUM*CO arrays, they will remain zeroed out.
12 Oct 2016 - R. Yantosca - Bug fix: convert OH from kg/m3 (which HEMCO
                            brings in from disk) to molec/cm3.
```

10.11.2 calc_diurnal

Subroutine CALC_DIRUNAL computes the sume of the cosine of the solar zenith angle over a 24 hour day as well as the total length of daylight to scale the offline OH concentrations.

INTERFACE:

```
SUBROUTINE CALC_DIURNAL
```

USES:

```
USE CMN_SIZE_MOD
USE GC_GRID_MOD, ONLY : GET_YMID_R
USE TIME_MOD, ONLY : ITS_A_NEW_DAY, GET_MINUTE,      GET_HOUR
USE TIME_MOD, ONLY : GET_TS_CHEM,   GET_DAY_OF_YEAR, GET_LOCALTIME
```

REVISION HISTORY:

```
12 Mar 2014 - J. Fisher   - Copied from OHNO3TIME in carbon_mod and
                            COSSZA in dao_mod
```

10.11.3 get_alpha_isop

Function GET_ALPHA_ISOP returns the CO yield from Isoprene (ALPHA_ISOP) either as a function of NOx or as a constant.

INTERFACE:

```
FUNCTION GET_ALPHA_ISOP( FROM_NOX, NOX ) RESULT( ALPHA_ISOP )
```

USES:

```
USE ERROR_MOD, ONLY : ERROR_STOP
```

INPUT PARAMETERS:

```
LOGICAL, INTENT(IN)           :: FROM_NOX    ! If =T, will take ALPHA_ISOP
                                             ! as f(NOx).  If =F, will set
                                             ! ALPHA_ISOP to a constant
REAL(fp),  INTENT(IN), OPTIONAL :: NOX         ! NOx concentration [ppbv]
```

RETURN VALUE:

```
REAL(fp)                        :: ALPHA_ISOP  ! CO yield from ISOP
```

REVISION HISTORY:

```
13 Jun 2001 - B. Duncan - Initial version
01 Oct 1995 - R. Yantosca - Initial version
(1 ) Now make NOx an optional argument (bmy, 8/28/01)
(2 ) Now reference ERROR_STOP from "error_mod.f" (bmy, 10/15/02)
(3 ) Updated comments (bmy, 7/20/04)
23 Oct 2012 - R. Yantosca - Added ProTeX headers
```

10.11.4 init_tagged_co

Subroutine INIT_TAGGED_CO allocates memory to module arrays.

INTERFACE:

```
SUBROUTINE INIT_TAGGED_CO( am_I_Root, Input_Opt, RC )
```

USES:

```
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : Alloc_Err
USE Input_Opt_Mod,      ONLY : OptInput
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
```

OUTPUT PARAMETERS:

```
INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?
```

REVISION HISTORY:

```
19 Jul 2000 - R. Yantosca - Initial version
(1 ) Added ISOP96, MONO96, CH3OH96 for GEOS-3 (bnd, bmy, 6/14/01)
(2 ) Removed ISOP96, MONO96, CH3OH96 for GEOS-3, since the new GEOS-3
     fields make these no longer necessary (bmy, 8/21/09)
(3 ) Now allocate BB_REGION, FF_REGION as (IIPAR,JJPAR) (bmy, 9/28/01)
(4 ) Removed obsolete code from 9/28/01 (bmy, 10/22/01)
(5 ) Now references ALLOC_ERR from "error_mod.f" (bmy, 10/15/02)
(6 ) Now remove IJLOOP_CO (bmy, 7/20/04)
(7 ) Now public. Now references ITS_A_H2HD_SIM from "tracer_mod.f".
     Allocate needed variables if H2/HD simulation (phs, 9/18/07)
23 Oct 2012 - R. Yantosca - Added ProTeX headers
23 Oct 2012 - J. Fisher   - Dimension CO_PRODS and CO_LOSSS with
                            (IIPAR,JJPAR,LLPAR) for new GMI strat chem
10 Apr 2014 - R. Yantosca - Now call DEFINE* routines to define the
                            fossil fuel and biofuel regions
10 Apr 2014 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC arguments
21 Mar 2016 - R. Yantosca - Remove CO_PRODS, CO_LOSSS arrays
28 Jun 2016 - R. Yantosca - Remove EMACET array
```

10.11.5 cleanup_tagged_co

Subroutine CLEANUP_TAGGED_CO deallocates memory from previously allocated module arrays.

INTERFACE:

```
SUBROUTINE CLEANUP_TAGGED_CO
```

REVISION HISTORY:

```
19 Jul 2000 - R. Yantosca - Initial version
(1 ) Added ISOP96, MONO96, CH3OH96 for GEOS-3 (bnd, bmy, 6/14/01)
(2 ) Removed ISOP96, MONO96, CH3OH96 for GEOS-3, since the new GEOS-3
      fields make these no longer necessary (bmy, 8/21/09)
(3 ) Now remove IJLOOP_CO (bmy, 7/20/04)
23 Oct 2012 - R. Yantosca - Added ProTeX headers
11 Mar 2015 - R. Yantosca - Now free the OH pointer
21 Mar 2016 - R. Yantosca - Remove CO_PRODS, CO_LOSSS
21 Mar 2016 - R. Yantosca - Also nullify GMI_PROD_CO and GMI_LOSS_CO ptrs
28 Jun 2016 - R. Yantosca - Remove EMACET array
```

10.12 Fortran: Module Interface tagged_o3_mod.F

Module TAGGED_O3_MOD contains variables and routines to perform a tagged O3 simulation. P(O3) and L(O3) rates need to be archived from a full chemistry simulation before you can run w/ Tagged O3.

INTERFACE:

```
MODULE TAGGED_O3_MOD
```

USES:

```
USE PRECISION_MOD    ! For GEOS-Chem Precision (fp, f4, f8)

IMPLICIT NONE
PRIVATE
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% If you want to the EXTENDED SIMULATION with all 13 tagged O3 species,
%%% then uncomment this #ifdef statement. (bmy, 4/11/14)
#define USE_ALL_TAGO3_SPECIES 1
%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

PUBLIC MEMBER FUNCTIONS:

```
PUBLIC  :: CHEM_TAGGED_O3
PUBLIC  :: CLEANUP_TAGGED_O3
PUBLIC  :: INIT_TAGGED_O3
```

PRIVATE MEMBER FUNCTIONS:

```
PRIVATE :: GET_REGIONAL_PO3
```

REMARKS:

```
THE SIMPLE TAGGED O3 SIMULATION (default setting) HAS THESE ADVECTED SPECIES:
-----------------------------------------------------------------------------
(1 ) O3      : Total O3
(2 ) O3Strt  : Stratospheric O3

                                                                            .
THE EXTENDED TAGGED O3 SIMULATION HAS THESE ADVECTED SPECIES:
-----------------------------------------------------------------------------
(1 ) O3      : Total O3
(2 ) O3Strt  : O3 from the Stratosphere      (tropopause - atm top   )
(3 ) O3Ut    : O3 produced in Upper Trop     (350 hPa    - tropopause)
(4 ) O3Mt    : O3 produced in Middle Trop    (PBL top    - 350 hPa   )
(5 ) O3Row   : O3 produced in Rest of World  (surface    - PBL top   )
(6 ) O3PcBl  : O3 produced in Pacific BL     (surface    - PBL top   )
(7 ) O3NaBl  : O3 produced in N. American BL (surface    - PBL top   )
(8 ) O3AtBl  : O3 produced in Atlantic BL    (surface    - PBL top   )
(9 ) O3EuBl  : O3 produced in European BL    (surface    - PBL top   )
(10) O3AfBl  : O3 produced in N. African BL  (surface    - PBL top   )
(11) O3AsBl  : O3 produced in Asian          (surface    - PBL top   )
(12) O3Init  : O3 initial conditions         (all levels              )
(13) O3USA   : O3 produced over the USA      (all levels              )

                                                                            .
NOTES:
-----------------------------------------------------------------------------
(1) The stratospheric O3 species must be species #2.  This is due to how
    the Linoz stratospheric O3 chemistry scheme is written.  We have
    accordingly reorganized the species numbers below.
(2) The name "tagged_ox_mod.F" is historical.  The Ox species in GEOS-Chem
    has now been replaced with O3.  O3 usually makes up about 95% of Ox.
    The nomenclature "tagged Ox" is interchangeable with "tagged O3".
    As of Aug 2016, most uses of "tagged Ox" have been replaced with
    "tagged O3".
```

REVISION HISTORY:

```
20 Aug 2003 - A. Fiore    - Initial version
(1 ) Now accounts for GEOS-4 PBL being in meters (bmy, 1/15/04)
(2 ) Bug fix: don't put function call in WRITE statement (bmy, 2/20/04)
(3 ) Now bracket AD44 with an !$OMP CRITICAL block (bmy, 3/24/04)
(4 ) Now define regions w/ levels in GET_REGIONAL_POX (amf,rch,bmy,5/27/04)
(5 ) Bug fix-avoid seg fault if PBLFRAC isn't allocated (bdf, bmy, 10/12/04)
(6 ) Now reference "pbl_mix_mod.f" (bmy, 2/17/05)
(7 ) Now make sure all USE statements are USE, ONLY (bmy, 10/3/05)
(8 ) Now references XNUMOL from "tracer_mod.f" (bmy, 10/25/05)
(9 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
(10) Modified for variable tropopause (phs, bmy, 1/19/07)
(11) Now use LLTROP instead of LLTROP_FIX everywhere (bmy, 12/4/07)
(12) Now use LD65 instead of LLTROP everywhere (phs, 11/17/08)
(13) Updates for LINOZ (dbj, jliu, bmy, 10/26/09)
19 Nov 2010 - R. Yantosca - Added ProTeX headers
```

```
28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
01 Mar 2012 - R. Yantosca - Now reference new grid_mod.F90
14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                            partitioning
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
23 Jan 2014 - M. Sulprizio- Now use LLTROP instead of LD65 or LLTROP_FIX
                            everywhere (hyl, bmy, 11/3/11)
11 Apr 2014 - R. Yantosca - Add #ifdef USE_ALL_TAGO3_SPECIES to select
                            between the simple and extended simulations
11 Apr 2014 - R. Yantosca - Updated comments
11 Apr 2014 - R. Yantosca - Now make the O3Strt tracer #2 for both the
                            simple and extended tagged O3 simulations
11 Apr 2014 - R. Yantosca - Now make INIT_TAGGED_OX a public routine
17 Sep 2014 - C. Keller   - Now use HEMCO for prod./loss rates. This makes
                            subroutine READ_POX_LOX obsolete.
06 Nov 2014 - R. Yantosca - Removed code orphaned by HEMCO
21 Nov 2014 - M. Yannetti - Added PRECISION_MOD
04 Mar 2015 - R. Yantosca - Declare pointer args to HCO_GetPtr with REAL(f4)
16 Jun 2016 - M. Sulprizio- Replace IDTO3Strt from tracerid_mod.F with
                            a local definition (module variable id_O3Strat)
12 Jul 2016 - R. Yantosca - Remove routine ADD_STRAT_POX, we now just
                            directly add into State_Chm%Species in
                            strat_chm_mod.F90
10 Aug 2016 - M. Sulprizio- Rename from tagged_ox_mod.F to tagged_o3_mod.F
29 Nov 2016 - R. Yantosca - grid_mod.F90 is now gc_grid_mod.F90
```

10.12.1 get_regional_po3

Subroutine GET_REGIONAL_PO3 returns the P(O3) for each of the tagged O3 species. Tagged O3 species are defined by both geographic location and altitude.

INTERFACE:

```
SUBROUTINE GET_REGIONAL_PO3( I, J, L, PP, State_Met )
```

USES:

```
USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
USE CMN_DIAG_MOD             ! ND44, ND65, LD65
USE CMN_SIZE_MOD             ! Size parameters
USE GC_GRID_MOD,        ONLY : GET_XMID,  GET_YMID
USE PhysConstants            ! SCALE_HEIGHT
USE State_Met_Mod,      ONLY : MetState
USE TIME_MOD,           ONLY : GET_TS_CHEM
```

INPUT PARAMETERS:

```
! GEOS-Chem grid box indices for lon, lat, alt
```

```
      INTEGER,        INTENT(IN)  :: I, J, L

      ! Meteorology State object
      TYPE(MetState), INTENT(IN)  :: State_Met
```

OUTPUT PARAMETERS:

```
      ! Array containing P(O3) for each tagged species
      REAL(fp),  INTENT(OUT) :: PP(IIPAR,JJPAR,LLTROP,N_TAGGED)
```

REVISION HISTORY:

```
    19 Aug 2003 - A. Fiore - Initial version
    (1 ) Updated from the old routine "chemo3_split.f" (rch, bmy, 8/20/03)
    (2 ) For GEOS-4, convert PBL from [m] to [hPa] w/ the hydrostatic law.
         Now references SCALE_HEIGHT from "CMN_GCTM". (bmy, 1/15/04)
    (3 ) Now uses model levels instead of pressure in order to delineate
         between PBL, MT, and UT regions (amf, rch, bmy, 5/27/04)
    (4 ) Now references ITS_IN_THE_TROP from "tropopause_mod.f".  Now remove
         reference to "CMN", it's obsolete. (bmy, 8/22/05)
    (5 ) Remove support for GEOS-1 and GEOS-STRAT met fields (bmy, 8/4/06)
    (6 ) Resize the PP array from LLTROP to LLTROP_FIX (phs, 1/19/07)
    (7 ) Now use LLTROP instead of LLTROP_FIX (bmy, 12/4/07)
    (8 ) Now use LD65 instead of LLTROP (phs, 11/17/08)
    08 Dec 2009 - R. Yantosca - Added ProTeX headers
    28 Feb 2012 - R. Yantosca - Removed support for GEOS-3
    01 Mar 2012 - R. Yantosca - Now use GET_XMID(I,J,L) from grid_mod.F90
    01 Mar 2012 - R. Yantosca - Now use GET_YMID(I,J,L) from grid_mod.F90
    26 Sep 2013 - R. Yantosca - Renamed GEOS_57 Cpp switch to GEOS_FP
    23 Jan 2014 - M. Sulprizio- Now use LLTROP instead of LD65 (hyl,bmy,11/3/11)
    24 Jul 2014 - R. Yantosca - Now compute BOXVL internally\
    11 Aug 2015 - R. Yantosca - MERRA2 behaves the same way as GEOS-FP
    25 Sep 2015 - E. Lundgren - Fix bug in setting X upper bound for ITS_IN_EUR
    22 Oct 2015 - E. Lundgren - Fix PBLTOP and MTTOP levels for 750 hPa and
                                350 hPa for GEOS-5, MERRA, GEOS-FP and MERRA2
```

10.12.2 chem_tagged_o3

Subroutine CHEM_TAGGED_O3 performs chemistry for several O3 species which are tagged by geographic and altitude regions.

INTERFACE:

```
      SUBROUTINE CHEM_TAGGED_O3( am_I_Root, Input_Opt,
     &                           State_Met, State_Chm, RC )
```

USES:

```
      USE CHEMGRID_MOD,       ONLY : ITS_IN_THE_TROP
      USE CMN_DIAG_MOD
      USE CMN_SIZE_MOD
      USE DIAG_MOD,           ONLY : AD65
      USE ErrCode_Mod
      USE ERROR_MOD,          ONLY : ERROR_STOP
      USE ERROR_MOD,          ONLY : GEOS_CHEM_STOP
      USE HCO_EMISLIST_MOD,   ONLY : HCO_GetPtr
      USE HCO_INTERFACE_MOD,  ONLY : HcoState
      USE Input_Opt_Mod,      ONLY : OptInput
      USE State_Chm_Mod,      ONLY : ChmState
      USE State_Met_Mod,      ONLY : MetState
      USE TIME_MOD,           ONLY : GET_TS_CHEM

      IMPLICIT NONE
```

INPUT PARAMETERS:

```
      LOGICAL,        INTENT(IN)    :: am_I_Root   ! Are we on the root CPU?
      TYPE(OptInput), INTENT(IN)    :: Input_Opt   ! Input Options object
      TYPE(MetState), INTENT(IN)    :: State_Met   ! Meteorology State object
```

INPUT/OUTPUT PARAMETERS:

```
      TYPE(ChmState), INTENT(INOUT) :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT)   :: RC          ! Success or failure?

   !REMAKRS:
    Dry deposition is now applied in mixing_mod.F90.  We have the application
    of Ox dry deposition from this routine, as well as the archival of the
    ND44 drydep diagnostic. (bmy, 6/15/15)
```

REVISION HISTORY:

```
    20 Aug 2003 - R. Hudman   - Initial version
    (1 ) Updated from the old routine "chemo3_split.f" (rch, bmy, 8/20/03)
    (2 ) Bug fix: don't put function call in WRITE statement (bmy, 2/20/04)
    (3 ) Now use ND44_TMP array to store vertical levels of drydep flux, then
         sum into AD44 array.  This prevents numerical differences when using
         multiple processors. (bmy, 3/24/04)
    (4 ) Now references LDRYD from "logical_mod.f".  Now references STT
         and N_TRACERS from "tracer_mod.f".  Now references AD65 from
         "diag_pl_mod.f".  Now uses ITS_A_NEW_DAY from "time_mod.f".
         (bmy, 7/20/04)
    (5 ) Bug fix: Now avoid a SEG FAULT error if PBLFRAC isn't allocated.
         (bdf, bmy, 10/12/04)
    (6 ) Replace PBLFRAC from "drydep_mod.f" with GET_FRAC_UNDER_PBLTOP
         from "pbl_mix_mod.f".  Now only sum ND44 diagnostic up to the
```

```
      maximum tropopsheric level. (bmy, 2/17/05)
(7 ) Resize PP, N D44_TMP arrays from LLTROP to LLTROP_FIX.  Now only loop
      up to LLTROP_FIX (phs, 1/19/07)
(8 ) Now use LLTROP instead of LLTROP_FIX (bmy, 12/4/07)
(9 ) Now use LD65 instead of LLTROP (phs, 11/17/08)
(10) Now only compute loss rate in troposphere (dbj, bmy, 10/26/09)
08 Dec 2009 - R. Yantosca - Added ProTeX headers
01 Mar 2012 - R. Yantosca - Now use GET_AREA_CM2(I,J,L) from grid_mod.F90
14 Mar 2013 - M. Payer    - Replace Ox with O3 as part of removal of NOx-Ox
                            partitioning
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, State_Chm, RC
20 Aug 2013 - R. Yantosca - Removed "define.h", this is now obsolete
23 Jan 2014 - M. Sulprizio- Now use LLTROP instead of LD65 (hyl,bmy,11/3/11)
11 Apr 2014 - R. Yantosca - Remove call to INIT_TAGGED_OX
24 Jul 2014 - R. Yantosca - Now compute BOXVL internally
17 Sep 2014 - C. Keller   - Now use HEMCO for prod. and loss arrays
12 Jun 2015 - R. Yantosca - Now remove orphaned ND44 variables
15 Jun 2015 - R. Yantosca - Bug fix: PP doesn't have to be held PRIVATE
15 Jun 2015 - R. Yantosca - Updated comments for removal of drydep
29 Apr 2016 - R. Yantosca - Don't initialize pointers in declaration stmts
30 Jun 2016 - R. Yantosca - Remove instances of STT.  Now get the advected
                            species ID from State_Chm%Map_Advect.
```

10.12.3 init_tagged_o3

Subroutine INIT_TAGGED_O3 allocates and zeroes all module arrays.

INTERFACE:

```
SUBROUTINE INIT_TAGGED_O3( am_I_Root, Input_Opt, State_Chm, RC )
```

USES:

```
USE CMN_DIAG_MOD
USE CMN_SIZE_MOD
USE ErrCode_Mod
USE ERROR_MOD,          ONLY : ALLOC_ERR
USE ERROR_MOD,          ONLY : ERROR_STOP
USE Input_Opt_Mod,      ONLY : OptInput
USE State_Chm_Mod,      ONLY : ChmState
USE State_Chm_Mod,      ONLY : Ind_
```

INPUT PARAMETERS:

```
LOGICAL,        INTENT(IN)  :: am_I_Root   ! Are we on the root CPU?
TYPE(OptInput), INTENT(IN)  :: Input_Opt   ! Input Options object
TYPE(ChmState), INTENT(IN)  :: State_Chm   ! Chemistry State object
```

OUTPUT PARAMETERS:

```
      INTEGER,        INTENT(OUT) :: RC          ! Success or failure?
```

REMARKS:

```
This routine is now called from GC_INIT_EXTRA in GeosCore/input_mod.F.
```

REVISION HISTORY:

```
20 Aug 2003 - R. Yantosca - Initial version
(1 ) Now reference N_TRACERS from "tracer_mod.f" (bmy, 7/20/04)
(2 ) Now use LD65 instead of LLTROP to dimension P24H, L24H (phs, 11/18/08)
08 Dec 2009 - R. Yantosca - Added ProTeX headers
25 Mar 2013 - R. Yantosca - Now accept am_I_Root, Input_Opt, RC args
23 Jan 2014 - M. Sulprizio- Now use LLTROP instead of LD65 to dimension P24H,
                            L24H (hyl, bmy, 11/3/11)
20 Jun 2016 - R. Yantosca - Now define species ID's in the init phase
20 Jun 2016 - R. Yantosca - Add check to prevent array OOB errors
21 Jun 2016 - R. Yantosca - Rename IDTO3Strt to id_O3Strat
```

10.12.4 cleanup_tagged_o3

CLEANUP_TAGGED_O3 deallocates all module arrays.

INTERFACE:

```
      SUBROUTINE CLEANUP_TAGGED_O3()
```

REVISION HISTORY:

```
20 Aug 2003 - R. Yantosca - Initial version
08 Dec 2009 - R. Yantosca - Added ProTeX headers
```