Reference Manual

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Contents

Chapter 1

Modular arbitrary-order ocean-atmosphere model: MAOOAM -- Fortran implementation

Lyapunov exponents computation version

About

This software is provided as supplementary material with:

- De Cruz, L., Demaeyer, J. and Vannitsem, S.: The Modular Arbitrary-Order Ocean-Atmosphere Model: M↩ AOOAM v1.0, Geosci. Model Dev., 9, 2793-2808, doi:10.5194/gmd-9-2793-2016, 2016.

Please cite this article if you use (a part of) this software for a publication.

The authors would appreciate it if you could also send a reprint of your paper to lesley.decruz@meteo.be, jonathan.demaeyer@meteo.be and svn@meteo.be.

Consult the MAOOAM code repository for updates, and our website for additional resources.

A pdf version of this manual is available here.

Note on the Lyapunov exponents computation

This version of the code allows for the computation of the backward Lyapunov exponents. The method used is described in

- Benettin, G., Galgani, L., Giorgilli, A., and Strelcyn, J. M. : Lyapunov characteristic exponents for smooth dynamical systems; a method for computing all of them. Part 2: Numerical application. Meccanica, 15, 21-30, doi:10.1007/BF02128237, 1980.

This version has been used to compute the Lyapunov exponents of MAOOAM in the following manuscript:

- De Cruz, L., Schubert, S., Demaeyer, J., Lucarini, V., and Vannitsem, S.: Exploring the Lyapunov instability properties of high-dimensional atmospheric and climate models, Nonlin. Processes Geophys. Discuss., doi:10.5194/npg-2017-76, in review, 2018.

Installation

The program can be installed with Makefile. We provide configuration files for two compilers : gfortran and ifort.

By default, gfortran is selected. To select one or the other, simply modify the Makefile accordingly or pass the COMPILER flag to `make`. If gfortran is selected, the code should be compiled with gfortran 4.7+ (allows for allocatable arrays in namelists). If ifort is selected, the code has been tested with the version 14.0.2 and we do not guarantee compatibility with older compiler version.

To install, unpack the archive in a folder or clone with git:

```
git clone https://github.com/Climdyn/MAOOAM.git
cd MAOOAM
```

and run:

```
make
```

By default, the inner products of the basis functions, used to compute the coefficients of the ODEs, are not stored in memory. If you want to enable the storage in memory of these inner products, run make with the following flag:

```
make RES=store
```

Depending on the chosen resolution, storing the inner products may result in a huge memory usage and is not recommended unless you need them for a specific purpose.

Remark: The command "make clean" removes the compiled files.

For Windows users, a minimalistic GNU development environment (including gfortran and make) is available at `www.mingw.org` .

Description of the files

The model tendencies are represented through a tensor called aotensor which includes all the coefficients. This tensor is computed once at the program initialization.

- maooam.f90 : Main program.
- maooam_lyap.f90 : Version of the main program with the computation of the Lyapunov exponents.
- maooam_lyap_div.f90 : Version of the main program with the computation of the first Lyapunov exponents with the divergence method.
- aotensor_def.f90 : Tensor aotensor computation module.
- lyap_vectors.f90 : Module for the computation of Lyapunov exponents and vectors
- IC_def.f90 : A module which loads the user specified initial condition.
- inprod_analytic.f90 : Inner products computation module.
- rk2_integrator.f90 : A module which contains the Heun integrator for the model equations.
- rk4_integrator.f90 : A module which contains the RK4 integrator for the model equations.
- Makefile : The Makefile.

- params.f90 : The model parameters module.
- tl_ad_tensor.f90 : Tangent Linear (TL) and Adjoint (AD) model tensors definition module
- rk2_tl_ad_integrator.f90 : Heun Tangent Linear (TL) and Adjoint (AD) model integrators module
- rk4_tl_ad_integrator.f90 : RK4 Tangent Linear (TL) and Adjoint (AD) model integrators module
- test_tl_ad.f90 : Tests for the Tangent Linear (TL) and Adjoint (AD) model versions
- README.md : A read me file.
- LICENSE.txt : The license text of the program.
- util.f90 : A module with various useful functions.
- tensor.f90 : Tensor utility module.
- stat.f90 : A module for statistic accumulation.
- params.nml : A namelist to specify the model parameters.
- int_params.nml : A namelist to specify the integration parameters.
- modeselection.nml : A namelist to specify which spectral decomposition will be used.

Usage

The user first has to fill the params.nml and int_params.nml namelist files according to their needs. Indeed, model and integration parameters can be specified respectively in the params.nml and int_params.nml namelist files. Some examples related to already published article are available in the params folder.

The parameters related to the Lyapunov exponents computation are located in the int_params.nml namelist file.

The modeselection.nml namelist can then be filled :

- NBOC and NBATM specify the number of blocks that will be used in respectively the ocean and the atmosphere. Each block corresponds to a given x and y wavenumber.
- The OMS and AMS arrays are integer arrays which specify which wavenumbers of the spectral decomposition will be used in respectively the ocean and the atmosphere. Their shapes are OMS(NBOC,2) and AMS(NB←ATM,2).
- The first dimension specifies the number attributed by the user to the block and the second dimension specifies the x and the y wavenumbers.
- The VDDG model, described in Vannitsem et al. (2015) is given as an example in the archive.
- Note that the variables of the model are numbered according to the chosen order of the blocks.

The Makefile allows to change the integrator being used for the time evolution. The user should modify it according to its need. By default a RK2 scheme is selected.

Finally, the IC.nml file specifying the initial condition should be defined. To obtain an example of this configuration file corresponding to the model you have previously defined, simply delete the current IC.nml file (if it exists) and run the main program :

```
./maooam
```

It will generate a new one and start with the 0 initial condition. If you want another initial condition, stop the program, fill the newly generated file and restart :

```
./maooam
```

It will generate two files :

- evol_field.dat : the recorded time evolution of the variables.
- mean_field.dat : the mean field (the climatology)

The tangent linear and adjoint models of MAOOAM are provided in the tl_ad_tensor, rk2_tl_ad_integrator and rk4_tl_ad_integrator modules. It is documented `here`.

The computation of the Lyapunov exponents can be done by running the program :

```
./maooam_lyap
```

It will generate four files:

- evol_field.dat : the recorded time evolution of the variables.
- mean_field.dat : the mean field (the climatology)
- lyapunov_exponents.dat : the recorded time evolution of the Lyapunov exponents
- mean_lyapunov.dat : the mean Lyapunov exponents as well as their variance.

Alternatively, the first Lyapunov exponent can be computed by the divergence method, by running :

./maooam_lyap_div

It will generate three files :

- evol_field.dat : the recorded time evolution of the variables.
- mean_field.dat : the mean field (the climatology)
- lyapunov_exponents_div.dat : the recorded time evolution of the first Lyapunov exponent

Implementation notes

As the system of differential equations is at most bilinear in y_j ($j = 1..n$), $\boldsymbol{y}$ being the array of variables, it can be expressed as a tensor contraction :

$$\frac{dy_i}{dt} = \sum_{j,k=0}^{ndim} \mathcal{T}_{i,j,k} \, y_k \, y_j$$

with $y_0 = 1$.

The tensor aotensor_def::aotensor is the tensor $\mathcal{T}$ that encodes the differential equations is composed so that:

- $\mathcal{T}_{i,j,k}$ contains the contribution of dy_i/dt proportional to $y_j \, y_k$.
- Furthermore, y_0 is always equal to 1, so that $\mathcal{T}_{i,0,0}$ is the constant contribution to dy_i/dt
- $\mathcal{T}_{i,j,0} + \mathcal{T}_{i,0,j}$ is the contribution to dy_i/dt which is linear in y_j.

Ideally, the tensor aotensor_def::aotensor is composed as an upper triangular matrix (in the last two coordinates).

The tensor for this model is composed in the aotensor_def module and uses the inner products defined in the inprod_analytic module.

Final Remarks

The authors would like to thank Kris for help with the lua2fortran project. It has greatly reduced the amount of (error-prone) work.

No animals were harmed during the coding process.

Chapter 2

Modular arbitrary-order ocean-atmosphere model: The Tangent Linear and Adjoint model

Description :

The Tangent Linear and Adjoint model model are implemented in the same way as the nonlinear model, with a tensor storing the different terms. The Tangent Linear (TL) tensor $\mathcal{T}_{i,j,k}^{TD}$ is defined as:

$$\mathcal{T}_{i,j,k}^{TL} = \mathcal{T}_{i,k,j} + \mathcal{T}_{i,j,k}$$

while the Adjoint (AD) tensor $\mathcal{T}_{i,j,k}^{AD}$ is defined as:

$$\mathcal{T}_{i,j,k}^{AD} = \mathcal{T}_{j,k,i} + \mathcal{T}_{j,i,k}.$$

where $\mathcal{T}_{i,j,k}$ is the tensor of the nonlinear model.

These two tensors are used to compute the trajectories of the models, with the equations

$$\frac{d\delta y_i}{dt} = \sum_{j=1}^{ndim} \sum_{k=0}^{ndim} \mathcal{T}_{i,j,k}^{TL} \, y_k^* \, \delta y_j.$$

$$-\frac{d\delta y_i}{dt} = \sum_{j=1}^{ndim} \sum_{k=0}^{ndim} \mathcal{T}_{i,j,k}^{AD} \, y_k^* \, \delta y_j.$$

where $\boldsymbol{y}^*$ is the point where the Tangent model is defined (with $y_0^* = 1$).

Implementation :

The two tensors are implemented in the module tl_ad_tensor and must be initialized (after calling params::init_params and aotensor_def::aotensor) by calling tl_ad_tensor::init_tltensor() and tl_ad_tensor::init_adtensor(). The tendencies are then given by the routine tl(t,ystar,deltay,buf) and ad(t,ystar,deltay,buf). An integrator with the Heun method is available in the module rk2_tl_ad_integrator and a fourth-order Runge-Kutta integrator in rk4_tl_ad_integrator. An example on how to use it can be found in the test file test_tl_ad.f90

Chapter 3

Modules Index

3.1 Modules List

Here is a list of all modules with brief descriptions:

Chapter 4

Data Type Index

4.1 Data Types List

Here are the data types with brief descriptions:

Chapter 5

File Index

5.1 File List

Here is a list of all files with brief descriptions:

Chapter 6

Module Documentation

6.1 aotensor_def Module Reference

The equation tensor for the coupled ocean-atmosphere model with temperature which allows for an extensible set of modes in the ocean and in the atmosphere.

Functions/Subroutines

- integer function psi (i)

  Translate the $\psi_{a,i}$ coefficients into effective coordinates.
- integer function theta (i)

  Translate the $\theta_{a,i}$ coefficients into effective coordinates.
- integer function a (i)

  Translate the $\psi_{o,i}$ coefficients into effective coordinates.
- integer function t (i)

  Translate the $\delta T_{o,i}$ coefficients into effective coordinates.
- integer function kdelta (i, j)

  Kronecker delta function.
- subroutine coeff (i, j, k, v)

  Subroutine to add element in the aotensor $\mathcal{T}_{i,j,k}$ structure.
- subroutine add_count (i, j, k, v)

  Subroutine to count the elements of the aotensor $\mathcal{T}_{i,j,k}$. Add +1 to count_elems(i) for each value that is added to the tensor i-th component.
- subroutine compute_aotensor (func)

  Subroutine to compute the tensor aotensor.
- subroutine, public init_aotensor

  Subroutine to initialise the aotensor tensor.

Variables

- integer, dimension(:), allocatable count_elems

  Vector used to count the tensor elements.
- real(kind=8), parameter real_eps = 2.2204460492503131e-16

  Epsilon to test equality with 0.
- type(coolist), dimension(:), allocatable, public aotensor

  $\mathcal{T}_{i,j,k}$ *- Tensor representation of the tendencies.*

6.1.1 Detailed Description

The equation tensor for the coupled ocean-atmosphere model with temperature which allows for an extensible set of modes in the ocean and in the atmosphere.

Remarks

Generated Fortran90/95 code from aotensor.lua

6.1.2 Function/Subroutine Documentation

6.1.2.1 integer function aotensor_def::a (integer *i*) [private]

Translate the $\psi_{o,i}$ coefficients into effective coordinates.

Definition at line 76 of file aotensor_def.f90.

```
76      INTEGER :: i,a
77      a = i + 2 * natm
```

6.1.2.2 subroutine aotensor_def::add_count (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Subroutine to count the elements of the aotensor $\mathcal{T}_{i,j,k}$. Add +1 to count_elems(i) for each value that is added to the tensor i-th component.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value that will be added

Definition at line 124 of file aotensor_def.f90.

```
124      INTEGER, INTENT(IN) :: i,j,k
125      REAL(KIND=8), INTENT(IN)  :: v
126      IF (abs(v) .ge. real_eps) count_elems(i)=count_elems(i)+1
```

6.1.2.3 subroutine aotensor_def::coeff (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Subroutine to add element in the aotensor $\mathcal{T}_{i,j,k}$ structure.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value to add

Definition at line 99 of file aotensor_def.f90.

```
99      INTEGER, INTENT(IN) :: i,j,k
100      REAL(KIND=8), INTENT(IN) :: v
101      INTEGER :: n
102      IF (.NOT. ALLOCATED(aotensor)) stop "*** coeff routine : tensor not yet allocated ***"
103      IF (.NOT. ALLOCATED(aotensor(i)%elems)) stop "*** coeff routine : tensor not yet allocated ***"
104      IF (abs(v) .ge. real_eps) THEN
105         n=(aotensor(i)%nelems)+1
106         IF (j .LE. k) THEN
107            aotensor(i)%elems(n)%j=j
108            aotensor(i)%elems(n)%k=k
109         ELSE
110            aotensor(i)%elems(n)%j=k
111            aotensor(i)%elems(n)%k=j
112         END IF
113         aotensor(i)%elems(n)%v=v
114         aotensor(i)%nelems=n
115      END IF
```

6.1.2.4 subroutine aotensor_def::compute_aotensor (external *func*) [private]

Subroutine to compute the tensor aotensor.

Parameters

func	External function to be used

Definition at line 132 of file aotensor_def.f90.

6.1.2.5 subroutine, public aotensor_def::init_aotensor ( )

Subroutine to initialise the aotensor tensor.

Remarks

> This procedure will also call params::init_params() and inprod_analytic::init_inprod() . It will finally call inprod_analytic::deallocate_inprod() to remove the inner products, which are not needed anymore at this point.

Definition at line 203 of file aotensor_def.f90.

```
203      INTEGER :: i
204      INTEGER :: allocstat
205
206      CALL init_params  ! Iniatialise the parameter
207
208      CALL init_inprod  ! Initialise the inner product tensors
209
210      ALLOCATE(aotensor(ndim),count_elems(ndim), stat=allocstat)
211      IF (allocstat /= 0) stop "*** Not enough memory ! ***"
```

```
count_elems=0

CALL compute_aotensor(add_count)

DO i=1,ndim
   ALLOCATE(aotensor(i)%elems(count_elems(i)), stat=allocstat)
   IF (allocstat /= 0) stop "*** Not enough memory ! ***"
END DO

DEALLOCATE(count_elems, stat=allocstat)
IF (allocstat /= 0) stop "*** Deallocation problem ! ***"

CALL compute_aotensor(coeff)

CALL simplify(aotensor)
```

6.1.2.6 integer function aotensor_def::kdelta (integer *i*, integer *j*) [private]

Kronecker delta function.

Definition at line 88 of file aotensor_def.f90.

```
INTEGER :: i,j,kdelta
kdelta=0
IF (i == j) kdelta = 1
```

6.1.2.7 integer function aotensor_def::psi (integer *i*) [private]

Translate the $\psi_{a,i}$ coefficients into effective coordinates.

Definition at line 64 of file aotensor_def.f90.

```
INTEGER :: i,psi
psi = i
```

6.1.2.8 integer function aotensor_def::t (integer *i*) [private]

Translate the $\delta T_{o,i}$ coefficients into effective coordinates.

Definition at line 82 of file aotensor_def.f90.

```
INTEGER :: i,t
t = i + 2 * natm + noc
```

6.1.2.9 integer function aotensor_def::theta (integer *i*) [private]

Translate the $\theta_{a,i}$ coefficients into effective coordinates.

Definition at line 70 of file aotensor_def.f90.

```
INTEGER :: i,theta
theta = i + natm
```

6.1.3 Variable Documentation

6.1.3.1 type(coolist), dimension(:), allocatable, public aotensor_def::aotensor

$\mathcal{T}_{i,j,k}$ - Tensor representation of the tendencies.

Definition at line 45 of file aotensor_def.f90.

```
45   TYPE(coolist), DIMENSION(:), ALLOCATABLE, PUBLIC :: aotensor
```

6.1.3.2 integer, dimension(:), allocatable aotensor_def::count_elems [private]

Vector used to count the tensor elements.

Definition at line 37 of file aotensor_def.f90.

```
37   INTEGER, DIMENSION(:), ALLOCATABLE :: count_elems
```

6.1.3.3 real(kind=8), parameter aotensor_def::real_eps = 2.2204460492503131e-16 [private]

Epsilon to test equality with 0.

Definition at line 40 of file aotensor_def.f90.

```
40   REAL(KIND=8), PARAMETER :: real_eps = 2.2204460492503131e-16
```

6.2 ic_def Module Reference

Module to load the initial condition.

Functions/Subroutines

- subroutine, public load_ic

  Subroutine to load the initial condition if IC.nml exists. If it does not, then write IC.nml with 0 as initial condition.

Variables

- logical exists

  Boolean to test for file existence.
- real(kind=8), dimension(:), allocatable, public ic

  Initial condition vector.

6.2.1 Detailed Description

Module to load the initial condition.

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6.2.2 Function/Subroutine Documentation

6.2.2.1 subroutine, public ic_def::load_ic ( )

Subroutine to load the initial condition if IC.nml exists. If it does not, then write IC.nml with 0 as initial condition.

Definition at line 32 of file ic_def.f90.

```
32      INTEGER :: i,allocstat,j
33      CHARACTER(len=20) :: fm
34      REAL(KIND=8) :: size_of_random_noise
35      INTEGER, DIMENSION(:), ALLOCATABLE :: seed
36      CHARACTER(LEN=4) :: init_type
37      namelist /iclist/ ic
38      namelist /rand/ init_type,size_of_random_noise,seed
39
40
41      fm(1:6)='(F3.1)'
42
43      CALL random_seed(size=j)
44
45      IF (ndim == 0) stop "*** Number of dimensions is 0! ***"
46      ALLOCATE(ic(0:ndim),seed(j), stat=allocstat)
47      IF (allocstat /= 0) stop "*** Not enough memory ! ***"
48
49      INQUIRE(file='./IC.nml',exist=exists)
50
51      IF (exists) THEN
52         OPEN(8, file="IC.nml", status='OLD', recl=80, delim='APOSTROPHE')
53         READ(8,nml=iclist)
54         READ(8,nml=rand)
55         CLOSE(8)
56         SELECT CASE (init_type)
57           CASE ('seed')
58             CALL random_seed(put=seed)
59             CALL random_number(ic)
60             ic=2*(ic-0.5)
61             ic=ic*size_of_random_noise*10.d0
62             ic(0)=1.0d0
63             WRITE(6,*) "*** IC.nml namelist written. Starting with 'seeded' random initial condition !***"
64           CASE ('rand')
65             CALL init_random_seed()
66             CALL random_seed(get=seed)
67             CALL random_number(ic)
68             ic=2*(ic-0.5)
69             ic=ic*size_of_random_noise*10.d0
70             ic(0)=1.0d0
71             WRITE(6,*) "*** IC.nml namelist written. Starting with random initial condition !***"
72           CASE ('zero')
73             CALL init_random_seed()
74             CALL random_seed(get=seed)
75             ic=0
76             ic(0)=1.0d0
77             WRITE(6,*) "*** IC.nml namelist written. Starting with initial condition in IC.nml !***"
78           CASE ('read')
79             CALL init_random_seed()
80             CALL random_seed(get=seed)
81             ic(0)=1.0d0
82             ! except IC(0), nothing has to be done IC has already the right values
83             WRITE(6,*) "*** IC.nml namelist written. Starting with initial condition in IC.nml !***"
84         END SELECT
85      ELSE
86         CALL init_random_seed()
87         CALL random_seed(get=seed)
88         ic=0
89         ic(0)=1.0d0
```

```
      init_type="zero"
      size_of_random_noise=0.d0
      WRITE(6,*) "*** IC.nml namelist written. Starting with 0 as initial condition !***"
   END IF
   OPEN(8, file="IC.nml", status='REPLACE')
   WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
   WRITE(8,'(a)') "! Namelist file :                                                              !"
   WRITE(8,'(a)') "! Initial condition.                                                           !"
   WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
   WRITE(8,*) ""
    WRITE(8,'(a)') "&ICLIST"
    WRITE(8,*) " ! psi variables"
    DO i=1,natm
       WRITE(8,*) " IC("//trim(str(i))//") = ",ic(i),"   ! typ= "&
            &//awavenum(i)%typ//", Nx= "//trim(rstr(awavenum(i)&
            &%Nx,fm))//", Ny= "//trim(rstr(awavenum(i)%Ny,fm))
    END DO
    WRITE(8,*) " ! theta variables"
    DO i=1,natm
       WRITE(8,*) " IC("//trim(str(i+natm))//") = ",ic(i+natm),"   ! typ= "&
            &//awavenum(i)%typ//", Nx= "//trim(rstr(awavenum(i)&
            &%Nx,fm))//", Ny= "//trim(rstr(awavenum(i)%Ny,fm))
    END DO

    WRITE(8,*) " ! A variables"
    DO i=1,noc
       WRITE(8,*) " IC("//trim(str(i+2*natm))//") = ",ic(i+2*natm),"   ! Nx&
            &= "//trim(rstr(owavenum(i)%Nx,fm))//", Ny= "&
            &//trim(rstr(owavenum(i)%Ny,fm))
    END DO
    WRITE(8,*) " ! T variables"
    DO i=1,noc
       WRITE(8,*) " IC("//trim(str(i+noc+2*natm))//") = ",ic(i+2*natm+noc),"   &
            &! Nx= "//trim(rstr(owavenum(i)%Nx,fm))//", Ny= "&
            &//trim(rstr(owavenum(i)%Ny,fm))
    END DO

    WRITE(8,'(a)') "&END"
    WRITE(8,*) ""
    WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
    WRITE(8,'(a)') "! Initialisation type.                                                         !"
    WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
    WRITE(8,'(a)') "! type = 'read': use IC above (will generate a new seed);"
    WRITE(8,'(a)') "!        'rand': random state (will generate a new seed);"
    WRITE(8,'(a)') "!        'zero': zero IC (will generate a new seed);"
    WRITE(8,'(a)') "!        'seed': use the seed below (generate the same IC)"
    WRITE(8,*) ""
    WRITE(8,'(a)') "&RAND"
    WRITE(8,'(a)') "  init_type= '"//init_type//"'"
    WRITE(8,'(a,d15.7)') "  size_of_random_noise = ",size_of_random_noise
    DO i=1,j
       WRITE(8,*) " seed("//trim(str(i))//") = ",seed(i)
    END DO
    WRITE(8,'(a)') "&END"
    WRITE(8,*) ""
    CLOSE(8)
```

6.2.3 Variable Documentation

6.2.3.1 logical ic_def::exists [private]

Boolean to test for file existence.

Definition at line 21 of file ic_def.f90.

```
21   LOGICAL :: exists !< Boolean to test for file existence.
```

6.2.3.2 real(kind=8), dimension(:), allocatable, public ic_def::ic

Initial condition vector.

Definition at line 23 of file ic_def.f90.

```
23   REAL(KIND=8), DIMENSION(:), ALLOCATABLE, PUBLIC :: ic !< Initial condition vector
```

6.3 icdelta_def Module Reference

Module to load the perturbation initial condition.

Functions/Subroutines

- subroutine, public load_icdelta

  Subroutine to load the initial condition if ICdelta.nml exists. If it does not, then write ICdelta.nml with random initial condition.

Variables

- logical exists

  Boolean to test for file existence.
- real(kind=8), dimension(:), allocatable, public icdelta

  Initial condition vector.

6.3.1 Detailed Description

Module to load the perturbation initial condition.

Copyright

6.3.2 Function/Subroutine Documentation

6.3.2.1 subroutine, public icdelta_def::load_icdelta ( )

Subroutine to load the initial condition if ICdelta.nml exists. If it does not, then write ICdelta.nml with random initial condition.

Definition at line 32 of file icdelta_def.f90.

```
32      INTEGER :: i,allocstat
33      CHARACTER(len=20) :: fm
34      REAL(KIND=8) :: size_of_random_noise
35      CHARACTER(LEN=4) :: init_type
36      namelist /iclist/ icdelta
37      namelist /rand/ init_type,size_of_random_noise
38
39
40
41      fm(1:6)='(F3.1)'
42
43      IF (ndim == 0) stop "*** Number of dimensions is 0! ***"
44      ALLOCATE(icdelta(0:ndim), stat=allocstat)
45      IF (allocstat /= 0) stop "*** Not enough memory ! ***"
46
47      INQUIRE(file='./ICdelta.nml',exist=exists)
48
49      IF (exists) THEN
50         OPEN(8, file="ICdelta.nml", status='OLD', recl=80, delim='APOSTROPHE')
51         READ(8,nml=iclist)
52         READ(8,nml=rand)
53         SELECT CASE (init_type)
```

```
         CASE ('rand')
           CALL random_number(icdelta)
           icdelta=2*(icdelta-0.5)
           icdelta=icdelta*size_of_random_noise*10.d0
           icdelta(0)=1.0d0
           WRITE(6,*) "*** ICdelta.nml namelist written. Starting with random initial condition !***"
         CASE ('zero')
           icdelta=0
           icdelta(0)=1.0d0
           WRITE(6,*) "*** ICdelta.nml namelist written. Starting with initial condition in ICdelta.nml
!***"
         CASE ('read')
           !nothing has to be done ICdelta has already the right values
           WRITE(6,*) "*** ICdelta.nml namelist written. Starting with initial condition in ICdelta.nml
!***"
       END SELECT
       CLOSE(8)
    ELSE
       CALL random_number(icdelta)
       icdelta=2*(icdelta-0.5)
       size_of_random_noise=1.d-3
       icdelta=icdelta*size_of_random_noise*10.d0
       icdelta(0)=1.0d0
       init_type="rand"
       WRITE(6,*) "*** ICdelta.nml namelist written. Starting with 0 as initial condition !***"

    END IF
    OPEN(8, file="ICdelta.nml", status='REPLACE')
    WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
    WRITE(8,'(a)') "! Namelist file :                                                              !"
    WRITE(8,'(a)') "! Initial condition.                                                           !"
    WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
    WRITE(8,*) ""
    WRITE(8,'(a)') "&ICLIST"
    WRITE(8,*) " ! psi variables"
    DO i=1,natm
       WRITE(8,*) " ICdelta("//trim(str(i))//") = ",icdelta(i+natm)," ! typ= "&
            &//awavenum(i)%typ//", Nx= "//trim(rstr(awavenum(i)&
            &%Nx,fm))//", Ny= "//trim(rstr(awavenum(i)%Ny,fm))
    END DO
    WRITE(8,*) " ! theta variables"
    DO i=1,natm
       WRITE(8,*) " ICdelta("//trim(str(i+natm))//") = ",icdelta(i+natm)," ! typ= "&
            &//awavenum(i)%typ//", Nx= "//trim(rstr(awavenum(i)&
            &%Nx,fm))//", Ny= "//trim(rstr(awavenum(i)%Ny,fm))
    END DO

    WRITE(8,*) " ! A variables"
     DO i=1,noc
        WRITE(8,*) " ICdelta("//trim(str(i+2*natm))//") = ",icdelta(i+2*natm)," ! Nx&
             &= "//trim(rstr(owavenum(i)%Nx,fm))//", Ny= "&
             &//trim(rstr(owavenum(i)%Ny,fm))
     END DO
     WRITE(8,*) " ! T variables"
     DO i=1,noc
        WRITE(8,*) " ICdelta("//trim(str(i+noc+2*natm))//") = ",icdelta(i+2*natm+noc)," &
             &! Nx= "//trim(rstr(owavenum(i)%Nx,fm))//", Ny= "&
             &//trim(rstr(owavenum(i)%Ny,fm))
     END DO

     WRITE(8,'(a)') "&END"
     WRITE(8,*) ""
     WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
     WRITE(8,'(a)') "! Initialisation type.                                                         !"
     WRITE(8,'(a)') "!------------------------------------------------------------------------------!"
     WRITE(8,'(a)') "! type = 'read': use ICdelta; 'rand': random state; 'zero': zero condition "
     WRITE(8,'(a)') "! The seed is specified in IC.nml"
     WRITE(8,*) ""
     WRITE(8,'(a)') "&RAND"
     WRITE(8,'(a)') "  init_type= '"//init_type//"'"
     WRITE(8,'(a,d15.7)') "  size_of_random_noise = ",size_of_random_noise
     WRITE(8,'(a)') "&END"
     WRITE(8,*) ""
     CLOSE(8)
```

6.3.3 Variable Documentation

6.3.3.1 logical icdelta_def::exists [private]

Boolean to test for file existence.

Definition at line 21 of file icdelta_def.f90.

```
21 LOGICAL :: exists !< Boolean to test for file existence.
```

6.3.3.2 real(kind=8), dimension(:), allocatable, public icdelta_def::icdelta

Initial condition vector.

Definition at line 23 of file icdelta_def.f90.

```
23 REAL(KIND=8), DIMENSION(:), ALLOCATABLE, PUBLIC :: icdelta !< Initial condition vector
```

6.4 inprod_analytic Module Reference

Inner products between the truncated set of basis functions for the ocean and atmosphere streamfunction fields. These are partly calculated using the analytical expressions from Cehelsky, P., & Tung, K. K. : Theories of multiple equilibria and weather regimes-A critical reexamination. Part II: Baroclinic two-layer models. Journal of the atmospheric sciences, 44(21), 3282-3303, 1987.

Data Types

- type atm_tensors
  Type holding the atmospheric inner products tensors.
- type atm_wavenum
  Atmospheric bloc specification type.
- type ocean_tensors
  Type holding the oceanic inner products tensors.
- type ocean_wavenum
  Oceanic bloc specification type.

Functions/Subroutines

- real(kind=8) function b1 (Pi, Pj, Pk)
  Cehelsky & Tung Helper functions.
- real(kind=8) function b2 (Pi, Pj, Pk)
  Cehelsky & Tung Helper functions.
- real(kind=8) function delta (r)
  Integer Dirac delta function.
- real(kind=8) function flambda (r)
  "Odd or even" function
- real(kind=8) function s1 (Pj, Pk, Mj, Hk)
  Cehelsky & Tung Helper functions.
- real(kind=8) function s2 (Pj, Pk, Mj, Hk)
  Cehelsky & Tung Helper functions.
- real(kind=8) function s3 (Pj, Pk, Hj, Hk)
  Cehelsky & Tung Helper functions.
- real(kind=8) function s4 (Pj, Pk, Hj, Hk)
  Cehelsky & Tung Helper functions.

- real(kind=8) function calculate_a (i, j)

  Eigenvalues of the Laplacian (atmospheric)
- real(kind=8) function calculate_b (i, j, k)

  Streamfunction advection terms (atmospheric)
- real(kind=8) function calculate_c_atm (i, j)

  Beta term for the atmosphere.
- real(kind=8) function calculate_d (i, j)

  Forcing of the ocean on the atmosphere.
- real(kind=8) function calculate_g (i, j, k)

  Temperature advection terms (atmospheric)
- real(kind=8) function calculate_s (i, j)

  Forcing (thermal) of the ocean on the atmosphere.
- real(kind=8) function calculate_k (i, j)

  Forcing of the atmosphere on the ocean.
- real(kind=8) function calculate_m (i, j)

  Forcing of the ocean fields on the ocean.
- real(kind=8) function calculate_n (i, j)

  Beta term for the ocean.
- real(kind=8) function calculate_o (i, j, k)

  Temperature advection term (passive scalar)
- real(kind=8) function calculate_c_oc (i, j, k)

  Streamfunction advection terms (oceanic)
- real(kind=8) function calculate_w (i, j)

  Short-wave radiative forcing of the ocean.
- subroutine, public init_inprod

  Initialisation of the inner product.

Variables

- type(atm_wavenum), dimension(:), allocatable, public awavenum

  Atmospheric blocs specification.
- type(ocean_wavenum), dimension(:), allocatable, public owavenum

  Oceanic blocs specification.
- type(atm_tensors), public atmos

  Atmospheric tensors.
- type(ocean_tensors), public ocean

  Oceanic tensors.

6.4.1 Detailed Description

Inner products between the truncated set of basis functions for the ocean and atmosphere streamfunction fields. These are partly calculated using the analytical expressions from Cehelsky, P., & Tung, K. K. : Theories of multiple equilibria and weather regimes-A critical reexamination. Part II: Baroclinic two-layer models. Journal of the atmospheric sciences, 44(21), 3282-3303, 1987.

Copyright

Remarks

Generated Fortran90/95 code from inprod_analytic.lua

6.4.2 Function/Subroutine Documentation

6.4.2.1 real(kind=8) function inprod_analytic::b1 (integer *Pi*, integer *Pj*, integer *Pk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 100 of file inprod_analytic.f90.

```
100     INTEGER :: pi,pj,pk
101     b1 = (pk + pj) / REAL(pi)
```

6.4.2.2 real(kind=8) function inprod_analytic::b2 (integer *Pi*, integer *Pj*, integer *Pk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 106 of file inprod_analytic.f90.

```
106     INTEGER :: pi,pj,pk
107     b2 = (pk - pj) / REAL(pi)
```

6.4.2.3 real(kind=8) function inprod_analytic::calculate_a (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Eigenvalues of the Laplacian (atmospheric)

$a_{i,j} = (F_i, \nabla^2 F_j)$.

Definition at line 164 of file inprod_analytic.f90.

```
164     INTEGER, INTENT(IN) :: i,j
165     TYPE(atm_wavenum) :: ti
166
167     calculate_a = 0.d0
168     IF (i==j) THEN
169        ti = awavenum(i)
170        calculate_a = -(n**2) * ti%Nx**2 - ti%Ny**2
171     END IF
```

6.4.2.4 real(kind=8) function inprod_analytic::calculate_b (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*) [private]

Streamfunction advection terms (atmospheric)

$b_{i,j,k} = (F_i, J(F_j, \nabla^2 F_k))$.

Definition at line 178 of file inprod_analytic.f90.

```
178     INTEGER, INTENT(IN) :: i,j,k
179
180     calculate_b = calculate_a(k,k) * calculate_g(i,j,k)
181
```

6.4.2.5 real(kind=8) function inprod_analytic::calculate_c_atm (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Beta term for the atmosphere.

$$c_{i,j} = (F_i, \partial_x F_j) \ .$$

Definition at line 188 of file inprod_analytic.f90.

```
188     INTEGER, INTENT(IN) :: i,j
189     TYPE(atm_wavenum) :: ti, tj
190
191     ti = awavenum(i)
192     tj = awavenum(j)
193     calculate_c_atm = 0.d0
194     IF ((ti%typ == "K") .AND. (tj%typ == "L")) THEN
195        calculate_c_atm = n * ti%M * delta(ti%M - tj%H) * delta(ti%P - tj%P)
196     ELSE IF ((ti%typ == "L") .AND. (tj%typ == "K")) THEN
197        ti = awavenum(j)
198        tj = awavenum(i)
199        calculate_c_atm = - n * ti%M * delta(ti%M - tj%H) * delta(ti%P - tj%P)
200     END IF
201
```

6.4.2.6 real(kind=8) function inprod_analytic::calculate_c_oc (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*) [private]

Streamfunction advection terms (oceanic)

$$C_{i,j,k} = (\eta_i, J(\eta_j, \nabla^2 \eta_k)) \ .$$

Definition at line 412 of file inprod_analytic.f90.

```
412     INTEGER, INTENT(IN) :: i,j,k
413
414     calculate_c_oc = calculate_m(k,k) * calculate_o(i,j,k)
415
```

6.4.2.7 real(kind=8) function inprod_analytic::calculate_d (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Forcing of the ocean on the atmosphere.

$$d_{i,j} = (F_i, \nabla^2 \eta_j) \ .$$

Definition at line 208 of file inprod_analytic.f90.

```
208     INTEGER, INTENT(IN) :: i,j
209
210     calculate_d=calculate_s(i,j) * calculate_m(j,j)
211
```

6.4.2.8 real(kind=8) function inprod_analytic::calculate_g (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*) [private]

Temperature advection terms (atmospheric)

$$g_{i,j,k} = (F_i, J(F_j, F_k)) \, .$$

Definition at line 218 of file inprod_analytic.f90.

```
218     INTEGER, INTENT(IN) :: i,j,k
219     TYPE(atm_wavenum) :: ti,tj,tk
220     REAL(KIND=8) :: val,vb1, vb2, vs1, vs2, vs3, vs4
221     INTEGER, DIMENSION(3) :: a,b
222     INTEGER, DIMENSION(3,3) :: w
223     CHARACTER, DIMENSION(3) :: s
224     INTEGER :: par
225
226     ti = awavenum(i)
227     tj = awavenum(j)
228     tk = awavenum(k)
229
230     a(1)=i
231     a(2)=j
232     a(3)=k
233
234     val=0.d0
235
236     IF ((ti%typ == "L") .AND. (tj%typ == "L") .AND. (tk%typ == "L")) THEN
237
238        CALL piksrt(3,a,par)
239
240        ti = awavenum(a(1))
241        tj = awavenum(a(2))
242        tk = awavenum(a(3))
243
244        vs3 = s3(tj%P,tk%P,tj%H,tk%H)
245        vs4 = s4(tj%P,tk%P,tj%H,tk%H)
246        val = vs3 * ((delta(tk%H - tj%H - ti%H) - delta(tk%H &
247             &- tj%H + ti%H)) * delta(tk%P + tj%P - ti%P) +&
248             & delta(tk%H + tj%H - ti%H) * (delta(tk%P - tj%P&
249             & + ti%P) - delta(tk%P - tj%P - ti%P))) + vs4 *&
250             & ((delta(tk%H + tj%H - ti%H) * delta(tk%P - tj&
251             &%P - ti%P)) + (delta(tk%H - tj%H + ti%H) -&
252             & delta(tk%H - tj%H - ti%H)) * (delta(tk%P - tj&
253             &%P - ti%P) - delta(tk%P - tj%P + ti%P)))
254     ELSE
255
256        s(1)=ti%typ
257        s(2)=tj%typ
258        s(3)=tk%typ
259
260        w(1,:)=isin("A",s)
261        w(2,:)=isin("K",s)
262        w(3,:)=isin("L",s)
263
264        IF (any(w(1,:)/=0) .AND. any(w(2,:)/=0) .AND. any(w(3,:)/=0)) THEN
265           b=w(:,1)
266           ti = awavenum(a(b(1)))
267           tj = awavenum(a(b(2)))
268           tk = awavenum(a(b(3)))
269           call piksrt(3,b,par)
270           vb1 = b1(ti%P,tj%P,tk%P)
271           vb2 = b2(ti%P,tj%P,tk%P)
272           val = -2 * sqrt(2.) / pi * tj%M * delta(tj%M - tk%H) * flambda(ti%P + tj%P + tk%P)
273           IF (val /= 0.d0) val = val * (vb1**2 / (vb1**2 - 1) - vb2**2 / (vb2**2 - 1))
274        ELSEIF ((w(2,2)/=0) .AND. (w(2,3)==0) .AND. any(w(3,:)/=0)) THEN
275           ti = awavenum(a(w(2,1)))
276           tj = awavenum(a(w(2,2)))
277           tk = awavenum(a(w(3,1)))
278           b(1)=w(2,1)
279           b(2)=w(2,2)
280           b(3)=w(3,1)
281           call piksrt(3,b,par)
282           vs1 = s1(tj%P,tk%P,tj%M,tk%H)
283           vs2 = s2(tj%P,tk%P,tj%M,tk%H)
284           val = vs1 * (delta(ti%M - tk%H - tj%M) * delta(ti%P -&
285                & tk%P + tj%P) - delta(ti%M- tk%H - tj%M) *&
286                & delta(ti%P + tk%P - tj%P) + (delta(tk%H - tj%M&
287                & + ti%M) + delta(tk%H - tj%M - ti%M)) *&
288                & delta(tk%P + tj%P - ti%P)) + vs2 * (delta(ti%M&
289                & - tk%H - tj%M) * delta(ti%P - tk%P - tj%P) +&
```

```
               & (delta(tk%H - tj%M - ti%M) + delta(ti%M + tk%H&
               & - tj%M)) * (delta(ti%P - tk%P + tj%P) -&
               & delta(tk%P - tj%P + ti%P)))
         ENDIF
      ENDIF
      calculate_g=par*val*n

```

6.4.2.9 real(kind=8) function inprod_analytic::calculate_k (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Forcing of the atmosphere on the ocean.

$$K_{i,j} = (\eta_i, \nabla^2 F_j) \ .$$

Definition at line 336 of file inprod_analytic.f90.

```
336      INTEGER, INTENT(IN) :: i,j
337
338      calculate_k = calculate_s(j,i) * calculate_a(j,j)
```

6.4.2.10 real(kind=8) function inprod_analytic::calculate_m (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Forcing of the ocean fields on the ocean.

$$M_{i,j} = (eta_i, \nabla^2 \eta_j) \ .$$

Definition at line 345 of file inprod_analytic.f90.

```
345      INTEGER, INTENT(IN) :: i,j
346      TYPE(ocean_wavenum) :: di
347
348      calculate_m=0.d0
349      IF (i==j) THEN
350         di = owavenum(i)
351         calculate_m = -(n**2) * di%Nx**2 - di%Ny**2
352      END IF
```

6.4.2.11 real(kind=8) function inprod_analytic::calculate_n (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Beta term for the ocean.

$$N_{i,j} = (\eta_i, \partial_x \eta_j).$$

Definition at line 359 of file inprod_analytic.f90.

```
359      INTEGER, INTENT(IN) :: i,j
360      TYPE(ocean_wavenum) :: di,dj
361      REAL(KIND=8) :: val
362
363      di = owavenum(i)
364      dj = owavenum(j)
365      calculate_n = 0.d0
366      IF (dj%H/=di%H) THEN
367         val = delta(di%P - dj%P) * flambda(di%H + dj%H)
368         calculate_n = val * (-2) * dj%H * di%H * n / ((dj%H**2 - di%H**2) * pi)
369      ENDIF
370
```

6.4.2.12 real(kind=8) function inprod_analytic::calculate_o (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*) [private]

Temperature advection term (passive scalar)

$O_{i,j,k} = (\eta_i, J(\eta_j, \eta_k))$.

Definition at line 377 of file inprod_analytic.f90.

```
INTEGER, INTENT(IN) :: i,j,k
TYPE(ocean_wavenum) :: di,dj,dk
REAL(KIND=8) :: vs3,vs4,val
INTEGER, DIMENSION(3) :: a
INTEGER :: par

val=0.d0

a(1)=i
a(2)=j
a(3)=k

CALL piksrt(3,a,par)

di = owavenum(a(1))
dj = owavenum(a(2))
dk = owavenum(a(3))

vs3 = s3(dj%P,dk%P,dj%H,dk%H)
vs4 = s4(dj%P,dk%P,dj%H,dk%H)
val = vs3*((delta(dk%H - dj%H - di%H) - delta(dk%H - dj&
     &%H + di%H)) * delta(dk%P + dj%P - di%P) + delta(dk&
     &%H + dj%H - di%H) * (delta(dk%P - dj%P + di%P) -&
     & delta(dk%P - dj%P - di%P))) + vs4 * ((delta(dk%H &
     &+ dj%H - di%H) * delta(dk%P - dj%P - di%P)) +&
     & (delta(dk%H - dj%H + di%H) - delta(dk%H - dj%H -&
     & di%H)) * (delta(dk%P - dj%P - di%P) - delta(dk%P &
     &- dj%P + di%P)))
calculate_o = par * val * n / 2
```

6.4.2.13 real(kind=8) function inprod_analytic::calculate_s (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Forcing (thermal) of the ocean on the atmosphere.

$s_{i,j} = (F_i, \eta_j)$.

Definition at line 303 of file inprod_analytic.f90.

```
INTEGER, INTENT(IN) :: i,j
TYPE(atm_wavenum) :: ti
TYPE(ocean_wavenum) :: dj
REAL(KIND=8) :: val

ti = awavenum(i)
dj = owavenum(j)
val=0.d0
IF (ti%typ == "A") THEN
   val = flambda(dj%H) * flambda(dj%P + ti%P)
   IF (val /= 0.d0) THEN
      val = val*8*sqrt(2.)*dj%P/(pi**2 * (dj%P**2 - ti%P**2) * dj%H)
   END IF
ELSEIF (ti%typ == "K") THEN
   val = flambda(2 * ti%M + dj%H) * delta(dj%P - ti%P)
   IF (val /= 0.d0) THEN
      val = val*4*dj%H/(pi * (-4 * ti%M**2 + dj%H**2))
   END IF
ELSEIF (ti%typ == "L") THEN
   val = delta(dj%P - ti%P) * delta(2 * ti%H - dj%H)
END IF
calculate_s=val
```

6.4.2.14 real(kind=8) function inprod_analytic::calculate_w (integer, intent(in) *i*, integer, intent(in) *j*) [private]

Short-wave radiative forcing of the ocean.

$W_{i,j} = (\eta_i, F_j)$.

Definition at line 422 of file inprod_analytic.f90.

```
422      INTEGER, INTENT(IN) :: i,j
423
424      calculate_w = calculate_s(j,i)
425
```

6.4.2.15 real(kind=8) function inprod_analytic::delta (integer *r*) [private]

Integer Dirac delta function.

Definition at line 112 of file inprod_analytic.f90.

```
112      INTEGER :: r
113      IF (r==0) THEN
114         delta = 1.d0
115      ELSE
116         delta = 0.d0
117      ENDIF
```

6.4.2.16 real(kind=8) function inprod_analytic::flambda (integer *r*) [private]

"Odd or even" function

Definition at line 122 of file inprod_analytic.f90.

```
122      INTEGER :: r
123      IF (mod(r,2)==0) THEN
124         flambda = 0.d0
125      ELSE
126         flambda = 1.d0
127      ENDIF
```

6.4.2.17 subroutine, public inprod_analytic::init_inprod ( )

Initialisation of the inner product.

Definition at line 436 of file inprod_analytic.f90.

```
INTEGER :: i,j
INTEGER :: allocstat

IF (natm == 0 ) THEN
   stop "*** Problem : natm==0 ! ***"
ELSEIF (noc == 0) then
   stop "*** Problem : noc==0 ! ***"
END IF


! Definition of the types and wave numbers tables

ALLOCATE(owavenum(noc),awavenum(natm), stat=allocstat)
IF (allocstat /= 0) stop "*** Not enough memory ! ***"

j=0
DO i=1,nbatm
   IF (ams(i,1)==1) THEN
      awavenum(j+1)%typ='A'
      awavenum(j+2)%typ='K'
      awavenum(j+3)%typ='L'

      awavenum(j+1)%P=ams(i,2)
      awavenum(j+2)%M=ams(i,1)
      awavenum(j+2)%P=ams(i,2)
      awavenum(j+3)%H=ams(i,1)
      awavenum(j+3)%P=ams(i,2)

      awavenum(j+1)%Ny=REAL(ams(i,2))
      awavenum(j+2)%Nx=REAL(ams(i,1))
      awavenum(j+2)%Ny=REAL(ams(i,2))
      awavenum(j+3)%Nx=REAL(ams(i,1))
      awavenum(j+3)%Ny=REAL(ams(i,2))

      j=j+3
   ELSE
      awavenum(j+1)%typ='K'
      awavenum(j+2)%typ='L'

      awavenum(j+1)%M=ams(i,1)
      awavenum(j+1)%P=ams(i,2)
      awavenum(j+2)%H=ams(i,1)
      awavenum(j+2)%P=ams(i,2)

      awavenum(j+1)%Nx=REAL(ams(i,1))
      awavenum(j+1)%Ny=REAL(ams(i,2))
      awavenum(j+2)%Nx=REAL(ams(i,1))
      awavenum(j+2)%Ny=REAL(ams(i,2))

      j=j+2

   ENDIF
ENDDO

DO i=1,noc
   owavenum(i)%H=oms(i,1)
   owavenum(i)%P=oms(i,2)

   owavenum(i)%Nx=oms(i,1)/2.d0
   owavenum(i)%Ny=oms(i,2)

ENDDO

! Pointing to the atmospheric inner products functions

atmos%a => calculate_a
atmos%g => calculate_g
atmos%s => calculate_s
atmos%b => calculate_b
atmos%d => calculate_d
atmos%c => calculate_c_atm

! Pointing to the oceanic inner products functions

ocean%M => calculate_m
ocean%N => calculate_n
ocean%O => calculate_o
ocean%C => calculate_c_oc
ocean%W => calculate_w
ocean%K => calculate_k

```

6.4.2.18 real(kind=8) function inprod_analytic::s1 (integer *Pj*, integer *Pk*, integer *Mj*, integer *Hk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 132 of file inprod_analytic.f90.

```
132     INTEGER :: pk,pj,mj,hk
133     s1 = -((pk * mj + pj * hk)) / 2.d0
```

6.4.2.19 real(kind=8) function inprod_analytic::s2 (integer *Pj*, integer *Pk*, integer *Mj*, integer *Hk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 138 of file inprod_analytic.f90.

```
138     INTEGER :: pk,pj,mj,hk
139     s2 = (pk * mj - pj * hk) / 2.d0
```

6.4.2.20 real(kind=8) function inprod_analytic::s3 (integer *Pj*, integer *Pk*, integer *Hj*, integer *Hk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 144 of file inprod_analytic.f90.

```
144     INTEGER :: pj,pk,hj,hk
145     s3 = (pk * hj + pj * hk) / 2.d0
```

6.4.2.21 real(kind=8) function inprod_analytic::s4 (integer *Pj*, integer *Pk*, integer *Hj*, integer *Hk*) [private]

Cehelsky & Tung Helper functions.

Definition at line 150 of file inprod_analytic.f90.

```
150     INTEGER :: pj,pk,hj,hk
151     s4 = (pk * hj - pj * hk) / 2.d0
```

6.4.3 Variable Documentation

6.4.3.1 type(atm_tensors), public inprod_analytic::atmos

Atmospheric tensors.

Definition at line 78 of file inprod_analytic.f90.

```
78   TYPE(atm_tensors), PUBLIC :: atmos
```

6.4.3.2 type(atm_wavenum), dimension(:), allocatable, public inprod_analytic::awavenum

Atmospheric blocs specification.

Definition at line 73 of file inprod_analytic.f90.

```
73 TYPE(atm_wavenum), DIMENSION(:), ALLOCATABLE, PUBLIC :: awavenum
```

6.4.3.3 type(ocean_tensors), public inprod_analytic::ocean

Oceanic tensors.

Definition at line 80 of file inprod_analytic.f90.

```
80 TYPE(ocean_tensors), PUBLIC :: ocean
```

6.4.3.4 type(ocean_wavenum), dimension(:), allocatable, public inprod_analytic::owavenum

Oceanic blocs specification.

Definition at line 75 of file inprod_analytic.f90.

```
75 TYPE(ocean_wavenum), DIMENSION(:), ALLOCATABLE, PUBLIC :: owavenum
```

6.5 integrator Module Reference

Module with the integration routines.

Functions/Subroutines

- subroutine, public init_integrator

  Routine to initialise the integration buffers.
- subroutine tendencies (t, y, res)

  Routine computing the tendencies of the model.
- subroutine, public step (y, t, dt, res)

  Routine to perform an integration step (Heun algorithm). The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable buf_y1

  Buffer to hold the intermediate position (Heun algorithm)
- real(kind=8), dimension(:), allocatable buf_f0

  Buffer to hold tendencies at the initial position.
- real(kind=8), dimension(:), allocatable buf_f1

  Buffer to hold tendencies at the intermediate position.
- real(kind=8), dimension(:), allocatable buf_ka

  Buffer A to hold tendencies.
- real(kind=8), dimension(:), allocatable buf_kb

  Buffer B to hold tendencies.

6.5.1 Detailed Description

Module with the integration routines.

Module with the RK4 integration routines.

Copyright

Remarks

This module actually contains the Heun algorithm routines. The user can modify it according to its preferred integration scheme. For higher-order schemes, additional buffers will probably have to be defined.

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Remarks

This module actually contains the RK4 algorithm routines. The user can modify it according to its preferred integration scheme. For higher-order schemes, additional buffers will probably have to be defined.

6.5.2 Function/Subroutine Documentation

6.5.2.1 subroutine public integrator::init_integrator ( )

Routine to initialise the integration buffers.

Definition at line 37 of file rk2_integrator.f90.

```
37      INTEGER :: allocstat
38      ALLOCATE(buf_y1(0:ndim),buf_f0(0:ndim),buf_f1(0:ndim) ,stat=allocstat)
39      IF (allocstat /= 0) stop "*** Not enough memory ! ***"
```

6.5.2.2 subroutine public integrator::step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *res*)

Routine to perform an integration step (Heun algorithm). The incremented time is returned.

Routine to perform an integration step (RK4 algorithm). The incremented time is returned.

Parameters

y	Initial point.
t	Actual integration time
dt	Integration timestep.
res	Final point after the step.

Definition at line 61 of file rk2_integrator.f90.

```
61     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y
62     REAL(KIND=8), INTENT(INOUT) :: t
63     REAL(KIND=8), INTENT(IN) :: dt
64     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
65
66     CALL tendencies(t,y,buf_f0)
67     buf_y1 = y+dt*buf_f0
68     CALL tendencies(t+dt,buf_y1,buf_f1)
69     res=y+0.5*(buf_f0+buf_f1)*dt
70     t=t+dt
```

6.5.2.3 subroutine integrator::tendencies (real(kind=8), intent(in) *t*, real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(out) *res*) [private]

Routine computing the tendencies of the model.

Parameters

t	Time at which the tendencies have to be computed. Actually not needed for autonomous systems.
y	Point at which the tendencies have to be computed.
res	vector to store the result.

Remarks

Note that it is NOT safe to pass `y` as a result buffer, as this operation does multiple passes.

Definition at line 49 of file rk2_integrator.f90.

```
49     REAL(KIND=8), INTENT(IN) :: t
50     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y
51     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
52     CALL sparse_mul3(aotensor, y, y, res)
```

6.5.3 Variable Documentation

6.5.3.1 real(kind=8), dimension(:), allocatable integrator::buf_f0 [private]

Buffer to hold tendencies at the initial position.

Definition at line 28 of file rk2_integrator.f90.

```
28   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f0 !< Buffer to hold tendencies at the initial position
```

6.5.3.2 real(kind=8), dimension(:), allocatable integrator::buf_f1 [private]

Buffer to hold tendencies at the intermediate position.

Definition at line 29 of file rk2_integrator.f90.

```
29   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f1 !< Buffer to hold tendencies at the intermediate
       position
```

6.5.3.3 real(kind=8), dimension(:), allocatable integrator::buf_ka [private]

Buffer A to hold tendencies.

Definition at line 28 of file rk4_integrator.f90.

```
28    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_ka !< Buffer A to hold tendencies
```

6.5.3.4 real(kind=8), dimension(:), allocatable integrator::buf_kb [private]

Buffer B to hold tendencies.

Definition at line 29 of file rk4_integrator.f90.

```
29    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kb !< Buffer B to hold tendencies
```

6.5.3.5 real(kind=8), dimension(:), allocatable integrator::buf_y1 [private]

Buffer to hold the intermediate position (Heun algorithm)

Definition at line 27 of file rk2_integrator.f90.

```
27    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_y1 !< Buffer to hold the intermediate position (Heun
        algorithm)
```

6.6 lyap_stat Module Reference

Statistics accumulators for the Lyapunov exponents.

Functions/Subroutines

- subroutine, public lyap_init_stat

    Initialise the accumulators.
- subroutine, public lyap_acc (x)

    Accumulate one state.
- real(kind=8) function, dimension(0:ndim), public lyap_mean ()

    Function returning the mean.
- real(kind=8) function, dimension(0:ndim), public lyap_var ()

    Function returning the variance.
- integer function, public lyap_iter ()

    Function returning the number of data accumulated.
- subroutine, public lyap_reset

    Routine resetting the accumulators.

Variables

- integer i =0
  Number of stats accumulated.
- real(kind=8), dimension(:), allocatable m
  Vector storing the inline mean.
- real(kind=8), dimension(:), allocatable mprev
  Previous mean vector.
- real(kind=8), dimension(:), allocatable v
  Vector storing the inline variance.
- real(kind=8), dimension(:), allocatable mtmp

6.6.1 Detailed Description

Statistics accumulators for the Lyapunov exponents.

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6.6.2 Function/Subroutine Documentation

6.6.2.1 subroutine, public lyap_stat::lyap_acc (real(kind=8), dimension(0:ndim), intent(in) *x*)

Accumulate one state.

Definition at line 48 of file lyap_stat.f90.

```
48        IMPLICIT NONE
49        REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: x
50        i=i+1
51        mprev=m+(x-m)/i
52        mtmp=mprev
53        mprev=m
54        m=mtmp
55        v=v+(x-mprev)*(x-m)
```

6.6.2.2 subroutine, public lyap_stat::lyap_init_stat ( )

Initialise the accumulators.

Definition at line 35 of file lyap_stat.f90.

```
35        INTEGER :: allocstat
36
37        ALLOCATE(m(0:ndim),mprev(0:ndim),v(0:ndim),mtmp(0:ndim), stat=allocstat)
38        IF (allocstat /= 0) stop '*** Not enough memory ***'
39        m=0.d0
40        mprev=0.d0
41        v=0.d0
42        mtmp=0.d0
43
```

6.6.2.3 integer function, public lyap_stat::lyap_iter ( )

Function returning the number of data accumulated.

Definition at line 72 of file lyap_stat.f90.

```
72      INTEGER :: lyap_iter
73      lyap_iter=i
```

6.6.2.4 real(kind=8) function, dimension(0:ndim), public lyap_stat::lyap_mean ( )

Function returning the mean.

Definition at line 60 of file lyap_stat.f90.

```
60      REAL(KIND=8), DIMENSION(0:ndim) :: lyap_mean
61      lyap_mean=m
```

6.6.2.5 subroutine, public lyap_stat::lyap_reset ( )

Routine resetting the accumulators.

Definition at line 78 of file lyap_stat.f90.

```
78      m=0.d0
79      mprev=0.d0
80      v=0.d0
81      i=0
```

6.6.2.6 real(kind=8) function, dimension(0:ndim), public lyap_stat::lyap_var ( )

Function returning the variance.

Definition at line 66 of file lyap_stat.f90.

```
66      REAL(KIND=8), DIMENSION(0:ndim) :: lyap_var
67      lyap_var=v/(i-1)
```

6.6.3 Variable Documentation

6.6.3.1 integer lyap_stat::i =0 [private]

Number of stats accumulated.

Definition at line 20 of file lyap_stat.f90.

```
20  INTEGER :: i=0 !< Number of stats accumulated
```

6.6.3.2 real(kind=8), dimension(:), allocatable lyap_stat::m [private]

Vector storing the inline mean.

Definition at line 23 of file lyap_stat.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: m       !< Vector storing the inline mean
```

6.6.3.3 real(kind=8), dimension(:), allocatable lyap_stat::mprev [private]

Previous mean vector.

Definition at line 24 of file lyap_stat.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: mprev   !< Previous mean vector
```

6.6.3.4 real(kind=8), dimension(:), allocatable lyap_stat::mtmp [private]

Definition at line 26 of file lyap_stat.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: mtmp
```

6.6.3.5 real(kind=8), dimension(:), allocatable lyap_stat::v [private]

Vector storing the inline variance.

Definition at line 25 of file lyap_stat.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: v       !< Vector storing the inline variance
```

6.7 lyap_vectors Module Reference

Module for computation of Lyapunov exponents and vectors.

Functions/Subroutines

- subroutine, public init_lyap

  Initialize Lyapunov computation (possibly also vectors in later version) and initializes also a random orthogonal matrix for the matrix ensemble.
- subroutine, public multiply_prop (prop_mul)

  Multiplies prop_mul from the left with the prop matrix defined in this module and saves the result to prop_mul.
- subroutine, public benettin_step

  Performs the benettin step in integration. Multiplies the aggregated propagators in prop with ensemble and performs QR decomposition (Gram-Schmidt orthogonalization gives Q and upper triangular matrix R). Computes also the Lyapunov exponents via the diagonal of R. WATCH OUT: prop is changed during the subroutine and restored to a unit matrix.
- subroutine, public get_lyap_state (prop_ret, ensemble_ret)

  Routine that returns the current global propagator and ensemble of lyapunov vectors.

Variables

- real(kind=8), dimension(:), allocatable, public loclyap

  Buffer containing the local Lyapunov exponent.
- real(kind=8), dimension(:), allocatable, public lyapunov

  Buffer containing the averaged Lyapunov exponent.
- real(kind=8), dimension(:,:), allocatable, public ensemble

  Buffer containing the QR decompsoition of the ensemble.
- real(kind=8), dimension(:,:), allocatable prop

  Buffer holding the propagator matrix.
- integer lwork
- real(kind=8), dimension(:), allocatable work

  Temporary buffer for QR decomposition.
- real(kind=8), dimension(:), allocatable work2

  Temporary buffer for QR decomposition.
- real(kind=8), dimension(:), allocatable tau

  Temporary buffer for QR decomposition.
- real(kind=8), dimension(:,:), allocatable prop_buf

  Buffer holding the local propagator matrix.

6.7.1 Detailed Description

Module for computation of Lyapunov exponents and vectors.

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Remarks

This module contains the necessary tools to perform the Benettin steps to compute the lyapunov exponents. (Ginelli for CLV will be added later)

References : Benettin, G., Galgani, L., Giorgilli, A., & Strelcyn, J. M. (1980). Lyapunov characteristic exponents for smooth dynamical systems; a method for computing all of them. Part 2: Numerical application. *Meccanica* , 15, 21-30.

6.7.2 Function/Subroutine Documentation

6.7.2.1 subroutine, public lyap_vectors::benettin_step ( )

Performs the benettin step in integration. Multiplies the aggregated propagators in prop with ensemble and performs QR decomposition (Gram-Schmidt orthogonalization gives Q and upper triangular matrix R). Computes also the Lyapunov exponents via the diagonal of R. WATCH OUT: prop is changed during the subroutine and restored to a unit matrix.

Definition at line 99 of file lyap_vectors.f90.

```
INTEGER :: info,k

 ! Multiply the Propagator prop from the right side with the non transposed q matrix
 ! from the qr decomposition which is stored in ensemble.
 CALL dorm2r("r","n",ndim,ndim,ndim,ensemble,ndim,tau,prop,ndim,work2,info)
 ! prop contains prop*ensemble but QR decomposed(tau is needed for that as
 ! well !) => copy to ensemble
 ensemble=prop

 ! From here on ensemble contains the new information prop*ensemble
 CALL dgeqrf(ndim,ndim,ensemble,ndim,tau,work,lwork, info) ! qr decomposition

 DO k=1,ndim
   loclyap(k)=log(abs(ensemble(k,k)))/rescaling_time
 END DO

 !
 ! Add here save for
 !

 ! Initialise prop again with unit matrix
 CALL init_one(prop)

```

6.7.2.2 subroutine, public lyap_vectors::get_lyap_state (real(kind=8), dimension(ndim,ndim), intent(out) *prop_ret*, real(kind=8), dimension(ndim,ndim), intent(out) *ensemble_ret*)

Routine that returns the current global propagator and ensemble of lyapunov vectors.

Definition at line 127 of file lyap_vectors.f90.

```
127     REAL(KIND=8), DIMENSION(ndim,ndim),INTENT(OUT) :: prop_ret,ensemble_ret
128     prop_ret=prop
129     ensemble_ret=ensemble
```

6.7.2.3 subroutine, public lyap_vectors::init_lyap ( )

Initialize Lyapunov computation (possibly also vectors in later version) and initializes also a random orthogonal matrix for the matrix ensemble.

Definition at line 69 of file lyap_vectors.f90.

```
69    INTEGER :: allocstat,ilaenv,info
70    lwork=ilaenv(1,"dgeqrf"," ",ndim,ndim,ndim,-1)
71    lwork=ndim*lwork
72    ALLOCATE(prop_buf(ndim,ndim),lyapunov(ndim),loclyap(ndim),ensemble(ndim,ndim),tau(ndim),prop(ndim,ndim)
     , &
73    & work2(ndim),work(lwork),stat=allocstat)
74    IF (allocstat /= 0) stop "*** Not enough memory ! ***"
75
76    lyapunov=0.0d0
77    loclyap=0.0d0
78    CALL init_one(prop)
79    CALL random_number(ensemble)
80    ensemble=2*(ensemble-0.5)
81    CALL dgeqrf(ndim,ndim,ensemble,ndim,tau,work,lwork, info) ! qr decomposition
```

6.7.2.4 subroutine, public lyap_vectors::multiply_prop (real(kind=8), dimension(ndim,ndim), intent(in) *prop_mul*)

Multiplies prop_mul from the left with the prop matrix defined in this module and saves the result to prop_mul.

Parameters

prop_mul	local propagator to multiply with the global one

Definition at line 88 of file lyap_vectors.f90.

```
88      REAL(KIND=8), DIMENSION(ndim,ndim),INTENT(IN) :: prop_mul
89      prop_buf=prop
90      CALL dgemm ('n', 'n', ndim, ndim, ndim, 1.0d0, prop_mul, ndim,prop_buf, ndim,0.0d0, prop, ndim)
```

6.7.3 Variable Documentation

6.7.3.1 real(kind=8), dimension(:,:), allocatable, public lyap_vectors::ensemble

Buffer containing the QR decompsoition of the ensemble.

Definition at line 42 of file lyap_vectors.f90.

```
42    REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: ensemble !< Buffer containing the QR decompsoition of the
      ensemble
```

6.7.3.2 real(kind=8), dimension(:), allocatable, public lyap_vectors::loclyap

Buffer containing the local Lyapunov exponent.

Definition at line 40 of file lyap_vectors.f90.

```
40    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: loclyap    !< Buffer containing the local Lyapunov exponent
```

6.7.3.3 integer lyap_vectors::lwork [private]

Definition at line 45 of file lyap_vectors.f90.

```
45    INTEGER :: lwork
```

6.7.3.4 real(kind=8), dimension(:), allocatable, public lyap_vectors::lyapunov

Buffer containing the averaged Lyapunov exponent.

Definition at line 41 of file lyap_vectors.f90.

```
41    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: lyapunov   !< Buffer containing the averaged Lyapunov exponent
```

6.7.3.5 real(kind=8), dimension(:,:), allocatable lyap_vectors::prop [private]

Buffer holding the propagator matrix.

Definition at line 43 of file lyap_vectors.f90.

```
43    REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: prop     !< Buffer holding the propagator matrix
```

6.7.3.6 real(kind=8), dimension(:,:), allocatable lyap_vectors::prop_buf [private]

Buffer holding the local propagator matrix.

Definition at line 49 of file lyap_vectors.f90.

```
49    REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: prop_buf !< Buffer holding the local propagator matrix
```

6.7.3.7 real(kind=8), dimension(:), allocatable lyap_vectors::tau [private]

Temporary buffer for QR decomposition.

Definition at line 48 of file lyap_vectors.f90.

```
48    REAL(kind=8), DIMENSION(:), ALLOCATABLE :: tau        !< Temporary buffer for QR decomposition
```

6.7.3.8 real(kind=8), dimension(:), allocatable lyap_vectors::work [private]

Temporary buffer for QR decomposition.

Definition at line 46 of file lyap_vectors.f90.

```
46    REAL(kind=8), DIMENSION(:), ALLOCATABLE :: work       !< Temporary buffer for QR decomposition
```

6.7.3.9 real(kind=8), dimension(:), allocatable lyap_vectors::work2 [private]

Temporary buffer for QR decomposition.

Definition at line 47 of file lyap_vectors.f90.

```
47    REAL(kind=8), DIMENSION(:), ALLOCATABLE :: work2      !< Temporary buffer for QR decomposition
```

6.8 params Module Reference

The model parameters module.

Functions/Subroutines

- subroutine, private init_nml

  Read the basic parameters and mode selection from the namelist.
- subroutine init_params

  Parameters initialisation routine.

Variables

- real(kind=8) n

  $n = 2L_y/L_x$ *- Aspect ratio*
- real(kind=8) phi0

  Latitude in radian.
- real(kind=8) rra

  Earth radius.
- real(kind=8) sig0

  σ_0 *- Non-dimensional static stability of the atmosphere.*
- real(kind=8) k

  Bottom atmospheric friction coefficient.
- real(kind=8) kp

  k' *- Internal atmospheric friction coefficient.*
- real(kind=8) r

  Frictional coefficient at the bottom of the ocean.
- real(kind=8) d

  Merchanical coupling parameter between the ocean and the atmosphere.
- real(kind=8) f0

  f_0 *- Coriolis parameter*
- real(kind=8) gp

  g' *Reduced gravity*
- real(kind=8) h

  Depth of the active water layer of the ocean.
- real(kind=8) phi0_npi

  Latitude exprimed in fraction of pi.
- real(kind=8) lambda

  λ *- Sensible + turbulent heat exchange between the ocean and the atmosphere.*
- real(kind=8) co

  C_a *- Constant short-wave radiation of the ocean.*
- real(kind=8) go

  γ_o *- Specific heat capacity of the ocean.*
- real(kind=8) ca

  C_a *- Constant short-wave radiation of the atmosphere.*
- real(kind=8) to0

  T_o^0 *- Stationary solution for the 0-th order ocean temperature.*
- real(kind=8) ta0

  T_a^0 *- Stationary solution for the 0-th order atmospheric temperature.*
- real(kind=8) epsa

  ϵ_a *- Emissivity coefficient for the grey-body atmosphere.*
- real(kind=8) ga

  γ_a *- Specific heat capacity of the atmosphere.*
- real(kind=8) rr

R - *Gas constant of dry air*

- real(kind=8) scale

  $L_y = L\,\pi$ - *The characteristic space scale.*
- real(kind=8) pi

  π
- real(kind=8) lr

  L_R - *Rossby deformation radius*
- real(kind=8) g

  γ
- real(kind=8) rp

  r' - *Frictional coefficient at the bottom of the ocean.*
- real(kind=8) dp

  d' - *Non-dimensional mechanical coupling parameter between the ocean and the atmosphere.*
- real(kind=8) kd

  k_d - *Non-dimensional bottom atmospheric friction coefficient.*
- real(kind=8) kdp

  k'_d - *Non-dimensional internal atmospheric friction coefficient.*
- real(kind=8) cpo

  C'_a - *Non-dimensional constant short-wave radiation of the ocean.*
- real(kind=8) lpo

  λ'_o - *Non-dimensional sensible + turbulent heat exchange from ocean to atmosphere.*
- real(kind=8) cpa

  C'_a - *Non-dimensional constant short-wave radiation of the atmosphere.*
- real(kind=8) lpa

  λ'_a - *Non-dimensional sensible + turbulent heat exchange from atmosphere to ocean.*
- real(kind=8) sbpo

  $\sigma'_{B,o}$ - *Long wave radiation lost by ocean to atmosphere & space.*
- real(kind=8) sbpa

  $\sigma'_{B,a}$ - *Long wave radiation from atmosphere absorbed by ocean.*
- real(kind=8) lsbpo

  $S'_{B,o}$ - *Long wave radiation from ocean absorbed by atmosphere.*
- real(kind=8) lsbpa

  $S'_{B,a}$ - *Long wave radiation lost by atmosphere to space & ocean.*
- real(kind=8) l

  L - *Domain length scale*
- real(kind=8) sc

  Ratio of surface to atmosphere temperature.
- real(kind=8) sb

  Stefan–Boltzmann constant.
- real(kind=8) betp

  β' - *Non-dimensional beta parameter*
- real(kind=8) nua =0.D0

  Dissipation in the atmosphere.
- real(kind=8) nuo =0.D0

  Dissipation in the ocean.
- real(kind=8) nuap

  Non-dimensional dissipation in the atmosphere.
- real(kind=8) nuop

  Non-dimensional dissipation in the ocean.
- real(kind=8) t_trans

  Transient time period.

- real(kind=8) t_run

  Effective intergration time (length of the generated trajectory)
- real(kind=8) dt

  Integration time step.
- real(kind=8) tw

  Write all variables every tw time units.
- logical writeout

  Write to file boolean.
- real(kind=8) rescaling_time

  Rescaling time for the Lyapunov computation.
- integer nboc

  Number of atmospheric blocks.
- integer nbatm

  Number of oceanic blocks.
- integer natm =0

  Number of atmospheric basis functions.
- integer noc =0

  Number of oceanic basis functions.
- integer ndim

  Number of variables (dimension of the model)
- integer, dimension(:,:), allocatable oms

  Ocean mode selection array.
- integer, dimension(:,:), allocatable ams

  Atmospheric mode selection array.

6.8.1 Detailed Description

The model parameters module.

Copyright

Remarks

Once the init_params() subroutine is called, the parameters are loaded globally in the main program and its subroutines and function

6.8.2 Function/Subroutine Documentation

6.8.2.1 subroutine, private params::init_nml ( ) [private]

Read the basic parameters and mode selection from the namelist.

Definition at line 99 of file params.f90.

```
   INTEGER :: allocstat

    namelist /aoscale/  scale,f0,n,rra,phi0_npi
    namelist /oparams/  gp,r,h,d,nuo
    namelist /aparams/  k,kp,sig0,nua
    namelist /toparams/ go,co,to0
    namelist /taparams/ ga,ca,epsa,ta0
    namelist /otparams/ sc,lambda,rr,sb

    namelist /modeselection/ oms,ams
    namelist /numblocs/ nboc,nbatm

    namelist /int_params/ t_trans,t_run,dt,tw,writeout
    namelist /lyap_params/ rescaling_time

    OPEN(8, file="params.nml", status='OLD', recl=80, delim='APOSTROPHE')

    READ(8,nml=aoscale)
    READ(8,nml=oparams)
    READ(8,nml=aparams)
    READ(8,nml=toparams)
    READ(8,nml=taparams)
    READ(8,nml=otparams)

    CLOSE(8)

    OPEN(8, file="modeselection.nml", status='OLD', recl=80, delim='APOSTROPHE')
    READ(8,nml=numblocs)

    ALLOCATE(oms(nboc,2),ams(nbatm,2), stat=allocstat)
    IF (allocstat /= 0) stop "*** Not enough memory ! ***"

    READ(8,nml=modeselection)
    CLOSE(8)

    OPEN(8, file="int_params.nml", status='OLD', recl=80, delim='APOSTROPHE')
    READ(8,nml=int_params)
    READ(8,nml=lyap_params)

```

6.8.2.2 subroutine params::init_params ( )

Parameters initialisation routine.

Definition at line 142 of file params.f90.

```
142    INTEGER, DIMENSION(2) :: s
143    INTEGER :: i
144    CALL init_nml
145
146    !---------------------------------------------------------!
147    !                                                         !
148    ! Computation of the dimension of the atmospheric         !
149    ! and oceanic components                                  !
150    !                                                         !
151    !---------------------------------------------------------!
152
153    natm=0
154    DO i=1,nbatm
155       IF (ams(i,1)==1) THEN
156          natm=natm+3
157       ELSE
158          natm=natm+2
159       ENDIF
160    ENDDO
161    s=shape(oms)
162    noc=s(1)
163
164    ndim=2*natm+2*noc
165
166    !---------------------------------------------------------!
167    !                                                         !
168    ! Some general parameters (Domain, beta, gamma, coupling) !
169    !                                                         !
170    !---------------------------------------------------------!
171
172    pi=dacos(-1.d0)
173    l=scale/pi
174    phi0=phi0_npi*pi
```

```
    lr=sqrt(gp*h)/f0
    g=-l**2/lr**2
    betp=l/rra*cos(phi0)/sin(phi0)
    rp=r/f0
    dp=d/f0
    kd=k*2
    kdp=kp

    !-----------------------------------------------------!
    !                                                     !
    ! DERIVED QUANTITIES                                  !
    !                                                     !
    !-----------------------------------------------------!

    cpo=co/(go*f0) * rr/(f0**2*l**2)
    lpo=lambda/(go*f0)
    cpa=ca/(ga*f0) * rr/(f0**2*l**2)/2 ! Cpa acts on psi1-psi3, not on theta
    lpa=lambda/(ga*f0)
    sbpo=4*sb*to0**3/(go*f0) ! long wave radiation lost by ocean to atmosphere space
    sbpa=8*epsa*sb*ta0**3/(go*f0) ! long wave radiation from atmosphere absorbed by ocean
    lsbpo=2*epsa*sb*to0**3/(ga*f0) ! long wave radiation from ocean absorbed by atmosphere
    lsbpa=8*epsa*sb*ta0**3/(ga*f0) ! long wave radiation lost by atmosphere to space & ocea
    nuap=nua/(f0*l**2)
    nuop=nuo/(f0*l**2)

```

6.8.3 Variable Documentation

6.8.3.1 integer, dimension(:,:), allocatable params::ams

Atmospheric mode selection array.

Definition at line 89 of file params.f90.

```
89   INTEGER, DIMENSION(:,:), ALLOCATABLE :: ams   !< Atmospheric mode selection array
```

6.8.3.2 real(kind=8) params::betp

β' - Non-dimensional beta parameter

Definition at line 67 of file params.f90.

```
67   REAL(KIND=8) :: betp      !< \f$\beta'\f$ - Non-dimensional beta parameter
```

6.8.3.3 real(kind=8) params::ca

C_a - Constant short-wave radiation of the atmosphere.

Definition at line 40 of file params.f90.

```
40   REAL(KIND=8) :: ca        !< \f$C_a\f$ - Constant short-wave radiation of the atmosphere.
```

6.8.3.4 real(kind=8) params::co

C_a - Constant short-wave radiation of the ocean.

Definition at line 38 of file params.f90.

```
38    REAL(KIND=8) :: co        !< \f$C_a\f$ - Constant short-wave radiation of the ocean.
```

6.8.3.5 real(kind=8) params::cpa

C'_a - Non-dimensional constant short-wave radiation of the atmosphere.

Remarks

Cpa acts on psi1-psi3, not on theta.

Definition at line 58 of file params.f90.

```
58    REAL(KIND=8) :: cpa       !< \f$C'_a\f$ - Non-dimensional constant short-wave radiation of the
        atmosphere. @remark Cpa acts on psi1-psi3, not on theta.
```

6.8.3.6 real(kind=8) params::cpo

C'_a - Non-dimensional constant short-wave radiation of the ocean.

Definition at line 56 of file params.f90.

```
56    REAL(KIND=8) :: cpo       !< \f$C'_a\f$ - Non-dimensional constant short-wave radiation of the ocean.
```

6.8.3.7 real(kind=8) params::d

Merchanical coupling parameter between the ocean and the atmosphere.

Definition at line 31 of file params.f90.

```
31    REAL(KIND=8) :: d         !< Merchanical coupling parameter between the ocean and the atmosphere.
```

6.8.3.8 real(kind=8) params::dp

d' - Non-dimensional mechanical coupling parameter between the ocean and the atmosphere.

Definition at line 52 of file params.f90.

```
52    REAL(KIND=8) :: dp        !< \f$d'\f$ - Non-dimensional mechanical coupling parameter between the ocean
        and the atmosphere.
```

6.8.3.9 real(kind=8) params::dt

Integration time step.

Definition at line 77 of file params.f90.

```
77    REAL(KIND=8) :: dt        !< Integration time step
```

6.8.3.10 real(kind=8) params::epsa

ϵ_a - Emissivity coefficient for the grey-body atmosphere.

Definition at line 43 of file params.f90.

```
43    REAL(KIND=8) :: epsa      !< \f$\epsilon_a\f$ - Emissivity coefficient for the grey-body atmosphere.
```

6.8.3.11 real(kind=8) params::f0

f_0 - Coriolis parameter

Definition at line 32 of file params.f90.

```
32    REAL(KIND=8) :: f0        !< \f$f_0\f$ - Coriolis parameter
```

6.8.3.12 real(kind=8) params::g

γ

Definition at line 50 of file params.f90.

```
50    REAL(KIND=8) :: g         !< \f$\gamma\f$
```

6.8.3.13 real(kind=8) params::ga

γ_a - Specific heat capacity of the atmosphere.

Definition at line 44 of file params.f90.

```
44    REAL(KIND=8) :: ga        !< \f$\gamma_a\f$ - Specific heat capacity of the atmosphere.
```

6.8.3.14 real(kind=8) params::go

γ_o - Specific heat capacity of the ocean.

Definition at line 39 of file params.f90.

```
39 REAL(KIND=8) :: go        !< \f$\gamma_o\f$ - Specific heat capacity of the ocean.
```

6.8.3.15 real(kind=8) params::gp

g'Reduced gravity

Definition at line 33 of file params.f90.

```
33 REAL(KIND=8) :: gp        !< \f$g'\f$Reduced gravity
```

6.8.3.16 real(kind=8) params::h

Depth of the active water layer of the ocean.

Definition at line 34 of file params.f90.

```
34 REAL(KIND=8) :: h         !< Depth of the active water layer of the ocean.
```

6.8.3.17 real(kind=8) params::k

Bottom atmospheric friction coefficient.

Definition at line 28 of file params.f90.

```
28 REAL(KIND=8) :: k         !< Bottom atmospheric friction coefficient.
```

6.8.3.18 real(kind=8) params::kd

k_d - Non-dimensional bottom atmospheric friction coefficient.

Definition at line 53 of file params.f90.

```
53 REAL(KIND=8) :: kd        !< \f$k_d\f$ - Non-dimensional bottom atmospheric friction coefficient.
```

6.8.3.19 real(kind=8) params::kdp

k'_d - Non-dimensional internal atmospheric friction coefficient.

Definition at line 54 of file params.f90.

```
54    REAL(KIND=8) :: kdp       !< \f$k'_d\f$ - Non-dimensional internal atmospheric friction coefficient.
```

6.8.3.20 real(kind=8) params::kp

k' - Internal atmospheric friction coefficient.

Definition at line 29 of file params.f90.

```
29    REAL(KIND=8) :: kp        !< \f$k'\f$ - Internal atmospheric friction coefficient.
```

6.8.3.21 real(kind=8) params::l

L - Domain length scale

Definition at line 64 of file params.f90.

```
64    REAL(KIND=8) :: l         !< \f$L\f$ - Domain length scale
```

6.8.3.22 real(kind=8) params::lambda

λ - Sensible + turbulent heat exchange between the ocean and the atmosphere.

Definition at line 37 of file params.f90.

```
37    REAL(KIND=8) :: lambda    !< \f$\lambda\f$ - Sensible + turbulent heat exchange between the ocean and the
        atmosphere.
```

6.8.3.23 real(kind=8) params::lpa

λ'_a - Non-dimensional sensible + turbulent heat exchange from atmosphere to ocean.

Definition at line 59 of file params.f90.

```
59    REAL(KIND=8) :: lpa       !< \f$\lambda'_a\f$ - Non-dimensional sensible + turbulent heat exchange from
        atmosphere to ocean.
```

6.8.3.24 real(kind=8) params::lpo

λ'_o - Non-dimensional sensible + turbulent heat exchange from ocean to atmosphere.

Definition at line 57 of file params.f90.

```
57 REAL(KIND=8) :: lpo       !< \f$\lambda'_o\f$ - Non-dimensional sensible + turbulent heat exchange from
     ocean to atmosphere.
```

6.8.3.25 real(kind=8) params::lr

L_R - Rossby deformation radius

Definition at line 49 of file params.f90.

```
49 REAL(KIND=8) :: lr        !< \f$L_R\f$ - Rossby deformation radius
```

6.8.3.26 real(kind=8) params::lsbpa

$S'_{B,a}$ - Long wave radiation lost by atmosphere to space & ocean.

Definition at line 63 of file params.f90.

```
63 REAL(KIND=8) :: lsbpa     !< \f$S'_{B,a}\f$ - Long wave radiation lost by atmosphere to space & ocean.
```

6.8.3.27 real(kind=8) params::lsbpo

$S'_{B,o}$ - Long wave radiation from ocean absorbed by atmosphere.

Definition at line 62 of file params.f90.

```
62 REAL(KIND=8) :: lsbpo     !< \f$S'_{B,o}\f$ - Long wave radiation from ocean absorbed by atmosphere.
```

6.8.3.28 real(kind=8) params::n

$n = 2L_y/L_x$ - Aspect ratio

Definition at line 24 of file params.f90.

```
24 REAL(KIND=8) :: n         !< \f$n = 2 L_y / L_x\f$ - Aspect ratio
```

6.8.3.29 integer params::natm =0

Number of atmospheric basis functions.

Definition at line 85 of file params.f90.

```
85   INTEGER :: natm=0 !< Number of atmospheric basis functions
```

6.8.3.30 integer params::nbatm

Number of oceanic blocks.

Definition at line 84 of file params.f90.

```
84   INTEGER :: nbatm  !< Number of oceanic blocks
```

6.8.3.31 integer params::nboc

Number of atmospheric blocks.

Definition at line 83 of file params.f90.

```
83   INTEGER :: nboc   !< Number of atmospheric blocks
```

6.8.3.32 integer params::ndim

Number of variables (dimension of the model)

Definition at line 87 of file params.f90.

```
87   INTEGER :: ndim   !< Number of variables (dimension of the model)
```

6.8.3.33 integer params::noc =0

Number of oceanic basis functions.

Definition at line 86 of file params.f90.

```
86   INTEGER :: noc=0  !< Number of oceanic basis functions
```

6.8.3.34 real(kind=8) params::nua =0.D0

Dissipation in the atmosphere.

Definition at line 69 of file params.f90.

```
69   REAL(KIND=8) :: nua=0.d0  !< Dissipation in the atmosphere
```

6.8.3.35 real(kind=8) params::nuap

Non-dimensional dissipation in the atmosphere.

Definition at line 72 of file params.f90.

```
72   REAL(KIND=8) :: nuap      !< Non-dimensional dissipation in the atmosphere
```

6.8.3.36 real(kind=8) params::nuo =0.D0

Dissipation in the ocean.

Definition at line 70 of file params.f90.

```
70   REAL(KIND=8) :: nuo=0.d0  !< Dissipation in the ocean
```

6.8.3.37 real(kind=8) params::nuop

Non-dimensional dissipation in the ocean.

Definition at line 73 of file params.f90.

```
73   REAL(KIND=8) :: nuop      !< Non-dimensional dissipation in the ocean
```

6.8.3.38 integer, dimension(:,:), allocatable params::oms

Ocean mode selection array.

Definition at line 88 of file params.f90.

```
88   INTEGER, DIMENSION(:,:), ALLOCATABLE :: oms   !< Ocean mode selection array
```

6.8.3.39 real(kind=8) params::phi0

Latitude in radian.

Definition at line 25 of file params.f90.

```
25 REAL(KIND=8) :: phi0      !< Latitude in radian
```

6.8.3.40 real(kind=8) params::phi0_npi

Latitude exprimed in fraction of pi.

Definition at line 35 of file params.f90.

```
35 REAL(KIND=8) :: phi0_npi  !< Latitude exprimed in fraction of pi.
```

6.8.3.41 real(kind=8) params::pi

π

Definition at line 48 of file params.f90.

```
48 REAL(KIND=8) :: pi        !< \f$\pi\f$
```

6.8.3.42 real(kind=8) params::r

Frictional coefficient at the bottom of the ocean.

Definition at line 30 of file params.f90.

```
30 REAL(KIND=8) :: r         !< Frictional coefficient at the bottom of the ocean.
```

6.8.3.43 real(kind=8) params::rescaling_time

Rescaling time for the Lyapunov computation.

Definition at line 81 of file params.f90.

```
81 REAL(KIND=8) :: rescaling_time !< Rescaling time for the Lyapunov computation
```

6.8.3.44 real(kind=8) params::rp

r' - Frictional coefficient at the bottom of the ocean.

Definition at line 51 of file params.f90.

```
51    REAL(KIND=8) :: rp        !< \f$r'\f$ - Frictional coefficient at the bottom of the ocean.
```

6.8.3.45 real(kind=8) params::rr

R - Gas constant of dry air

Definition at line 45 of file params.f90.

```
45    REAL(KIND=8) :: rr        !< \f$R\f$ - Gas constant of dry air
```

6.8.3.46 real(kind=8) params::rra

Earth radius.

Definition at line 26 of file params.f90.

```
26    REAL(KIND=8) :: rra       !< Earth radius
```

6.8.3.47 real(kind=8) params::sb

Stefan–Boltzmann constant.

Definition at line 66 of file params.f90.

```
66    REAL(KIND=8) :: sb        !< Stefan-Boltzmann constant
```

6.8.3.48 real(kind=8) params::sbpa

$\sigma'_{B,a}$ - Long wave radiation from atmosphere absorbed by ocean.

Definition at line 61 of file params.f90.

```
61    REAL(KIND=8) :: sbpa      !< \f$\sigma'_{B,a}\f$ - Long wave radiation from atmosphere absorbed by ocean.
```

6.8.3.49 real(kind=8) params::sbpo

$\sigma'_{B,o}$ - Long wave radiation lost by ocean to atmosphere & space.

Definition at line 60 of file params.f90.

```
60   REAL(KIND=8) :: sbpo       !< \f$\sigma'_{B,o}\f$ - Long wave radiation lost by ocean to atmosphere &
       space.
```

6.8.3.50 real(kind=8) params::sc

Ratio of surface to atmosphere temperature.

Definition at line 65 of file params.f90.

```
65   REAL(KIND=8) :: sc         !< Ratio of surface to atmosphere temperature.
```

6.8.3.51 real(kind=8) params::scale

$L_y = L\,\pi$ - The characteristic space scale.

Definition at line 47 of file params.f90.

```
47   REAL(KIND=8) :: scale      !< \f$L_y = L \, \pi\f$ - The characteristic space scale.
```

6.8.3.52 real(kind=8) params::sig0

σ_0 - Non-dimensional static stability of the atmosphere.

Definition at line 27 of file params.f90.

```
27   REAL(KIND=8) :: sig0       !< \f$\sigma_0\f$ - Non-dimensional static stability of the atmosphere.
```

6.8.3.53 real(kind=8) params::t_run

Effective intergration time (length of the generated trajectory)

Definition at line 76 of file params.f90.

```
76   REAL(KIND=8) :: t_run      !< Effective intergration time (length of the generated trajectory)
```

6.8.3.54 real(kind=8) params::t_trans

Transient time period.

Definition at line 75 of file params.f90.

```
75   REAL(KIND=8) :: t_trans   !< Transient time period
```

6.8.3.55 real(kind=8) params::ta0

T_a^0 - Stationary solution for the 0-th order atmospheric temperature.

Definition at line 42 of file params.f90.

```
42   REAL(KIND=8) :: ta0       !< \f$T_a^0\f$ -  Stationary solution for the 0-th order atmospheric
       temperature.
```

6.8.3.56 real(kind=8) params::to0

T_o^0 - Stationary solution for the 0-th order ocean temperature.

Definition at line 41 of file params.f90.

```
41   REAL(KIND=8) :: to0       !< \f$T_o^0\f$ -  Stationary solution for the 0-th order ocean temperature.
```

6.8.3.57 real(kind=8) params::tw

Write all variables every tw time units.

Definition at line 78 of file params.f90.

```
78   REAL(KIND=8) :: tw        !< Write all variables every tw time units
```

6.8.3.58 logical params::writeout

Write to file boolean.

Definition at line 79 of file params.f90.

```
79   LOGICAL :: writeout       !< Write to file boolean
```

6.9 stat Module Reference

Statistics accumulators.

Functions/Subroutines

- subroutine, public init_stat

  Initialise the accumulators.
- subroutine, public acc (x)

  Accumulate one state.
- real(kind=8) function, dimension(0:ndim), public mean ()

  Function returning the mean.
- real(kind=8) function, dimension(0:ndim), public var ()

  Function returning the variance.
- integer function, public iter ()

  Function returning the number of data accumulated.
- subroutine, public reset

  Routine resetting the accumulators.

Variables

- integer i =0

  Number of stats accumulated.
- real(kind=8), dimension(:), allocatable m

  Vector storing the inline mean.
- real(kind=8), dimension(:), allocatable mprev

  Previous mean vector.
- real(kind=8), dimension(:), allocatable v

  Vector storing the inline variance.
- real(kind=8), dimension(:), allocatable mtmp

6.9.1 Detailed Description

Statistics accumulators.

Copyright

6.9.2 Function/Subroutine Documentation

6.9.2.1 subroutine, public stat::acc (real(kind=8), dimension(0:ndim), intent(in) *x*)

Accumulate one state.

Definition at line 48 of file stat.f90.

```
IMPLICIT NONE
REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: x
i=i+1
mprev=m+(x-m)/i
mtmp=mprev
mprev=m
m=mtmp
v=v+(x-mprev)*(x-m)
```

6.9.2.2 subroutine, public stat::init_stat ( )

Initialise the accumulators.

Definition at line 35 of file stat.f90.

```
35        INTEGER :: allocstat
36
37        ALLOCATE(m(0:ndim),mprev(0:ndim),v(0:ndim),mtmp(0:ndim), stat=allocstat)
38        IF (allocstat /= 0) stop '*** Not enough memory ***'
39        m=0.d0
40        mprev=0.d0
41        v=0.d0
42        mtmp=0.d0
43
```

6.9.2.3 integer function, public stat::iter ( )

Function returning the number of data accumulated.

Definition at line 72 of file stat.f90.

```
72        INTEGER :: iter
73        iter=i
```

6.9.2.4 real(kind=8) function, dimension(0:ndim), public stat::mean ( )

Function returning the mean.

Definition at line 60 of file stat.f90.

```
60        REAL(KIND=8), DIMENSION(0:ndim) :: mean
61        mean=m
```

6.9.2.5 subroutine, public stat::reset ( )

Routine resetting the accumulators.

Definition at line 78 of file stat.f90.

```
78        m=0.d0
79        mprev=0.d0
80        v=0.d0
81        i=0
```

6.9.2.6 real(kind=8) function, dimension(0:ndim), public stat::var ( )

Function returning the variance.

Definition at line 66 of file stat.f90.

```
66        REAL(KIND=8), DIMENSION(0:ndim) :: var
67        var=v/(i-1)
```

6.9.3 Variable Documentation

6.9.3.1 integer stat::i =0 [private]

Number of stats accumulated.

Definition at line 20 of file stat.f90.

```
20    INTEGER :: i=0 !< Number of stats accumulated
```

6.9.3.2 real(kind=8), dimension(:), allocatable stat::m [private]

Vector storing the inline mean.

Definition at line 23 of file stat.f90.

```
23    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: m       !< Vector storing the inline mean
```

6.9.3.3 real(kind=8), dimension(:), allocatable stat::mprev [private]

Previous mean vector.

Definition at line 24 of file stat.f90.

```
24    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: mprev   !< Previous mean vector
```

6.9.3.4 real(kind=8), dimension(:), allocatable stat::mtmp [private]

Definition at line 26 of file stat.f90.

```
26    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: mtmp
```

6.9.3.5 real(kind=8), dimension(:), allocatable stat::v [private]

Vector storing the inline variance.

Definition at line 25 of file stat.f90.

```
25    REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: v       !< Vector storing the inline variance
```

6.10 tensor Module Reference

Tensor utility module.

Data Types

- type coolist

    Coordinate list. Type used to represent the sparse tensor.
- type coolist_elem

    Coordinate list element type. Elementary elements of the sparse tensors.

Functions/Subroutines

- subroutine, public copy_coo (src, dst)

    Routine to copy a coolist.
- subroutine, public mat_to_coo (src, dst)

    Routine to convert a matrix to a tensor.
- subroutine, public sparse_mul3 (coolist_ijk, arr_j, arr_k, res)

    Sparse multiplication of a tensor with two vectors: $\sum_{j,k=0}^{ndim} \mathcal{T}_{i,j,k} \, a_j \, b_k$.
- subroutine, public jsparse_mul (coolist_ijk, arr_j, jcoo_ij)

    Sparse multiplication of two tensors to determine the Jacobian:

    $$J_{i,j} = \sum_{k=0}^{ndim} \left(\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j} \right) \, a_k.$$

    It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$*, we add to* $J_{i,j}$ *as follows:*

    $$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k} \, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k} \, a_j$$

    This version return a coolist (sparse tensor).
- subroutine, public jsparse_mul_mat (coolist_ijk, arr_j, jcoo_ij)

    Sparse multiplication of two tensors to determine the Jacobian:

    $$J_{i,j} = \sum_{k=0}^{ndim} \left(\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j} \right) \, a_k.$$

    It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$*, we add to* $J_{i,j}$ *as follows:*

    $$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k} \, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k} \, a_j$$

    This version return a matrix.
- subroutine, public sparse_mul2 (coolist_ij, arr_j, res)

    Sparse multiplication of a 2d sparse tensor with a vector: $\sum_{j=0}^{ndim} \mathcal{T}_{i,j,k} \, a_j$.
- subroutine, public simplify (tensor)

    Routine to simplify a coolist (sparse tensor). For each index i*, it upper triangularize the matrix*

    $$\mathcal{T}_{i,j,k} \qquad 0 \leq j,k \leq ndim.$$

    .
- subroutine, public add_elem (t, i, j, k, v)

    Subroutine to add element to a coolist.
- subroutine, public add_check (t, i, j, k, v, dst)

    Subroutine to add element to a coolist and check for overflow. Once the t buffer tensor is full, add it to the destination buffer.
- subroutine, public add_to_tensor (src, dst)

    Routine to add a rank-3 tensor to another one.
- subroutine, public print_tensor (t, s)

    Routine to print a rank 3 tensor coolist.
- subroutine, public write_tensor_to_file (s, t)

    Load a rank-4 tensor coolist from a file definition.
- subroutine, public load_tensor_from_file (s, t)

    Load a rank-4 tensor coolist from a file definition.

Variables

- real(kind=8), parameter real_eps = 2.2204460492503131e-16
  Parameter to test the equality with zero.

6.10.1 Detailed Description

Tensor utility module.

Copyright

6.10.2 Function/Subroutine Documentation

6.10.2.1 subroutine, public tensor::add_check (type(coolist), dimension(ndim), intent(inout) *t*, integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*, type(coolist), dimension(ndim), intent(inout) *dst*)

Subroutine to add element to a coolist and check for overflow. Once the t buffer tensor is full, add it to the destination buffer.

Parameters

t	temporary buffer tensor for the destination tensor
i	tensor i index
j	tensor j index
k	tensor k index
v	value to add
dst	destination tensor

Definition at line 303 of file tensor.f90.

```
TYPE(coolist), DIMENSION(ndim), INTENT(INOUT) :: t
TYPE(coolist), DIMENSION(ndim), INTENT(INOUT) :: dst
INTEGER, INTENT(IN) :: i,j,k
REAL(KIND=8), INTENT(IN) :: v
INTEGER :: n
CALL add_elem(t,i,j,k,v)
IF (t(i)%nelems==size(t(i)%elems)) THEN
   CALL add_to_tensor(t,dst)
   DO n=1,ndim
      t(n)%nelems=0
   ENDDO
ENDIF
```

6.10.2.2 subroutine, public tensor::add_elem (type(coolist), dimension(ndim), intent(inout) *t*, integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*)

Subroutine to add element to a coolist.

Parameters

t	destination tensor
i	tensor i index
j	tensor j index
k	tensor k index
v	value to add

Definition at line 281 of file tensor.f90.

```
281     TYPE(coolist), DIMENSION(ndim), INTENT(INOUT) :: t
282     INTEGER, INTENT(IN) :: i,j,k
283     REAL(KIND=8), INTENT(IN) :: v
284     INTEGER :: n
285     IF (abs(v) .ge. real_eps) THEN
286        n=(t(i)%nelems)+1
287        t(i)%elems(n)%j=j
288        t(i)%elems(n)%k=k
289        t(i)%elems(n)%v=v
290        t(i)%nelems=n
291     END IF
```

6.10.2.3 subroutine, public tensor::add_to_tensor (type(coolist), dimension(ndim), intent(in) *src*, type(coolist), dimension(ndim), intent(inout) *dst*)

Routine to add a rank-3 tensor to another one.

Parameters

src	Tensor to add
dst	Destination tensor

Definition at line 321 of file tensor.f90.

```
321     TYPE(coolist), DIMENSION(ndim), INTENT(IN) :: src
322     TYPE(coolist), DIMENSION(ndim), INTENT(INOUT) :: dst
323     TYPE(coolist_elem), DIMENSION(:), ALLOCATABLE :: celems
324     INTEGER :: i,j,n,allocstat
325
326     DO i=1,ndim
327        IF (src(i)%nelems/=0) THEN
328           IF (dst(i)%nelems==0) THEN
329              IF (ALLOCATED(dst(i)%elems)) THEN
330                 DEALLOCATE(dst(i)%elems, stat=allocstat)
331                 IF (allocstat /= 0) stop "*** Deallocation problem ! ***"
332              ENDIF
333              ALLOCATE(dst(i)%elems(src(i)%nelems), stat=allocstat)
334              IF (allocstat /= 0) stop "*** Not enough memory ! ***"
335              n=0
336           ELSE
337              n=dst(i)%nelems
338              ALLOCATE(celems(n), stat=allocstat)
339              DO j=1,n
340                 celems(j)%j=dst(i)%elems(j)%j
341                 celems(j)%k=dst(i)%elems(j)%k
342                 celems(j)%v=dst(i)%elems(j)%v
343              ENDDO
344              DEALLOCATE(dst(i)%elems, stat=allocstat)
345              IF (allocstat /= 0) stop "*** Deallocation problem ! ***"
346              ALLOCATE(dst(i)%elems(src(i)%nelems+n), stat=allocstat)
347              IF (allocstat /= 0) stop "*** Not enough memory ! ***"
348              DO j=1,n
349                 dst(i)%elems(j)%j=celems(j)%j
350                 dst(i)%elems(j)%k=celems(j)%k
351                 dst(i)%elems(j)%v=celems(j)%v
```

```
            ENDDO
            DEALLOCATE(celems, stat=allocstat)
            IF (allocstat /= 0) stop "*** Deallocation problem ! ***"
         ENDIF
         DO j=1,src(i)%nelems
            dst(i)%elems(n+j)%j=src(i)%elems(j)%j
            dst(i)%elems(n+j)%k=src(i)%elems(j)%k
            dst(i)%elems(n+j)%v=src(i)%elems(j)%v
         ENDDO
         dst(i)%nelems=src(i)%nelems+n
      ENDIF
   ENDDO

```

6.10.2.4 subroutine, public tensor::copy_coo (type(coolist), dimension(ndim), intent(in) *src*, type(coolist), dimension(ndim), intent(out) *dst*)

Routine to copy a coolist.

Parameters

src	Source coolist
dst	Destination coolist

Remarks

The destination tensor have to be an empty tensor, i.e. with unallocated list of elements and nelems set to 0.

Definition at line 45 of file tensor.f90.

```
45      TYPE(coolist), DIMENSION(ndim), INTENT(IN) :: src
46      TYPE(coolist), DIMENSION(ndim), INTENT(OUT) :: dst
47      INTEGER :: i,j,allocstat
48
49      DO i=1,ndim
50         IF (dst(i)%nelems/=0) stop "*** copy_coo : Destination coolist not empty ! ***"
51         ALLOCATE(dst(i)%elems(src(i)%nelems), stat=allocstat)
52         IF (allocstat /= 0) stop "*** Not enough memory ! ***"
53         DO j=1,src(i)%nelems
54            dst(i)%elems(j)%j=src(i)%elems(j)%j
55            dst(i)%elems(j)%k=src(i)%elems(j)%k
56            dst(i)%elems(j)%v=src(i)%elems(j)%v
57         ENDDO
58         dst(i)%nelems=src(i)%nelems
59      ENDDO
```

6.10.2.5 subroutine, public tensor::jsparse_mul (type(coolist), dimension(ndim), intent(in) *coolist_ijk*, real(kind=8), dimension(0:ndim), intent(in) *arr_j*, type(coolist), dimension(ndim), intent(out) *jcoo_ij*)

Sparse multiplication of two tensors to determine the Jacobian:

$$J_{i,j} = \sum_{k=0}^{ndim} \left(\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j}\right) a_k .$$

It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$, we add to $J_{i,j}$ as follows:

$$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k}\, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k}\, a_j$$

This version return a coolist (sparse tensor).

Parameters

coolist_ijk	a coordinate list (sparse tensor) of which index 2 or 3 will be contracted.
arr_j	the vector to be contracted with index 2 and then index 3 of ffi_coo_ijk
jcoo_ij	a coolist (sparse tensor) to store the result of the contraction

Definition at line 124 of file tensor.f90.

```
TYPE(coolist), DIMENSION(ndim), INTENT(IN):: coolist_ijk
TYPE(coolist), DIMENSION(ndim), INTENT(OUT):: jcoo_ij
REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN)  :: arr_j
REAL(KIND=8) :: v
INTEGER :: i,j,k,n,nj,allocstat
DO i=1,ndim
   IF (jcoo_ij(i)%nelems/=0) stop "*** jsparse_mul : Destination coolist not empty ! ***"
   nj=2*coolist_ijk(i)%nelems
   ALLOCATE(jcoo_ij(i)%elems(nj), stat=allocstat)
   IF (allocstat /= 0) stop "*** Not enough memory ! ***"
   nj=0
   DO n=1,coolist_ijk(i)%nelems
      j=coolist_ijk(i)%elems(n)%j
      k=coolist_ijk(i)%elems(n)%k
      v=coolist_ijk(i)%elems(n)%v
      IF (j /=0) THEN
         nj=nj+1
         jcoo_ij(i)%elems(nj)%j=j
         jcoo_ij(i)%elems(nj)%k=0
         jcoo_ij(i)%elems(nj)%v=v*arr_j(k)
      END IF

      IF (k /=0) THEN
         nj=nj+1
         jcoo_ij(i)%elems(nj)%j=k
         jcoo_ij(i)%elems(nj)%k=0
         jcoo_ij(i)%elems(nj)%v=v*arr_j(j)
      END IF
   END DO
   jcoo_ij(i)%nelems=nj
END DO
```

6.10.2.6 subroutine, public tensor::jsparse_mul_mat (type(coolist), dimension(ndim), intent(in) *coolist_ijk,* real(kind=8), dimension(0:ndim), intent(in) *arr_j,* real(kind=8), dimension(ndim,ndim), intent(out) *jcoo_ij*)

Sparse multiplication of two tensors to determine the Jacobian:

$$J_{i,j} = \sum_{k=0}^{ndim} \left(\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j}\right) \, a_k.$$

It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$, we add to $J_{i,j}$ as follows:

$$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k} \, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k} \, a_j$$

This version return a matrix.

Parameters

coolist_ijk	a coordinate list (sparse tensor) of which index 2 or 3 will be contracted.
arr_j	the vector to be contracted with index 2 and then index 3 of ffi_coo_ijk
jcoo_ij	a matrix to store the result of the contraction

Definition at line 167 of file tensor.f90.

```
167     TYPE(coolist), DIMENSION(ndim), INTENT(IN):: coolist_ijk
168     REAL(KIND=8), DIMENSION(ndim,ndim), INTENT(OUT):: jcoo_ij
169     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN)   :: arr_j
170     REAL(KIND=8) :: v
171     INTEGER :: i,j,k,n
172     jcoo_ij=0.d0
173     DO i=1,ndim
174        DO n=1,coolist_ijk(i)%nelems
175           j=coolist_ijk(i)%elems(n)%j
176           k=coolist_ijk(i)%elems(n)%k
177           v=coolist_ijk(i)%elems(n)%v
178           IF (j /=0) jcoo_ij(i,j)=jcoo_ij(i,j)+v*arr_j(k)
179           IF (k /=0) jcoo_ij(i,k)=jcoo_ij(i,k)+v*arr_j(j)
180        END DO
181     END DO
```

6.10.2.7 subroutine, public tensor::load_tensor_from_file (character (len=∗), intent(in) *s*, type(coolist), dimension(ndim), intent(out) *t*)

Load a rank-4 tensor coolist from a file definition.

Parameters

s	Filename of the tensor definition file
t	The loaded coolist

Remarks

The destination tensor have to be an empty tensor, i.e. with unallocated list of elements and nelems set to 0.

Definition at line 416 of file tensor.f90.

```
416     CHARACTER (LEN=*), INTENT(IN) :: s
417     TYPE(coolist), DIMENSION(ndim), INTENT(OUT) :: t
418     INTEGER :: i,ir,j,k,n,allocstat
419     REAL(KIND=8) :: v
420     OPEN(30,file=s,status='old')
421     DO i=1,ndim
422        READ(30,*) ir,n
423        IF (n /= 0) THEN
424           ALLOCATE(t(i)%elems(n), stat=allocstat)
425           IF (allocstat /= 0) stop "*** Not enough memory ! ***"
426           t(i)%nelems=n
427        ENDIF
428        DO n=1,t(i)%nelems
429           READ(30,*) ir,j,k,v
430           t(i)%elems(n)%j=j
431           t(i)%elems(n)%k=k
432           t(i)%elems(n)%v=v
433        ENDDO
434     END DO
435     CLOSE(30)
```

6.10.2.8 subroutine, public tensor::mat_to_coo (real(kind=8), dimension(0:ndim,0:ndim), intent(in) *src*, type(coolist), dimension(ndim), intent(out) *dst*)

Routine to convert a matrix to a tensor.

Parameters

src	Source matrix
dst	Destination tensor

Remarks

The destination tensor have to be an empty tensor, i.e. with unallocated list of elements and nelems set to 0.

Definition at line 67 of file tensor.f90.

```
67      REAL(KIND=8), DIMENSION(0:ndim,0:ndim), INTENT(IN) :: src
68      TYPE(coolist), DIMENSION(ndim), INTENT(OUT) :: dst
69      INTEGER :: i,j,n,allocstat
70      DO i=1,ndim
71         n=0
72         DO j=1,ndim
73            IF (abs(src(i,j))>real_eps) n=n+1
74         ENDDO
75         IF (dst(i)%nelems/=0) stop "*** mat_to_coo : Destination coolist not empty ! ***"
76         ALLOCATE(dst(i)%elems(n), stat=allocstat)
77         IF (allocstat /= 0) stop "*** Not enough memory ! ***"
78         n=0
79         DO j=1,ndim
80            IF (abs(src(i,j))>real_eps) THEN
81               n=n+1
82               dst(i)%elems(n)%j=j
83               dst(i)%elems(n)%k=0
84               dst(i)%elems(n)%v=src(i,j)
85            ENDIF
86         ENDDO
87         dst(i)%nelems=n
88      ENDDO
```

6.10.2.9 subroutine, public tensor::print_tensor (type(coolist), dimension(ndim), intent(in) *t*, character, intent(in), optional *s*)

Routine to print a rank 3 tensor coolist.

Parameters

t	coolist to print

Definition at line 370 of file tensor.f90.

```
370      USE util, only: str
371      TYPE(coolist), DIMENSION(ndim), INTENT(IN) :: t
372      CHARACTER, INTENT(IN), OPTIONAL :: s
373      CHARACTER :: r
374      INTEGER :: i,n,j,k
375      IF (PRESENT(s)) THEN
376         r=s
377      ELSE
378         r="t"
379      END IF
380      DO i=1,ndim
381         DO n=1,t(i)%nelems
382            j=t(i)%elems(n)%j
383            k=t(i)%elems(n)%k
384            IF( abs(t(i)%elems(n)%v) .GE. real_eps) THEN
385               write(*,"(A,ES12.5)") s//"["//trim(str(i))//"]["//trim(str(j)) &
386                    &//"]["//trim(str(k))//"] = ",t(i)%elems(n)%v
387            END IF
388         END DO
389      END DO
```

6.10.2.10 subroutine, public tensor::simplify (type(coolist), dimension(ndim), intent(inout) *tensor*)

Routine to simplify a coolist (sparse tensor). For each index i, it upper triangularize the matrix

$$\mathcal{T}_{i,j,k} \qquad 0 \leq j,k \leq ndim.$$

.

Parameters

tensor	a coordinate list (sparse tensor) which will be simplified.

Definition at line 209 of file tensor.f90.

```
209   TYPE(coolist), DIMENSION(ndim), INTENT(INOUT):: tensor
210   INTEGER :: i,j,k
211   INTEGER :: li,lii,liii,n
212   DO i= 1,ndim
213      n=tensor(i)%nelems
214      DO li=n,2,-1
215         j=tensor(i)%elems(li)%j
216         k=tensor(i)%elems(li)%k
217         DO lii=li-1,1,-1
218            IF (((j==tensor(i)%elems(lii)%j).AND.(k==tensor(i)&
219                 &%elems(lii)%k)).OR.((j==tensor(i)%elems(lii)%k).AND.(k==
      tensor(i)%elems(lii)%j))) THEN
220               ! Found another entry with the same i,j,k: merge both into
221               ! the one listed first (of those two).
222               tensor(i)%elems(lii)%v=tensor(i)%elems(lii)%v+tensor(i)%elems(li)%v
223               IF (j>k) THEN
224                  tensor(i)%elems(lii)%j=tensor(i)%elems(li)%k
225                  tensor(i)%elems(lii)%k=tensor(i)%elems(li)%j
226               ENDIF
227
228               ! Shift the rest of the items one place down.
229               DO liii=li+1,n
230                  tensor(i)%elems(liii-1)%j=tensor(i)%elems(liii)%j
231                  tensor(i)%elems(liii-1)%k=tensor(i)%elems(liii)%k
232                  tensor(i)%elems(liii-1)%v=tensor(i)%elems(liii)%v
233               END DO
234               tensor(i)%nelems=tensor(i)%nelems-1
235               ! Here we should stop because the li no longer points to the
236               ! original i,j,k element
237               EXIT
238            ENDIF
239         ENDDO
240      ENDDO
241      n=tensor(i)%nelems
242      DO li=1,n
243         ! Clear new "almost" zero entries and shift rest of the items one place down.
244         ! Make sure not to skip any entries while shifting!
245         DO WHILE (abs(tensor(i)%elems(li)%v) < real_eps)
246            DO liii=li+1,n
247               tensor(i)%elems(liii-1)%j=tensor(i)%elems(liii)%j
248               tensor(i)%elems(liii-1)%k=tensor(i)%elems(liii)%k
249               tensor(i)%elems(liii-1)%v=tensor(i)%elems(liii)%v
250            ENDDO
251            tensor(i)%nelems=tensor(i)%nelems-1
252            if (li > tensor(i)%nelems) THEN
253               EXIT
254            ENDIF
255         ENDDO
256      ENDDO
257
258      n=tensor(i)%nelems
259      DO li=1,n
260         ! Upper triangularize
261         j=tensor(i)%elems(li)%j
262         k=tensor(i)%elems(li)%k
263         IF (j>k) THEN
264            tensor(i)%elems(li)%j=k
265            tensor(i)%elems(li)%k=j
266         ENDIF
267      ENDDO
268
269
270   ENDDO
```

6.10.2.11 subroutine, public tensor::sparse_mul2 (type(coolist), dimension(ndim), intent(in) *coolist_ij*, real(kind=8), dimension(0:ndim), intent(in) *arr_j*, real(kind=8), dimension(0:ndim), intent(out) *res*)

Sparse multiplication of a 2d sparse tensor with a vector: $\sum_{j=0}^{ndim} \mathcal{T}_{i,j,k} \, a_j$.

Parameters

coolist←_ij	a coordinate list (sparse tensor) of which index 2 will be contracted.
arr_j	the vector to be contracted with index 2 of coolist_ijk
res	vector (buffer) to store the result of the contraction

Remarks

Note that it is NOT safe to pass `arr_j` as a result buffer, as this operation does multiple passes.

Definition at line 192 of file tensor.f90.

```
192     TYPE(coolist), DIMENSION(ndim), INTENT(IN):: coolist_ij
193     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN)  :: arr_j
194     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
195     INTEGER :: i,j,n
196     res=0.d0
197     DO i=1,ndim
198        DO n=1,coolist_ij(i)%nelems
199          j=coolist_ij(i)%elems(n)%j
200          res(i) = res(i) + coolist_ij(i)%elems(n)%v * arr_j(j)
201       END DO
202    END DO
```

6.10.2.12 subroutine, public tensor::sparse_mul3 (type(coolist), dimension(ndim), intent(in) *coolist_ijk*, real(kind=8), dimension(0:ndim), intent(in) *arr_j*, real(kind=8), dimension(0:ndim), intent(in) *arr_k*, real(kind=8), dimension(0:ndim), intent(out) *res*)

Sparse multiplication of a tensor with two vectors: $\sum_{j,k=0}^{ndim} \mathcal{T}_{i,j,k} \, a_j \, b_k$.

Parameters

coolist←_ijk	a coordinate list (sparse tensor) of which index 2 and 3 will be contracted.
arr_j	the vector to be contracted with index 2 of coolist_ijk
arr_k	the vector to be contracted with index 3 of coolist_ijk
res	vector (buffer) to store the result of the contraction

Remarks

Note that it is NOT safe to pass `arr_j`/`arr_k` as a result buffer, as this operation does multiple passes.

Definition at line 100 of file tensor.f90.

```
TYPE(coolist), DIMENSION(ndim), INTENT(IN):: coolist_ijk
REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN)  :: arr_j, arr_k
REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
INTEGER :: i,j,k,n
res=0.d0
DO i=1,ndim
   DO n=1,coolist_ijk(i)%nelems
     j=coolist_ijk(i)%elems(n)%j
     k=coolist_ijk(i)%elems(n)%k
     res(i) = res(i) + coolist_ijk(i)%elems(n)%v * arr_j(j)*arr_k(k)
  END DO
END DO
```

6.10.2.13 subroutine, public tensor::write_tensor_to_file (character (len=∗), intent(in) *s*, type(coolist), dimension(ndim), intent(in) *t*)

Load a rank-4 tensor coolist from a file definition.

Parameters

s	Destination filename
t	The coolist to write

Definition at line 396 of file tensor.f90.

```
CHARACTER (LEN=*), INTENT(IN) :: s
TYPE(coolist), DIMENSION(ndim), INTENT(IN) :: t
INTEGER :: i,j,k,n
OPEN(30,file=s)
DO i=1,ndim
   WRITE(30,*) i,t(i)%nelems
   DO n=1,t(i)%nelems
      j=t(i)%elems(n)%j
      k=t(i)%elems(n)%k
      WRITE(30,*) i,j,k,t(i)%elems(n)%v
   END DO
END DO
CLOSE(30)
```

6.10.3 Variable Documentation

6.10.3.1 real(kind=8), parameter tensor::real_eps = 2.2204460492503131e-16

Parameter to test the equality with zero.

Definition at line 33 of file tensor.f90.

```
REAL(KIND=8), PARAMETER :: real_eps = 2.2204460492503131e-16
```

6.11 tl_ad_integrator Module Reference

Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Integrators module.

Functions/Subroutines

- subroutine tendencies (t, y, res)

  Routine computing the tendencies of the nonlinear model.
- subroutine, public init_tl_ad_integrator

  Routine to initialise the integration buffers.
- subroutine, public ad_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the adjoint model. The incremented time is returned.
- subroutine, public evolve_ad_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and adjoint together. The incremented time is returned.
- subroutine, public tl_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the tangent linear model. The incremented time is returned.
- subroutine, public evolve_tl_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and the tangent linear model together. The incremented time is returned.
- subroutine, public prop_step (y, propagator, t, dt, ynew, adjoint)

  Routine to perform a simultaneously an integration step (Heun algorithm) of the nonlinear and computes the Heun tangent linear propagator. The boolean variable adjoint allows for an adjoint forward integration. The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable buf_y1

  Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_f0

  Buffer to hold tendencies at the initial position of the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_f1

  Buffer to hold tendencies at the intermediate position of the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_y11

  Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_f00

  Buffer to hold tendencies at the initial position of the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_f11

  Buffer to hold tendencies at the intermediate position of the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j1

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j2

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j1h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j2h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable one

  unit matrix
- real(kind=8), dimension(:), allocatable buf_ka

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_kb

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_kc

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

- real(kind=8), dimension(:), allocatable buf_kd

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j3

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j4

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j3h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable buf_j4h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_kaa

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable buf_kbb

  Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

6.11.1 Detailed Description

Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Integrators module.

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Remarks

This module actually contains the Heun algorithm routines. The user can modify it according to its preferred integration scheme. For higher-order schemes, additional buffers will probably have to be defined.

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Remarks

This module actually contains the RK4 algorithm routines. The user can modify it according to its preferred integration scheme. For higher-order schemes, additional bufers will probably have to be defined.

6.11.2 Function/Subroutine Documentation

6.11.2.1 subroutine public tl_ad_integrator::ad_step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(in) *ystar*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *res*)

Routine to perform an integration step (Heun algorithm) of the adjoint model. The incremented time is returned.

Routine to perform an integration step (RK4 algorithm) of the adjoint model. The incremented time is returned.

Parameters

y	Initial point.
ystar	Adjoint model at the point ystar.
t	Actual integration time
dt	Integration timestep.
res	Final point after the step.

Definition at line 92 of file rk2_tl_ad_integrator.f90.

```
92      REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y,ystar
93      REAL(KIND=8), INTENT(INOUT) :: t
94      REAL(KIND=8), INTENT(IN) :: dt
95      REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
96
97      CALL ad(t,ystar,y,buf_f0)
98      buf_y1 = y+dt*buf_f0
99      CALL ad(t+dt,ystar,buf_y1,buf_f1)
100      res=y+0.5*(buf_f0+buf_f1)*dt
101      t=t+dt
```

6.11.2.2 subroutine public tl_ad_integrator::evolve_ad_step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(in) *deltay*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *ynew*, real(kind=8), dimension(0:ndim), intent(out) *deltaynew*)

Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and adjoint together. The incremented time is returned.

Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and adjoint model together. The incremented time is returned.

Parameters

y	Model variable at time t
deltay	Perturbation at time t
t	Actual integration time
dt	Integration timestep.
ynew	Model variable at time t+dt
deltaynew	Perturbation at time t+dt

Definition at line 112 of file rk2_tl_ad_integrator.f90.

```
112     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y,deltay
113     REAL(KIND=8), INTENT(INOUT) :: t
114     REAL(KIND=8), INTENT(IN) :: dt
115     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: ynew,deltaynew
116
117     CALL tendencies(t,y,buf_f0)
118     CALL ad(t,y,deltay,buf_f00)
119
120     buf_y1 = y + dt*buf_f0
121     buf_y11 = deltay + dt*buf_f00
122
123     CALL tendencies(t+dt,buf_y1,buf_f1)
124     CALL ad(t+dt,buf_y1,buf_y11,buf_f11)
125
126     t=t+dt
127     ynew=y+0.5*(buf_f0+buf_f1)*dt
128     deltaynew=deltay+0.5*(buf_f00+buf_f11)*dt
```

6.11.2.3 subroutine public tl_ad_integrator::evolve_tl_step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(in) *deltay*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *ynew*, real(kind=8), dimension(0:ndim), intent(out) *deltaynew*)

Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and the tangent linear model together. The incremented time is returned.

Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and tangent linear model togheter. The incremented time is returned.

Parameters

y	Model variable at time t
deltay	Perturbation at time t
t	Actual integration time
dt	Integration timestep.
ynew	Model variable at time t+dt
deltaynew	Perturbation at time t+dt

Definition at line 165 of file rk2_tl_ad_integrator.f90.

```
165     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y,deltay
166     REAL(KIND=8), INTENT(INOUT) :: t
167     REAL(KIND=8), INTENT(IN) :: dt
168     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: ynew,deltaynew
169
170     CALL tendencies(t,y,buf_f0)
171     CALL ad(t,y,deltay,buf_f00)
172
173     buf_y1 = y + dt*buf_f0
174     buf_y11 = deltay + dt*buf_f00
175
176     CALL tendencies(t+dt,buf_y1,buf_f1)
177     CALL ad(t+dt,buf_y1,buf_y11,buf_f11)
178
179     t=t+dt
180     ynew=y+0.5*(buf_f0+buf_f1)*dt
181     deltaynew=deltay+0.5*(buf_f00+buf_f11)*dt
```

6.11.2.4 subroutine public tl_ad_integrator::init_tl_ad_integrator ( )

Routine to initialise the integration buffers.

Routine to initialise the TL-AD integration bufers.

Definition at line 68 of file rk2_tl_ad_integrator.f90.

```
68     INTEGER :: allocstat
69     ALLOCATE(buf_y1(0:ndim),buf_f0(0:ndim),buf_f1(0:ndim),&
70          &buf_y11(0:ndim),buf_f00(0:ndim),buf_f11(0:ndim),&
71          &buf_j1(ndim,ndim),buf_j2(ndim,ndim),one(ndim,ndim),&
72          &buf_j1h(ndim,ndim),buf_j2h(ndim,ndim),stat=allocstat)
73     IF (allocstat /= 0) stop "*** Not enough memory ! ***"
74     CALL init_one(one)
```

6.11.2.5 subroutine public tl_ad_integrator::prop_step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(ndim,ndim), intent(out) *propagator*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *ynew*, logical, intent(in) *adjoint*)

Routine to perform a simultaneously an integration step (Heun algorithm) of the nonlinear and computes the Heun tangent linear propagator. The boolean variable adjoint allows for an adjoint forward integration. The incremented time is returned.

Routine to perform a simultaneously an integration step (RK4 algorithm) of the nonlinear and computes the RK4 tangent linear propagator. The boolean variable adjoint allows for an adjoint forward integration. The incremented time is returned.

Parameters

y	Model variable at time t
propagator	Propagator at time t
t	Actual integration time
dt	Integration timestep.
ynew	Model variable at time t+dt
adjoint	If true, compute the propagator of the adjoint model (AD) instead of the tangent one (TL)
y	Model variable at time t
propagator	Propagator at time t
t	Actual integration time
dt	Integration timestep
ynew	Model variable at time t+dt
adjoint	If true, compute the propagator of the adjoint model (AD) instead of the tangent one (TL)

Definition at line 193 of file rk2_tl_ad_integrator.f90.

```
    REAL(KIND=8), INTENT(INOUT) :: t
    REAL(KIND=8), INTENT(IN) :: dt
    REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y
    LOGICAL, INTENT(IN) :: adjoint
    REAL(KIND=8), DIMENSION(ndim,ndim), INTENT(OUT) :: propagator
    REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: ynew

    CALL tendencies(t,y,buf_f0)
    buf_j1=jacobian_mat(y)

    buf_y1 = y + dt*buf_f0

    CALL tendencies(t+dt,buf_y1,buf_f1)
    buf_j2=jacobian_mat(buf_y1)

    buf_j1h=buf_j1
    buf_j2h=buf_j2
    CALL dgemm ('n', 'n', ndim, ndim, ndim, dt, buf_j2, ndim,buf_j1h, ndim,1.0d0, buf_j2h, ndim)

    ynew=y  + dt/2.0d0*(buf_f0 + buf_f1)
    IF (adjoint) THEN
            propagator=one - dt/2.0d0*(buf_j1h + buf_j2h)
    ELSE
            propagator=one + dt/2.0d0*(buf_j1h + buf_j2h)
    END IF
    t=t+dt

```

6.11.2.6 subroutine tl_ad_integrator::tendencies (real(kind=8), intent(in) *t*, real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(out) *res*) [private]

Routine computing the tendencies of the nonlinear model.

Parameters

t	Time at which the tendencies have to be computed. Actually not needed for autonomous systems.
y	Point at which the tendencies have to be computed.
res	vector to store the result.

Remarks

Note that it is NOT safe to pass `y` as a result bufer, as this operation does multiple passes.

Definition at line 60 of file rk2_tl_ad_integrator.f90.

```
REAL(KIND=8), INTENT(IN) :: t
REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y
REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res
CALL sparse_mul3(aotensor, y, y, res)
```

6.11.2.7 subroutine public tl_ad_integrator::tl_step (real(kind=8), dimension(0:ndim), intent(in) *y*, real(kind=8), dimension(0:ndim), intent(in) *ystar*, real(kind=8), intent(inout) *t*, real(kind=8), intent(in) *dt*, real(kind=8), dimension(0:ndim), intent(out) *res*)

Routine to perform an integration step (Heun algorithm) of the tangent linear model. The incremented time is returned.

Routine to perform an integration step (RK4 algorithm) of the tangent linear model. The incremented time is returned.

Parameters

y	Initial point.
ystar	Adjoint model at the point ystar.
t	Actual integration time
dt	Integration timestep.
res	Final point after the step.

Definition at line 145 of file rk2_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: y,ystar
REAL(KIND=8), INTENT(INOUT) :: t
REAL(KIND=8), INTENT(IN) :: dt
REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: res

CALL tl(t,ystar,y,buf_f0)
buf_y1 = y+dt*buf_f0
CALL tl(t+dt,ystar,buf_y1,buf_f1)
res=y+0.5*(buf_f0+buf_f1)*dt
t=t+dt
```

6.11.3 Variable Documentation

6.11.3.1 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f0 [private]

Buffer to hold tendencies at the initial position of the tangent linear model.

Definition at line 35 of file rk2_tl_ad_integrator.f90.

```
35 REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f0 !< Buffer to hold tendencies at the initial position of
   the tangent linear model
```

6.11.3.2 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f00 [private]

Buffer to hold tendencies at the initial position of the tangent linear model.

Definition at line 39 of file rk2_tl_ad_integrator.f90.

```
39 REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f00 !< Buffer to hold tendencies at the initial position
   of the tangent linear model
```

6.11.3.3 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f1 [private]

Buffer to hold tendencies at the intermediate position of the tangent linear model.

Definition at line 36 of file rk2_tl_ad_integrator.f90.

```
36 REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f1 !< Buffer to hold tendencies at the intermediate
   position of the tangent linear model
```

6.11.3.4 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f11 [private]

Buffer to hold tendencies at the intermediate position of the tangent linear model.

Definition at line 40 of file rk2_tl_ad_integrator.f90.

```
40 REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_f11 !< Buffer to hold tendencies at the intermediate
   position of the tangent linear model
```

6.11.3.5 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j1 [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 42 of file rk2_tl_ad_integrator.f90.

```
42 REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j1 !< Buffer to hold jacobians in the RK4 scheme for the
   tangent linear model
```

6.11.3.6 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j1h [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 44 of file rk2_tl_ad_integrator.f90.

```
44 REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j1h !< Buffer to hold jacobians in the RK4 scheme for
   the tangent linear model
```

6.11.3.7 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j2 [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 43 of file rk2_tl_ad_integrator.f90.

```
43   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j2 !< Buffer to hold jacobians in the RK4 scheme for the
       tangent linear model
```

6.11.3.8 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j2h [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 45 of file rk2_tl_ad_integrator.f90.

```
45   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j2h !< Buffer to hold jacobians in the RK4 scheme for
       the tangent linear model
```

6.11.3.9 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j3 [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 42 of file rk4_tl_ad_integrator.f90.

```
42   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j3 !< Buffer to hold jacobians in the RK4 scheme for the
       tangent linear model
```

6.11.3.10 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j3h [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 46 of file rk4_tl_ad_integrator.f90.

```
46   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j3h !< Buffer to hold jacobians in the RK4 scheme for
       the tangent linear model
```

6.11.3.11 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j4 [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 43 of file rk4_tl_ad_integrator.f90.

```
43   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j4 !< Buffer to hold jacobians in the RK4 scheme for the
       tangent linear model
```

6.11.3.12 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j4h [private]

Buffer to hold jacobians in the RK4 scheme for the tangent linear model.

Definition at line 47 of file rk4_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: buf_j4h !< Buffer to hold jacobians in the RK4 scheme for
  the tangent linear model
```

6.11.3.13 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_ka [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 35 of file rk4_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_ka !< Buffer to hold tendencies in the RK4 scheme for the
  tangent linear model
```

6.11.3.14 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kaa [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 48 of file rk4_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kaa !< Buffer to hold tendencies in the RK4 scheme for the
  tangent linear model
```

6.11.3.15 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kb [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 36 of file rk4_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kb !< Buffer to hold tendencies in the RK4 scheme for the
  tangent linear model
```

6.11.3.16 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kbb [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 49 of file rk4_tl_ad_integrator.f90.

```
REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kbb !< Buffer to hold tendencies in the RK4 scheme for the
  tangent linear model
```

6.11.3.17 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kc [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 38 of file rk4_tl_ad_integrator.f90.

```
38   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kc !< Buffer to hold tendencies in the RK4 scheme for the
       tangent linear model
```

6.11.3.18 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kd [private]

Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

Definition at line 39 of file rk4_tl_ad_integrator.f90.

```
39   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_kd !< Buffer to hold tendencies in the RK4 scheme for the
       tangent linear model
```

6.11.3.19 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_y1 [private]

Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.

Buffer to hold the intermediate position of the tangent linear model.

Definition at line 34 of file rk2_tl_ad_integrator.f90.

```
34   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_y1 !< Buffer to hold the intermediate position (Heun
       algorithm) of the tangent linear model
```

6.11.3.20 real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_y11 [private]

Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.

Buffer to hold the intermediate position of the tangent linear model.

Definition at line 38 of file rk2_tl_ad_integrator.f90.

```
38   REAL(KIND=8), DIMENSION(:), ALLOCATABLE :: buf_y11 !< Buffer to hold the intermediate position (Heun
       algorithm) of the tangent linear model
```

6.11.3.21 real(kind=8), dimension(:,:), allocatable tl_ad_integrator::one [private]

unit matrix

Definition at line 46 of file rk2_tl_ad_integrator.f90.

```
46   REAL(KIND=8), DIMENSION(:,:), ALLOCATABLE :: one        !< unit matrix
```

6.12 tl_ad_tensor Module Reference

Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Tensors definition module.

Functions/Subroutines

- type(coolist) function, dimension(ndim) jacobian (ystar)

  Compute the Jacobian of MAOOAM in point ystar.
- real(kind=8) function, dimension(ndim, ndim), public jacobian_mat (ystar)

  Compute the Jacobian of MAOOAM in point ystar.
- subroutine, public init_tltensor

  Routine to initialize the TL tensor.
- subroutine compute_tltensor (func)

  Routine to compute the TL tensor from the original MAOOAM one.
- subroutine tl_add_count (i, j, k, v)

  Subroutine used to count the number of TL tensor entries.
- subroutine tl_coeff (i, j, k, v)

  Subroutine used to compute the TL tensor entries.
- subroutine, public init_adtensor

  Routine to initialize the AD tensor.
- subroutine compute_adtensor (func)

  Subroutine to compute the AD tensor from the original MAOOAM one.
- subroutine ad_add_count (i, j, k, v)

  Subroutine used to count the number of AD tensor entries.
- subroutine ad_coeff (i, j, k, v)
- subroutine, public init_adtensor_ref

  Alternate method to initialize the AD tensor from the TL tensor.
- subroutine compute_adtensor_ref (func)

  Alternate subroutine to compute the AD tensor from the TL one.
- subroutine ad_add_count_ref (i, j, k, v)

  Alternate subroutine used to count the number of AD tensor entries from the TL tensor.
- subroutine ad_coeff_ref (i, j, k, v)

  Alternate subroutine used to compute the AD tensor entries from the TL tensor.
- subroutine, public ad (t, ystar, deltay, buf)

  Tendencies for the AD of MAOOAM in point ystar for perturbation deltay.
- subroutine, public tl (t, ystar, deltay, buf)

  Tendencies for the TL of MAOOAM in point ystar for perturbation deltay.

Variables

- real(kind=8), parameter real_eps = 2.2204460492503131e-16

  Epsilon to test equality with 0.
- integer, dimension(:), allocatable count_elems

  Vector used to count the tensor elements.
- type(coolist), dimension(:), allocatable, public tltensor

  Tensor representation of the Tangent Linear tendencies.
- type(coolist), dimension(:), allocatable, public adtensor

  Tensor representation of the Adjoint tendencies.

6.12.1 Detailed Description

Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Tensors definition module.

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Remarks

The routines of this module should be called only after params::init_params() and aotensor_def::init_aotensor() have been called !

6.12.2 Function/Subroutine Documentation

6.12.2.1 subroutine, public tl_ad_tensor::ad (real(kind=8), intent(in) *t*, real(kind=8), dimension(0:ndim), intent(in) *ystar*, real(kind=8), dimension(0:ndim), intent(in) *deltay*, real(kind=8), dimension(0:ndim), intent(out) *buf*)

Tendencies for the AD of MAOOAM in point ystar for perturbation deltay.

Parameters

t	time
ystar	vector with the variables (current point in trajectory)
deltay	vector with the perturbation of the variables at time t
buf	vector (buffer) to store derivatives.

Definition at line 384 of file tl_ad_tensor.f90.

```
384     REAL(KIND=8), INTENT(IN) :: t
385     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: ystar,deltay
386     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: buf
387     CALL sparse_mul3(adtensor,deltay,ystar,buf)
```

6.12.2.2 subroutine tl_ad_tensor::ad_add_count (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Subroutine used to count the number of AD tensor entries.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value that will be added

Definition at line 243 of file tl_ad_tensor.f90.

```
    INTEGER, INTENT(IN) :: i,j,k
    REAL(KIND=8), INTENT(IN)  :: v
    IF ((abs(v) .ge. real_eps).AND.(i /= 0)) THEN
       IF (k /= 0) count_elems(k)=count_elems(k)+1
       IF (j /= 0) count_elems(j)=count_elems(j)+1
    ENDIF
```

6.12.2.3 subroutine tl_ad_tensor::ad_add_count_ref (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Alternate subroutine used to count the number of AD tensor entries from the TL tensor.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value that will be added

Definition at line 346 of file tl_ad_tensor.f90.

```
    INTEGER, INTENT(IN) :: i,j,k
    REAL(KIND=8), INTENT(IN)  :: v
    IF ((abs(v) .ge. real_eps).AND.(j /= 0)) count_elems(j)=count_elems(j)+1
```

6.12.2.4 subroutine tl_ad_tensor::ad_coeff (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value to add

Definition at line 257 of file tl_ad_tensor.f90.

```
    INTEGER, INTENT(IN) :: i,j,k
    REAL(KIND=8), INTENT(IN) :: v
    INTEGER :: n
    IF (.NOT. ALLOCATED(adtensor)) stop "*** ad_coeff routine : tensor not yet allocated ***"
    IF ((abs(v) .ge. real_eps).AND.(i /=0)) THEN
       IF (k /=0) THEN
          IF (.NOT. ALLOCATED(adtensor(k)%elems)) stop "*** ad_coeff routine : tensor not yet allocated
 ***"
          n=(adtensor(k)%nelems)+1
          adtensor(k)%elems(n)%j=i
          adtensor(k)%elems(n)%k=j
          adtensor(k)%elems(n)%v=v
          adtensor(k)%nelems=n
       END IF
       IF (j /=0) THEN
          IF (.NOT. ALLOCATED(adtensor(j)%elems)) stop "*** ad_coeff routine : tensor not yet allocated
 ***"
          n=(adtensor(j)%nelems)+1
          adtensor(j)%elems(n)%j=i
          adtensor(j)%elems(n)%k=k
```

```
        adtensor(j)%elems(n)%v=v
        adtensor(j)%nelems=n
      END IF
    END IF
```

6.12.2.5 subroutine tl_ad_tensor::ad_coeff_ref (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Alternate subroutine used to compute the AD tensor entries from the TL tensor.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value to add

Definition at line 358 of file tl_ad_tensor.f90.

```
    INTEGER, INTENT(IN) :: i,j,k
    REAL(KIND=8), INTENT(IN) :: v
    INTEGER :: n
    IF (.NOT. ALLOCATED(adtensor)) stop "*** ad_coeff_ref routine : tensor not yet allocated ***"
    IF ((abs(v) .ge. real_eps).AND.(j /=0)) THEN
      IF (.NOT. ALLOCATED(adtensor(j)%elems)) stop "*** ad_coeff_ref routine : tensor not yet allocated
   ***"
      n=(adtensor(j)%nelems)+1
      adtensor(j)%elems(n)%j=i
      adtensor(j)%elems(n)%k=k
      adtensor(j)%elems(n)%v=v
      adtensor(j)%nelems=n
    END IF
```

6.12.2.6 subroutine tl_ad_tensor::compute_adtensor (external *func*) [private]

Subroutine to compute the AD tensor from the original MAOOAM one.

Parameters

func	subroutine used to do the computation

Definition at line 217 of file tl_ad_tensor.f90.

6.12.2.7 subroutine tl_ad_tensor::compute_adtensor_ref (external *func*) [private]

Alternate subroutine to compute the AD tensor from the TL one.

Parameters

func	subroutine used to do the computation

Definition at line 318 of file tl_ad_tensor.f90.

6.12.2.8 subroutine tl_ad_tensor::compute_tltensor (external *func*) [private]

Routine to compute the TL tensor from the original MAOOAM one.

Parameters

func	subroutine used to do the computation

Definition at line 121 of file tl_ad_tensor.f90.

6.12.2.9 subroutine, public tl_ad_tensor::init_adtensor ( )

Routine to initialize the AD tensor.

Definition at line 193 of file tl_ad_tensor.f90.

```
193     INTEGER :: i
194     INTEGER :: allocstat
195     ALLOCATE(adtensor(ndim),count_elems(ndim), stat=allocstat)
196     IF (allocstat /= 0) stop "*** Not enough memory ! ***"
197     count_elems=0
198     CALL compute_adtensor(ad_add_count)
199
200     DO i=1,ndim
201        ALLOCATE(adtensor(i)%elems(count_elems(i)), stat=allocstat)
202        IF (allocstat /= 0) stop "*** Not enough memory ! ***"
203     END DO
204
205     DEALLOCATE(count_elems, stat=allocstat)
206     IF (allocstat /= 0) stop "*** Deallocation problem ! ***"
207
208     CALL compute_adtensor(ad_coeff)
209
210     CALL simplify(adtensor)
211
```

6.12.2.10 subroutine, public tl_ad_tensor::init_adtensor_ref ( )

Alternate method to initialize the AD tensor from the TL tensor.

Remarks

The tltensor must be initialised before using this method.

Definition at line 294 of file tl_ad_tensor.f90.

```
294     INTEGER :: i
295     INTEGER :: allocstat
296     ALLOCATE(adtensor(ndim),count_elems(ndim), stat=allocstat)
297     IF (allocstat /= 0) stop "*** Not enough memory ! ***"
298     count_elems=0
299     CALL compute_adtensor_ref(ad_add_count_ref)
300
301     DO i=1,ndim
302        ALLOCATE(adtensor(i)%elems(count_elems(i)), stat=allocstat)
303        IF (allocstat /= 0) stop "*** Not enough memory ! ***"
304     END DO
305
306     DEALLOCATE(count_elems, stat=allocstat)
307     IF (allocstat /= 0) stop "*** Deallocation problem ! ***"
308
309     CALL compute_adtensor_ref(ad_coeff_ref)
310
311     CALL simplify(adtensor)
312
```

6.12.2.11 subroutine, public tl_ad_tensor::init_tltensor ( )

Routine to initialize the TL tensor.

Definition at line 97 of file tl_ad_tensor.f90.

```
    INTEGER :: i
    INTEGER :: allocstat
    ALLOCATE(tltensor(ndim),count_elems(ndim), stat=allocstat)
     IF (allocstat /= 0) stop "*** Not enough memory ! ***"
     count_elems=0
     CALL compute_tltensor(tl_add_count)

     DO i=1,ndim
        ALLOCATE(tltensor(i)%elems(count_elems(i)), stat=allocstat)
        IF (allocstat /= 0) stop "*** Not enough memory ! ***"
     END DO

     DEALLOCATE(count_elems, stat=allocstat)
     IF (allocstat /= 0) stop "*** Deallocation problem ! ***"

     CALL compute_tltensor(tl_coeff)

     CALL simplify(tltensor)

```

6.12.2.12 type(coolist) function, dimension(ndim) tl_ad_tensor::jacobian (real(kind=8), dimension(0:ndim), intent(in) *ystar*) [private]

Compute the Jacobian of MAOOAM in point ystar.

Parameters

ystar	array with variables in which the jacobian should be evaluated.

Returns

Jacobian in coolist-form (table of tuples {i,j,0,value})

Definition at line 75 of file tl_ad_tensor.f90.

```
    REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: ystar
    TYPE(coolist), DIMENSION(ndim) :: jacobian
    CALL jsparse_mul(aotensor,ystar,jacobian)
```

6.12.2.13 real(kind=8) function, dimension(ndim,ndim), public tl_ad_tensor::jacobian_mat (real(kind=8), dimension(0:ndim), intent(in) *ystar*)

Compute the Jacobian of MAOOAM in point ystar.

Parameters

ystar	array with variables in which the jacobian should be evaluated.

Returns

Jacobian in matrix form

Definition at line 84 of file tl_ad_tensor.f90.

```
84     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: ystar
85     REAL(KIND=8), DIMENSION(ndim,ndim) :: jacobian_mat
86     CALL jsparse_mul_mat(aotensor,ystar,jacobian_mat)
```

6.12.2.14 subroutine, public tl_ad_tensor::tl (real(kind=8), intent(in) *t*, real(kind=8), dimension(0:ndim), intent(in) *ystar*, real(kind=8), dimension(0:ndim), intent(in) *deltay*, real(kind=8), dimension(0:ndim), intent(out) *buf*)

Tendencies for the TL of MAOOAM in point ystar for perturbation deltay.

Parameters

t	time
ystar	vector with the variables (current point in trajectory)
deltay	vector with the perturbation of the variables at time t
buf	vector (buffer) to store derivatives.

Definition at line 396 of file tl_ad_tensor.f90.

```
396     REAL(KIND=8), INTENT(IN) :: t
397     REAL(KIND=8), DIMENSION(0:ndim), INTENT(IN) :: ystar,deltay
398     REAL(KIND=8), DIMENSION(0:ndim), INTENT(OUT) :: buf
399     CALL sparse_mul3(tltensor,deltay,ystar,buf)
```

6.12.2.15 subroutine tl_ad_tensor::tl_add_count (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Subroutine used to count the number of TL tensor entries.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value that will be added

Definition at line 147 of file tl_ad_tensor.f90.

```
147     INTEGER, INTENT(IN) :: i,j,k
148     REAL(KIND=8), INTENT(IN)  :: v
149     IF (abs(v) .ge. real_eps) THEN
150        IF (j /= 0) count_elems(i)=count_elems(i)+1
151        IF (k /= 0) count_elems(i)=count_elems(i)+1
152     ENDIF
```

6.12.2.16 subroutine tl_ad_tensor::tl_coeff (integer, intent(in) *i*, integer, intent(in) *j*, integer, intent(in) *k*, real(kind=8), intent(in) *v*) [private]

Subroutine used to compute the TL tensor entries.

Parameters

i	tensor i index
j	tensor j index
k	tensor k index
v	value to add

Definition at line 161 of file tl_ad_tensor.f90.

```
161     INTEGER, INTENT(IN) :: i,j,k
162     REAL(KIND=8), INTENT(IN) :: v
163     INTEGER :: n
164     IF (.NOT. ALLOCATED(tltensor)) stop "*** tl_coeff routine : tensor not yet allocated ***"
165     IF (.NOT. ALLOCATED(tltensor(i)%elems)) stop "*** tl_coeff routine : tensor not yet allocated ***"
166     IF (abs(v) .ge. real_eps) THEN
167        IF (j /=0) THEN
168           n=(tltensor(i)%nelems)+1
169           tltensor(i)%elems(n)%j=j
170           tltensor(i)%elems(n)%k=k
171           tltensor(i)%elems(n)%v=v
172           tltensor(i)%nelems=n
173        END IF
174        IF (k /=0) THEN
175           n=(tltensor(i)%nelems)+1
176           tltensor(i)%elems(n)%j=k
177           tltensor(i)%elems(n)%k=j
178           tltensor(i)%elems(n)%v=v
179           tltensor(i)%nelems=n
180        END IF
181     END IF
```

6.12.3 Variable Documentation

6.12.3.1 type(coolist), dimension(:), allocatable, public tl_ad_tensor::adtensor

Tensor representation of the Adjoint tendencies.

Definition at line 44 of file tl_ad_tensor.f90.

```
44   TYPE(coolist), DIMENSION(:), ALLOCATABLE, PUBLIC :: adtensor
```

6.12.3.2 integer, dimension(:), allocatable tl_ad_tensor::count_elems [private]

Vector used to count the tensor elements.

Definition at line 38 of file tl_ad_tensor.f90.

```
38   INTEGER, DIMENSION(:), ALLOCATABLE :: count_elems
```

6.12.3.3 real(kind=8), parameter tl_ad_tensor::real_eps = 2.2204460492503131e-16 [private]

Epsilon to test equality with 0.

Definition at line 35 of file tl_ad_tensor.f90.

```
35   REAL(KIND=8), PARAMETER :: real_eps = 2.2204460492503131e-16
```

6.12.3.4 type(coolist), dimension(:), allocatable, public tl_ad_tensor::tltensor

Tensor representation of the Tangent Linear tendencies.

Definition at line 41 of file tl_ad_tensor.f90.

```
41   TYPE(coolist), DIMENSION(:), ALLOCATABLE, PUBLIC :: tltensor
```

6.13 util Module Reference

Utility module.

Functions/Subroutines

- character(len=20) function, public str (k)

  Convert an integer to string.
- character(len=40) function, public rstr (x, fm)

  Convert a real to string with a given format.
- integer function, dimension(size(s)), public isin (c, s)

  Determine if a character is in a string and where.
- subroutine, public init_random_seed ()

  Random generator initialization routine.
- subroutine, public piksrt (k, arr, par)

  Simple card player sorting function.
- subroutine, public init_one (A)

  Initialize a square matrix A as a unit matrix.

6.13.1 Detailed Description

Utility module.

6.13.2 Function/Subroutine Documentation

6.13.2.1 subroutine, public util::init_one (real(kind=8), dimension(:,:), intent(inout) *A*)

Initialize a square matrix A as a unit matrix.

Definition at line 137 of file util.f90.

```
137      REAL(KIND=8), DIMENSION(:,:),INTENT(INOUT) :: a
138      INTEGER :: i,n
139      n=size(a,1)
140      a=0.0d0
141      DO i=1,n
142        a(i,i)=1.0d0
143      END DO
144
```

6.13.2.2 subroutine, public util::init_random_seed ( )

Random generator initialization routine.

Definition at line 62 of file util.f90.

6.13.2.3 integer function, dimension(size(s)), public util::isin (character, intent(in) *c*, character, dimension(:), intent(in) *s*)

Determine if a character is in a string and where.

Remarks

: return positions in a vector if found and 0 vector if not found

Definition at line 45 of file util.f90.

```
45     CHARACTER, INTENT(IN) :: c
46     CHARACTER, DIMENSION(:), INTENT(IN) :: s
47     INTEGER, DIMENSION(size(s)) :: isin
48     INTEGER :: i,j
49
50     isin=0
51     j=0
52     DO i=size(s),1,-1
53        IF (c==s(i)) THEN
54           j=j+1
55           isin(j)=i
56        END IF
57     END DO
```

6.13.2.4 subroutine, public util::piksrt (integer, intent(in) *k*, integer, dimension(k), intent(inout) *arr*, integer, intent(out) *par*)

Simple card player sorting function.

Definition at line 116 of file util.f90.

```
116     INTEGER, INTENT(IN) :: k
117     INTEGER, DIMENSION(k), INTENT(INOUT) :: arr
118     INTEGER, INTENT(OUT) :: par
119     INTEGER :: i,j,a,b
120
121     par=1
122
123     DO j=2,k
124        a=arr(j)
125        DO i=j-1,1,-1
126           if(arr(i).le.a) EXIT
127           arr(i+1)=arr(i)
128           par=-par
129        END DO
130        arr(i+1)=a
131     ENDDO
132     RETURN
```

6.13.2.5 character(len=40) function, public util::rstr (real(kind=8), intent(in) *x*, character(len=20), intent(in) *fm*)

Convert a real to string with a given format.

Definition at line 36 of file util.f90.

```
36      REAL(KIND=8), INTENT(IN) :: x
37      CHARACTER(len=20), INTENT(IN) :: fm
38      WRITE (rstr, trim(adjustl(fm))) x
39      rstr = adjustl(rstr)
```

6.13.2.6 character(len=20) function, public util::str (integer, intent(in) *k*)

Convert an integer to string.

Definition at line 29 of file util.f90.

```
29      INTEGER, INTENT(IN) :: k
30      WRITE (str, *) k
31      str = adjustl(str)
```

Chapter 7

Data Type Documentation

7.1 inprod_analytic::atm_tensors Type Reference

Type holding the atmospheric inner products tensors.

Private Attributes

- procedure(calculate_a), pointer, nopass a
- procedure(calculate_b), pointer, nopass b
- procedure(calculate_c_atm), pointer, nopass c
- procedure(calculate_d), pointer, nopass d
- procedure(calculate_g), pointer, nopass g
- procedure(calculate_s), pointer, nopass s

7.1.1 Detailed Description

Type holding the atmospheric inner products tensors.

Definition at line 53 of file inprod_analytic.f90.

7.1.2 Member Data Documentation

7.1.2.1 procedure(calculate_a), pointer, nopass inprod_analytic::atm_tensors::a [private]

Definition at line 54 of file inprod_analytic.f90.

```
54      PROCEDURE(calculate_a), POINTER, NOPASS :: a
```

7.1.2.2 procedure(calculate_b), pointer, nopass inprod_analytic::atm_tensors::b [private]

Definition at line 55 of file inprod_analytic.f90.

```
55      PROCEDURE(calculate_b), POINTER, NOPASS :: b
```

7.1.2.3 procedure(calculate_c_atm), pointer, nopass inprod_analytic::atm_tensors::c [private]

Definition at line 56 of file inprod_analytic.f90.

```
56      PROCEDURE(calculate_c_atm), POINTER, NOPASS :: c
```

7.1.2.4 procedure(calculate_d), pointer, nopass inprod_analytic::atm_tensors::d [private]

Definition at line 57 of file inprod_analytic.f90.

```
57      PROCEDURE(calculate_d), POINTER, NOPASS :: d
```

7.1.2.5 procedure(calculate_g), pointer, nopass inprod_analytic::atm_tensors::g [private]

Definition at line 58 of file inprod_analytic.f90.

```
58      PROCEDURE(calculate_g), POINTER, NOPASS :: g
```

7.1.2.6 procedure(calculate_s), pointer, nopass inprod_analytic::atm_tensors::s [private]

Definition at line 59 of file inprod_analytic.f90.

```
59      PROCEDURE(calculate_s), POINTER, NOPASS :: s
```

The documentation for this type was generated from the following file:

- inprod_analytic.f90

7.2 inprod_analytic::atm_wavenum Type Reference

Atmospheric bloc specification type.

Private Attributes

- character typ
- integer m =0
- integer p =0
- integer h =0
- real(kind=8) nx =0.
- real(kind=8) ny =0.

7.2.1 Detailed Description

Atmospheric bloc specification type.

Definition at line 40 of file inprod_analytic.f90.

7.2.2 Member Data Documentation

7.2.2.1 integer inprod_analytic::atm_wavenum::h =0 [private]

Definition at line 42 of file inprod_analytic.f90.

7.2.2.2 integer inprod_analytic::atm_wavenum::m =0 [private]

Definition at line 42 of file inprod_analytic.f90.

```
42      INTEGER :: m=0,p=0,h=0
```

7.2.2.3 real(kind=8) inprod_analytic::atm_wavenum::nx =0. [private]

Definition at line 43 of file inprod_analytic.f90.

```
43      REAL(KIND=8) :: nx=0.,ny=0.
```

7.2.2.4 real(kind=8) inprod_analytic::atm_wavenum::ny =0. [private]

Definition at line 43 of file inprod_analytic.f90.

7.2.2.5 integer inprod_analytic::atm_wavenum::p =0 [private]

Definition at line 42 of file inprod_analytic.f90.

7.2.2.6 character inprod_analytic::atm_wavenum::typ [private]

Definition at line 41 of file inprod_analytic.f90.

```
41      CHARACTER :: typ
```

The documentation for this type was generated from the following file:

- inprod_analytic.f90

7.3 tensor::coolist Type Reference

Coordinate list. Type used to represent the sparse tensor.

Public Attributes

- type(coolist_elem), dimension(:), allocatable elems

  Lists of elements tensor::coolist_elem.
- integer nelems = 0

  Number of elements in the list.

7.3.1 Detailed Description

Coordinate list. Type used to represent the sparse tensor.

Definition at line 27 of file tensor.f90.

7.3.2 Member Data Documentation

7.3.2.1 type(coolist_elem), dimension(:), allocatable tensor::coolist::elems

Lists of elements tensor::coolist_elem.

Definition at line 28 of file tensor.f90.

```
28      TYPE(coolist_elem), DIMENSION(:), ALLOCATABLE :: elems !< Lists of elements tensor::coolist_elem
```

7.3.2.2 integer tensor::coolist::nelems = 0

Number of elements in the list.

Definition at line 29 of file tensor.f90.

```
29      INTEGER :: nelems = 0 !< Number of elements in the list.
```

The documentation for this type was generated from the following file:

- tensor.f90

7.4 tensor::coolist_elem Type Reference

Coordinate list element type. Elementary elements of the sparse tensors.

Private Attributes

- integer j

  Index j of the element.
- integer k

  Index k of the element.
- real(kind=8) v

  Value of the element.

7.4.1 Detailed Description

Coordinate list element type. Elementary elements of the sparse tensors.

Definition at line 20 of file tensor.f90.

7.4.2 Member Data Documentation

7.4.2.1 integer tensor::coolist_elem::j [private]

Index j of the element.

Definition at line 21 of file tensor.f90.

```
21     INTEGER :: j !< Index \f$j\f$ of the element
```

7.4.2.2 integer tensor::coolist_elem::k [private]

Index k of the element.

Definition at line 22 of file tensor.f90.

```
22     INTEGER :: k !< Index \f$k\f$ of the element
```

7.4.2.3 real(kind=8) tensor::coolist_elem::v [private]

Value of the element.

Definition at line 23 of file tensor.f90.

```
23     REAL(KIND=8) :: v !< Value of the element
```

The documentation for this type was generated from the following file:

- tensor.f90

7.5 inprod_analytic::ocean_tensors Type Reference

Type holding the oceanic inner products tensors.

Private Attributes

- procedure(calculate_k), pointer, nopass k
- procedure(calculate_m), pointer, nopass m
- procedure(calculate_c_oc), pointer, nopass c
- procedure(calculate_n), pointer, nopass n
- procedure(calculate_o), pointer, nopass o
- procedure(calculate_w), pointer, nopass w

7.5.1 Detailed Description

Type holding the oceanic inner products tensors.

Definition at line 63 of file inprod_analytic.f90.

7.5.2 Member Data Documentation

7.5.2.1 procedure(calculate_c_oc), pointer, nopass inprod_analytic::ocean_tensors::c [private]

Definition at line 66 of file inprod_analytic.f90.

```
66      PROCEDURE(calculate_c_oc), POINTER, NOPASS :: c
```

7.5.2.2 procedure(calculate_k), pointer, nopass inprod_analytic::ocean_tensors::k [private]

Definition at line 64 of file inprod_analytic.f90.

```
64      PROCEDURE(calculate_k), POINTER, NOPASS :: k
```

7.5.2.3 procedure(calculate_m), pointer, nopass inprod_analytic::ocean_tensors::m [private]

Definition at line 65 of file inprod_analytic.f90.

```
65      PROCEDURE(calculate_m), POINTER, NOPASS :: m
```

7.5.2.4 procedure(calculate_n), pointer, nopass inprod_analytic::ocean_tensors::n [private]

Definition at line 67 of file inprod_analytic.f90.

```
67      PROCEDURE(calculate_n), POINTER, NOPASS :: n
```

7.5.2.5 procedure(calculate_o), pointer, nopass inprod_analytic::ocean_tensors::o [private]

Definition at line 68 of file inprod_analytic.f90.

```
68     PROCEDURE(calculate_o), POINTER, NOPASS :: o
```

7.5.2.6 procedure(calculate_w), pointer, nopass inprod_analytic::ocean_tensors::w [private]

Definition at line 69 of file inprod_analytic.f90.

```
69     PROCEDURE(calculate_w), POINTER, NOPASS :: w
```

The documentation for this type was generated from the following file:

- inprod_analytic.f90

7.6 inprod_analytic::ocean_wavenum Type Reference

Oceanic bloc specification type.

Private Attributes

- integer p
- integer h
- real(kind=8) nx
- real(kind=8) ny

7.6.1 Detailed Description

Oceanic bloc specification type.

Definition at line 47 of file inprod_analytic.f90.

7.6.2 Member Data Documentation

7.6.2.1 integer inprod_analytic::ocean_wavenum::h [private]

Definition at line 48 of file inprod_analytic.f90.

7.6.2.2 real(kind=8) inprod_analytic::ocean_wavenum::nx [private]

Definition at line 49 of file inprod_analytic.f90.

```
49     REAL(KIND=8) :: nx,ny
```

7.6.2.3 real(kind=8) inprod_analytic::ocean_wavenum::ny [private]

Definition at line 49 of file inprod_analytic.f90.

7.6.2.4 integer inprod_analytic::ocean_wavenum::p [private]

Definition at line 48 of file inprod_analytic.f90.

```
48      INTEGER :: p,h
```

The documentation for this type was generated from the following file:

- inprod_analytic.f90

Chapter 8

File Documentation

8.1 aotensor_def.f90 File Reference

Modules

- module aotensor_def

  The equation tensor for the coupled ocean-atmosphere model with temperature which allows for an extensible set of modes in the ocean and in the atmosphere.

Functions/Subroutines

- integer function aotensor_def::psi (i)

  Translate the $\psi_{a,i}$ coefficients into effective coordinates.
- integer function aotensor_def::theta (i)

  Translate the $\theta_{a,i}$ coefficients into effective coordinates.
- integer function aotensor_def::a (i)

  Translate the $\psi_{o,i}$ coefficients into effective coordinates.
- integer function aotensor_def::t (i)

  Translate the $\delta T_{o,i}$ coefficients into effective coordinates.
- integer function aotensor_def::kdelta (i, j)

  Kronecker delta function.
- subroutine aotensor_def::coeff (i, j, k, v)

  Subroutine to add element in the aotensor $\mathcal{T}_{i,j,k}$ structure.
- subroutine aotensor_def::add_count (i, j, k, v)

  Subroutine to count the elements of the aotensor $\mathcal{T}_{i,j,k}$. Add +1 to count_elems(i) for each value that is added to the tensor i-th component.
- subroutine aotensor_def::compute_aotensor (func)

  Subroutine to compute the tensor aotensor.
- subroutine, public aotensor_def::init_aotensor

  Subroutine to initialise the aotensor tensor.

Variables

- integer, dimension(:), allocatable aotensor_def::count_elems

    Vector used to count the tensor elements.
- real(kind=8), parameter aotensor_def::real_eps = 2.2204460492503131e-16

    Epsilon to test equality with 0.
- type(coolist), dimension(:), allocatable, public aotensor_def::aotensor

    $\mathcal{T}_{i,j,k}$ *- Tensor representation of the tendencies.*

8.2 doc/gen_doc.md File Reference

8.3 doc/tl_ad_doc.md File Reference

8.4 ic_def.f90 File Reference

Modules

- module ic_def

    Module to load the initial condition.

Functions/Subroutines

- subroutine, public ic_def::load_ic

    Subroutine to load the initial condition if IC.nml exists. If it does not, then write IC.nml with 0 as initial condition.

Variables

- logical ic_def::exists

    Boolean to test for file existence.
- real(kind=8), dimension(:), allocatable, public ic_def::ic

    Initial condition vector.

8.5 icdelta_def.f90 File Reference

Modules

- module icdelta_def

    Module to load the perturbation initial condition.

Functions/Subroutines

- subroutine, public icdelta_def::load_icdelta

    Subroutine to load the initial condition if ICdelta.nml exists. If it does not, then write ICdelta.nml with random initial condition.

Variables

- logical icdelta_def::exists

  Boolean to test for file existence.
- real(kind=8), dimension(:), allocatable, public icdelta_def::icdelta

  Initial condition vector.

8.6 inprod_analytic.f90 File Reference

Data Types

- type inprod_analytic::atm_wavenum

  Atmospheric bloc specification type.
- type inprod_analytic::ocean_wavenum

  Oceanic bloc specification type.
- type inprod_analytic::atm_tensors

  Type holding the atmospheric inner products tensors.
- type inprod_analytic::ocean_tensors

  Type holding the oceanic inner products tensors.

Modules

- module inprod_analytic

  Inner products between the truncated set of basis functions for the ocean and atmosphere streamfunction fields. These are partly calculated using the analytical expressions from Cehelsky, P., & Tung, K. K. : Theories of multiple equilibria and weather regimes-A critical reexamination. Part II: Baroclinic two-layer models. Journal of the atmospheric sciences, 44(21), 3282-3303, 1987.

Functions/Subroutines

- real(kind=8) function inprod_analytic::b1 (Pi, Pj, Pk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::b2 (Pi, Pj, Pk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::delta (r)

  Integer Dirac delta function.
- real(kind=8) function inprod_analytic::flambda (r)

  "Odd or even" function
- real(kind=8) function inprod_analytic::s1 (Pj, Pk, Mj, Hk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::s2 (Pj, Pk, Mj, Hk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::s3 (Pj, Pk, Hj, Hk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::s4 (Pj, Pk, Hj, Hk)

  Cehelsky & Tung Helper functions.
- real(kind=8) function inprod_analytic::calculate_a (i, j)

  Eigenvalues of the Laplacian (atmospheric)

- real(kind=8) function inprod_analytic::calculate_b (i, j, k)

  Streamfunction advection terms (atmospheric)
- real(kind=8) function inprod_analytic::calculate_c_atm (i, j)

  Beta term for the atmosphere.
- real(kind=8) function inprod_analytic::calculate_d (i, j)

  Forcing of the ocean on the atmosphere.
- real(kind=8) function inprod_analytic::calculate_g (i, j, k)

  Temperature advection terms (atmospheric)
- real(kind=8) function inprod_analytic::calculate_s (i, j)

  Forcing (thermal) of the ocean on the atmosphere.
- real(kind=8) function inprod_analytic::calculate_k (i, j)

  Forcing of the atmosphere on the ocean.
- real(kind=8) function inprod_analytic::calculate_m (i, j)

  Forcing of the ocean fields on the ocean.
- real(kind=8) function inprod_analytic::calculate_n (i, j)

  Beta term for the ocean.
- real(kind=8) function inprod_analytic::calculate_o (i, j, k)

  Temperature advection term (passive scalar)
- real(kind=8) function inprod_analytic::calculate_c_oc (i, j, k)

  Streamfunction advection terms (oceanic)
- real(kind=8) function inprod_analytic::calculate_w (i, j)

  Short-wave radiative forcing of the ocean.
- subroutine, public inprod_analytic::init_inprod

  Initialisation of the inner product.

Variables

- type(atm_wavenum), dimension(:), allocatable, public inprod_analytic::awavenum

  Atmospheric blocs specification.
- type(ocean_wavenum), dimension(:), allocatable, public inprod_analytic::owavenum

  Oceanic blocs specification.
- type(atm_tensors), public inprod_analytic::atmos

  Atmospheric tensors.
- type(ocean_tensors), public inprod_analytic::ocean

  Oceanic tensors.

8.7 LICENSE.txt File Reference

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8.8 lyap_stat.f90 File Reference

Modules

- module lyap_stat

  Statistics accumulators for the Lyapunov exponents.

Functions/Subroutines

- subroutine, public lyap_stat::lyap_init_stat

    Initialise the accumulators.
- subroutine, public lyap_stat::lyap_acc (x)

    Accumulate one state.
- real(kind=8) function, dimension(0:ndim), public lyap_stat::lyap_mean ()

    Function returning the mean.
- real(kind=8) function, dimension(0:ndim), public lyap_stat::lyap_var ()

    Function returning the variance.
- integer function, public lyap_stat::lyap_iter ()

    Function returning the number of data accumulated.
- subroutine, public lyap_stat::lyap_reset

    Routine resetting the accumulators.

Variables

- integer lyap_stat::i =0

    Number of stats accumulated.
- real(kind=8), dimension(:), allocatable lyap_stat::m

    Vector storing the inline mean.
- real(kind=8), dimension(:), allocatable lyap_stat::mprev

    Previous mean vector.
- real(kind=8), dimension(:), allocatable lyap_stat::v

    Vector storing the inline variance.
- real(kind=8), dimension(:), allocatable lyap_stat::mtmp

8.9 lyap_vectors.f90 File Reference

Modules

- module lyap_vectors

    Module for computation of Lyapunov exponents and vectors.

Functions/Subroutines

- subroutine, public lyap_vectors::init_lyap

    Initialize Lyapunov computation (possibly also vectors in later version) and initializes also a random orthogonal matrix for the matrix ensemble.
- subroutine, public lyap_vectors::multiply_prop (prop_mul)

    Multiplies prop_mul from the left with the prop matrix defined in this module and saves the result to prop_mul.
- subroutine, public lyap_vectors::benettin_step

    Performs the benettin step in integration. Multiplies the aggregated propagators in prop with ensemble and performs QR decomposition (Gram-Schmidt orthogonalization gives Q and upper triangular matrix R). Computes also the Lyapunov exponents via the diagonal of R. WATCH OUT: prop is changed during the subroutine and restored to a unit matrix.
- subroutine, public lyap_vectors::get_lyap_state (prop_ret, ensemble_ret)

    Routine that returns the current global propagator and ensemble of lyapunov vectors.

Variables

- real(kind=8), dimension(:), allocatable, public lyap_vectors::loclyap
    Buffer containing the local Lyapunov exponent.
- real(kind=8), dimension(:), allocatable, public lyap_vectors::lyapunov
    Buffer containing the averaged Lyapunov exponent.
- real(kind=8), dimension(:,:), allocatable, public lyap_vectors::ensemble
    Buffer containing the QR decompsoition of the ensemble.
- real(kind=8), dimension(:,:), allocatable lyap_vectors::prop
    Buffer holding the propagator matrix.
- integer lyap_vectors::lwork
- real(kind=8), dimension(:), allocatable lyap_vectors::work
    Temporary buffer for QR decomposition.
- real(kind=8), dimension(:), allocatable lyap_vectors::work2
    Temporary buffer for QR decomposition.
- real(kind=8), dimension(:), allocatable lyap_vectors::tau
    Temporary buffer for QR decomposition.
- real(kind=8), dimension(:,:), allocatable lyap_vectors::prop_buf
    Buffer holding the local propagator matrix.

8.10 maooam.f90 File Reference

Functions/Subroutines

- program maooam
    Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM.

8.10.1 Function/Subroutine Documentation

8.10.1.1 program maooam ( )

Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM.

Copyright

Definition at line 13 of file maooam.f90.

8.11 maooam_lyap.f90 File Reference

Functions/Subroutines

- program maooam_lyap
    Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM computing the Lyapunov spectrum.

8.11.1 Function/Subroutine Documentation

8.11.1.1 program maooam_lyap ( )

Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM computing the Lyapunov spectrum.

Copyright

Definition at line 13 of file maooam_lyap.f90.

8.12 maooam_lyap_div.f90 File Reference

Functions/Subroutines

- program maooam_lyap_div

  Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM computing the first Lyapunov exponent with the divergence method.

8.12.1 Function/Subroutine Documentation

8.12.1.1 program maooam_lyap_div ( )

Fortran 90 implementation of the modular arbitrary-order ocean-atmosphere model MAOOAM computing the first Lyapunov exponent with the divergence method.

Copyright

Definition at line 14 of file maooam_lyap_div.f90.

8.13 params.f90 File Reference

Modules

- module params

  The model parameters module.

Functions/Subroutines

- subroutine, private params::init_nml

  Read the basic parameters and mode selection from the namelist.
- subroutine params::init_params

  Parameters initialisation routine.

Variables

- real(kind=8) params::n

  $n = 2L_y/L_x$ - *Aspect ratio*
- real(kind=8) params::phi0

  Latitude in radian.
- real(kind=8) params::rra

  Earth radius.
- real(kind=8) params::sig0

  σ_0 - *Non-dimensional static stability of the atmosphere.*
- real(kind=8) params::k

  Bottom atmospheric friction coefficient.
- real(kind=8) params::kp

  k' - *Internal atmospheric friction coefficient.*
- real(kind=8) params::r

  Frictional coefficient at the bottom of the ocean.
- real(kind=8) params::d

  Merchanical coupling parameter between the ocean and the atmosphere.
- real(kind=8) params::f0

  f_0 - *Coriolis parameter*
- real(kind=8) params::gp

  g' *Reduced gravity*
- real(kind=8) params::h

  Depth of the active water layer of the ocean.
- real(kind=8) params::phi0_npi

  Latitude exprimed in fraction of pi.
- real(kind=8) params::lambda

  λ - *Sensible + turbulent heat exchange between the ocean and the atmosphere.*
- real(kind=8) params::co

  C_a - *Constant short-wave radiation of the ocean.*
- real(kind=8) params::go

  γ_o - *Specific heat capacity of the ocean.*
- real(kind=8) params::ca

  C_a - *Constant short-wave radiation of the atmosphere.*
- real(kind=8) params::to0

  T_o^0 - *Stationary solution for the 0-th order ocean temperature.*
- real(kind=8) params::ta0

  T_a^0 - *Stationary solution for the 0-th order atmospheric temperature.*
- real(kind=8) params::epsa

  ϵ_a - *Emissivity coefficient for the grey-body atmosphere.*
- real(kind=8) params::ga

  γ_a - *Specific heat capacity of the atmosphere.*
- real(kind=8) params::rr

  R - *Gas constant of dry air*
- real(kind=8) params::scale

  $L_y = L\,\pi$ - *The characteristic space scale.*
- real(kind=8) params::pi

  π
- real(kind=8) params::lr

  L_R - *Rossby deformation radius*
- real(kind=8) params::g

γ

- real(kind=8) params::rp

  r' *- Frictional coefficient at the bottom of the ocean.*
- real(kind=8) params::dp

  d' *- Non-dimensional mechanical coupling parameter between the ocean and the atmosphere.*
- real(kind=8) params::kd

  k_d *- Non-dimensional bottom atmospheric friction coefficient.*
- real(kind=8) params::kdp

  k'_d *- Non-dimensional internal atmospheric friction coefficient.*
- real(kind=8) params::cpo

  C'_a *- Non-dimensional constant short-wave radiation of the ocean.*
- real(kind=8) params::lpo

  λ'_o *- Non-dimensional sensible + turbulent heat exchange from ocean to atmosphere.*
- real(kind=8) params::cpa

  C'_a *- Non-dimensional constant short-wave radiation of the atmosphere.*
- real(kind=8) params::lpa

  λ'_a *- Non-dimensional sensible + turbulent heat exchange from atmosphere to ocean.*
- real(kind=8) params::sbpo

  $\sigma'_{B,o}$ *- Long wave radiation lost by ocean to atmosphere & space.*
- real(kind=8) params::sbpa

  $\sigma'_{B,a}$ *- Long wave radiation from atmosphere absorbed by ocean.*
- real(kind=8) params::lsbpo

  $S'_{B,o}$ *- Long wave radiation from ocean absorbed by atmosphere.*
- real(kind=8) params::lsbpa

  $S'_{B,a}$ *- Long wave radiation lost by atmosphere to space & ocean.*
- real(kind=8) params::l

  L *- Domain length scale*
- real(kind=8) params::sc

  Ratio of surface to atmosphere temperature.
- real(kind=8) params::sb

  Stefan–Boltzmann constant.
- real(kind=8) params::betp

  β' *- Non-dimensional beta parameter*
- real(kind=8) params::nua =0.D0

  Dissipation in the atmosphere.
- real(kind=8) params::nuo =0.D0

  Dissipation in the ocean.
- real(kind=8) params::nuap

  Non-dimensional dissipation in the atmosphere.
- real(kind=8) params::nuop

  Non-dimensional dissipation in the ocean.
- real(kind=8) params::t_trans

  Transient time period.
- real(kind=8) params::t_run

  Effective intergration time (length of the generated trajectory)
- real(kind=8) params::dt

  Integration time step.
- real(kind=8) params::tw

  Write all variables every tw time units.
- logical params::writeout

  Write to file boolean.

- real(kind=8) params::rescaling_time

  Rescaling time for the Lyapunov computation.
- integer params::nboc

  Number of atmospheric blocks.
- integer params::nbatm

  Number of oceanic blocks.
- integer params::natm =0

  Number of atmospheric basis functions.
- integer params::noc =0

  Number of oceanic basis functions.
- integer params::ndim

  Number of variables (dimension of the model)
- integer, dimension(:,:), allocatable params::oms

  Ocean mode selection array.
- integer, dimension(:,:), allocatable params::ams

  Atmospheric mode selection array.

8.14 rk2_integrator.f90 File Reference

Modules

- module integrator

  Module with the integration routines.

Functions/Subroutines

- subroutine, public integrator::init_integrator

  Routine to initialise the integration buffers.
- subroutine integrator::tendencies (t, y, res)

  Routine computing the tendencies of the model.
- subroutine, public integrator::step (y, t, dt, res)

  Routine to perform an integration step (Heun algorithm). The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable integrator::buf_y1

  Buffer to hold the intermediate position (Heun algorithm)
- real(kind=8), dimension(:), allocatable integrator::buf_f0

  Buffer to hold tendencies at the initial position.
- real(kind=8), dimension(:), allocatable integrator::buf_f1

  Buffer to hold tendencies at the intermediate position.

8.15 rk2_tl_ad_integrator.f90 File Reference

Modules

- module tl_ad_integrator

  Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Integrators module.

Functions/Subroutines

- subroutine tl_ad_integrator::tendencies (t, y, res)

  Routine computing the tendencies of the nonlinear model.
- subroutine, public tl_ad_integrator::init_tl_ad_integrator

  Routine to initialise the integration buffers.
- subroutine, public tl_ad_integrator::ad_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the adjoint model. The incremented time is returned.
- subroutine, public tl_ad_integrator::evolve_ad_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and adjoint together. The incremented time is returned.
- subroutine, public tl_ad_integrator::tl_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the tangent linear model. The incremented time is returned.
- subroutine, public tl_ad_integrator::evolve_tl_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and the tangent linear model together. The incremented time is returned.
- subroutine, public tl_ad_integrator::prop_step (y, propagator, t, dt, ynew, adjoint)

  Routine to perform a simultaneously an integration step (Heun algorithm) of the nonlinear and computes the Heun tangent linear propagator. The boolean variable adjoint allows for an adjoint forward integration. The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_y1

  Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f0

  Buffer to hold tendencies at the initial position of the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f1

  Buffer to hold tendencies at the intermediate position of the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_y11

  Buffer to hold the intermediate position (Heun algorithm) of the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f00

  Buffer to hold tendencies at the initial position of the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_f11

  Buffer to hold tendencies at the intermediate position of the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j1

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j2

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j1h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j2h

  Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::one

  unit matrix

8.16 rk4_integrator.f90 File Reference

Modules

- module integrator

  Module with the integration routines.

Functions/Subroutines

- subroutine, public integrator::init_integrator

  Routine to initialise the integration buffers.
- subroutine integrator::tendencies (t, y, res)

  Routine computing the tendencies of the model.
- subroutine, public integrator::step (y, t, dt, res)

  Routine to perform an integration step (Heun algorithm). The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable integrator::buf_ka

  Buffer A to hold tendencies.
- real(kind=8), dimension(:), allocatable integrator::buf_kb

  Buffer B to hold tendencies.

8.17 rk4_tl_ad_integrator.f90 File Reference

Modules

- module tl_ad_integrator

  Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Integrators module.

Functions/Subroutines

- subroutine tl_ad_integrator::tendencies (t, y, res)

  Routine computing the tendencies of the nonlinear model.
- subroutine, public tl_ad_integrator::init_tl_ad_integrator

  Routine to initialise the integration buffers.
- subroutine, public tl_ad_integrator::ad_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the adjoint model. The incremented time is returned.
- subroutine, public tl_ad_integrator::evolve_ad_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and adjoint together. The incremented time is returned.
- subroutine, public tl_ad_integrator::tl_step (y, ystar, t, dt, res)

  Routine to perform an integration step (Heun algorithm) of the tangent linear model. The incremented time is returned.
- subroutine, public tl_ad_integrator::evolve_tl_step (y, deltay, t, dt, ynew, deltaynew)

  Routine to perform a simultaneous integration step (RK4 algorithm) of the nonlinear and the tangent linear model together. The incremented time is returned.
- subroutine, public tl_ad_integrator::prop_step (y, propagator, t, dt, ynew, adjoint)

  Routine to perform a simultaneously an integration step (Heun algorithm) of the nonlinear and computes the Heun tangent linear propagator. The boolean variable adjoint allows for an adjoint forward integration. The incremented time is returned.

Variables

- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_ka

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kb

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kc

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kd

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j3

    Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j4

    Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j3h

    Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:,:), allocatable tl_ad_integrator::buf_j4h

    Buffer to hold jacobians in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kaa

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.
- real(kind=8), dimension(:), allocatable tl_ad_integrator::buf_kbb

    Buffer to hold tendencies in the RK4 scheme for the tangent linear model.

8.18 stat.f90 File Reference

Modules

- module stat

    Statistics accumulators.

Functions/Subroutines

- subroutine, public stat::init_stat

    Initialise the accumulators.
- subroutine, public stat::acc (x)

    Accumulate one state.
- real(kind=8) function, dimension(0:ndim), public stat::mean ()

    Function returning the mean.
- real(kind=8) function, dimension(0:ndim), public stat::var ()

    Function returning the variance.
- integer function, public stat::iter ()

    Function returning the number of data accumulated.
- subroutine, public stat::reset

    Routine resetting the accumulators.

Variables

- integer stat::i =0
  Number of stats accumulated.
- real(kind=8), dimension(:), allocatable stat::m
  Vector storing the inline mean.
- real(kind=8), dimension(:), allocatable stat::mprev
  Previous mean vector.
- real(kind=8), dimension(:), allocatable stat::v
  Vector storing the inline variance.
- real(kind=8), dimension(:), allocatable stat::mtmp

8.19 tensor.f90 File Reference

Data Types

- type tensor::coolist_elem
  Coordinate list element type. Elementary elements of the sparse tensors.
- type tensor::coolist
  Coordinate list. Type used to represent the sparse tensor.

Modules

- module tensor
  Tensor utility module.

Functions/Subroutines

- subroutine, public tensor::copy_coo (src, dst)
  Routine to copy a coolist.
- subroutine, public tensor::mat_to_coo (src, dst)
  Routine to convert a matrix to a tensor.
- subroutine, public tensor::sparse_mul3 (coolist_ijk, arr_j, arr_k, res)
  Sparse multiplication of a tensor with two vectors: $\sum_{j,k=0}^{ndim} \mathcal{T}_{i,j,k}\, a_j\, b_k$.
- subroutine, public tensor::jsparse_mul (coolist_ijk, arr_j, jcoo_ij)
  Sparse multiplication of two tensors to determine the Jacobian:

$$J_{i,j} = \sum_{k=0}^{ndim} \left(\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j}\right)\, a_k.$$

  It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$*, we add to* $J_{i,j}$ *as follows:*

$$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k}\, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k}\, a_j$$

  This version return a coolist (sparse tensor).
- subroutine, public tensor::jsparse_mul_mat (coolist_ijk, arr_j, jcoo_ij)

Sparse multiplication of two tensors to determine the Jacobian:

$$J_{i,j} = \sum_{k=0}^{ndim} (\mathcal{T}_{i,j,k} + \mathcal{T}_{i,k,j})\, a_k.$$

It's implemented slightly differently: for every $\mathcal{T}_{i,j,k}$, we add to $J_{i,j}$ as follows:

$$J_{i,j} = J_{i,j} + \mathcal{T}_{i,j,k}\, a_k J_{i,k} = J_{i,k} + \mathcal{T}_{i,j,k}\, a_j$$

This version return a matrix.

- subroutine, public tensor::sparse_mul2 (coolist_ij, arr_j, res)

  Sparse multiplication of a 2d sparse tensor with a vector: $\sum_{j=0}^{ndim} \mathcal{T}_{i,j,k}\, a_j.$
- subroutine, public tensor::simplify (tensor)

  Routine to simplify a coolist (sparse tensor). For each index i, it upper triangularize the matrix

  $$\mathcal{T}_{i,j,k} \qquad 0 \leq j,k \leq ndim.$$

  .
- subroutine, public tensor::add_elem (t, i, j, k, v)

  Subroutine to add element to a coolist.
- subroutine, public tensor::add_check (t, i, j, k, v, dst)

  Subroutine to add element to a coolist and check for overflow. Once the t buffer tensor is full, add it to the destination buffer.
- subroutine, public tensor::add_to_tensor (src, dst)

  Routine to add a rank-3 tensor to another one.
- subroutine, public tensor::print_tensor (t, s)

  Routine to print a rank 3 tensor coolist.
- subroutine, public tensor::write_tensor_to_file (s, t)

  Load a rank-4 tensor coolist from a file definition.
- subroutine, public tensor::load_tensor_from_file (s, t)

  Load a rank-4 tensor coolist from a file definition.

Variables

- real(kind=8), parameter tensor::real_eps = 2.2204460492503131e-16

  Parameter to test the equality with zero.

8.20 test_aotensor.f90 File Reference

Functions/Subroutines

- program test_aotensor

  Small program to print the inner products.

8.20.1 Function/Subroutine Documentation

8.20.1.1 program test_aotensor ( )

Small program to print the inner products.

Copyright

Definition at line 13 of file test_aotensor.f90.

8.21 test_inprod_analytic.f90 File Reference

Functions/Subroutines

- program inprod_analytic_test

    Small program to print the inner products.

8.21.1 Function/Subroutine Documentation

8.21.1.1 program inprod_analytic_test ( )

Small program to print the inner products.

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Remarks

Print in the same order as test_inprod.lua

Definition at line 18 of file test_inprod_analytic.f90.

8.22 test_tl_ad.f90 File Reference

Functions/Subroutines

- program test_tl_ad

    Tests for the Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM.
- real(kind=8) function gasdev (idum)
- real(kind=8) function ran2 (idum)

8.22.1 Function/Subroutine Documentation

8.22.1.1 real(kind=8) function gasdev (integer *idum*)

Definition at line 149 of file test_tl_ad.f90.

```
149   INTEGER :: idum
150   REAL(KIND=8) ::  gasdev,ran2
151   !    USES ran2
152   INTEGER :: iset
153   REAL(KIND=8) :: fac,gset,rsq,v1,v2
154   SAVE iset,gset
155   DATA iset/0/
156   if (idum.lt.0) iset=0
157   if (iset.eq.0) then
158 1    v1=2.d0*ran2(idum)-1.
159      v2=2.d0*ran2(idum)-1.
160      rsq=v1**2+v2**2
161      if (rsq.ge.1.d0.or.rsq.eq.0.d0) goto 1
162      fac=sqrt(-2.*log(rsq)/rsq)
163      gset=v1*fac
164      gasdev=v2*fac
165      iset=1
166   else
167      gasdev=gset
168      iset=0
169   endif
170   return
```

8.22.1.2 real(kind=8) function ran2 (integer *idum*)

Definition at line 174 of file test_tl_ad.f90.

```
INTEGER :: idum,im1,im2,imm1,ia1,ia2,iq1,iq2,ir1,ir2,ntab,ndiv
REAL(KIND=8) :: ran2,am,eps,rnmx
parameter(im1=2147483563,im2=2147483399,am=1.d0/im1,imm1=im1-1&
     &,ia1=40014,ia2=40692,iq1=53668,iq2=52774,ir1=12211,ir2&
     &=3791,ntab=32,ndiv=1+imm1/ntab,eps=1.2d-7,rnmx=1.d0-eps)
INTEGER :: idum2,j,k,iv(ntab),iy
SAVE iv,iy,idum2
DATA idum2/123456789/, iv/ntab*0/, iy/0/
if (idum.le.0) then
   idum=max(-idum,1)
   idum2=idum
   do j=ntab+8,1,-1
      k=idum/iq1
      idum=ia1*(idum-k*iq1)-k*ir1
      if (idum.lt.0) idum=idum+im1
      if (j.le.ntab) iv(j)=idum
   enddo
   iy=iv(1)
endif
k=idum/iq1
idum=ia1*(idum-k*iq1)-k*ir1
if (idum.lt.0) idum=idum+im1
k=idum2/iq2
idum2=ia2*(idum2-k*iq2)-k*ir2
if (idum2.lt.0) idum2=idum2+im2
j=1+iy/ndiv
iy=iv(j)-idum2
iv(j)=idum
if (iy.lt.1) iy=iy+imm1
ran2=min(am*iy,rnmx)
return
```

8.22.1.3 program test_tl_ad ( )

Tests for the Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM.

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Definition at line 14 of file test_tl_ad.f90.

8.23 tl_ad_tensor.f90 File Reference

Modules

- module tl_ad_tensor

  Tangent Linear (TL) and Adjoint (AD) model versions of MAOOAM. Tensors definition module.

Functions/Subroutines

- type(coolist) function, dimension(ndim) tl_ad_tensor::jacobian (ystar)

  Compute the Jacobian of MAOOAM in point ystar.
- real(kind=8) function, dimension(ndim, ndim), public tl_ad_tensor::jacobian_mat (ystar)

  Compute the Jacobian of MAOOAM in point ystar.
- subroutine, public tl_ad_tensor::init_tltensor

  Routine to initialize the TL tensor.
- subroutine tl_ad_tensor::compute_tltensor (func)

  Routine to compute the TL tensor from the original MAOOAM one.
- subroutine tl_ad_tensor::tl_add_count (i, j, k, v)

  Subroutine used to count the number of TL tensor entries.
- subroutine tl_ad_tensor::tl_coeff (i, j, k, v)

  Subroutine used to compute the TL tensor entries.
- subroutine, public tl_ad_tensor::init_adtensor

  Routine to initialize the AD tensor.
- subroutine tl_ad_tensor::compute_adtensor (func)

  Subroutine to compute the AD tensor from the original MAOOAM one.
- subroutine tl_ad_tensor::ad_add_count (i, j, k, v)

  Subroutine used to count the number of AD tensor entries.
- subroutine tl_ad_tensor::ad_coeff (i, j, k, v)
- subroutine, public tl_ad_tensor::init_adtensor_ref

  Alternate method to initialize the AD tensor from the TL tensor.
- subroutine tl_ad_tensor::compute_adtensor_ref (func)

  Alternate subroutine to compute the AD tensor from the TL one.
- subroutine tl_ad_tensor::ad_add_count_ref (i, j, k, v)

  Alternate subroutine used to count the number of AD tensor entries from the TL tensor.
- subroutine tl_ad_tensor::ad_coeff_ref (i, j, k, v)

  Alternate subroutine used to compute the AD tensor entries from the TL tensor.
- subroutine, public tl_ad_tensor::ad (t, ystar, deltay, buf)

  Tendencies for the AD of MAOOAM in point ystar for perturbation deltay.
- subroutine, public tl_ad_tensor::tl (t, ystar, deltay, buf)

  Tendencies for the TL of MAOOAM in point ystar for perturbation deltay.

Variables

- real(kind=8), parameter tl_ad_tensor::real_eps = 2.2204460492503131e-16

  Epsilon to test equality with 0.
- integer, dimension(:), allocatable tl_ad_tensor::count_elems

  Vector used to count the tensor elements.
- type(coolist), dimension(:), allocatable, public tl_ad_tensor::tltensor

  Tensor representation of the Tangent Linear tendencies.
- type(coolist), dimension(:), allocatable, public tl_ad_tensor::adtensor

  Tensor representation of the Adjoint tendencies.

8.24 tr_jacob_mat.f90 File Reference

Functions/Subroutines

- program tr_jacob_mat

  Tests to obtain the trace of the Jacobian matrix.

8.24.1 Function/Subroutine Documentation

8.24.1.1 program tr_jacob_mat ( )

Tests to obtain the trace of the Jacobian matrix.

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Definition at line 13 of file tr_jacob_mat.f90.

8.25 util.f90 File Reference

Modules

- module util

  Utility module.

Functions/Subroutines

- character(len=20) function, public util::str (k)

  Convert an integer to string.
- character(len=40) function, public util::rstr (x, fm)

  Convert a real to string with a given format.
- integer function, dimension(size(s)), public util::isin (c, s)

  Determine if a character is in a string and where.
- subroutine, public util::init_random_seed ()

  Random generator initialization routine.
- integer function lcg (s)
- subroutine, public util::piksrt (k, arr, par)

  Simple card player sorting function.
- subroutine, public util::init_one (A)

  Initialize a square matrix A as a unit matrix.

8.25.1 Function/Subroutine Documentation

8.25.1.1 integer function init_random_seed::lcg (integer(int64) *s*)

Definition at line 102 of file util.f90.

```
      integer :: lcg
      integer(int64) :: s
      IF (s == 0) THEN
         s = 104729
      ELSE
         s = mod(s, 4294967296_int64)
      END IF
      s = mod(s * 279470273_int64, 4294967291_int64)
      lcg = int(mod(s, int(huge(0), int64)), kind(0))
    END FUNCTION lcg
```

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