# MPTRAC

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# 1 Main Page

Massive-Parallel Trajectory Calculations (MPTRAC) is a Lagrangian particle dispersion model for the free troposphere and stratosphere.

This reference manual provides information on the algorithms and data structures used in the code.

Further information can be found at: `https://github.com/slcs-jsc/mptrac`

# 2 Data Structure Index

## 2.1 Data Structures

Here are the data structures with brief descriptions:



# 3 File Index

## 3.1 File List

Here is a list of all files with brief descriptions:

# 4 Data Structure Documentation

## 4.1 atm_t Struct Reference

Atmospheric data.

```
#include <libtrac.h>
```

### Data Fields

- int np

  *Number of air parcels.*
- double time [NP]

  *Time [s].*
- double p [NP]

  *Pressure [hPa].*
- double lon [NP]

  *Longitude [deg].*

- double lat [NP]

  *Latitude [deg].*
- double q [NQ][NP]

  *Quantity data (for various, user-defined attributes).*

### 4.1.1 Detailed Description

Atmospheric data.

Definition at line 1088 of file libtrac.h.

### 4.1.2 Field Documentation

#### 4.1.2.1 np `int atm_t::np`

Number of air parcels.

Definition at line 1091 of file libtrac.h.

#### 4.1.2.2 time `double atm_t::time[NP]`

Time [s].

Definition at line 1094 of file libtrac.h.

#### 4.1.2.3 p `double atm_t::p[NP]`

Pressure [hPa].

Definition at line 1097 of file libtrac.h.

#### 4.1.2.4 lon `double atm_t::lon[NP]`

Longitude [deg].

Definition at line 1100 of file libtrac.h.

#### 4.1.2.5 lat `double atm_t::lat[NP]`

Latitude [deg].

Definition at line 1103 of file libtrac.h.

#### 4.1.2.6 q `double atm_t::q[NQ][NP]`

Quantity data (for various, user-defined attributes).

Definition at line 1106 of file libtrac.h.

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

- libtrac.h

## 4.2 cache_t Struct Reference

Cache data.

```
#include <libtrac.h>
```

### Data Fields

- double tsig [EX][EY][EP]

  *Cache for reference time of wind standard deviations.*
- float uvwsig [EX][EY][EP][3]

  *Cache for wind standard deviations.*
- float uvwp [NP][3]

  *Wind perturbations [m/s].*
- double iso_var [NP]

  *Isosurface variables.*
- double iso_ps [NP]

  *Isosurface balloon pressure [hPa].*
- double iso_ts [NP]

  *Isosurface balloon time [s].*
- int iso_n

  *Isosurface balloon number of data points.*

### 4.2.1 Detailed Description

Cache data.

Definition at line 1111 of file libtrac.h.

### 4.2.2 Field Documentation

#### 4.2.2.1 tsig `double cache_t::tsig[EX][EY][EP]`

Cache for reference time of wind standard deviations.

Definition at line 1114 of file libtrac.h.

#### 4.2.2.2 uvwsig `float cache_t::uvwsig[EX][EY][EP][3]`

Cache for wind standard deviations.

Definition at line 1117 of file libtrac.h.

#### 4.2.2.3 uvwp `float cache_t::uvwp[NP][3]`

Wind perturbations [m/s].

Definition at line 1120 of file libtrac.h.

#### 4.2.2.4 iso_var `double cache_t::iso_var[NP]`

Isosurface variables.

Definition at line 1123 of file libtrac.h.

#### 4.2.2.5 iso_ps `double cache_t::iso_ps[NP]`

Isosurface balloon pressure [hPa].

Definition at line 1126 of file libtrac.h.

#### 4.2.2.6 iso_ts `double cache_t::iso_ts[NP]`

Isosurface balloon time [s].

Definition at line 1129 of file libtrac.h.

#### 4.2.2.7 iso_n `int cache_t::iso_n`

Isosurface balloon number of data points.

Definition at line 1132 of file libtrac.h.

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

- libtrac.h

## 4.3 ctl_t Struct Reference

Control parameters.

`#include <libtrac.h>`

### Data Fields

- size_t chunkszhint

    *Chunk size hint for nc__open.*
- int read_mode

    *Read mode for nc__open.*
- int nq

    *Number of quantities.*
- char qnt_name [NQ][LEN]

    *Quantity names.*
- char qnt_unit [NQ][LEN]

    *Quantity units.*
- char qnt_format [NQ][LEN]

    *Quantity output format.*
- int qnt_ens

    *Quantity array index for ensemble IDs.*
- int qnt_stat

    *Quantity array index for station flag.*
- int qnt_m

    *Quantity array index for mass.*
- int qnt_vmr

    *Quantity array index for volume mixing ratio.*
- int qnt_rho

    *Quantity array index for particle density.*
- int qnt_r

    *Quantity array index for particle radius.*
- int qnt_ps

    *Quantity array index for surface pressure.*
- int qnt_ts

    *Quantity array index for surface temperature.*
- int qnt_zs

    *Quantity array index for surface geopotential height.*
- int qnt_us

    *Quantity array index for surface zonal wind.*

- int qnt_vs

  *Quantity array index for surface meridional wind.*
- int qnt_pbl

  *Quantity array index for boundary layer pressure.*
- int qnt_pt

  *Quantity array index for tropopause pressure.*
- int qnt_tt

  *Quantity array index for tropopause temperature.*
- int qnt_zt

  *Quantity array index for tropopause geopotential height.*
- int qnt_h2ot

  *Quantity array index for tropopause water vapor vmr.*
- int qnt_z

  *Quantity array index for geopotential height.*
- int qnt_p

  *Quantity array index for pressure.*
- int qnt_t

  *Quantity array index for temperature.*
- int qnt_u

  *Quantity array index for zonal wind.*
- int qnt_v

  *Quantity array index for meridional wind.*
- int qnt_w

  *Quantity array index for vertical velocity.*
- int qnt_h2o

  *Quantity array index for water vapor vmr.*
- int qnt_o3

  *Quantity array index for ozone vmr.*
- int qnt_lwc

  *Quantity array index for cloud liquid water content.*
- int qnt_iwc

  *Quantity array index for cloud ice water content.*
- int qnt_pct

  *Quantity array index for cloud top pressure.*
- int qnt_pcb

  *Quantity array index for cloud bottom pressure.*
- int qnt_cl

  *Quantity array index for total column cloud water.*
- int qnt_plcl

  *Quantity array index for pressure at lifted condensation level (LCL).*
- int qnt_plfc

  *Quantity array index for pressure at level of free convection (LCF).*
- int qnt_pel

  *Quantity array index for pressure at equilibrium level (EL).*
- int qnt_cape

  *Quantity array index for convective available potential energy (CAPE).*
- int qnt_cin

  *Quantity array index for convective inhibition (CIN).*
- int qnt_hno3

  *Quantity array index for nitric acid vmr.*
- int qnt_oh

*Quantity array index for hydroxyl number concentrations.*
- int qnt_psat

  *Quantity array index for saturation pressure over water.*
- int qnt_psice

  *Quantity array index for saturation pressure over ice.*
- int qnt_pw

  *Quantity array index for partial water vapor pressure.*
- int qnt_sh

  *Quantity array index for specific humidity.*
- int qnt_rh

  *Quantity array index for relative humidity over water.*
- int qnt_rhice

  *Quantity array index for relative humidity over ice.*
- int qnt_theta

  *Quantity array index for potential temperature.*
- int qnt_zeta

  *Quantity array index for zeta vertical coordinate.*
- int qnt_tvirt

  *Quantity array index for virtual temperature.*
- int qnt_lapse

  *Quantity array index for lapse rate.*
- int qnt_vh

  *Quantity array index for horizontal wind.*
- int qnt_vz

  *Quantity array index for vertical velocity.*
- int qnt_pv

  *Quantity array index for potential vorticity.*
- int qnt_tdew

  *Quantity array index for dew point temperature.*
- int qnt_tice

  *Quantity array index for T_ice.*
- int qnt_tsts

  *Quantity array index for T_STS.*
- int qnt_tnat

  *Quantity array index for T_NAT.*
- int direction

  *Direction flag (1=forward calculation, -1=backward calculation).*
- double t_start

  *Start time of simulation [s].*
- double t_stop

  *Stop time of simulation [s].*
- double dt_mod

  *Time step of simulation [s].*
- char metbase [LEN]

  *Basename for meteorological data.*
- double dt_met

  *Time step of meteorological data [s].*
- int met_dx

  *Stride for longitudes.*
- int met_dy

  *Stride for latitudes.*

- int met_dp
  *Stride for pressure levels.*
- int met_sx
  *Smoothing for longitudes.*
- int met_sy
  *Smoothing for latitudes.*
- int met_sp
  *Smoothing for pressure levels.*
- double met_detrend
  *FWHM of horizontal Gaussian used for detrending [km].*
- int met_np
  *Number of target pressure levels.*
- double met_p [EP]
  *Target pressure levels [hPa].*
- int met_geopot_sx
  *Longitudinal smoothing of geopotential heights.*
- int met_geopot_sy
  *Latitudinal smoothing of geopotential heights.*
- int met_tropo
  *Tropopause definition (0=none, 1=clim, 2=cold point, 3=WMO_1st, 4=WMO_2nd, 5=dynamical).*
- double met_tropo_lapse
  *WMO tropopause lapse rate [K/km].*
- int met_tropo_nlev
  *WMO tropopause layer width (number of levels).*
- double met_tropo_lapse_sep
  *WMO tropopause separation layer lapse rate [K/km].*
- int met_tropo_nlev_sep
  *WMO tropopause separation layer width (number of levels).*
- double met_tropo_pv
  *Dyanmical tropopause potential vorticity threshold [PVU].*
- double met_tropo_theta
  *Dynamical tropopause potential temperature threshold [K].*
- int met_tropo_spline
  *Tropopause interpolation method (0=linear, 1=spline).*
- double met_cloud
  *Cloud data (0=none, 1=LWC+IWC, 2=RWC+SWC, 3=all).*
- double met_dt_out
  *Time step for sampling of meteo data along trajectories [s].*
- int met_cache
  *Preload meteo data into disk cache (0=no, 1=yes).*
- int isosurf
  *Isosurface parameter (0=none, 1=pressure, 2=density, 3=theta, 4=balloon).*
- char balloon [LEN]
  *Balloon position filename.*
- int advect
  *Advection scheme (0=midpoint, 1=Runge-Kutta).*
- int reflect
  *Reflection of particles at top and bottom boundary (0=no, 1=yes).*
- double turb_dx_trop
  *Horizontal turbulent diffusion coefficient (troposphere) [m^2/s].*
- double turb_dx_strat

*Horizontal turbulent diffusion coefficient (stratosphere) [m^2/s].*

- double turb_dz_trop

  *Vertical turbulent diffusion coefficient (troposphere) [m^2/s].*
- double turb_dz_strat

  *Vertical turbulent diffusion coefficient (stratosphere) [m^2/s].*
- double turb_mesox

  *Horizontal scaling factor for mesoscale wind fluctuations.*
- double turb_mesoz

  *Vertical scaling factor for mesoscale wind fluctuations.*
- double conv_cape

  *CAPE threshold for convection module [J/kg].*
- double conv_cin

  *CIN threshold for convection module [J/kg].*
- double conv_wmax

  *Maximum vertical velocity for convection module [m/s].*
- double conv_wcape

  *Limit vertical velocity based on CAPE (0=no, 1=yes).*
- double conv_dt

  *Time interval for convection module [s].*
- int conv_mix_bot

  *Lower level for mixing (0=particle pressure, 1=surface).*
- int conv_mix_top

  *Upper level for mixing (0=particle pressure, 1=EL).*
- double bound_mass

  *Boundary conditions mass per particle [kg].*
- double bound_vmr

  *Boundary conditions volume mixing ratio [ppv].*
- double bound_lat0

  *Boundary conditions minimum longitude [deg].*
- double bound_lat1

  *Boundary conditions maximum longitude [deg].*
- double bound_p0

  *Boundary conditions bottom pressure [hPa].*
- double bound_p1

  *Boundary conditions top pressure [hPa].*
- double bound_dps

  *Boundary conditions delta to surface pressure [hPa].*
- char species [LEN]

  *Species.*
- double molmass

  *Molar mass [g/mol].*
- double tdec_trop

  *Life time of particles (troposphere) [s].*
- double tdec_strat

  *Life time of particles (stratosphere) [s].*
- int oh_chem_reaction

  *Reaction type for OH chemistry (0=none, 2=bimolecular, 3=termolecular).*
- double oh_chem [4]

  *Coefficients for OH reaction rate (A, E/R or k0, n, kinf, m).*
- double dry_depo [1]

  *Coefficients for dry deposition (v).*

- double wet_depo [8]

  *Coefficients for wet deposition (Ai, Bi, Hi, Ci, Ab, Bb, Hb, Cb).*
- double psc_h2o

  *H2O volume mixing ratio for PSC analysis.*
- double psc_hno3

  *HNO3 volume mixing ratio for PSC analysis.*
- char atm_basename [LEN]

  *Basename of atmospheric data files.*
- char atm_gpfile [LEN]

  *Gnuplot file for atmospheric data.*
- double atm_dt_out

  *Time step for atmospheric data output [s].*
- int atm_filter

  *Time filter for atmospheric data output (0=none, 1=missval, 2=remove).*
- int atm_stride

  *Particle index stride for atmospheric data files.*
- int atm_type

  *Type of atmospheric data files (0=ASCII, 1=binary, 2=netCDF).*
- char csi_basename [LEN]

  *Basename of CSI data files.*
- double csi_dt_out

  *Time step for CSI data output [s].*
- char csi_obsfile [LEN]

  *Observation data file for CSI analysis.*
- double csi_obsmin

  *Minimum observation index to trigger detection.*
- double csi_modmin

  *Minimum column density to trigger detection [kg/m^2].*
- int csi_nz

  *Number of altitudes of gridded CSI data.*
- double csi_z0

  *Lower altitude of gridded CSI data [km].*
- double csi_z1

  *Upper altitude of gridded CSI data [km].*
- int csi_nx

  *Number of longitudes of gridded CSI data.*
- double csi_lon0

  *Lower longitude of gridded CSI data [deg].*
- double csi_lon1

  *Upper longitude of gridded CSI data [deg].*
- int csi_ny

  *Number of latitudes of gridded CSI data.*
- double csi_lat0

  *Lower latitude of gridded CSI data [deg].*
- double csi_lat1

  *Upper latitude of gridded CSI data [deg].*
- char grid_basename [LEN]

  *Basename of grid data files.*
- char grid_gpfile [LEN]

  *Gnuplot file for gridded data.*
- double grid_dt_out

*Time step for gridded data output [s].*
- int grid_sparse

  *Sparse output in grid data files (0=no, 1=yes).*
- int grid_nz

  *Number of altitudes of gridded data.*
- double grid_z0

  *Lower altitude of gridded data [km].*
- double grid_z1

  *Upper altitude of gridded data [km].*
- int grid_nx

  *Number of longitudes of gridded data.*
- double grid_lon0

  *Lower longitude of gridded data [deg].*
- double grid_lon1

  *Upper longitude of gridded data [deg].*
- int grid_ny

  *Number of latitudes of gridded data.*
- double grid_lat0

  *Lower latitude of gridded data [deg].*
- double grid_lat1

  *Upper latitude of gridded data [deg].*
- char prof_basename [LEN]

  *Basename for profile output file.*
- char prof_obsfile [LEN]

  *Observation data file for profile output.*
- int prof_nz

  *Number of altitudes of gridded profile data.*
- double prof_z0

  *Lower altitude of gridded profile data [km].*
- double prof_z1

  *Upper altitude of gridded profile data [km].*
- int prof_nx

  *Number of longitudes of gridded profile data.*
- double prof_lon0

  *Lower longitude of gridded profile data [deg].*
- double prof_lon1

  *Upper longitude of gridded profile data [deg].*
- int prof_ny

  *Number of latitudes of gridded profile data.*
- double prof_lat0

  *Lower latitude of gridded profile data [deg].*
- double prof_lat1

  *Upper latitude of gridded profile data [deg].*
- char ens_basename [LEN]

  *Basename of ensemble data file.*
- char sample_basename [LEN]

  *Basename of sample data file.*
- char sample_obsfile [LEN]

  *Observation data file for sample output.*
- double sample_dx

  *Horizontal radius for sample output [km].*

- double sample_dz

  *Layer width for sample output [km].*
- char stat_basename [LEN]

  *Basename of station data file.*
- double stat_lon

  *Longitude of station [deg].*
- double stat_lat

  *Latitude of station [deg].*
- double stat_r

  *Search radius around station [km].*
- double stat_t0

  *Start time for station output [s].*
- double stat_t1

  *Stop time for station output [s].*

### 4.3.1 Detailed Description

Control parameters.

Definition at line 553 of file libtrac.h.

### 4.3.2 Field Documentation

#### 4.3.2.1 chunkszhint `size_t ctl_t::chunkszhint`

Chunk size hint for nc__open.

Definition at line 556 of file libtrac.h.

#### 4.3.2.2 read_mode `int ctl_t::read_mode`

Read mode for nc__open.

Definition at line 559 of file libtrac.h.

#### 4.3.2.3 nq `int ctl_t::nq`

Number of quantities.

Definition at line 562 of file libtrac.h.

#### 4.3.2.4 qnt_name `char ctl_t::qnt_name[NQ][LEN]`

Quantity names.

Definition at line 565 of file libtrac.h.

#### 4.3.2.5 qnt_unit `char ctl_t::qnt_unit[NQ][LEN]`

Quantity units.

Definition at line 568 of file libtrac.h.

#### 4.3.2.6 qnt_format `char ctl_t::qnt_format[NQ][LEN]`

Quantity output format.

Definition at line 571 of file libtrac.h.

#### 4.3.2.7 qnt_ens `int ctl_t::qnt_ens`

Quantity array index for ensemble IDs.

Definition at line 574 of file libtrac.h.

#### 4.3.2.8 qnt_stat `int ctl_t::qnt_stat`

Quantity array index for station flag.

Definition at line 577 of file libtrac.h.

#### 4.3.2.9 qnt_m `int ctl_t::qnt_m`

Quantity array index for mass.

Definition at line 580 of file libtrac.h.

#### 4.3.2.10 qnt_vmr `int ctl_t::qnt_vmr`

Quantity array index for volume mixing ratio.

Definition at line 583 of file libtrac.h.

#### 4.3.2.11 qnt_rho `int ctl_t::qnt_rho`

Quantity array index for particle density.

Definition at line 586 of file libtrac.h.

#### 4.3.2.12 qnt_r `int ctl_t::qnt_r`

Quantity array index for particle radius.

Definition at line 589 of file libtrac.h.

#### 4.3.2.13 qnt_ps `int ctl_t::qnt_ps`

Quantity array index for surface pressure.

Definition at line 592 of file libtrac.h.

#### 4.3.2.14 qnt_ts `int ctl_t::qnt_ts`

Quantity array index for surface temperature.

Definition at line 595 of file libtrac.h.

#### 4.3.2.15 qnt_zs `int ctl_t::qnt_zs`

Quantity array index for surface geopotential height.

Definition at line 598 of file libtrac.h.

#### 4.3.2.16 qnt_us `int ctl_t::qnt_us`

Quantity array index for surface zonal wind.

Definition at line 601 of file libtrac.h.

#### 4.3.2.17 qnt_vs `int ctl_t::qnt_vs`

Quantity array index for surface meridional wind.

Definition at line 604 of file libtrac.h.

#### 4.3.2.18 qnt_pbl `int ctl_t::qnt_pbl`

Quantity array index for boundary layer pressure.

Definition at line 607 of file libtrac.h.

#### 4.3.2.19 qnt_pt `int ctl_t::qnt_pt`

Quantity array index for tropopause pressure.

Definition at line 610 of file libtrac.h.

#### 4.3.2.20 qnt_tt `int ctl_t::qnt_tt`

Quantity array index for tropopause temperature.

Definition at line 613 of file libtrac.h.

#### 4.3.2.21 qnt_zt `int ctl_t::qnt_zt`

Quantity array index for tropopause geopotential height.

Definition at line 616 of file libtrac.h.

#### 4.3.2.22 qnt_h2ot `int ctl_t::qnt_h2ot`

Quantity array index for tropopause water vapor vmr.

Definition at line 619 of file libtrac.h.

#### 4.3.2.23 qnt_z `int ctl_t::qnt_z`

Quantity array index for geopotential height.

Definition at line 622 of file libtrac.h.

#### 4.3.2.24 qnt_p `int ctl_t::qnt_p`

Quantity array index for pressure.

Definition at line 625 of file libtrac.h.

#### 4.3.2.25 qnt_t `int ctl_t::qnt_t`

Quantity array index for temperature.

Definition at line 628 of file libtrac.h.

#### 4.3.2.26 qnt_u `int ctl_t::qnt_u`

Quantity array index for zonal wind.

Definition at line 631 of file libtrac.h.

#### 4.3.2.27 qnt_v `int ctl_t::qnt_v`

Quantity array index for meridional wind.

Definition at line 634 of file libtrac.h.

#### 4.3.2.28 qnt_w `int ctl_t::qnt_w`

Quantity array index for vertical velocity.

Definition at line 637 of file libtrac.h.

#### 4.3.2.29 qnt_h2o `int ctl_t::qnt_h2o`

Quantity array index for water vapor vmr.

Definition at line 640 of file libtrac.h.

#### 4.3.2.30 qnt_o3 `int ctl_t::qnt_o3`

Quantity array index for ozone vmr.

Definition at line 643 of file libtrac.h.

#### 4.3.2.31 qnt_lwc `int ctl_t::qnt_lwc`

Quantity array index for cloud liquid water content.

Definition at line 646 of file libtrac.h.

#### 4.3.2.32 qnt_iwc `int ctl_t::qnt_iwc`

Quantity array index for cloud ice water content.

Definition at line 649 of file libtrac.h.

#### 4.3.2.33 qnt_pct `int ctl_t::qnt_pct`

Quantity array index for cloud top pressure.

Definition at line 652 of file libtrac.h.

#### 4.3.2.34 qnt_pcb `int ctl_t::qnt_pcb`

Quantity array index for cloud bottom pressure.

Definition at line 655 of file libtrac.h.

#### 4.3.2.35 qnt_cl `int ctl_t::qnt_cl`

Quantity array index for total column cloud water.

Definition at line 658 of file libtrac.h.

#### 4.3.2.36 qnt_plcl `int ctl_t::qnt_plcl`

Quantity array index for pressure at lifted condensation level (LCL).

Definition at line 661 of file libtrac.h.

#### 4.3.2.37 qnt_plfc `int ctl_t::qnt_plfc`

Quantity array index for pressure at level of free convection (LCF).

Definition at line 664 of file libtrac.h.

#### 4.3.2.38 qnt_pel `int ctl_t::qnt_pel`

Quantity array index for pressure at equilibrium level (EL).

Definition at line 667 of file libtrac.h.

#### 4.3.2.39 qnt_cape `int ctl_t::qnt_cape`

Quantity array index for convective available potential energy (CAPE).

Definition at line 670 of file libtrac.h.

#### 4.3.2.40 qnt_cin `int ctl_t::qnt_cin`

Quantity array index for convective inhibition (CIN).

Definition at line 673 of file libtrac.h.

#### 4.3.2.41 qnt_hno3 `int ctl_t::qnt_hno3`

Quantity array index for nitric acid vmr.

Definition at line 676 of file libtrac.h.

#### 4.3.2.42 qnt_oh `int ctl_t::qnt_oh`

Quantity array index for hydroxyl number concentrations.

Definition at line 679 of file libtrac.h.

#### 4.3.2.43 qnt_psat `int ctl_t::qnt_psat`

Quantity array index for saturation pressure over water.

Definition at line 682 of file libtrac.h.

#### 4.3.2.44 qnt_psice `int ctl_t::qnt_psice`

Quantity array index for saturation pressure over ice.

Definition at line 685 of file libtrac.h.

#### 4.3.2.45 qnt_pw `int ctl_t::qnt_pw`

Quantity array index for partial water vapor pressure.

Definition at line 688 of file libtrac.h.

#### 4.3.2.46 qnt_sh `int ctl_t::qnt_sh`

Quantity array index for specific humidity.

Definition at line 691 of file libtrac.h.

#### 4.3.2.47 qnt_rh `int ctl_t::qnt_rh`

Quantity array index for relative humidity over water.

Definition at line 694 of file libtrac.h.

#### 4.3.2.48 qnt_rhice `int ctl_t::qnt_rhice`

Quantity array index for relative humidity over ice.

Definition at line 697 of file libtrac.h.

#### 4.3.2.49 qnt_theta `int ctl_t::qnt_theta`

Quantity array index for potential temperature.

Definition at line 700 of file libtrac.h.

#### 4.3.2.50 qnt_zeta `int ctl_t::qnt_zeta`

Quantity array index for zeta vertical coordinate.

Definition at line 703 of file libtrac.h.

#### 4.3.2.51 qnt_tvirt `int ctl_t::qnt_tvirt`

Quantity array index for virtual temperature.

Definition at line 706 of file libtrac.h.

#### 4.3.2.52 qnt_lapse `int ctl_t::qnt_lapse`

Quantity array index for lapse rate.

Definition at line 709 of file libtrac.h.

#### 4.3.2.53 qnt_vh `int ctl_t::qnt_vh`

Quantity array index for horizontal wind.

Definition at line 712 of file libtrac.h.

#### 4.3.2.54 qnt_vz `int ctl_t::qnt_vz`

Quantity array index for vertical velocity.

Definition at line 715 of file libtrac.h.

#### 4.3.2.55 qnt_pv `int ctl_t::qnt_pv`

Quantity array index for potential vorticity.

Definition at line 718 of file libtrac.h.

#### 4.3.2.56 qnt_tdew `int ctl_t::qnt_tdew`

Quantity array index for dew point temperature.

Definition at line 721 of file libtrac.h.

#### 4.3.2.57 qnt_tice `int ctl_t::qnt_tice`

Quantity array index for T_ice.

Definition at line 724 of file libtrac.h.

#### 4.3.2.58 qnt_tsts `int ctl_t::qnt_tsts`

Quantity array index for T_STS.

Definition at line 727 of file libtrac.h.

#### 4.3.2.59 qnt_tnat `int ctl_t::qnt_tnat`

Quantity array index for T_NAT.

Definition at line 730 of file libtrac.h.

#### 4.3.2.60 direction `int ctl_t::direction`

Direction flag (1=forward calculation, -1=backward calculation).

Definition at line 733 of file libtrac.h.

#### 4.3.2.61 t_start `double ctl_t::t_start`

Start time of simulation [s].

Definition at line 736 of file libtrac.h.

#### 4.3.2.62 t_stop `double ctl_t::t_stop`

Stop time of simulation [s].

Definition at line 739 of file libtrac.h.

#### 4.3.2.63 dt_mod `double ctl_t::dt_mod`

Time step of simulation [s].

Definition at line 742 of file libtrac.h.

#### 4.3.2.64 metbase `char ctl_t::metbase[LEN]`

Basename for meteorological data.

Definition at line 745 of file libtrac.h.

#### 4.3.2.65 dt_met `double ctl_t::dt_met`

Time step of meteorological data [s].

Definition at line 748 of file libtrac.h.

#### 4.3.2.66 met_dx `int ctl_t::met_dx`

Stride for longitudes.

Definition at line 751 of file libtrac.h.

#### 4.3.2.67 met_dy `int ctl_t::met_dy`

Stride for latitudes.

Definition at line 754 of file libtrac.h.

#### 4.3.2.68 met_dp `int ctl_t::met_dp`

Stride for pressure levels.

Definition at line 757 of file libtrac.h.

#### 4.3.2.69 met_sx `int ctl_t::met_sx`

Smoothing for longitudes.

Definition at line 760 of file libtrac.h.

#### 4.3.2.70 met_sy `int ctl_t::met_sy`

Smoothing for latitudes.

Definition at line 763 of file libtrac.h.

#### 4.3.2.71 met_sp `int ctl_t::met_sp`

Smoothing for pressure levels.

Definition at line 766 of file libtrac.h.

#### 4.3.2.72 met_detrend `double ctl_t::met_detrend`

FWHM of horizontal Gaussian used for detrending [km].

Definition at line 769 of file libtrac.h.

#### 4.3.2.73 met_np `int ctl_t::met_np`

Number of target pressure levels.

Definition at line 772 of file libtrac.h.

#### 4.3.2.74 met_p `double ctl_t::met_p[EP]`

Target pressure levels [hPa].

Definition at line 775 of file libtrac.h.

#### 4.3.2.75 met_geopot_sx `int ctl_t::met_geopot_sx`

Longitudinal smoothing of geopotential heights.

Definition at line 778 of file libtrac.h.

#### 4.3.2.76 met_geopot_sy `int ctl_t::met_geopot_sy`

Latitudinal smoothing of geopotential heights.

Definition at line 781 of file libtrac.h.

#### 4.3.2.77 met_tropo `int ctl_t::met_tropo`

Tropopause definition (0=none, 1=clim, 2=cold point, 3=WMO_1st, 4=WMO_2nd, 5=dynamical).

Definition at line 785 of file libtrac.h.

#### 4.3.2.78 met_tropo_lapse `double ctl_t::met_tropo_lapse`

WMO tropopause lapse rate [K/km].

Definition at line 788 of file libtrac.h.

#### 4.3.2.79 met_tropo_nlev `int ctl_t::met_tropo_nlev`

WMO tropopause layer width (number of levels).

Definition at line 791 of file libtrac.h.

#### 4.3.2.80 met_tropo_lapse_sep `double ctl_t::met_tropo_lapse_sep`

WMO tropopause separation layer lapse rate [K/km].

Definition at line 794 of file libtrac.h.

#### 4.3.2.81 met_tropo_nlev_sep `int ctl_t::met_tropo_nlev_sep`

WMO tropopause separation layer width (number of levels).

Definition at line 797 of file libtrac.h.

#### 4.3.2.82 met_tropo_pv `double ctl_t::met_tropo_pv`

Dyanmical tropopause potential vorticity threshold [PVU].

Definition at line 800 of file libtrac.h.

#### 4.3.2.83 met_tropo_theta `double ctl_t::met_tropo_theta`

Dynamical tropopause potential temperature threshold [K].

Definition at line 803 of file libtrac.h.

#### 4.3.2.84 met_tropo_spline `int ctl_t::met_tropo_spline`

Tropopause interpolation method (0=linear, 1=spline).

Definition at line 806 of file libtrac.h.

#### 4.3.2.85 met_cloud `double ctl_t::met_cloud`

Cloud data (0=none, 1=LWC+IWC, 2=RWC+SWC, 3=all).

Definition at line 809 of file libtrac.h.

#### 4.3.2.86 met_dt_out `double ctl_t::met_dt_out`

Time step for sampling of meteo data along trajectories [s].

Definition at line 812 of file libtrac.h.

#### 4.3.2.87 met_cache `int ctl_t::met_cache`

Preload meteo data into disk cache (0=no, 1=yes).

Definition at line 815 of file libtrac.h.

#### 4.3.2.88 isosurf `int ctl_t::isosurf`

Isosurface parameter (0=none, 1=pressure, 2=density, 3=theta, 4=balloon).

Definition at line 819 of file libtrac.h.

#### 4.3.2.89 balloon `char ctl_t::balloon[LEN]`

Balloon position filename.

Definition at line 822 of file libtrac.h.

#### 4.3.2.90 advect `int ctl_t::advect`

Advection scheme (0=midpoint, 1=Runge-Kutta).

Definition at line 825 of file libtrac.h.

#### 4.3.2.91 reflect `int ctl_t::reflect`

Reflection of particles at top and bottom boundary (0=no, 1=yes).

Definition at line 828 of file libtrac.h.

#### 4.3.2.92 turb_dx_trop `double ctl_t::turb_dx_trop`

Horizontal turbulent diffusion coefficient (troposphere) [m^2/s].

Definition at line 831 of file libtrac.h.

#### 4.3.2.93 turb_dx_strat `double ctl_t::turb_dx_strat`

Horizontal turbulent diffusion coefficient (stratosphere) [m^2/s].

Definition at line 834 of file libtrac.h.

#### 4.3.2.94 turb_dz_trop `double ctl_t::turb_dz_trop`

Vertical turbulent diffusion coefficient (troposphere) [m^2/s].

Definition at line 837 of file libtrac.h.

#### 4.3.2.95 turb_dz_strat `double ctl_t::turb_dz_strat`

Vertical turbulent diffusion coefficient (stratosphere) [m^2/s].

Definition at line 840 of file libtrac.h.

#### 4.3.2.96 turb_mesox `double ctl_t::turb_mesox`

Horizontal scaling factor for mesoscale wind fluctuations.

Definition at line 843 of file libtrac.h.

#### 4.3.2.97 turb_mesoz `double ctl_t::turb_mesoz`

Vertical scaling factor for mesoscale wind fluctuations.

Definition at line 846 of file libtrac.h.

#### 4.3.2.98 conv_cape `double ctl_t::conv_cape`

CAPE threshold for convection module [J/kg].

Definition at line 849 of file libtrac.h.

#### 4.3.2.99 conv_cin `double ctl_t::conv_cin`

CIN threshold for convection module [J/kg].

Definition at line 852 of file libtrac.h.

#### 4.3.2.100 conv_wmax `double ctl_t::conv_wmax`

Maximum vertical velocity for convection module [m/s].

Definition at line 855 of file libtrac.h.

#### 4.3.2.101 conv_wcape `double ctl_t::conv_wcape`

Limit vertical velocity based on CAPE (0=no, 1=yes).

Definition at line 858 of file libtrac.h.

#### 4.3.2.102 conv_dt `double ctl_t::conv_dt`

Time interval for convection module [s].

Definition at line 861 of file libtrac.h.

#### 4.3.2.103 conv_mix_bot `int ctl_t::conv_mix_bot`

Lower level for mixing (0=particle pressure, 1=surface).

Definition at line 864 of file libtrac.h.

#### 4.3.2.104 conv_mix_top `int ctl_t::conv_mix_top`

Upper level for mixing (0=particle pressure, 1=EL).

Definition at line 867 of file libtrac.h.

#### 4.3.2.105 bound_mass `double ctl_t::bound_mass`

Boundary conditions mass per particle [kg].

Definition at line 870 of file libtrac.h.

#### 4.3.2.106 bound_vmr `double ctl_t::bound_vmr`

Boundary conditions volume mixing ratio [ppv].

Definition at line 873 of file libtrac.h.

#### 4.3.2.107 bound_lat0 `double ctl_t::bound_lat0`

Boundary conditions minimum longitude [deg].

Definition at line 876 of file libtrac.h.

#### 4.3.2.108 bound_lat1 `double ctl_t::bound_lat1`

Boundary conditions maximum longitude [deg].

Definition at line 879 of file libtrac.h.

#### 4.3.2.109 bound_p0 `double ctl_t::bound_p0`

Boundary conditions bottom pressure [hPa].

Definition at line 882 of file libtrac.h.

#### 4.3.2.110 bound_p1 `double ctl_t::bound_p1`

Boundary conditions top pressure [hPa].

Definition at line 885 of file libtrac.h.

#### 4.3.2.111 bound_dps `double ctl_t::bound_dps`

Boundary conditions delta to surface pressure [hPa].

Definition at line 888 of file libtrac.h.

#### 4.3.2.112 species `char ctl_t::species[LEN]`

Species.

Definition at line 891 of file libtrac.h.

#### 4.3.2.113 molmass `double ctl_t::molmass`

Molar mass [g/mol].

Definition at line 894 of file libtrac.h.

#### 4.3.2.114 tdec_trop `double ctl_t::tdec_trop`

Life time of particles (troposphere) [s].

Definition at line 897 of file libtrac.h.

#### 4.3.2.115 tdec_strat `double ctl_t::tdec_strat`

Life time of particles (stratosphere) [s].

Definition at line 900 of file libtrac.h.

#### 4.3.2.116 oh_chem_reaction `int ctl_t::oh_chem_reaction`

Reaction type for OH chemistry (0=none, 2=bimolecular, 3=termolecular).

Definition at line 903 of file libtrac.h.

#### 4.3.2.117 oh_chem `double ctl_t::oh_chem[4]`

Coefficients for OH reaction rate (A, E/R or k0, n, kinf, m).

Definition at line 906 of file libtrac.h.

#### 4.3.2.118 dry_depo `double ctl_t::dry_depo[1]`

Coefficients for dry deposition (v).

Definition at line 909 of file libtrac.h.

#### 4.3.2.119 wet_depo `double ctl_t::wet_depo[8]`

Coefficients for wet deposition (Ai, Bi, Hi, Ci, Ab, Bb, Hb, Cb).

Definition at line 912 of file libtrac.h.

#### 4.3.2.120 psc_h2o `double ctl_t::psc_h2o`

H2O volume mixing ratio for PSC analysis.

Definition at line 915 of file libtrac.h.

#### 4.3.2.121 psc_hno3 `double ctl_t::psc_hno3`

HNO3 volume mixing ratio for PSC analysis.

Definition at line 918 of file libtrac.h.

#### 4.3.2.122 atm_basename `char ctl_t::atm_basename[LEN]`

Basename of atmospheric data files.

Definition at line 921 of file libtrac.h.

#### 4.3.2.123 atm_gpfile `char ctl_t::atm_gpfile[LEN]`

Gnuplot file for atmospheric data.

Definition at line 924 of file libtrac.h.

#### 4.3.2.124 atm_dt_out `double ctl_t::atm_dt_out`

Time step for atmospheric data output [s].

Definition at line 927 of file libtrac.h.

#### 4.3.2.125 atm_filter `int ctl_t::atm_filter`

Time filter for atmospheric data output (0=none, 1=missval, 2=remove).

Definition at line 930 of file libtrac.h.

#### 4.3.2.126 atm_stride `int ctl_t::atm_stride`

Particle index stride for atmospheric data files.

Definition at line 933 of file libtrac.h.

#### 4.3.2.127 atm_type `int ctl_t::atm_type`

Type of atmospheric data files (0=ASCII, 1=binary, 2=netCDF).

Definition at line 936 of file libtrac.h.

#### 4.3.2.128 csi_basename `char ctl_t::csi_basename[LEN]`

Basename of CSI data files.

Definition at line 939 of file libtrac.h.

#### 4.3.2.129 csi_dt_out `double ctl_t::csi_dt_out`

Time step for CSI data output [s].

Definition at line 942 of file libtrac.h.

#### 4.3.2.130 csi_obsfile `char ctl_t::csi_obsfile[LEN]`

Observation data file for CSI analysis.

Definition at line 945 of file libtrac.h.

#### 4.3.2.131 csi_obsmin `double ctl_t::csi_obsmin`

Minimum observation index to trigger detection.

Definition at line 948 of file libtrac.h.

#### 4.3.2.132 csi_modmin `double ctl_t::csi_modmin`

Minimum column density to trigger detection [kg/m^2].

Definition at line 951 of file libtrac.h.

#### 4.3.2.133 csi_nz `int ctl_t::csi_nz`

Number of altitudes of gridded CSI data.

Definition at line 954 of file libtrac.h.

#### 4.3.2.134 csi_z0 `double ctl_t::csi_z0`

Lower altitude of gridded CSI data [km].

Definition at line 957 of file libtrac.h.

#### 4.3.2.135 csi_z1 `double ctl_t::csi_z1`

Upper altitude of gridded CSI data [km].

Definition at line 960 of file libtrac.h.

#### 4.3.2.136 csi_nx `int ctl_t::csi_nx`

Number of longitudes of gridded CSI data.

Definition at line 963 of file libtrac.h.

#### 4.3.2.137 csi_lon0 `double ctl_t::csi_lon0`

Lower longitude of gridded CSI data [deg].

Definition at line 966 of file libtrac.h.

#### 4.3.2.138 csi_lon1 `double ctl_t::csi_lon1`

Upper longitude of gridded CSI data [deg].

Definition at line 969 of file libtrac.h.

#### 4.3.2.139 csi_ny `int ctl_t::csi_ny`

Number of latitudes of gridded CSI data.

Definition at line 972 of file libtrac.h.

#### 4.3.2.140 csi_lat0 `double ctl_t::csi_lat0`

Lower latitude of gridded CSI data [deg].

Definition at line 975 of file libtrac.h.

#### 4.3.2.141 csi_lat1 `double ctl_t::csi_lat1`

Upper latitude of gridded CSI data [deg].

Definition at line 978 of file libtrac.h.

#### 4.3.2.142 grid_basename `char ctl_t::grid_basename[LEN]`

Basename of grid data files.

Definition at line 981 of file libtrac.h.

#### 4.3.2.143 grid_gpfile `char ctl_t::grid_gpfile[LEN]`

Gnuplot file for gridded data.

Definition at line 984 of file libtrac.h.

#### 4.3.2.144 grid_dt_out `double ctl_t::grid_dt_out`

Time step for gridded data output [s].

Definition at line 987 of file libtrac.h.

#### 4.3.2.145 grid_sparse `int ctl_t::grid_sparse`

Sparse output in grid data files (0=no, 1=yes).

Definition at line 990 of file libtrac.h.

#### 4.3.2.146 grid_nz `int ctl_t::grid_nz`

Number of altitudes of gridded data.

Definition at line 993 of file libtrac.h.

#### 4.3.2.147 grid_z0 `double ctl_t::grid_z0`

Lower altitude of gridded data [km].

Definition at line 996 of file libtrac.h.

#### 4.3.2.148 grid_z1 `double ctl_t::grid_z1`

Upper altitude of gridded data [km].

Definition at line 999 of file libtrac.h.

#### 4.3.2.149 grid_nx `int ctl_t::grid_nx`

Number of longitudes of gridded data.

Definition at line 1002 of file libtrac.h.

#### 4.3.2.150 grid_lon0 `double ctl_t::grid_lon0`

Lower longitude of gridded data [deg].

Definition at line 1005 of file libtrac.h.

#### 4.3.2.151 grid_lon1 `double ctl_t::grid_lon1`

Upper longitude of gridded data [deg].

Definition at line 1008 of file libtrac.h.

#### 4.3.2.152 grid_ny `int ctl_t::grid_ny`

Number of latitudes of gridded data.

Definition at line 1011 of file libtrac.h.

#### 4.3.2.153 grid_lat0 `double ctl_t::grid_lat0`

Lower latitude of gridded data [deg].

Definition at line 1014 of file libtrac.h.

#### 4.3.2.154 grid_lat1 `double ctl_t::grid_lat1`

Upper latitude of gridded data [deg].

Definition at line 1017 of file libtrac.h.

#### 4.3.2.155 prof_basename `char ctl_t::prof_basename[LEN]`

Basename for profile output file.

Definition at line 1020 of file libtrac.h.

#### 4.3.2.156 prof_obsfile `char ctl_t::prof_obsfile[LEN]`

Observation data file for profile output.

Definition at line 1023 of file libtrac.h.

#### 4.3.2.157 prof_nz `int ctl_t::prof_nz`

Number of altitudes of gridded profile data.

Definition at line 1026 of file libtrac.h.

#### 4.3.2.158 prof_z0 `double ctl_t::prof_z0`

Lower altitude of gridded profile data [km].

Definition at line 1029 of file libtrac.h.

#### 4.3.2.159 prof_z1 `double ctl_t::prof_z1`

Upper altitude of gridded profile data [km].

Definition at line 1032 of file libtrac.h.

#### 4.3.2.160 prof_nx `int ctl_t::prof_nx`

Number of longitudes of gridded profile data.

Definition at line 1035 of file libtrac.h.

#### 4.3.2.161 prof_lon0 `double ctl_t::prof_lon0`

Lower longitude of gridded profile data [deg].

Definition at line 1038 of file libtrac.h.

#### 4.3.2.162 prof_lon1 `double ctl_t::prof_lon1`

Upper longitude of gridded profile data [deg].

Definition at line 1041 of file libtrac.h.

#### 4.3.2.163 prof_ny `int ctl_t::prof_ny`

Number of latitudes of gridded profile data.

Definition at line 1044 of file libtrac.h.

#### 4.3.2.164 prof_lat0 `double ctl_t::prof_lat0`

Lower latitude of gridded profile data [deg].

Definition at line 1047 of file libtrac.h.

#### 4.3.2.165 prof_lat1 `double ctl_t::prof_lat1`

Upper latitude of gridded profile data [deg].

Definition at line 1050 of file libtrac.h.

#### 4.3.2.166 ens_basename `char ctl_t::ens_basename[LEN]`

Basename of ensemble data file.

Definition at line 1053 of file libtrac.h.

#### 4.3.2.167 sample_basename `char ctl_t::sample_basename[LEN]`

Basename of sample data file.

Definition at line 1056 of file libtrac.h.

#### 4.3.2.168 sample_obsfile `char ctl_t::sample_obsfile[LEN]`

Observation data file for sample output.

Definition at line 1059 of file libtrac.h.

#### 4.3.2.169 sample_dx `double ctl_t::sample_dx`

Horizontal radius for sample output [km].

Definition at line 1062 of file libtrac.h.

#### 4.3.2.170 sample_dz `double ctl_t::sample_dz`

Layer width for sample output [km].

Definition at line 1065 of file libtrac.h.

#### 4.3.2.171 stat_basename `char ctl_t::stat_basename[LEN]`

Basename of station data file.

Definition at line 1068 of file libtrac.h.

#### 4.3.2.172 stat_lon `double ctl_t::stat_lon`

Longitude of station [deg].

Definition at line 1071 of file libtrac.h.

#### 4.3.2.173 stat_lat `double ctl_t::stat_lat`

Latitude of station [deg].

Definition at line 1074 of file libtrac.h.

#### 4.3.2.174 stat_r `double ctl_t::stat_r`

Search radius around station [km].

Definition at line 1077 of file libtrac.h.

#### 4.3.2.175 stat_t0 `double ctl_t::stat_t0`

Start time for station output [s].

Definition at line 1080 of file libtrac.h.

#### 4.3.2.176 stat_t1 `double ctl_t::stat_t1`

Stop time for station output [s].

Definition at line 1083 of file libtrac.h.

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

- libtrac.h

## 4.4 met_t Struct Reference

Meteorological data.

```
#include <libtrac.h>
```

### Data Fields

- double time

  *Time [s].*
- int nx

  *Number of longitudes.*
- int ny

  *Number of latitudes.*
- int np

  *Number of pressure levels.*
- double lon [EX]

  *Longitude [deg].*
- double lat [EY]

  *Latitude [deg].*
- double p [EP]

  *Pressure [hPa].*
- float ps [EX][EY]

  *Surface pressure [hPa].*
- float ts [EX][EY]

  *Surface temperature [K].*
- float zs [EX][EY]

  *Surface geopotential height [km].*
- float us [EX][EY]

  *Surface zonal wind [m/s].*
- float vs [EX][EY]

  *Surface meridional wind [m/s].*
- float pbl [EX][EY]

  *Boundary layer pressure [hPa].*
- float pt [EX][EY]

  *Tropopause pressure [hPa].*
- float tt [EX][EY]

  *Tropopause temperature [K].*
- float zt [EX][EY]

  *Tropopause geopotential height [km].*
- float h2ot [EX][EY]

  *Tropopause water vapor vmr [ppv].*
- float pct [EX][EY]

  *Cloud top pressure [hPa].*
- float pcb [EX][EY]

  *Cloud bottom pressure [hPa].*
- float cl [EX][EY]

  *Total column cloud water [kg/m^2].*
- float plcl [EX][EY]

  *Pressure at lifted condensation level (LCL) [hPa].*
- float plfc [EX][EY]

  *Pressure at level of free convection (LFC) [hPa].*
- float pel [EX][EY]

  *Pressure at equilibrium level [hPa].*
- float cape [EX][EY]

  *Convective available potential energy [J/kg].*
- float cin [EX][EY]

*Convective inhibition [J/kg].*
- float z [EX][EY][EP]

  *Geopotential height at model levels [km].*
- float t [EX][EY][EP]

  *Temperature [K].*
- float u [EX][EY][EP]

  *Zonal wind [m/s].*
- float v [EX][EY][EP]

  *Meridional wind [m/s].*
- float w [EX][EY][EP]

  *Vertical velocity [hPa/s].*
- float pv [EX][EY][EP]

  *Potential vorticity [PVU].*
- float h2o [EX][EY][EP]

  *Water vapor volume mixing ratio [1].*
- float o3 [EX][EY][EP]

  *Ozone volume mixing ratio [1].*
- float lwc [EX][EY][EP]

  *Cloud liquid water content [kg/kg].*
- float iwc [EX][EY][EP]

  *Cloud ice water content [kg/kg].*
- float pl [EX][EY][EP]

  *Pressure on model levels [hPa].*

### 4.4.1 Detailed Description

Meteorological data.

Definition at line 1137 of file libtrac.h.

### 4.4.2 Field Documentation

#### 4.4.2.1 time `double met_t::time`

Time [s].

Definition at line 1140 of file libtrac.h.

#### 4.4.2.2 nx `int met_t::nx`

Number of longitudes.

Definition at line 1143 of file libtrac.h.

#### 4.4.2.3 ny `int met_t::ny`

Number of latitudes.

Definition at line 1146 of file libtrac.h.

#### 4.4.2.4 np `int met_t::np`

Number of pressure levels.

Definition at line 1149 of file libtrac.h.

#### 4.4.2.5 lon `double met_t::lon[EX]`

Longitude [deg].

Definition at line 1152 of file libtrac.h.

#### 4.4.2.6 lat `double met_t::lat[EY]`

Latitude [deg].

Definition at line 1155 of file libtrac.h.

#### 4.4.2.7 p `double met_t::p[EP]`

Pressure [hPa].

Definition at line 1158 of file libtrac.h.

#### 4.4.2.8 ps `float met_t::ps[EX][EY]`

Surface pressure [hPa].

Definition at line 1161 of file libtrac.h.

#### 4.4.2.9 ts `float met_t::ts[EX][EY]`

Surface temperature [K].

Definition at line 1164 of file libtrac.h.

#### 4.4.2.10 zs `float met_t::zs[EX][EY]`

Surface geopotential height [km].

Definition at line 1167 of file libtrac.h.

#### 4.4.2.11 us `float met_t::us[EX][EY]`

Surface zonal wind [m/s].

Definition at line 1170 of file libtrac.h.

#### 4.4.2.12 vs `float met_t::vs[EX][EY]`

Surface meridional wind [m/s].

Definition at line 1173 of file libtrac.h.

#### 4.4.2.13 pbl `float met_t::pbl[EX][EY]`

Boundary layer pressure [hPa].

Definition at line 1176 of file libtrac.h.

#### 4.4.2.14 pt `float met_t::pt[EX][EY]`

Tropopause pressure [hPa].

Definition at line 1179 of file libtrac.h.

#### 4.4.2.15 tt `float met_t::tt[EX][EY]`

Tropopause temperature [K].

Definition at line 1182 of file libtrac.h.

#### 4.4.2.16 zt `float met_t::zt[EX][EY]`

Tropopause geopotential height [km].

Definition at line 1185 of file libtrac.h.

#### 4.4.2.17 h2ot `float met_t::h2ot[EX][EY]`

Tropopause water vapor vmr [ppv].

Definition at line 1188 of file libtrac.h.

#### 4.4.2.18 pct `float met_t::pct[EX][EY]`

Cloud top pressure [hPa].

Definition at line 1191 of file libtrac.h.

#### 4.4.2.19 pcb `float met_t::pcb[EX][EY]`

Cloud bottom pressure [hPa].

Definition at line 1194 of file libtrac.h.

#### 4.4.2.20 cl `float met_t::cl[EX][EY]`

Total column cloud water [kg/m^2].

Definition at line 1197 of file libtrac.h.

#### 4.4.2.21 plcl `float met_t::plcl[EX][EY]`

Pressure at lifted condensation level (LCL) [hPa].

Definition at line 1200 of file libtrac.h.

#### 4.4.2.22 plfc `float met_t::plfc[EX][EY]`

Pressure at level of free convection (LFC) [hPa].

Definition at line 1203 of file libtrac.h.

#### 4.4.2.23 pel `float met_t::pel[EX][EY]`

Pressure at equilibrium level [hPa].

Definition at line 1206 of file libtrac.h.

#### 4.4.2.24 cape `float met_t::cape[EX][EY]`

Convective available potential energy [J/kg].

Definition at line 1209 of file libtrac.h.

#### 4.4.2.25 cin `float met_t::cin[EX][EY]`

Convective inhibition [J/kg].

Definition at line 1212 of file libtrac.h.

#### 4.4.2.26 z `float met_t::z[EX][EY][EP]`

Geopotential height at model levels [km].

Definition at line 1215 of file libtrac.h.

#### 4.4.2.27 t `float met_t::t[EX][EY][EP]`

Temperature [K].

Definition at line 1218 of file libtrac.h.

#### 4.4.2.28 u `float met_t::u[EX][EY][EP]`

Zonal wind [m/s].

Definition at line 1221 of file libtrac.h.

#### 4.4.2.29 v `float met_t::v[EX][EY][EP]`

Meridional wind [m/s].

Definition at line 1224 of file libtrac.h.

#### 4.4.2.30 w `float met_t::w[EX][EY][EP]`

Vertical velocity [hPa/s].

Definition at line 1227 of file libtrac.h.

#### 4.4.2.31 pv `float met_t::pv[EX][EY][EP]`

Potential vorticity [PVU].

Definition at line 1230 of file libtrac.h.

#### 4.4.2.32 h2o `float met_t::h2o[EX][EY][EP]`

Water vapor volume mixing ratio [1].

Definition at line 1233 of file libtrac.h.

#### 4.4.2.33 o3 `float met_t::o3[EX][EY][EP]`

Ozone volume mixing ratio [1].

Definition at line 1236 of file libtrac.h.

#### 4.4.2.34 lwc `float met_t::lwc[EX][EY][EP]`

Cloud liquid water content [kg/kg].

Definition at line 1239 of file libtrac.h.

#### 4.4.2.35 iwc `float met_t::iwc[EX][EY][EP]`

Cloud ice water content [kg/kg].

Definition at line 1242 of file libtrac.h.

#### 4.4.2.36 pl `float met_t::pl[EX][EY][EP]`

Pressure on model levels [hPa].

Definition at line 1245 of file libtrac.h.

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

- libtrac.h

# 5 File Documentation

## 5.1 atm_conv.c File Reference

```
#include "libtrac.h"
```

**Functions**

- int main (int argc, char *argv[ ])

### 5.1.1 Detailed Description

Convert file format of air parcel data files.

Definition in file atm_conv.c.

### 5.1.2 Function Documentation

#### 5.1.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 27 of file atm_conv.c.

```
                      {

  ctl_t ctl;

  atm_t *atm;

  /* Check arguments... */
  if (argc < 6)
    ERRMSG("Give parameters: <ctl> <atm_in> <atm_in_type>"
           " <atm_out> <atm_out_type>");

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);

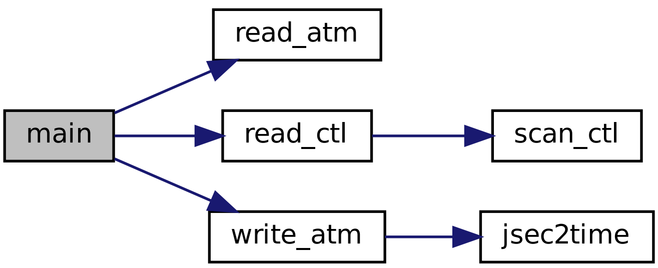
  /* Read atmospheric data... */
  ctl.atm_type = atoi(argv[3]);
  if (!read_atm(argv[2], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Write atmospheric data... */
  ctl.atm_type = atoi(argv[5]);
  write_atm(argv[4], &ctl, atm, 0);

  /* Free... */
  free(atm);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.2 atm_conv.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.
```

```

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  atm_t *atm;

  /* Check arguments... */
  if (argc < 6)
    ERRMSG("Give parameters: <ctl> <atm_in> <atm_in_type>"
           " <atm_out> <atm_out_type>");

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);

  /* Read atmospheric data... */
  ctl.atm_type = atoi(argv[3]);
  if (!read_atm(argv[2], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Write atmospheric data... */
  ctl.atm_type = atoi(argv[5]);
  write_atm(argv[4], &ctl, atm, 0);

  /* Free... */
  free(atm);

  return EXIT_SUCCESS;
}
```

## 5.3 atm_dist.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.3.1 Detailed Description

Calculate transport deviations of trajectories.

Definition in file atm_dist.c.

### 5.3.2 Function Documentation

#### 5.3.2.1 main()

```
int main (
        int argc,
        char * argv[] )
```

Definition at line 27 of file atm_dist.c.

```
                      {

  ctl_t ctl;

  atm_t *atm1, *atm2;

  FILE *out;

  char tstr[LEN];

  double *ahtd, *aqtd, *avtd, ahtdm, aqtdm[NQ], avtdm, lat0, lat1,
    *lat1_old, *lat2_old, *lh1, *lh2, lon0, lon1, *lon1_old, *lon2_old,
    *lv1, *lv2, p0, p1, *rhtd, *rqtd, *rvtd, rhtdm, rqtdm[NQ], rvtdm,
    t, t0 = 0, x0[3], x1[3], x2[3], z1, *z1_old, z2, *z2_old, *work, zscore;

  int ens, f, init = 0, ip, iq, np, year, mon, day, hour, min;

  /* Allocate... */
  ALLOC(atm1, atm_t, 1);
  ALLOC(atm2, atm_t, 1);
  ALLOC(lon1_old, double,
        NP);
  ALLOC(lat1_old, double,
        NP);
  ALLOC(z1_old, double,
        NP);
  ALLOC(lh1, double,
        NP);
  ALLOC(lv1, double,
        NP);
  ALLOC(lon2_old, double,
        NP);
  ALLOC(lat2_old, double,
        NP);
  ALLOC(z2_old, double,
        NP);
  ALLOC(lh2, double,
        NP);
  ALLOC(lv2, double,
        NP);
  ALLOC(ahtd, double,
        NP);
  ALLOC(avtd, double,
        NP);
  ALLOC(aqtd, double,
        NP * NQ);
  ALLOC(rhtd, double,
        NP);
  ALLOC(rvtd, double,
        NP);
  ALLOC(rqtd, double,
        NP * NQ);
  ALLOC(work, double,
        NP);

  /* Check arguments... */
  if (argc < 6)
    ERRMSG("Give parameters: <ctl> <dist.tab> <param> <atm1a> <atm1b>"
           " [<atm2a> <atm2b> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  ens = (int) scan_ctl(argv[1], argc, argv, "DIST_ENS", -1, "-999", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "DIST_Z0", -1, "-1000", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "DIST_Z1", -1, "1000", NULL));
  lat0 = scan_ctl(argv[1], argc, argv, "DIST_LAT0", -1, "-1000", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "DIST_LAT1", -1, "1000", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "DIST_LON0", -1, "-1000", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "DIST_LON1", -1, "1000", NULL);
  zscore = scan_ctl(argv[1], argc, argv, "DIST_ZSCORE", -1, "-999", NULL);

  /* Write info... */
  LOG(1, "Write transport deviations: %s", argv[2]);

  /* Create output file... */
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
```

```
          "# $1 = time [s]\n"
          "# $2 = time difference [s]\n"
          "# $3 = absolute horizontal distance (%s) [km]\n"
          "# $4 = relative horizontal distance (%s) [%%]\n"
          "# $5 = absolute vertical distance (%s) [km]\n"
          "# $6 = relative vertical distance (%s) [%%]\n",
          argv[3], argv[3], argv[3], argv[3]);
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out,
            "# $%d = %s absolute difference (%s) [%s]\n"
            "# $%d = %s relative difference (%s) [%%]\n",
            7 + 2 * iq, ctl.qnt_name[iq], argv[3], ctl.qnt_unit[iq],
            8 + 2 * iq, ctl.qnt_name[iq], argv[3]);
  fprintf(out, "# $%d = number of particles\n\n", 7 + 2 * ctl.nq);

  /* Loop over file pairs... */
  for (f = 4; f < argc; f += 2) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm1) || !read_atm(argv[f + 1], &ctl, atm2))
      continue;

    /* Check if structs match... */
    if (atm1->np != atm2->np)
      ERRMSG("Different numbers of particles!");

    /* Get time from filename... */
    sprintf(tstr, "%.4s", &argv[f][strlen(argv[f]) - 20]);
    year = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 15]);
    mon = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 12]);
    day = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 9]);
    hour = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 6]);
    min = atoi(tstr);
    time2jsec(year, mon, day, hour, min, 0, 0, &t);

    /* Check time... */
    if (year < 1900 || year > 2100 || mon < 1 || mon > 12 || day < 1
        || day > 31 || hour < 0 || hour > 23 || min < 0 || min > 59)
      ERRMSG("Cannot read time from filename!");

    /* Save initial time... */
    if (!init) {
      init = 1;
      t0 = t;
    }

    /* Init... */
    np = 0;
    for (ip = 0; ip < atm1->np; ip++) {
      ahtd[ip] = avtd[ip] = rhtd[ip] = rvtd[ip] = 0;
      for (iq = 0; iq < ctl.nq; iq++)
        aqtd[iq * NP + ip] = rqtd[iq * NP + ip] = 0;
    }

    /* Loop over air parcels... */
    for (ip = 0; ip < atm1->np; ip++) {

      /* Check data... */
      if (!gsl_finite(atm1->time[ip]) || !gsl_finite(atm2->time[ip]))
        continue;

      /* Check ensemble index... */
      if (ctl.qnt_ens > 0
          && (atm1->q[ctl.qnt_ens][ip] != ens
              || atm2->q[ctl.qnt_ens][ip] != ens))
        continue;

      /* Check spatial range... */
      if (atm1->p[ip] > p0 || atm1->p[ip] < p1
          || atm1->lon[ip] < lon0 || atm1->lon[ip] > lon1
          || atm1->lat[ip] < lat0 || atm1->lat[ip] > lat1)
        continue;
      if (atm2->p[ip] > p0 || atm2->p[ip] < p1
          || atm2->lon[ip] < lon0 || atm2->lon[ip] > lon1
          || atm2->lat[ip] < lat0 || atm2->lat[ip] > lat1)
        continue;

      /* Convert coordinates... */
      geo2cart(0, atm1->lon[ip], atm1->lat[ip], x1);
      geo2cart(0, atm2->lon[ip], atm2->lat[ip], x2);
      z1 = Z(atm1->p[ip]);
      z2 = Z(atm2->p[ip]);

```

```
      /* Calculate absolute transport deviations... */
      ahtd[np] = DIST(x1, x2);
      avtd[np] = z1 - z2;
      for (iq = 0; iq < ctl.nq; iq++)
        aqtd[iq * NP + np] = atm1->q[iq][ip] - atm2->q[iq][ip];

      /* Calculate relative transport deviations... */
      if (f > 4) {

        /* Get trajectory lengths... */
        geo2cart(0, lon1_old[ip], lat1_old[ip], x0);
        lh1[ip] += DIST(x0, x1);
        lv1[ip] += fabs(z1_old[ip] - z1);

        geo2cart(0, lon2_old[ip], lat2_old[ip], x0);
        lh2[ip] += DIST(x0, x2);
        lv2[ip] += fabs(z2_old[ip] - z2);

        /* Get relative transport deviations... */
        if (lh1[ip] + lh2[ip] > 0)
          rhtd[np] = 200. * DIST(x1, x2) / (lh1[ip] + lh2[ip]);
        if (lv1[ip] + lv2[ip] > 0)
          rvtd[np] = 200. * (z1 - z2) / (lv1[ip] + lv2[ip]);
      }

      /* Get relative transport deviations... */
      for (iq = 0; iq < ctl.nq; iq++)
        rqtd[iq * NP + np] = 200. * (atm1->q[iq][ip] - atm2->q[iq][ip])
          / (fabs(atm1->q[iq][ip]) + fabs(atm2->q[iq][ip]));

      /* Save positions of air parcels... */
      lon1_old[ip] = atm1->lon[ip];
      lat1_old[ip] = atm1->lat[ip];
      z1_old[ip] = z1;

      lon2_old[ip] = atm2->lon[ip];
      lat2_old[ip] = atm2->lat[ip];
      z2_old[ip] = z2;

      /* Increment air parcel counter... */
      np++;
    }

    /* Filter data... */
    if (zscore > 0 && np > 1) {

      /* Get means and standard deviations of transport deviations... */
      size_t n = (size_t) np;
      double muh = gsl_stats_mean(ahtd, 1, n);
      double muv = gsl_stats_mean(avtd, 1, n);
      double sigh = gsl_stats_sd(ahtd, 1, n);
      double sigv = gsl_stats_sd(avtd, 1, n);

      /* Filter data... */
      np = 0;
      for (size_t i = 0; i < n; i++)
        if (fabs((ahtd[i] - muh) / sigh) < zscore
            && fabs((avtd[i] - muv) / sigv) < zscore) {
          ahtd[np] = ahtd[i];
          rhtd[np] = rhtd[i];
          avtd[np] = avtd[i];
          rvtd[np] = rvtd[i];
          for (iq = 0; iq < ctl.nq; iq++) {
            aqtd[iq * NP + np] = aqtd[iq * NP + (int) i];
            rqtd[iq * NP + np] = rqtd[iq * NP + (int) i];
          }
          np++;
        }
    }

    /* Get statistics... */
    if (strcasecmp(argv[3], "mean") == 0) {
      ahtdm = gsl_stats_mean(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_mean(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_mean(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_mean(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_mean(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_mean(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "stddev") == 0) {
      ahtdm = gsl_stats_sd(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_sd(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_sd(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_sd(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_sd(&aqtd[iq * NP], 1, (size_t) np);
```

```
        rqtdm[iq] = gsl_stats_sd(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "min") == 0) {
      ahtdm = gsl_stats_min(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_min(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_min(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_min(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_min(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_min(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "max") == 0) {
      ahtdm = gsl_stats_max(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_max(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_max(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_max(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_max(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_max(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "skew") == 0) {
      ahtdm = gsl_stats_skew(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_skew(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_skew(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_skew(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_skew(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_skew(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "kurt") == 0) {
      ahtdm = gsl_stats_kurtosis(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_kurtosis(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_kurtosis(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_kurtosis(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_kurtosis(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_kurtosis(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "absdev") == 0) {
      ahtdm = gsl_stats_absdev_m(ahtd, 1, (size_t) np, 0.0);
      rhtdm = gsl_stats_absdev_m(rhtd, 1, (size_t) np, 0.0);
      avtdm = gsl_stats_absdev_m(avtd, 1, (size_t) np, 0.0);
      rvtdm = gsl_stats_absdev_m(rvtd, 1, (size_t) np, 0.0);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_absdev_m(&aqtd[iq * NP], 1, (size_t) np, 0.0);
        rqtdm[iq] = gsl_stats_absdev_m(&rqtd[iq * NP], 1, (size_t) np, 0.0);
      }
    } else if (strcasecmp(argv[3], "median") == 0) {
      ahtdm = gsl_stats_median(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_median(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_median(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_median(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_median(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_median(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "mad") == 0) {
      ahtdm = gsl_stats_mad0(ahtd, 1, (size_t) np, work);
      rhtdm = gsl_stats_mad0(rhtd, 1, (size_t) np, work);
      avtdm = gsl_stats_mad0(avtd, 1, (size_t) np, work);
      rvtdm = gsl_stats_mad0(rvtd, 1, (size_t) np, work);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_mad0(&aqtd[iq * NP], 1, (size_t) np, work);
        rqtdm[iq] = gsl_stats_mad0(&rqtd[iq * NP], 1, (size_t) np, work);
      }
    } else
      ERRMSG("Unknown parameter!");

    /* Write output... */
    fprintf(out, "%.2f %.2f %g %g %g %g", t, t - t0,
            ahtdm, rhtdm, avtdm, rvtdm);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], aqtdm[iq]);
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], rqtdm[iq]);
    }
    fprintf(out, " %d\n", np);
  }

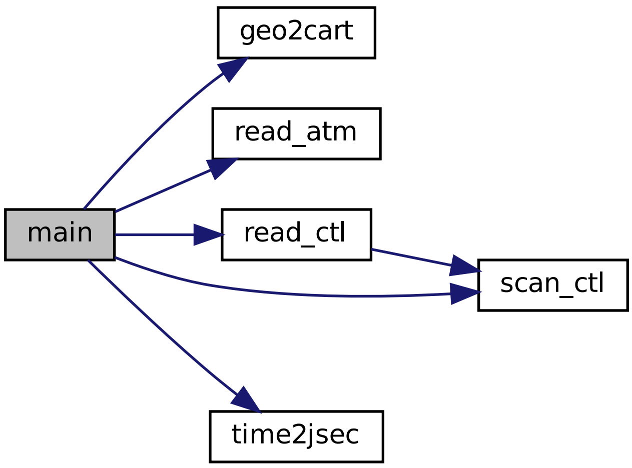
  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm1);
  free(atm2);
  free(lon1_old);
```

```
  free(lat1_old);
  free(z1_old);
  free(lh1);
  free(lv1);
  free(lon2_old);
  free(lat2_old);
  free(z2_old);
  free(lh2);
  free(lv2);
  free(ahtd);
  free(avtd);
  free(aqtd);
  free(rhtd);
  free(rvtd);
  free(rqtd);
  free(work);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.4 atm_dist.c

```
/*
  This file is part of MPTRAC.

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  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

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  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

```

```
  ctl_t ctl;

  atm_t *atm1, *atm2;

  FILE *out;

  char tstr[LEN];

  double *ahtd, *aqtd, *avtd, ahtdm, aqtdm[NQ], avtdm, lat0, lat1,
    *lat1_old, *lat2_old, *lh1, *lh2, lon0, lon1, *lon1_old, *lon2_old,
    *lv1, *lv2, p0, p1, *rhtd, *rqtd, *rvtd, rhtdm, rqtdm[NQ], rvtdm,
    t, t0 = 0, x0[3], x1[3], x2[3], z1, *z1_old, z2, *z2_old, *work, zscore;

  int ens, f, init = 0, ip, iq, np, year, mon, day, hour, min;

  /* Allocate... */
  ALLOC(atm1, atm_t, 1);
  ALLOC(atm2, atm_t, 1);
  ALLOC(lon1_old, double,
        NP);
  ALLOC(lat1_old, double,
        NP);
  ALLOC(z1_old, double,
        NP);
  ALLOC(lh1, double,
        NP);
  ALLOC(lv1, double,
        NP);
  ALLOC(lon2_old, double,
        NP);
  ALLOC(lat2_old, double,
        NP);
  ALLOC(z2_old, double,
        NP);
  ALLOC(lh2, double,
        NP);
  ALLOC(lv2, double,
        NP);
  ALLOC(ahtd, double,
        NP);
  ALLOC(avtd, double,
        NP);
  ALLOC(aqtd, double,
        NP * NQ);
  ALLOC(rhtd, double,
        NP);
  ALLOC(rvtd, double,
        NP);
  ALLOC(rqtd, double,
        NP * NQ);
  ALLOC(work, double,
        NP);

  /* Check arguments... */
  if (argc < 6)
    ERRMSG("Give parameters: <ctl> <dist.tab> <param> <atm1a> <atm1b>"
           " [<atm2a> <atm2b> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  ens = (int) scan_ctl(argv[1], argc, argv, "DIST_ENS", -1, "-999", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "DIST_Z0", -1, "-1000", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "DIST_Z1", -1, "1000", NULL));
  lat0 = scan_ctl(argv[1], argc, argv, "DIST_LAT0", -1, "-1000", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "DIST_LAT1", -1, "1000", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "DIST_LON0", -1, "-1000", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "DIST_LON1", -1, "1000", NULL);
  zscore = scan_ctl(argv[1], argc, argv, "DIST_ZSCORE", -1, "-999", NULL);

  /* Write info... */
  LOG(1, "Write transport deviations: %s", argv[2]);

  /* Create output file... */
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = time difference [s]\n"
          "# $3 = absolute horizontal distance (%s) [km]\n"
          "# $4 = relative horizontal distance (%s) [%%]\n"
          "# $5 = absolute vertical distance (%s) [km]\n"
          "# $6 = relative vertical distance (%s) [%%]\n",
          argv[3], argv[3], argv[3], argv[3]);
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out,
```

```
            "# $%d = %s absolute difference (%s) [%s]\n"
            "# $%d = %s relative difference (%s) [%%]\n",
            7 + 2 * iq, ctl.qnt_name[iq], argv[3], ctl.qnt_unit[iq],
            8 + 2 * iq, ctl.qnt_name[iq], argv[3]);
  fprintf(out, "# $%d = number of particles\n\n", 7 + 2 * ctl.nq);

  /* Loop over file pairs... */
  for (f = 4; f < argc; f += 2) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm1) || !read_atm(argv[f + 1], &ctl, atm2))
      continue;

    /* Check if structs match... */
    if (atm1->np != atm2->np)
      ERRMSG("Different numbers of particles!");

    /* Get time from filename... */
    sprintf(tstr, "%.4s", &argv[f][strlen(argv[f]) - 20]);
    year = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 15]);
    mon = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 12]);
    day = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 9]);
    hour = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 6]);
    min = atoi(tstr);
    time2jsec(year, mon, day, hour, min, 0, 0, &t);

    /* Check time... */
    if (year < 1900 || year > 2100 || mon < 1 || mon > 12 || day < 1
        || day > 31 || hour < 0 || hour > 23 || min < 0 || min > 59)
      ERRMSG("Cannot read time from filename!");

    /* Save initial time... */
    if (!init) {
      init = 1;
      t0 = t;
    }

    /* Init... */
    np = 0;
    for (ip = 0; ip < atm1->np; ip++) {
      ahtd[ip] = avtd[ip] = rhtd[ip] = rvtd[ip] = 0;
      for (iq = 0; iq < ctl.nq; iq++)
        aqtd[iq * NP + ip] = rqtd[iq * NP + ip] = 0;
    }

    /* Loop over air parcels... */
    for (ip = 0; ip < atm1->np; ip++) {

      /* Check data... */
      if (!gsl_finite(atm1->time[ip]) || !gsl_finite(atm2->time[ip]))
        continue;

      /* Check ensemble index... */
      if (ctl.qnt_ens > 0
          && (atm1->q[ctl.qnt_ens][ip] != ens
              || atm2->q[ctl.qnt_ens][ip] != ens))
        continue;

      /* Check spatial range... */
      if (atm1->p[ip] > p0 || atm1->p[ip] < p1
          || atm1->lon[ip] < lon0 || atm1->lon[ip] > lon1
          || atm1->lat[ip] < lat0 || atm1->lat[ip] > lat1)
        continue;
      if (atm2->p[ip] > p0 || atm2->p[ip] < p1
          || atm2->lon[ip] < lon0 || atm2->lon[ip] > lon1
          || atm2->lat[ip] < lat0 || atm2->lat[ip] > lat1)
        continue;

      /* Convert coordinates... */
      geo2cart(0, atm1->lon[ip], atm1->lat[ip], x1);
      geo2cart(0, atm2->lon[ip], atm2->lat[ip], x2);
      z1 = Z(atm1->p[ip]);
      z2 = Z(atm2->p[ip]);

      /* Calculate absolute transport deviations... */
      ahtd[np] = DIST(x1, x2);
      avtd[np] = z1 - z2;
      for (iq = 0; iq < ctl.nq; iq++)
        aqtd[iq * NP + np] = atm1->q[iq][ip] - atm2->q[iq][ip];

      /* Calculate relative transport deviations... */
      if (f > 4) {

```

```
      /* Get trajectory lengths... */
      geo2cart(0, lon1_old[ip], lat1_old[ip], x0);
      lh1[ip] += DIST(x0, x1);
      lv1[ip] += fabs(z1_old[ip] - z1);

      geo2cart(0, lon2_old[ip], lat2_old[ip], x0);
      lh2[ip] += DIST(x0, x2);
      lv2[ip] += fabs(z2_old[ip] - z2);

      /* Get relative transport deviations... */
      if (lh1[ip] + lh2[ip] > 0)
        rhtd[np] = 200. * DIST(x1, x2) / (lh1[ip] + lh2[ip]);
      if (lv1[ip] + lv2[ip] > 0)
        rvtd[np] = 200. * (z1 - z2) / (lv1[ip] + lv2[ip]);
    }

    /* Get relative transport deviations... */
    for (iq = 0; iq < ctl.nq; iq++)
      rqtd[iq * NP + np] = 200. * (atm1->q[iq][ip] - atm2->q[iq][ip])
        / (fabs(atm1->q[iq][ip]) + fabs(atm2->q[iq][ip]));

    /* Save positions of air parcels... */
    lon1_old[ip] = atm1->lon[ip];
    lat1_old[ip] = atm1->lat[ip];
    z1_old[ip] = z1;

    lon2_old[ip] = atm2->lon[ip];
    lat2_old[ip] = atm2->lat[ip];
    z2_old[ip] = z2;

    /* Increment air parcel counter... */
    np++;
  }

  /* Filter data... */
  if (zscore > 0 && np > 1) {

    /* Get means and standard deviations of transport deviations... */
    size_t n = (size_t) np;
    double muh = gsl_stats_mean(ahtd, 1, n);
    double muv = gsl_stats_mean(avtd, 1, n);
    double sigh = gsl_stats_sd(ahtd, 1, n);
    double sigv = gsl_stats_sd(avtd, 1, n);

    /* Filter data... */
    np = 0;
    for (size_t i = 0; i < n; i++)
      if (fabs((ahtd[i] - muh) / sigh) < zscore
          && fabs((avtd[i] - muv) / sigv) < zscore) {
        ahtd[np] = ahtd[i];
        rhtd[np] = rhtd[i];
        avtd[np] = avtd[i];
        rvtd[np] = rvtd[i];
        for (iq = 0; iq < ctl.nq; iq++) {
          aqtd[iq * NP + np] = aqtd[iq * NP + (int) i];
          rqtd[iq * NP + np] = rqtd[iq * NP + (int) i];
        }
        np++;
      }
  }

  /* Get statistics... */
  if (strcasecmp(argv[3], "mean") == 0) {
    ahtdm = gsl_stats_mean(ahtd, 1, (size_t) np);
    rhtdm = gsl_stats_mean(rhtd, 1, (size_t) np);
    avtdm = gsl_stats_mean(avtd, 1, (size_t) np);
    rvtdm = gsl_stats_mean(rvtd, 1, (size_t) np);
    for (iq = 0; iq < ctl.nq; iq++) {
      aqtdm[iq] = gsl_stats_mean(&aqtd[iq * NP], 1, (size_t) np);
      rqtdm[iq] = gsl_stats_mean(&rqtd[iq * NP], 1, (size_t) np);
    }
  } else if (strcasecmp(argv[3], "stddev") == 0) {
    ahtdm = gsl_stats_sd(ahtd, 1, (size_t) np);
    rhtdm = gsl_stats_sd(rhtd, 1, (size_t) np);
    avtdm = gsl_stats_sd(avtd, 1, (size_t) np);
    rvtdm = gsl_stats_sd(rvtd, 1, (size_t) np);
    for (iq = 0; iq < ctl.nq; iq++) {
      aqtdm[iq] = gsl_stats_sd(&aqtd[iq * NP], 1, (size_t) np);
      rqtdm[iq] = gsl_stats_sd(&rqtd[iq * NP], 1, (size_t) np);
    }
  } else if (strcasecmp(argv[3], "min") == 0) {
    ahtdm = gsl_stats_min(ahtd, 1, (size_t) np);
    rhtdm = gsl_stats_min(rhtd, 1, (size_t) np);
    avtdm = gsl_stats_min(avtd, 1, (size_t) np);
    rvtdm = gsl_stats_min(rvtd, 1, (size_t) np);
    for (iq = 0; iq < ctl.nq; iq++) {
      aqtdm[iq] = gsl_stats_min(&aqtd[iq * NP], 1, (size_t) np);
```

```
        rqtdm[iq] = gsl_stats_min(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "max") == 0) {
      ahtdm = gsl_stats_max(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_max(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_max(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_max(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_max(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_max(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "skew") == 0) {
      ahtdm = gsl_stats_skew(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_skew(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_skew(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_skew(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_skew(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_skew(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "kurt") == 0) {
      ahtdm = gsl_stats_kurtosis(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_kurtosis(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_kurtosis(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_kurtosis(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_kurtosis(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_kurtosis(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "absdev") == 0) {
      ahtdm = gsl_stats_absdev_m(ahtd, 1, (size_t) np, 0.0);
      rhtdm = gsl_stats_absdev_m(rhtd, 1, (size_t) np, 0.0);
      avtdm = gsl_stats_absdev_m(avtd, 1, (size_t) np, 0.0);
      rvtdm = gsl_stats_absdev_m(rvtd, 1, (size_t) np, 0.0);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_absdev_m(&aqtd[iq * NP], 1, (size_t) np, 0.0);
        rqtdm[iq] = gsl_stats_absdev_m(&rqtd[iq * NP], 1, (size_t) np, 0.0);
      }
    } else if (strcasecmp(argv[3], "median") == 0) {
      ahtdm = gsl_stats_median(ahtd, 1, (size_t) np);
      rhtdm = gsl_stats_median(rhtd, 1, (size_t) np);
      avtdm = gsl_stats_median(avtd, 1, (size_t) np);
      rvtdm = gsl_stats_median(rvtd, 1, (size_t) np);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_median(&aqtd[iq * NP], 1, (size_t) np);
        rqtdm[iq] = gsl_stats_median(&rqtd[iq * NP], 1, (size_t) np);
      }
    } else if (strcasecmp(argv[3], "mad") == 0) {
      ahtdm = gsl_stats_mad0(ahtd, 1, (size_t) np, work);
      rhtdm = gsl_stats_mad0(rhtd, 1, (size_t) np, work);
      avtdm = gsl_stats_mad0(avtd, 1, (size_t) np, work);
      rvtdm = gsl_stats_mad0(rvtd, 1, (size_t) np, work);
      for (iq = 0; iq < ctl.nq; iq++) {
        aqtdm[iq] = gsl_stats_mad0(&aqtd[iq * NP], 1, (size_t) np, work);
        rqtdm[iq] = gsl_stats_mad0(&rqtd[iq * NP], 1, (size_t) np, work);
      }
    } else
      ERRMSG("Unknown parameter!");

    /* Write output... */
    fprintf(out, "%.2f %.2f %g %g %g %g", t, t - t0,
            ahtdm, rhtdm, avtdm, rvtdm);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], aqtdm[iq]);
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], rqtdm[iq]);
    }
    fprintf(out, " %d\n", np);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm1);
  free(atm2);
  free(lon1_old);
  free(lat1_old);
  free(z1_old);
  free(lh1);
  free(lv1);
  free(lon2_old);
  free(lat2_old);
  free(z2_old);
  free(lh2);
  free(lv2);
```

```
  free(ahtd);
  free(avtd);
  free(aqtd);
  free(rhtd);
  free(rvtd);
  free(rqtd);
  free(work);

  return EXIT_SUCCESS;
}
```

## 5.5 atm_init.c File Reference

`#include "libtrac.h"`

### Functions

- int main (int argc, char ∗argv[ ])

### 5.5.1 Detailed Description

Create atmospheric data file with initial air parcel positions.

Definition in file atm_init.c.

### 5.5.2 Function Documentation

#### 5.5.2.1 main()

```
int main (
    int argc,
    char ∗ argv[ ] )
```

Definition at line 27 of file atm_init.c.

```
                {

  atm_t *atm;

  ctl_t ctl;

  gsl_rng *rng;

  double dt, dz, dlon, dlat, lat0, lat1, lon0, lon1, t0, t1, z0, z1, t, z,
    lon, lat, st, sz, slon, slat, sx, ut, uz, ulon, ulat, m, vmr, bellrad;

  int even, ip, irep, rep;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <atm_out>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  t0 = scan_ctl(argv[1], argc, argv, "INIT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "INIT_T1", -1, "0", NULL);
  dt = scan_ctl(argv[1], argc, argv, "INIT_DT", -1, "1", NULL);
  z0 = scan_ctl(argv[1], argc, argv, "INIT_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "INIT_Z1", -1, "0", NULL);
  dz = scan_ctl(argv[1], argc, argv, "INIT_DZ", -1, "1", NULL);
```

```
  lon0 = scan_ctl(argv[1], argc, argv, "INIT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "INIT_LON1", -1, "0", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "INIT_DLON", -1, "1", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "INIT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "INIT_LAT1", -1, "0", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "INIT_DLAT", -1, "1", NULL);
  st = scan_ctl(argv[1], argc, argv, "INIT_ST", -1, "0", NULL);
  sz = scan_ctl(argv[1], argc, argv, "INIT_SZ", -1, "0", NULL);
  slon = scan_ctl(argv[1], argc, argv, "INIT_SLON", -1, "0", NULL);
  slat = scan_ctl(argv[1], argc, argv, "INIT_SLAT", -1, "0", NULL);
  sx = scan_ctl(argv[1], argc, argv, "INIT_SX", -1, "0", NULL);
  ut = scan_ctl(argv[1], argc, argv, "INIT_UT", -1, "0", NULL);
  uz = scan_ctl(argv[1], argc, argv, "INIT_UZ", -1, "0", NULL);
  ulon = scan_ctl(argv[1], argc, argv, "INIT_ULON", -1, "0", NULL);
  ulat = scan_ctl(argv[1], argc, argv, "INIT_ULAT", -1, "0", NULL);
  even = (int) scan_ctl(argv[1], argc, argv, "INIT_EVENLY", -1, "0", NULL);
  rep = (int) scan_ctl(argv[1], argc, argv, "INIT_REP", -1, "1", NULL);
  m = scan_ctl(argv[1], argc, argv, "INIT_MASS", -1, "0", NULL);
  vmr = scan_ctl(argv[1], argc, argv, "INIT_VMR", -1, "0", NULL);
  bellrad = scan_ctl(argv[1], argc, argv, "INIT_BELLRAD", -1, "0", NULL);

  /* Initialize random number generator... */
  gsl_rng_env_setup();
  rng = gsl_rng_alloc(gsl_rng_default);

  /* Create grid... */
  for (t = t0; t <= t1; t += dt)
    for (z = z0; z <= z1; z += dz)
      for (lon = lon0; lon <= lon1; lon += dlon)
        for (lat = lat0; lat <= lat1; lat += dlat)
          for (irep = 0; irep < rep; irep++) {

            /* Set position... */
            atm->time[atm->np]
              = (t + gsl_ran_gaussian_ziggurat(rng, st / 2.3548)
                 + ut * (gsl_rng_uniform(rng) - 0.5));
            atm->p[atm->np]
              = P(z + gsl_ran_gaussian_ziggurat(rng, sz / 2.3548)
                  + uz * (gsl_rng_uniform(rng) - 0.5));
            atm->lon[atm->np]
              = (lon + gsl_ran_gaussian_ziggurat(rng, slon / 2.3548)
                 + gsl_ran_gaussian_ziggurat(rng, DX2DEG(sx, lat) / 2.3548)
                 + ulon * (gsl_rng_uniform(rng) - 0.5));
            do {
              atm->lat[atm->np]
                = (lat + gsl_ran_gaussian_ziggurat(rng, slat / 2.3548)
                   + gsl_ran_gaussian_ziggurat(rng, DY2DEG(sx) / 2.3548)
                   + ulat * (gsl_rng_uniform(rng) - 0.5));
            } while (even && gsl_rng_uniform(rng) >
                     fabs(cos(atm->lat[atm->np] * M_PI / 180.)));

            /* Apply cosine bell (Williamson et al., 1992)... */
            if (bellrad > 0) {
              double x0[3], x1[3];
              geo2cart(0.0, 0.5 * (lon0 + lon1), 0.5 * (lat0 + lat1), x0);
              geo2cart(0.0, atm->lon[atm->np], atm->lat[atm->np], x1);
              double rad = RE * acos(DOTP(x0, x1) / NORM(x0) / NORM(x1));
              if (rad > bellrad)
                continue;
              if (ctl.qnt_m >= 0)
                atm->q[ctl.qnt_m][atm->np] =
                  0.5 * (1. + cos(M_PI * rad / bellrad));
              if (ctl.qnt_vmr >= 0)
                atm->q[ctl.qnt_vmr][atm->np] =
                  0.5 * (1. + cos(M_PI * rad / bellrad));
            }

            /* Set particle counter... */
            if ((++atm->np) > NP)
              ERRMSG("Too many particles!");
          }

  /* Check number of air parcels... */
  if (atm->np <= 0)
    ERRMSG("Did not create any air parcels!");

  /* Initialize mass... */
  if (ctl.qnt_m >= 0 && bellrad <= 0)
    for (ip = 0; ip < atm->np; ip++)
      atm->q[ctl.qnt_m][ip] = m / atm->np;

  /* Initialize volume mixing ratio... */
  if (ctl.qnt_vmr >= 0 && bellrad <= 0)
    for (ip = 0; ip < atm->np; ip++)
      atm->q[ctl.qnt_vmr][ip] = vmr;

  /* Save data... */
```

```
  write_atm(argv[2], &ctl, atm, 0);

  /* Free... */
  gsl_rng_free(rng);
  free(atm);

  return EXIT_SUCCESS;
}
```

## 5.6 atm_init.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  atm_t *atm;

  ctl_t ctl;

  gsl_rng *rng;

  double dt, dz, dlon, dlat, lat0, lat1, lon0, lon1, t0, t1, z0, z1, t, z,
    lon, lat, st, sz, slon, slat, sx, ut, uz, ulon, ulat, m, vmr, bellrad;

  int even, ip, irep, rep;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <atm_out>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  t0 = scan_ctl(argv[1], argc, argv, "INIT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "INIT_T1", -1, "0", NULL);
  dt = scan_ctl(argv[1], argc, argv, "INIT_DT", -1, "1", NULL);
  z0 = scan_ctl(argv[1], argc, argv, "INIT_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "INIT_Z1", -1, "0", NULL);
  dz = scan_ctl(argv[1], argc, argv, "INIT_DZ", -1, "1", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "INIT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "INIT_LON1", -1, "0", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "INIT_DLON", -1, "1", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "INIT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "INIT_LAT1", -1, "0", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "INIT_DLAT", -1, "1", NULL);
  st = scan_ctl(argv[1], argc, argv, "INIT_ST", -1, "0", NULL);
  sz = scan_ctl(argv[1], argc, argv, "INIT_SZ", -1, "0", NULL);
  slon = scan_ctl(argv[1], argc, argv, "INIT_SLON", -1, "0", NULL);
  slat = scan_ctl(argv[1], argc, argv, "INIT_SLAT", -1, "0", NULL);
  sx = scan_ctl(argv[1], argc, argv, "INIT_SX", -1, "0", NULL);
  ut = scan_ctl(argv[1], argc, argv, "INIT_UT", -1, "0", NULL);
  uz = scan_ctl(argv[1], argc, argv, "INIT_UZ", -1, "0", NULL);
  ulon = scan_ctl(argv[1], argc, argv, "INIT_ULON", -1, "0", NULL);
  ulat = scan_ctl(argv[1], argc, argv, "INIT_ULAT", -1, "0", NULL);
  even = (int) scan_ctl(argv[1], argc, argv, "INIT_EVENLY", -1, "0", NULL);
  rep = (int) scan_ctl(argv[1], argc, argv, "INIT_REP", -1, "1", NULL);
  m = scan_ctl(argv[1], argc, argv, "INIT_MASS", -1, "0", NULL);
  vmr = scan_ctl(argv[1], argc, argv, "INIT_VMR", -1, "0", NULL);
  bellrad = scan_ctl(argv[1], argc, argv, "INIT_BELLRAD", -1, "0", NULL);

  /* Initialize random number generator... */
```

```
  gsl_rng_env_setup();
  rng = gsl_rng_alloc(gsl_rng_default);

  /* Create grid... */
  for (t = t0; t <= t1; t += dt)
    for (z = z0; z <= z1; z += dz)
      for (lon = lon0; lon <= lon1; lon += dlon)
        for (lat = lat0; lat <= lat1; lat += dlat)
          for (irep = 0; irep < rep; irep++) {

            /* Set position... */
            atm->time[atm->np]
              = (t + gsl_ran_gaussian_ziggurat(rng, st / 2.3548)
                 + ut * (gsl_rng_uniform(rng) - 0.5));
            atm->p[atm->np]
              = P(z + gsl_ran_gaussian_ziggurat(rng, sz / 2.3548)
                  + uz * (gsl_rng_uniform(rng) - 0.5));
            atm->lon[atm->np]
              = (lon + gsl_ran_gaussian_ziggurat(rng, slon / 2.3548)
                 + gsl_ran_gaussian_ziggurat(rng, DX2DEG(sx, lat) / 2.3548)
                 + ulon * (gsl_rng_uniform(rng) - 0.5));
            do {
              atm->lat[atm->np]
                = (lat + gsl_ran_gaussian_ziggurat(rng, slat / 2.3548)
                   + gsl_ran_gaussian_ziggurat(rng, DY2DEG(sx) / 2.3548)
                   + ulat * (gsl_rng_uniform(rng) - 0.5));
            } while (even && gsl_rng_uniform(rng) >
                     fabs(cos(atm->lat[atm->np] * M_PI / 180.)));

            /* Apply cosine bell (Williamson et al., 1992)... */
            if (bellrad > 0) {
              double x0[3], x1[3];
              geo2cart(0.0, 0.5 * (lon0 + lon1), 0.5 * (lat0 + lat1), x0);
              geo2cart(0.0, atm->lon[atm->np], atm->lat[atm->np], x1);
              double rad = RE * acos(DOTP(x0, x1) / NORM(x0) / NORM(x1));
              if (rad > bellrad)
                continue;
              if (ctl.qnt_m >= 0)
                atm->q[ctl.qnt_m][atm->np] =
                  0.5 * (1. + cos(M_PI * rad / bellrad));
              if (ctl.qnt_vmr >= 0)
                atm->q[ctl.qnt_vmr][atm->np] =
                  0.5 * (1. + cos(M_PI * rad / bellrad));
            }

            /* Set particle counter... */
            if ((++atm->np) > NP)
              ERRMSG("Too many particles!");
          }

  /* Check number of air parcels... */
  if (atm->np <= 0)
    ERRMSG("Did not create any air parcels!");

  /* Initialize mass... */
  if (ctl.qnt_m >= 0 && bellrad <= 0)
    for (ip = 0; ip < atm->np; ip++)
      atm->q[ctl.qnt_m][ip] = m / atm->np;

  /* Initialize volume mixing ratio... */
  if (ctl.qnt_vmr >= 0 && bellrad <= 0)
    for (ip = 0; ip < atm->np; ip++)
      atm->q[ctl.qnt_vmr][ip] = vmr;

  /* Save data... */
  write_atm(argv[2], &ctl, atm, 0);

  /* Free... */
  gsl_rng_free(rng);
  free(atm);

  return EXIT_SUCCESS;
}
```

## 5.7 atm_select.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.7.1 Detailed Description

Extract subsets of air parcels from atmospheric data files.

Definition in file atm_select.c.

### 5.7.2 Function Documentation

#### 5.7.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 27 of file atm_select.c.

```
               {

  ctl_t ctl;

  atm_t *atm, *atm2;

  double lat0, lat1, lon0, lon1, p0, p1, r, r0, r1, rlon, rlat, t0, t1, x0[3],
    x1[3];

  int f, ip, ip0, ip1, iq, stride;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm2, atm_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <atm_select> <atm1> [<atm2> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  stride =
    (int) scan_ctl(argv[1], argc, argv, "SELECT_STRIDE", -1, "1", NULL);
  ip0 = (int) scan_ctl(argv[1], argc, argv, "SELECT_IP0", -1, "-999", NULL);
  ip1 = (int) scan_ctl(argv[1], argc, argv, "SELECT_IP1", -1, "-999", NULL);
  t0 = scan_ctl(argv[1], argc, argv, "SELECT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "SELECT_T1", -1, "0", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "SELECT_Z0", -1, "0", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "SELECT_Z1", -1, "0", NULL));
  lon0 = scan_ctl(argv[1], argc, argv, "SELECT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "SELECT_LON1", -1, "0", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "SELECT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "SELECT_LAT1", -1, "0", NULL);
  r0 = scan_ctl(argv[1], argc, argv, "SELECT_R0", -1, "0", NULL);
  r1 = scan_ctl(argv[1], argc, argv, "SELECT_R1", -1, "0", NULL);
  rlon = scan_ctl(argv[1], argc, argv, "SELECT_RLON", -1, "0", NULL);
  rlat = scan_ctl(argv[1], argc, argv, "SELECT_RLAT", -1, "0", NULL);

  /* Get Cartesian coordinates... */
  geo2cart(0, rlon, rlat, x0);

  /* Loop over files... */
  for (f = 3; f < argc; f++) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm))
      continue;

    /* Adjust range of air parcels... */
    if (ip0 < 0)
      ip0 = 0;
    ip0 = GSL_MIN(ip0, atm->np - 1);
    if (ip1 < 0)
      ip1 = atm->np - 1;
    ip1 = GSL_MIN(ip1, atm->np - 1);
    if (ip1 < ip0)
      ip1 = ip0;

    /* Loop over air parcels... */
    for (ip = ip0; ip <= ip1; ip += stride) {
```

```

      /* Check time... */
      if (t0 != t1)
        if ((t1 > t0 && (atm->time[ip] < t0 || atm->time[ip] > t1))
            || (t1 < t0 && (atm->time[ip] < t0 && atm->time[ip] > t1)))
          continue;

      /* Check vertical distance... */
      if (p0 != p1)
        if ((p0 > p1 && (atm->p[ip] > p0 || atm->p[ip] < p1))
            || (p0 < p1 && (atm->p[ip] > p0 && atm->p[ip] < p1)))
          continue;

      /* Check longitude... */
      if (lon0 != lon1)
        if ((lon1 > lon0 && (atm->lon[ip] < lon0 || atm->lon[ip] > lon1))
            || (lon1 < lon0 && (atm->lon[ip] < lon0 && atm->lon[ip] > lon1)))
          continue;

      /* Check latitude... */
      if (lat0 != lat1)
        if ((lat1 > lat0 && (atm->lat[ip] < lat0 || atm->lat[ip] > lat1))
            || (lat1 < lat0 && (atm->lat[ip] < lat0 && atm->lat[ip] > lat1)))
          continue;

      /* Check horizontal distace... */
      if (r0 != r1) {
        geo2cart(0, atm->lon[ip], atm->lat[ip], x1);
        r = DIST(x0, x1);
        if ((r1 > r0 && (r < r0 || r > r1))
            || (r1 < r0 && (r < r0 && r > r1)))
          continue;
      }

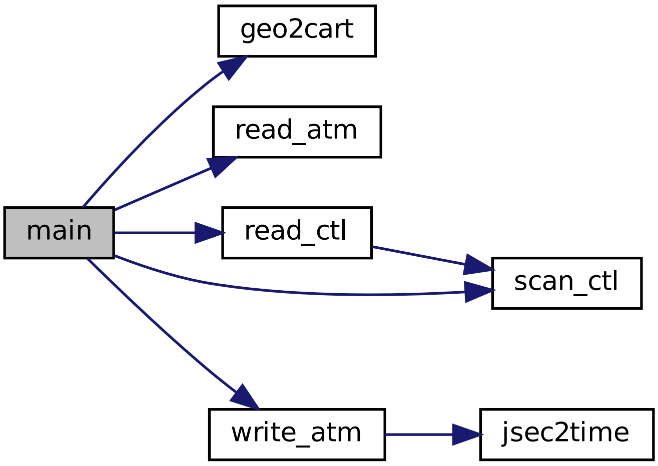
      /* Copy data... */
      atm2->time[atm2->np] = atm->time[ip];
      atm2->p[atm2->np] = atm->p[ip];
      atm2->lon[atm2->np] = atm->lon[ip];
      atm2->lat[atm2->np] = atm->lat[ip];
      for (iq = 0; iq < ctl.nq; iq++)
        atm2->q[iq][atm2->np] = atm->q[iq][ip];
      if ((++atm2->np) > NP)
        ERRMSG("Too many air parcels!");
    }
  }

  /* Close file... */
  write_atm(argv[2], &ctl, atm2, 0);

  /* Free... */
  free(atm);
  free(atm2);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.8 atm_select.c

```
/*
  This file is part of MPTRAC.

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  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

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  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  atm_t *atm, *atm2;

  double lat0, lat1, lon0, lon1, p0, p1, r, r0, r1, rlon, rlat, t0, t1, x0[3],
    x1[3];

  int f, ip, ip0, ip1, iq, stride;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm2, atm_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <atm_select> <atm1> [<atm2> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  stride =
    (int) scan_ctl(argv[1], argc, argv, "SELECT_STRIDE", -1, "1", NULL);
```

```
  ip0 = (int) scan_ctl(argv[1], argc, argv, "SELECT_IP0", -1, "-999", NULL);
  ip1 = (int) scan_ctl(argv[1], argc, argv, "SELECT_IP1", -1, "-999", NULL);
  t0 = scan_ctl(argv[1], argc, argv, "SELECT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "SELECT_T1", -1, "0", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "SELECT_Z0", -1, "0", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "SELECT_Z1", -1, "0", NULL));
  lon0 = scan_ctl(argv[1], argc, argv, "SELECT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "SELECT_LON1", -1, "0", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "SELECT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "SELECT_LAT1", -1, "0", NULL);
  r0 = scan_ctl(argv[1], argc, argv, "SELECT_R0", -1, "0", NULL);
  r1 = scan_ctl(argv[1], argc, argv, "SELECT_R1", -1, "0", NULL);
  rlon = scan_ctl(argv[1], argc, argv, "SELECT_RLON", -1, "0", NULL);
  rlat = scan_ctl(argv[1], argc, argv, "SELECT_RLAT", -1, "0", NULL);

  /* Get Cartesian coordinates... */
  geo2cart(0, rlon, rlat, x0);

  /* Loop over files... */
  for (f = 3; f < argc; f++) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm))
      continue;

    /* Adjust range of air parcels... */
    if (ip0 < 0)
      ip0 = 0;
    ip0 = GSL_MIN(ip0, atm->np - 1);
    if (ip1 < 0)
      ip1 = atm->np - 1;
    ip1 = GSL_MIN(ip1, atm->np - 1);
    if (ip1 < ip0)
      ip1 = ip0;

    /* Loop over air parcels... */
    for (ip = ip0; ip <= ip1; ip += stride) {

      /* Check time... */
      if (t0 != t1)
        if ((t1 > t0 && (atm->time[ip] < t0 || atm->time[ip] > t1))
            || (t1 < t0 && (atm->time[ip] < t0 && atm->time[ip] > t1)))
          continue;

      /* Check vertical distance... */
      if (p0 != p1)
        if ((p0 > p1 && (atm->p[ip] > p0 || atm->p[ip] < p1))
            || (p0 < p1 && (atm->p[ip] > p0 && atm->p[ip] < p1)))
          continue;

      /* Check longitude... */
      if (lon0 != lon1)
        if ((lon1 > lon0 && (atm->lon[ip] < lon0 || atm->lon[ip] > lon1))
            || (lon1 < lon0 && (atm->lon[ip] < lon0 && atm->lon[ip] > lon1)))
          continue;

      /* Check latitude... */
      if (lat0 != lat1)
        if ((lat1 > lat0 && (atm->lat[ip] < lat0 || atm->lat[ip] > lat1))
            || (lat1 < lat0 && (atm->lat[ip] < lat0 && atm->lat[ip] > lat1)))
          continue;

      /* Check horizontal distace... */
      if (r0 != r1) {
        geo2cart(0, atm->lon[ip], atm->lat[ip], x1);
        r = DIST(x0, x1);
        if ((r1 > r0 && (r < r0 || r > r1))
            || (r1 < r0 && (r < r0 && r > r1)))
          continue;
      }

      /* Copy data... */
      atm2->time[atm2->np] = atm->time[ip];
      atm2->p[atm2->np] = atm->p[ip];
      atm2->lon[atm2->np] = atm->lon[ip];
      atm2->lat[atm2->np] = atm->lat[ip];
      for (iq = 0; iq < ctl.nq; iq++)
        atm2->q[iq][atm2->np] = atm->q[iq][ip];
      if ((++atm2->np) > NP)
        ERRMSG("Too many air parcels!");
    }
  }

  /* Close file... */
  write_atm(argv[2], &ctl, atm2, 0);

  /* Free... */
```

```
  free(atm);
  free(atm2);

  return EXIT_SUCCESS;
}
```

## 5.9 atm_split.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char ∗argv[ ])

### 5.9.1 Detailed Description

Split air parcels into a larger number of parcels.

Definition in file atm_split.c.

### 5.9.2 Function Documentation

#### 5.9.2.1 main()

```
int main (
    int argc,
    char ∗ argv[ ] )
```

Definition at line 27 of file atm_split.c.

```
                  {

  atm_t *atm, *atm2;

  ctl_t ctl;

  gsl_rng *rng;

  FILE *in;

  char kernel[LEN], line[LEN];

  double dt, dx, dz, k, kk[GZ], kz[GZ], kmin, kmax, m, mmax = 0, mtot = 0,
    t0, t1, z, z0, z1, lon0, lon1, lat0, lat1, zmin, zmax;

  int i, ip, iq, iz, n, nz = 0;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm2, atm_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <atm_in> <atm_out>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  n = (int) scan_ctl(argv[1], argc, argv, "SPLIT_N", -1, "", NULL);
  m = scan_ctl(argv[1], argc, argv, "SPLIT_M", -1, "-999", NULL);
  dt = scan_ctl(argv[1], argc, argv, "SPLIT_DT", -1, "0", NULL);
  t0 = scan_ctl(argv[1], argc, argv, "SPLIT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "SPLIT_T1", -1, "0", NULL);
  dz = scan_ctl(argv[1], argc, argv, "SPLIT_DZ", -1, "0", NULL);
```

```
  z0 = scan_ctl(argv[1], argc, argv, "SPLIT_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "SPLIT_Z1", -1, "0", NULL);
  dx = scan_ctl(argv[1], argc, argv, "SPLIT_DX", -1, "0", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "SPLIT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "SPLIT_LON1", -1, "0", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "SPLIT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "SPLIT_LAT1", -1, "0", NULL);
  scan_ctl(argv[1], argc, argv, "SPLIT_KERNEL", -1, "-", kernel);

  /* Init random number generator... */
  gsl_rng_env_setup();
  rng = gsl_rng_alloc(gsl_rng_default);

  /* Read atmospheric data... */
  if (!read_atm(argv[2], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Read kernel function... */
  if (kernel[0] != '-') {

    /* Write info... */
    LOG(1, "Read kernel function: %s", kernel);

    /* Open file... */
    if (!(in = fopen(kernel, "r")))
      ERRMSG("Cannot open file!");

    /* Read data... */
    while (fgets(line, LEN, in))
      if (sscanf(line, "%lg %lg", &kz[nz], &kk[nz]) == 2)
        if ((++nz) >= GZ)
          ERRMSG("Too many height levels!");

    /* Close file... */
    fclose(in);

    /* Normalize kernel function... */
    zmax = gsl_stats_max(kz, 1, (size_t) nz);
    zmin = gsl_stats_min(kz, 1, (size_t) nz);
    kmax = gsl_stats_max(kk, 1, (size_t) nz);
    kmin = gsl_stats_min(kk, 1, (size_t) nz);
    for (iz = 0; iz < nz; iz++)
      kk[iz] = (kk[iz] - kmin) / (kmax - kmin);
  }

  /* Get total and maximum mass... */
  if (ctl.qnt_m >= 0)
    for (ip = 0; ip < atm->np; ip++) {
      mtot += atm->q[ctl.qnt_m][ip];
      mmax = GSL_MAX(mmax, atm->q[ctl.qnt_m][ip]);
    }
  if (m > 0)
    mtot = m;

  /* Loop over air parcels... */
  for (i = 0; i < n; i++) {

    /* Select air parcel... */
    if (ctl.qnt_m >= 0)
      do {
        ip = (int) gsl_rng_uniform_int(rng, (long unsigned int) atm->np);
      } while (gsl_rng_uniform(rng) > atm->q[ctl.qnt_m][ip] / mmax);
    else
      ip = (int) gsl_rng_uniform_int(rng, (long unsigned int) atm->np);

    /* Set time... */
    if (t1 > t0)
      atm2->time[atm2->np] = t0 + (t1 - t0) * gsl_rng_uniform_pos(rng);
    else
      atm2->time[atm2->np] = atm->time[ip]
        + gsl_ran_gaussian_ziggurat(rng, dt / 2.3548);

    /* Set vertical position... */
    do {
      if (nz > 0) {
        do {
          z = zmin + (zmax - zmin) * gsl_rng_uniform_pos(rng);
          iz = locate_irr(kz, nz, z);
          k = LIN(kz[iz], kk[iz], kz[iz + 1], kk[iz + 1], z);
        } while (gsl_rng_uniform(rng) > k);
        atm2->p[atm2->np] = P(z);
      } else if (z1 > z0)
        atm2->p[atm2->np] = P(z0 + (z1 - z0) * gsl_rng_uniform_pos(rng));
      else
        atm2->p[atm2->np] = atm->p[ip]
          + DZ2DP(gsl_ran_gaussian_ziggurat(rng, dz / 2.3548), atm->p[ip]);
    } while (atm2->p[atm2->np] < P(100.) || atm2->p[atm2->np] > P(-1.));
```

```
    /* Set horizontal position... */
    if (lon1 > lon0 && lat1 > lat0) {
      atm2->lon[atm2->np] = lon0 + (lon1 - lon0) * gsl_rng_uniform_pos(rng);
      atm2->lat[atm2->np] = lat0 + (lat1 - lat0) * gsl_rng_uniform_pos(rng);
    } else {
      atm2->lon[atm2->np] = atm->lon[ip]
        + gsl_ran_gaussian_ziggurat(rng, DX2DEG(dx, atm->lat[ip]) / 2.3548);
      atm2->lat[atm2->np] = atm->lat[ip]
        + gsl_ran_gaussian_ziggurat(rng, DY2DEG(dx) / 2.3548);
    }

    /* Copy quantities... */
    for (iq = 0; iq < ctl.nq; iq++)
      atm2->q[iq][atm2->np] = atm->q[iq][ip];

    /* Adjust mass... */
    if (ctl.qnt_m >= 0)
      atm2->q[ctl.qnt_m][atm2->np] = mtot / n;

    /* Increment particle counter... */
    if ((++atm2->np) > NP)
      ERRMSG("Too many air parcels!");
  }

  /* Save data and close file... */
  write_atm(argv[3], &ctl, atm2, 0);

  /* Free... */
  free(atm);
  free(atm2);

  return EXIT_SUCCESS;
}
```

## 5.10 atm_split.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  atm_t *atm, *atm2;

  ctl_t ctl;

  gsl_rng *rng;

  FILE *in;

  char kernel[LEN], line[LEN];

  double dt, dx, dz, k, kk[GZ], kz[GZ], kmin, kmax, m, mmax = 0, mtot = 0,
    t0, t1, z, z0, z1, lon0, lon1, lat0, lat1, zmin, zmax;

  int i, ip, iq, iz, n, nz = 0;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm2, atm_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <atm_in> <atm_out>");
```

```
  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  n = (int) scan_ctl(argv[1], argc, argv, "SPLIT_N", -1, "", NULL);
  m = scan_ctl(argv[1], argc, argv, "SPLIT_M", -1, "-999", NULL);
  dt = scan_ctl(argv[1], argc, argv, "SPLIT_DT", -1, "0", NULL);
  t0 = scan_ctl(argv[1], argc, argv, "SPLIT_T0", -1, "0", NULL);
  t1 = scan_ctl(argv[1], argc, argv, "SPLIT_T1", -1, "0", NULL);
  dz = scan_ctl(argv[1], argc, argv, "SPLIT_DZ", -1, "0", NULL);
  z0 = scan_ctl(argv[1], argc, argv, "SPLIT_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "SPLIT_Z1", -1, "0", NULL);
  dx = scan_ctl(argv[1], argc, argv, "SPLIT_DX", -1, "0", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "SPLIT_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "SPLIT_LON1", -1, "0", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "SPLIT_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "SPLIT_LAT1", -1, "0", NULL);
  scan_ctl(argv[1], argc, argv, "SPLIT_KERNEL", -1, "-", kernel);

  /* Init random number generator... */
  gsl_rng_env_setup();
  rng = gsl_rng_alloc(gsl_rng_default);

  /* Read atmospheric data... */
  if (!read_atm(argv[2], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Read kernel function... */
  if (kernel[0] != '-') {

    /* Write info... */
    LOG(1, "Read kernel function: %s", kernel);

    /* Open file... */
    if (!(in = fopen(kernel, "r")))
      ERRMSG("Cannot open file!");

    /* Read data... */
    while (fgets(line, LEN, in))
      if (sscanf(line, "%lg %lg", &kz[nz], &kk[nz]) == 2)
        if ((++nz) >= GZ)
          ERRMSG("Too many height levels!");

    /* Close file... */
    fclose(in);

    /* Normalize kernel function... */
    zmax = gsl_stats_max(kz, 1, (size_t) nz);
    zmin = gsl_stats_min(kz, 1, (size_t) nz);
    kmax = gsl_stats_max(kk, 1, (size_t) nz);
    kmin = gsl_stats_min(kk, 1, (size_t) nz);
    for (iz = 0; iz < nz; iz++)
      kk[iz] = (kk[iz] - kmin) / (kmax - kmin);
  }

  /* Get total and maximum mass... */
  if (ctl.qnt_m >= 0)
    for (ip = 0; ip < atm->np; ip++) {
      mtot += atm->q[ctl.qnt_m][ip];
      mmax = GSL_MAX(mmax, atm->q[ctl.qnt_m][ip]);
    }
  if (m > 0)
    mtot = m;

  /* Loop over air parcels... */
  for (i = 0; i < n; i++) {

    /* Select air parcel... */
    if (ctl.qnt_m >= 0)
      do {
        ip = (int) gsl_rng_uniform_int(rng, (long unsigned int) atm->np);
      } while (gsl_rng_uniform(rng) > atm->q[ctl.qnt_m][ip] / mmax);
    else
      ip = (int) gsl_rng_uniform_int(rng, (long unsigned int) atm->np);

    /* Set time... */
    if (t1 > t0)
      atm2->time[atm2->np] = t0 + (t1 - t0) * gsl_rng_uniform_pos(rng);
    else
      atm2->time[atm2->np] = atm->time[ip]
        + gsl_ran_gaussian_ziggurat(rng, dt / 2.3548);

    /* Set vertical position... */
    do {
      if (nz > 0) {
        do {
          z = zmin + (zmax - zmin) * gsl_rng_uniform_pos(rng);
          iz = locate_irr(kz, nz, z);
```

```
          k = LIN(kz[iz], kk[iz], kz[iz + 1], kk[iz + 1], z);
        } while (gsl_rng_uniform(rng) > k);
        atm2->p[atm2->np] = P(z);
      } else if (z1 > z0)
        atm2->p[atm2->np] = P(z0 + (z1 - z0) * gsl_rng_uniform_pos(rng));
      else
        atm2->p[atm2->np] = atm->p[ip]
          + DZ2DP(gsl_ran_gaussian_ziggurat(rng, dz / 2.3548), atm->p[ip]);
    } while (atm2->p[atm2->np] < P(100.) || atm2->p[atm2->np] > P(-1.));

    /* Set horizontal position... */
    if (lon1 > lon0 && lat1 > lat0) {
      atm2->lon[atm2->np] = lon0 + (lon1 - lon0) * gsl_rng_uniform_pos(rng);
      atm2->lat[atm2->np] = lat0 + (lat1 - lat0) * gsl_rng_uniform_pos(rng);
    } else {
      atm2->lon[atm2->np] = atm->lon[ip]
        + gsl_ran_gaussian_ziggurat(rng, DX2DEG(dx, atm->lat[ip]) / 2.3548);
      atm2->lat[atm2->np] = atm->lat[ip]
        + gsl_ran_gaussian_ziggurat(rng, DY2DEG(dx) / 2.3548);
    }

    /* Copy quantities... */
    for (iq = 0; iq < ctl.nq; iq++)
      atm2->q[iq][atm2->np] = atm->q[iq][ip];

    /* Adjust mass... */
    if (ctl.qnt_m >= 0)
      atm2->q[ctl.qnt_m][atm2->np] = mtot / n;

    /* Increment particle counter... */
    if ((++atm2->np) > NP)
      ERRMSG("Too many air parcels!");
  }

  /* Save data and close file... */
  write_atm(argv[3], &ctl, atm2, 0);

  /* Free... */
  free(atm);
  free(atm2);

  return EXIT_SUCCESS;
}
```

## 5.11 atm_stat.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.11.1 Detailed Description

Calculate air parcel statistics.

Definition in file atm_stat.c.

### 5.11.2 Function Documentation

#### 5.11.2.1 main()

```
int main (
        int argc,
        char * argv[] )
```

Definition at line 27 of file atm_stat.c.

```
                  {

  ctl_t ctl;

  atm_t *atm, *atm_filt;

  FILE *out;

  char tstr[LEN];

  double lat0, lat1, latm, lon0, lon1, lonm, p0, p1,
    t, t0 = GSL_NAN, qm[NQ], *work, zm, *zs;

  int ens, f, init = 0, ip, iq, year, mon, day, hour, min;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm_filt, atm_t, 1);
  ALLOC(work, double,
        NP);
  ALLOC(zs, double,
        NP);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <stat.tab> <param> <atm1> [<atm2> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  ens = (int) scan_ctl(argv[1], argc, argv, "STAT_ENS", -1, "-999", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "STAT_Z0", -1, "-1000", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "STAT_Z1", -1, "1000", NULL));
  lat0 = scan_ctl(argv[1], argc, argv, "STAT_LAT0", -1, "-1000", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "STAT_LAT1", -1, "1000", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "STAT_LON0", -1, "-1000", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "STAT_LON1", -1, "1000", NULL);

  /* Write info... */
  printf("Write air parcel statistics: %s\n", argv[2]);

  /* Create output file... */
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = time difference [s]\n"
          "# $3 = altitude (%s) [km]\n"
          "# $4 = longitude (%s) [deg]\n"
          "# $5 = latitude (%s) [deg]\n", argv[3], argv[3], argv[3]);
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out, "# $%d = %s (%s) [%s]\n", iq + 6,
            ctl.qnt_name[iq], argv[3], ctl.qnt_unit[iq]);
  fprintf(out, "# $%d = number of particles\n\n", ctl.nq + 6);

  /* Loop over files... */
  for (f = 4; f < argc; f++) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm))
      continue;

    /* Get time from filename... */
    sprintf(tstr, "%.4s", &argv[f][strlen(argv[f]) - 20]);
    year = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 15]);
    mon = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 12]);
    day = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 9]);
    hour = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 6]);
    min = atoi(tstr);
    time2jsec(year, mon, day, hour, min, 0, 0, &t);

    /* Check time... */
    if (year < 1900 || year > 2100 || mon < 1 || mon > 12 || day < 1
        || day > 31 || hour < 0 || hour > 23 || min < 0 || min > 59)
      ERRMSG("Cannot read time from filename!");
```

```
  /* Save initial time... */
  if (!init) {
    init = 1;
    t0 = t;
  }

  /* Filter data... */
  atm_filt->np = 0;
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (!gsl_finite(atm->time[ip]))
      continue;

    /* Check ensemble index... */
    if (ctl.qnt_ens > 0 && atm->q[ctl.qnt_ens][ip] != ens)
      continue;

    /* Check spatial range... */
    if (atm->p[ip] > p0 || atm->p[ip] < p1
        || atm->lon[ip] < lon0 || atm->lon[ip] > lon1
        || atm->lat[ip] < lat0 || atm->lat[ip] > lat1)
      continue;

    /* Save data... */
    atm_filt->time[atm_filt->np] = atm->time[ip];
    atm_filt->p[atm_filt->np] = atm->p[ip];
    atm_filt->lon[atm_filt->np] = atm->lon[ip];
    atm_filt->lat[atm_filt->np] = atm->lat[ip];
    for (iq = 0; iq < ctl.nq; iq++)
      atm_filt->q[iq][atm_filt->np] = atm->q[iq][ip];
    atm_filt->np++;
  }

  /* Get heights... */
  for (ip = 0; ip < atm_filt->np; ip++)
    zs[ip] = Z(atm_filt->p[ip]);

  /* Get statistics... */
  if (strcasecmp(argv[3], "mean") == 0) {
    zm = gsl_stats_mean(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_mean(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_mean(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_mean(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "stddev") == 0) {
    zm = gsl_stats_sd(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_sd(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_sd(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_sd(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "min") == 0) {
    zm = gsl_stats_min(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_min(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_min(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_min(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "max") == 0) {
    zm = gsl_stats_max(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_max(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_max(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_max(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "skew") == 0) {
    zm = gsl_stats_skew(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_skew(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_skew(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_skew(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "kurt") == 0) {
    zm = gsl_stats_kurtosis(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_kurtosis(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_kurtosis(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] =
        gsl_stats_kurtosis(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "median") == 0) {
    zm = gsl_stats_median(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_median(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_median(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_median(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "absdev") == 0) {
    zm = gsl_stats_absdev(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_absdev(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_absdev(atm_filt->lat, 1, (size_t) atm_filt->np);
```

```
      for (iq = 0; iq < ctl.nq; iq++)
        qm[iq] = gsl_stats_absdev(atm_filt->q[iq], 1, (size_t) atm_filt->np);
    } else if (strcasecmp(argv[3], "mad") == 0) {
      zm = gsl_stats_mad0(zs, 1, (size_t) atm_filt->np, work);
      lonm = gsl_stats_mad0(atm_filt->lon, 1, (size_t) atm_filt->np, work);
      latm = gsl_stats_mad0(atm_filt->lat, 1, (size_t) atm_filt->np, work);
      for (iq = 0; iq < ctl.nq; iq++)
        qm[iq] =
          gsl_stats_mad0(atm_filt->q[iq], 1, (size_t) atm_filt->np, work);
    } else
      ERRMSG("Unknown parameter!");

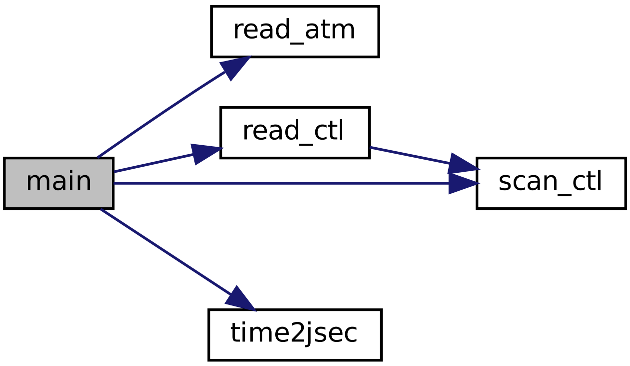
    /* Write data... */
    fprintf(out, "%.2f %.2f %g %g %g", t, t - t0, zm, lonm, latm);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], qm[iq]);
    }
    fprintf(out, " %d\n", atm_filt->np);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm);
  free(atm_filt);
  free(work);
  free(zs);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.12 atm_stat.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

```

```
  Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  atm_t *atm, *atm_filt;

  FILE *out;

  char tstr[LEN];

  double lat0, lat1, latm, lon0, lon1, lonm, p0, p1,
    t, t0 = GSL_NAN, qm[NQ], *work, zm, *zs;

  int ens, f, init = 0, ip, iq, year, mon, day, hour, min;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(atm_filt, atm_t, 1);
  ALLOC(work, double,
        NP);
  ALLOC(zs, double,
        NP);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <stat.tab> <param> <atm1> [<atm2> ...]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  ens = (int) scan_ctl(argv[1], argc, argv, "STAT_ENS", -1, "-999", NULL);
  p0 = P(scan_ctl(argv[1], argc, argv, "STAT_Z0", -1, "-1000", NULL));
  p1 = P(scan_ctl(argv[1], argc, argv, "STAT_Z1", -1, "1000", NULL));
  lat0 = scan_ctl(argv[1], argc, argv, "STAT_LAT0", -1, "-1000", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "STAT_LAT1", -1, "1000", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "STAT_LON0", -1, "-1000", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "STAT_LON1", -1, "1000", NULL);

  /* Write info... */
  printf("Write air parcel statistics: %s\n", argv[2]);

  /* Create output file... */
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = time difference [s]\n"
          "# $3 = altitude (%s) [km]\n"
          "# $4 = longitude (%s) [deg]\n"
          "# $5 = latitude (%s) [deg]\n", argv[3], argv[3], argv[3]);
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out, "# $%d = %s (%s) [%s]\n", iq + 6,
            ctl.qnt_name[iq], argv[3], ctl.qnt_unit[iq]);
  fprintf(out, "# $%d = number of particles\n\n", ctl.nq + 6);

  /* Loop over files... */
  for (f = 4; f < argc; f++) {

    /* Read atmopheric data... */
    if (!read_atm(argv[f], &ctl, atm))
      continue;

    /* Get time from filename... */
    sprintf(tstr, "%.4s", &argv[f][strlen(argv[f]) - 20]);
    year = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 15]);
    mon = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 12]);
    day = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 9]);
    hour = atoi(tstr);
    sprintf(tstr, "%.2s", &argv[f][strlen(argv[f]) - 6]);
    min = atoi(tstr);
    time2jsec(year, mon, day, hour, min, 0, 0, &t);

    /* Check time... */
    if (year < 1900 || year > 2100 || mon < 1 || mon > 12 || day < 1
        || day > 31 || hour < 0 || hour > 23 || min < 0 || min > 59)
      ERRMSG("Cannot read time from filename!");
```

```

  /* Save initial time... */
  if (!init) {
    init = 1;
    t0 = t;
  }

  /* Filter data... */
  atm_filt->np = 0;
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (!gsl_finite(atm->time[ip]))
      continue;

    /* Check ensemble index... */
    if (ctl.qnt_ens > 0 && atm->q[ctl.qnt_ens][ip] != ens)
      continue;

    /* Check spatial range... */
    if (atm->p[ip] > p0 || atm->p[ip] < p1
        || atm->lon[ip] < lon0 || atm->lon[ip] > lon1
        || atm->lat[ip] < lat0 || atm->lat[ip] > lat1)
      continue;

    /* Save data... */
    atm_filt->time[atm_filt->np] = atm->time[ip];
    atm_filt->p[atm_filt->np] = atm->p[ip];
    atm_filt->lon[atm_filt->np] = atm->lon[ip];
    atm_filt->lat[atm_filt->np] = atm->lat[ip];
    for (iq = 0; iq < ctl.nq; iq++)
      atm_filt->q[iq][atm_filt->np] = atm->q[iq][ip];
    atm_filt->np++;
  }

  /* Get heights... */
  for (ip = 0; ip < atm_filt->np; ip++)
    zs[ip] = Z(atm_filt->p[ip]);

  /* Get statistics... */
  if (strcasecmp(argv[3], "mean") == 0) {
    zm = gsl_stats_mean(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_mean(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_mean(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_mean(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "stddev") == 0) {
    zm = gsl_stats_sd(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_sd(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_sd(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_sd(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "min") == 0) {
    zm = gsl_stats_min(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_min(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_min(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_min(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "max") == 0) {
    zm = gsl_stats_max(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_max(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_max(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_max(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "skew") == 0) {
    zm = gsl_stats_skew(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_skew(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_skew(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_skew(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "kurt") == 0) {
    zm = gsl_stats_kurtosis(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_kurtosis(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_kurtosis(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] =
        gsl_stats_kurtosis(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "median") == 0) {
    zm = gsl_stats_median(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_median(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_median(atm_filt->lat, 1, (size_t) atm_filt->np);
    for (iq = 0; iq < ctl.nq; iq++)
      qm[iq] = gsl_stats_median(atm_filt->q[iq], 1, (size_t) atm_filt->np);
  } else if (strcasecmp(argv[3], "absdev") == 0) {
    zm = gsl_stats_absdev(zs, 1, (size_t) atm_filt->np);
    lonm = gsl_stats_absdev(atm_filt->lon, 1, (size_t) atm_filt->np);
    latm = gsl_stats_absdev(atm_filt->lat, 1, (size_t) atm_filt->np);
```

```
      for (iq = 0; iq < ctl.nq; iq++)
        qm[iq] = gsl_stats_absdev(atm_filt->q[iq], 1, (size_t) atm_filt->np);
    } else if (strcasecmp(argv[3], "mad") == 0) {
      zm = gsl_stats_mad0(zs, 1, (size_t) atm_filt->np, work);
      lonm = gsl_stats_mad0(atm_filt->lon, 1, (size_t) atm_filt->np, work);
      latm = gsl_stats_mad0(atm_filt->lat, 1, (size_t) atm_filt->np, work);
      for (iq = 0; iq < ctl.nq; iq++)
        qm[iq] =
          gsl_stats_mad0(atm_filt->q[iq], 1, (size_t) atm_filt->np, work);
    } else
      ERRMSG("Unknown parameter!");

    /* Write data... */
    fprintf(out, "%.2f %.2f %g %g %g", t, t - t0, zm, lonm, latm);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], qm[iq]);
    }
    fprintf(out, " %d\n", atm_filt->np);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm);
  free(atm_filt);
  free(work);
  free(zs);

  return EXIT_SUCCESS;
}
```

## 5.13 day2doy.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.13.1 Detailed Description

Convert date to day of year.

Definition in file day2doy.c.

### 5.13.2 Function Documentation

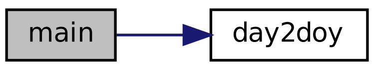
#### 5.13.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 27 of file day2doy.c.

```
00029                 {
00030
00031   int day, doy, mon, year;
00032
00033   /* Check arguments... */
00034   if (argc < 4)
00035     ERRMSG("Give parameters: <year> <mon> <day>");
00036
00037   /* Read arguments... */
00038   year = atoi(argv[1]);
00039   mon = atoi(argv[2]);
00040   day = atoi(argv[3]);
00041
00042   /* Convert... */
00043   day2doy(year, mon, day, &doy);
00044   printf("%d %d\n", year, doy);
00045
00046   return EXIT_SUCCESS;
00047 }
```

Here is the call graph for this function:




## 5.14 day2doy.c

```
00001 /*
00002   This file is part of MPTRAC.
00003
00004   MPTRAC is free software: you can redistribute it and/or modify
00005   it under the terms of the GNU General Public License as published by
00006   the Free Software Foundation, either version 3 of the License, or
00007   (at your option) any later version.
00008
00009   MPTRAC is distributed in the hope that it will be useful,
00010   but WITHOUT ANY WARRANTY; without even the implied warranty of
00011   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
00012   GNU General Public License for more details.
00013
00014   You should have received a copy of the GNU General Public License
00015   along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.
00016
00017   Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
00018 */
00019
00025 #include "libtrac.h"
00026
00027 int main(
00028   int argc,
00029   char *argv[]) {
00030
00031   int day, doy, mon, year;
00032
00033   /* Check arguments... */
00034   if (argc < 4)
00035     ERRMSG("Give parameters: <year> <mon> <day>");
00036
00037   /* Read arguments... */
00038   year = atoi(argv[1]);
00039   mon = atoi(argv[2]);
00040   day = atoi(argv[3]);
00041
00042   /* Convert... */
```

```
  day2doy(year, mon, day, &doy);
  printf("%d %d\n", year, doy);

  return EXIT_SUCCESS;
}
```

## 5.15 doy2day.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char ∗argv[ ])

### 5.15.1 Detailed Description

Convert day of year to date.

Definition in file doy2day.c.

### 5.15.2 Function Documentation

#### 5.15.2.1 main()

```
int main (
    int argc,
    char ∗ argv[ ] )
```

Definition at line 27 of file doy2day.c.

```
                  {

  int day, doy, mon, year;

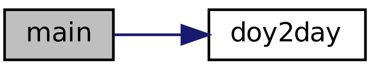
  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <year> <doy>");

  /* Read arguments... */
  year = atoi(argv[1]);
  doy = atoi(argv[2]);

  /* Convert... */
  doy2day(year, doy, &mon, &day);
  printf("%d %d %d\n", year, mon, day);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:



## 5.16 doy2day.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  int day, doy, mon, year;

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <year> <doy>");

  /* Read arguments... */
  year = atoi(argv[1]);
  doy = atoi(argv[2]);

  /* Convert... */
  doy2day(year, doy, &mon, &day);
  printf("%d %d %d\n", year, mon, day);

  return EXIT_SUCCESS;
}
```

## 5.17 jsec2time.c File Reference

`#include "libtrac.h"`

### Functions

- int main (int argc, char *argv[ ])

### 5.17.1 Detailed Description

Convert Julian seconds to date.

Definition in file jsec2time.c.

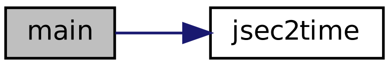
### 5.17.2 Function Documentation

#### 5.17.2.1 main() `int main ( int argc, char * argv[] )`

Definition at line 27 of file jsec2time.c.

```
00029                  {
00030 
00031   double jsec, remain;
00032 
00033   int day, hour, min, mon, sec, year;
00034 
00035   /* Check arguments... */
00036   if (argc < 2)
00037     ERRMSG("Give parameters: <jsec>");
00038 
00039   /* Read arguments... */
00040   jsec = atof(argv[1]);
00041 
00042   /* Convert time... */
00043   jsec2time(jsec, &year, &mon, &day, &hour, &min, &sec, &remain);
00044   printf("%d %d %d %d %d %d %g\n", year, mon, day, hour, min, sec, remain);
00045 
00046   return EXIT_SUCCESS;
00047 }
```

Here is the call graph for this function:




## 5.18 jsec2time.c

```
00001 /*
00002   This file is part of MPTRAC.
00003 
00004   MPTRAC is free software: you can redistribute it and/or modify
00005   it under the terms of the GNU General Public License as published by
00006   the Free Software Foundation, either version 3 of the License, or
00007   (at your option) any later version.
00008 
00009   MPTRAC is distributed in the hope that it will be useful,
00010   but WITHOUT ANY WARRANTY; without even the implied warranty of
00011   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
00012   GNU General Public License for more details.
00013 
00014   You should have received a copy of the GNU General Public License
00015   along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.
00016 
00017   Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
00018 */
00019 
00025 #include "libtrac.h"
00026 
00027 int main(
00028   int argc,
00029   char *argv[]) {
00030 
00031   double jsec, remain;
00032 
00033   int day, hour, min, mon, sec, year;
00034 
00035   /* Check arguments... */
00036   if (argc < 2)
00037     ERRMSG("Give parameters: <jsec>");
00038 
00039   /* Read arguments... */
00040   jsec = atof(argv[1]);
00041 
00042   /* Convert time... */
```

```
  jsec2time(jsec, &year, &mon, &day, &hour, &min, &sec, &remain);
  printf("%d %d %d %d %d %d %g\n", year, mon, day, hour, min, sec, remain);

  return EXIT_SUCCESS;
}
```

## 5.19 libtrac.c File Reference

```
#include "libtrac.h"
```

### Functions

- void cart2geo (double *x, double *z, double *lon, double *lat)

    *Convert Cartesian coordinates to geolocation.*
- double clim_hno3 (double t, double lat, double p)

    *Climatology of HNO3 volume mixing ratios.*
- double clim_oh (double t, double lat, double p)

    *Climatology of OH number concentrations.*
- double clim_tropo (double t, double lat)

    *Climatology of tropopause pressure.*
- void day2doy (int year, int mon, int day, int *doy)

    *Get day of year from date.*
- void doy2day (int year, int doy, int *mon, int *day)

    *Get date from day of year.*
- void geo2cart (double z, double lon, double lat, double *x)

    *Convert geolocation to Cartesian coordinates.*
- void get_met (ctl_t *ctl, double t, met_t **met0, met_t **met1)

    *Get meteorological data for given time step.*
- void get_met_help (double t, int direct, char *metbase, double dt_met, char *filename)

    *Get meteorological data for time step.*
- void get_met_replace (char *orig, char *search, char *repl)

    *Replace template strings in filename.*
- void intpol_met_space_3d (met_t *met, float array[EX][EY][EP], double p, double lon, double lat, double *var, int *ci, double *cw, int init)

    *Spatial interpolation of meteorological data.*
- void intpol_met_space_2d (met_t *met, float array[EX][EY], double lon, double lat, double *var, int *ci, double *cw, int init)

    *Spatial interpolation of meteorological data.*
- void intpol_met_time_3d (met_t *met0, float array0[EX][EY][EP], met_t *met1, float array1[EX][EY][EP], double ts, double p, double lon, double lat, double *var, int *ci, double *cw, int init)

    *Temporal interpolation of meteorological data.*
- void intpol_met_time_2d (met_t *met0, float array0[EX][EY], met_t *met1, float array1[EX][EY], double ts, double lon, double lat, double *var, int *ci, double *cw, int init)

    *Temporal interpolation of meteorological data.*
- void jsec2time (double jsec, int *year, int *mon, int *day, int *hour, int *min, int *sec, double *remain)

    *Convert seconds to date.*
- double lapse_rate (double t, double h2o)

    *Calculate moist adiabatic lapse rate.*
- int locate_irr (double *xx, int n, double x)

    *Find array index for irregular grid.*

- int locate_reg (double ∗xx, int n, double x)

  *Find array index for regular grid.*
- double nat_temperature (double p, double h2o, double hno3)

  *Calculate NAT existence temperature.*
- int read_atm (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm)

  *Read atmospheric data.*
- void read_ctl (const char ∗filename, int argc, char ∗argv[ ], ctl_t ∗ctl)

  *Read control parameters.*
- int read_met (ctl_t ∗ctl, char ∗filename, met_t ∗met)

  *Read meteorological data file.*
- void read_met_cape (met_t ∗met)

  *Calculate convective available potential energy.*
- void read_met_cloud (met_t ∗met)

  *Calculate cloud properties.*
- void read_met_detrend (ctl_t ∗ctl, met_t ∗met)

  *Apply detrending method to temperature and winds.*
- void read_met_extrapolate (met_t ∗met)

  *Extrapolate meteorological data at lower boundary.*
- void read_met_geopot (ctl_t ∗ctl, met_t ∗met)

  *Calculate geopotential heights.*
- void read_met_grid (char ∗filename, int ncid, ctl_t ∗ctl, met_t ∗met)

  *Read coordinates of meteorological data.*
- int read_met_help_3d (int ncid, char ∗varname, char ∗varname2, met_t ∗met, float dest[EX][EY][EP], float scl, int init)

  *Read and convert 3D variable from meteorological data file.*
- int read_met_help_2d (int ncid, char ∗varname, char ∗varname2, met_t ∗met, float dest[EX][EY], float scl, int init)

  *Read and convert 2D variable from meteorological data file.*
- void read_met_levels (int ncid, ctl_t ∗ctl, met_t ∗met)

  *Read meteorological data on vertical levels.*
- void read_met_ml2pl (ctl_t ∗ctl, met_t ∗met, float var[EX][EY][EP])

  *Convert meteorological data from model levels to pressure levels.*
- void read_met_pbl (met_t ∗met)

  *Calculate pressure of the boundary layer.*
- void read_met_periodic (met_t ∗met)

  *Create meteorological data with periodic boundary conditions.*
- void read_met_pv (met_t ∗met)

  *Calculate potential vorticity.*
- void read_met_sample (ctl_t ∗ctl, met_t ∗met)

  *Downsampling of meteorological data.*
- void read_met_surface (int ncid, met_t ∗met)

  *Read surface data.*
- void read_met_tropo (ctl_t ∗ctl, met_t ∗met)

  *Calculate tropopause data.*
- double scan_ctl (const char ∗filename, int argc, char ∗argv[ ], const char ∗varname, int arridx, const char ∗defvalue, char ∗value)

  *Read a control parameter from file or command line.*
- double sedi (double p, double T, double r_p, double rho_p)

  *Calculate sedimentation velocity.*
- void spline (double ∗x, double ∗y, int n, double ∗x2, double ∗y2, int n2, int method)

  *Spline interpolation.*

- float stddev (float *data, int n)

    *Calculate standard deviation.*
- void time2jsec (int year, int mon, int day, int hour, int min, int sec, double remain, double *jsec)

    *Convert date to seconds.*
- void timer (const char *name, const char *group, int output)

    *Measure wall-clock time.*
- double tropo_weight (double t, double lat, double p)

    *Get weighting factor based on tropopause distance.*
- void write_atm (const char *filename, ctl_t *ctl, atm_t *atm, double t)

    *Write atmospheric data.*
- void write_csi (const char *filename, ctl_t *ctl, atm_t *atm, double t)

    *Write CSI data.*
- void write_ens (const char *filename, ctl_t *ctl, atm_t *atm, double t)

    *Write ensemble data.*
- void write_grid (const char *filename, ctl_t *ctl, met_t *met0, met_t *met1, atm_t *atm, double t)

    *Write gridded data.*
- void write_prof (const char *filename, ctl_t *ctl, met_t *met0, met_t *met1, atm_t *atm, double t)

    *Write profile data.*
- void write_sample (const char *filename, ctl_t *ctl, met_t *met0, met_t *met1, atm_t *atm, double t)

    *Write sample data.*
- void write_station (const char *filename, ctl_t *ctl, atm_t *atm, double t)

    *Write station data.*

### 5.19.1 Detailed Description

MPTRAC library definitions.

Definition in file libtrac.c.

### 5.19.2 Function Documentation

#### 5.19.2.1 cart2geo()

```
void cart2geo (
        double * x,
        double * z,
        double * lon,
        double * lat )
```

Convert Cartesian coordinates to geolocation.

Definition at line 29 of file libtrac.c.

```
                {

  double radius = NORM(x);
  *lat = asin(x[2] / radius) * 180. / M_PI;
  *lon = atan2(x[1], x[0]) * 180. / M_PI;
  *z = radius - RE;
}
```

#### 5.19.2.2 clim_hno3()

```
double clim_hno3 (
        double t,
        double lat,
        double p )
```

Climatology of HNO3 volume mixing ratios.

Definition at line 295 of file libtrac.c.

```
                  {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Check pressure... */
  if (p < clim_hno3_ps[0])
    p = clim_hno3_ps[0];
  else if (p > clim_hno3_ps[9])
    p = clim_hno3_ps[9];

  /* Check latitude... */
  if (lat < clim_hno3_lats[0])
    lat = clim_hno3_lats[0];
  else if (lat > clim_hno3_lats[17])
    lat = clim_hno3_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_hno3_secs, 12, sec);
  int ilat = locate_reg(clim_hno3_lats, 18, lat);
  int ip = locate_irr(clim_hno3_ps, 10, p);

  /* Interpolate HNO3 climatology (Froidevaux et al., 2015)... */
  double aux00 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat][ip + 1], p);
  double aux11 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_hno3_lats[ilat], aux00,
              clim_hno3_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_hno3_lats[ilat], aux10,
              clim_hno3_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_hno3_secs[isec], aux00,
              clim_hno3_secs[isec + 1], aux11, sec);

  /* Convert from ppb to ppv... */
  return GSL_MAX(1e-9 * aux00, 0.0);
}
```

#### 5.19.2.3 clim_oh()

```
double clim_oh (
        double t,
        double lat,
        double p )
```

Climatology of OH number concentrations.

Definition at line 1331 of file libtrac.c.

```
                  {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

```

```
  /* Check pressure... */
  if (p < clim_oh_ps[0])
    p = clim_oh_ps[0];
  else if (p > clim_oh_ps[33])
    p = clim_oh_ps[33];

  /* Check latitude... */
  if (lat < clim_oh_lats[0])
    lat = clim_oh_lats[0];
  else if (lat > clim_oh_lats[17])
    lat = clim_oh_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_oh_secs, 12, sec);
  int ilat = locate_reg(clim_oh_lats, 18, lat);
  int ip = locate_irr(clim_oh_ps, 34, p);

  /* Interpolate OH climatology (Pommrich et al., 2014)... */
  double aux00 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat][ip + 1], p);
  double aux11 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_oh_lats[ilat], aux00, clim_oh_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_oh_lats[ilat], aux10, clim_oh_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_oh_secs[isec], aux00, clim_oh_secs[isec + 1], aux11, sec);
  return GSL_MAX(1e6 * aux00, 0.0);
}
```

#### 5.19.2.4 clim_tropo()

```
double clim_tropo (
        double t,
        double lat )
```

Climatology of tropopause pressure.

Definition at line 1512 of file libtrac.c.

```
                  {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Get indices... */
  int isec = locate_irr(clim_tropo_secs, 12, sec);
  int ilat = locate_reg(clim_tropo_lats, 73, lat);

  /* Interpolate tropopause data (NCEP/NCAR Reanalysis 1)... */
  double p0 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec][ilat + 1], lat);
  double p1 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec + 1][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec + 1][ilat + 1], lat);
  return LIN(clim_tropo_secs[isec], p0, clim_tropo_secs[isec + 1], p1, sec);
}
```

Here is the call graph for this function:


#### 5.19.2.5 day2doy()

```
void day2doy (
    int year,
    int mon,
    int day,
    int * doy )
```

Get day of year from date.

Definition at line 1539 of file libtrac.c.

```
                      {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d01[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  /* Get day of year... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0))
    *doy = d01[mon - 1] + day - 1;
  else
    *doy = d0[mon - 1] + day - 1;
}
```

#### 5.19.2.6 doy2day()

```
void doy2day (
    int year,
    int doy,
    int * mon,
    int * day )
```

Get date from day of year.

Definition at line 1558 of file libtrac.c.

```
                      {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d01[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  int i;

  /* Get month and day... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0)) {
    for (i = 11; i > 0; i--)
      if (d01[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d01[i] + 1;
  } else {
    for (i = 11; i > 0; i--)
      if (d0[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d0[i] + 1;
  }
}
```

#### 5.19.2.7 geo2cart()

```
void geo2cart (
        double z,
        double lon,
        double lat,
        double * x )
```

Convert geolocation to Cartesian coordinates.

Definition at line 1588 of file libtrac.c.

```
               {

  double radius = z + RE;
  x[0] = radius * cos(lat / 180. * M_PI) * cos(lon / 180. * M_PI);
  x[1] = radius * cos(lat / 180. * M_PI) * sin(lon / 180. * M_PI);
  x[2] = radius * sin(lat / 180. * M_PI);
}
```

#### 5.19.2.8 get_met()

```
void get_met (
        ctl_t * ctl,
        double t,
        met_t ** met0,
        met_t ** met1 )
```

Get meteorological data for given time step.

Definition at line 1602 of file libtrac.c.

```
                   {

  static int init;

  met_t *mets;

  char cachefile[LEN], cmd[2 * LEN], filename[LEN];

  /* Set timer... */
  SELECT_TIMER("GET_MET", "INPUT", NVTX_READ);

  /* Init... */
  if (t == ctl->t_start || !init) {
    init = 1;

    /* Read meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    get_met_help(t + 1.0 * ctl->direction, 1, ctl->metbase, ctl->dt_met,
                 filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
    met_t *met1up = *met1;
#pragma acc update device(met0up[:1],met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + 1.1 * ctl->dt_met * ctl->direction, ctl->direction,
                   ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for forward trajectories... */
  if (t > (*met1)->time) {

    /* Pointer swap... */
    mets = *met1;
```

```
    *met1 = *met0;
    *met0 = mets;

    /* Read new meteo data... */
    get_met_help(t, 1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met1up = *met1;
#pragma acc update device(met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + ctl->dt_met, 1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for backward trajectories... */
  if (t < (*met0)->time) {

    /* Pointer swap... */
    mets = *met1;
    *met1 = *met0;
    *met0 = mets;

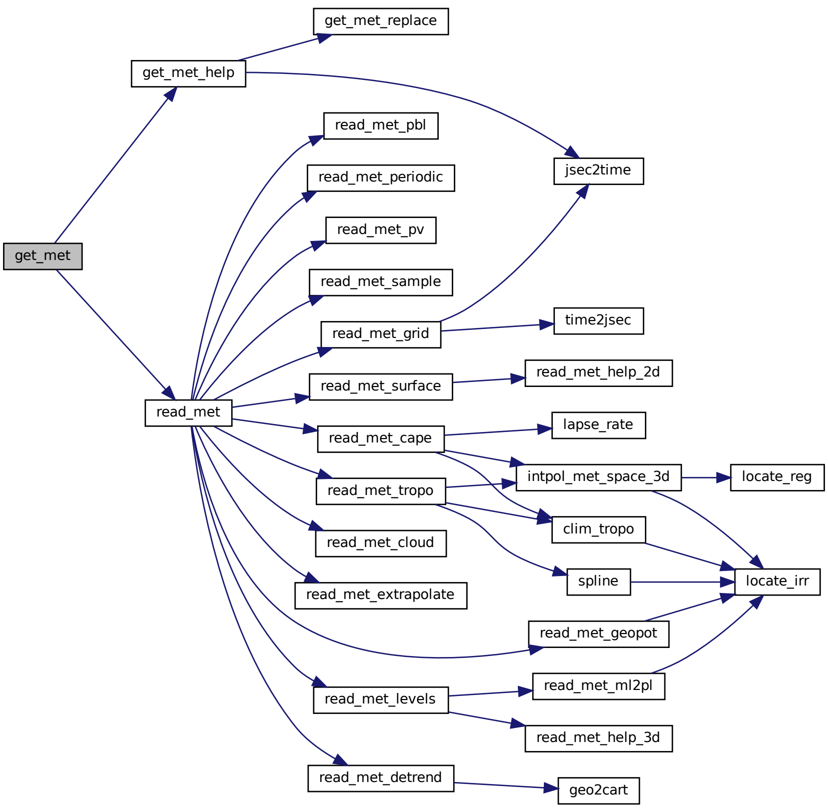
    /* Read new meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
#pragma acc update device(met0up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t - ctl->dt_met, -1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Check that grids are consistent... */
  if ((*met0)->nx != (*met1)->nx
      || (*met0)->ny != (*met1)->ny || (*met0)->np != (*met1)->np)
    ERRMSG("Meteo grid dimensions do not match!");
  for (int ix = 0; ix < (*met0)->nx; ix++)
    if (fabs((*met0)->lon[ix] - (*met1)->lon[ix]) > 0.001)
      ERRMSG("Meteo grid longitudes do not match!");
  for (int iy = 0; iy < (*met0)->ny; iy++)
    if (fabs((*met0)->lat[iy] - (*met1)->lat[iy]) > 0.001)
      ERRMSG("Meteo grid latitudes do not match!");
  for (int ip = 0; ip < (*met0)->np; ip++)
    if (fabs((*met0)->p[ip] - (*met1)->p[ip]) > 0.001)
      ERRMSG("Meteo grid pressure levels do not match!");
}
```

Here is the call graph for this function:




#### 5.19.2.9 get_met_help()

```
void get_met_help (
    double t,
    int direct,
    char * metbase,
    double dt_met,
    char * filename )
```

Get meteorological data for time step.

Definition at line 1724 of file libtrac.c.

```
                  {

  char repl[LEN];

  double t6, r;

  int year, mon, day, hour, min, sec;

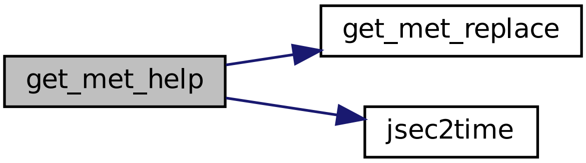
  /* Round time to fixed intervals... */
  if (direct == -1)
    t6 = floor(t / dt_met) * dt_met;
  else
    t6 = ceil(t / dt_met) * dt_met;

  /* Decode time... */
  jsec2time(t6, &year, &mon, &day, &hour, &min, &sec, &r);

  /* Set filename... */
```

```
  sprintf(filename, "%s_YYYY_MM_DD_HH.nc", metbase);
  sprintf(repl, "%d", year);
  get_met_replace(filename, "YYYY", repl);
  sprintf(repl, "%02d", mon);
  get_met_replace(filename, "MM", repl);
  sprintf(repl, "%02d", day);
  get_met_replace(filename, "DD", repl);
  sprintf(repl, "%02d", hour);
  get_met_replace(filename, "HH", repl);
}
```

Here is the call graph for this function:




#### 5.19.2.10 get_met_replace()

```
void get_met_replace (
    char * orig,
    char * search,
    char * repl )
```

Replace template strings in filename.

Definition at line 1760 of file libtrac.c.

```
                {

  char buffer[LEN], *ch;

  /* Iterate... */
  for (int i = 0; i < 3; i++) {

    /* Replace sub-string... */
    if (!(ch = strstr(orig, search)))
      return;
    strncpy(buffer, orig, (size_t) (ch - orig));
    buffer[ch - orig] = 0;
    sprintf(buffer + (ch - orig), "%s%s", repl, ch + strlen(search));
    orig[0] = 0;
    strcpy(orig, buffer);
  }
}
```

#### 5.19.2.11 intpol_met_space_3d()

```
void intpol_met_space_3d (
    met_t * met,
    float array[EX][EY][EP],
    double p,
    double lon,
    double lat,
    double * var,
```

```
int * ci,
double * cw,
int init )
```

Spatial interpolation of meteorological data.

Definition at line 1783 of file libtrac.c.

```
                 {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

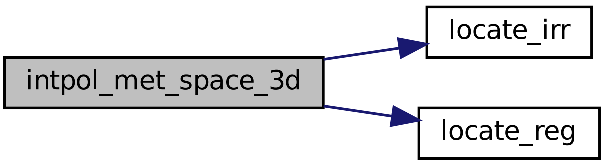
    /* Get interpolation indices... */
    ci[0] = locate_irr(met->p, met->np, p);
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[0] = (met->p[ci[0] + 1] - p)
      / (met->p[ci[0] + 1] - met->p[ci[0]]);
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Interpolate vertically... */
  double aux00 =
    cw[0] * (array[ci[1]][ci[2]][ci[0]] - array[ci[1]][ci[2]][ci[0] + 1])
    + array[ci[1]][ci[2]][ci[0] + 1];
  double aux01 =
    cw[0] * (array[ci[1]][ci[2] + 1][ci[0]] -
             array[ci[1]][ci[2] + 1][ci[0] + 1])
    + array[ci[1]][ci[2] + 1][ci[0] + 1];
  double aux10 =
    cw[0] * (array[ci[1] + 1][ci[2]][ci[0]] -
             array[ci[1] + 1][ci[2]][ci[0] + 1])
    + array[ci[1] + 1][ci[2]][ci[0] + 1];
  double aux11 =
    cw[0] * (array[ci[1] + 1][ci[2] + 1][ci[0]] -
             array[ci[1] + 1][ci[2] + 1][ci[0] + 1])
    + array[ci[1] + 1][ci[2] + 1][ci[0] + 1];

  /* Interpolate horizontally... */
  aux00 = cw[2] * (aux00 - aux01) + aux01;
  aux11 = cw[2] * (aux10 - aux11) + aux11;
  *var = cw[1] * (aux00 - aux11) + aux11;
}
```

Here is the call graph for this function:



### 5.19.2.12 intpol_met_space_2d()

```
void intpol_met_space_2d (
        met_t * met,
        float array[EX][EY],
        double lon,
        double lat,
        double * var,
        int * ci,
        double * cw,
        int init )
```

Spatial interpolation of meteorological data.

Definition at line 1841 of file libtrac.c.

```
                  {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

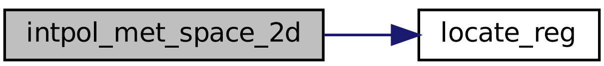
    /* Get interpolation indices... */
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Set variables... */
  double aux00 = array[ci[1]][ci[2]];
  double aux01 = array[ci[1]][ci[2] + 1];
  double aux10 = array[ci[1] + 1][ci[2]];
  double aux11 = array[ci[1] + 1][ci[2] + 1];

  /* Interpolate horizontally... */
  if (isfinite(aux00) && isfinite(aux01)
      && isfinite(aux10) && isfinite(aux11)) {
    aux00 = cw[2] * (aux00 - aux01) + aux01;
    aux11 = cw[2] * (aux10 - aux11) + aux11;
    *var = cw[1] * (aux00 - aux11) + aux11;
  } else {
    if (cw[2] < 0.5) {
      if (cw[1] < 0.5)
        *var = aux11;
      else
        *var = aux01;
    } else {
      if (cw[1] < 0.5)
        *var = aux10;
      else
        *var = aux00;
    }
  }
}
```

Here is the call graph for this function:



#### 5.19.2.13 intpol_met_time_3d()

```
void intpol_met_time_3d (
    met_t * met0,
    float array0[EX][EY][EP],
    met_t * met1,
    float array1[EX][EY][EP],
    double ts,
    double p,
    double lon,
    double lat,
    double * var,
    int * ci,
    double * cw,
    int init )
```

Temporal interpolation of meteorological data.

Definition at line 1898 of file libtrac.c.

```
                {

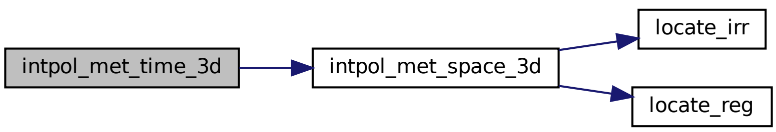
  double var0, var1, wt;

  /* Spatial interpolation... */
  intpol_met_space_3d(met0, array0, p, lon, lat, &var0, ci, cw, init);
  intpol_met_space_3d(met1, array1, p, lon, lat, &var1, ci, cw, 0);

  /* Get weighting factor... */
  wt = (met1->time - ts) / (met1->time - met0->time);

  /* Interpolate... */
  *var = wt * (var0 - var1) + var1;
}
```

Here is the call graph for this function:




#### 5.19.2.14 intpol_met_time_2d()

```
void intpol_met_time_2d (
    met_t * met0,
    float array0[EX][EY],
    met_t * met1,
    float array1[EX][EY],
    double ts,
    double lon,
    double lat,
    double * var,
    int * ci,
    double * cw,
    int init )
```

Temporal interpolation of meteorological data.

Definition at line 1927 of file libtrac.c.

```
                    {

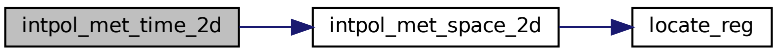
  double var0, var1, wt;

  /* Spatial interpolation... */
  intpol_met_space_2d(met0, array0, lon, lat, &var0, ci, cw, init);
  intpol_met_space_2d(met1, array1, lon, lat, &var1, ci, cw, 0);

  /* Get weighting factor... */
  wt = (met1->time - ts) / (met1->time - met0->time);

  /* Interpolate... */
  if (isfinite(var0) && isfinite(var1))
    *var = wt * (var0 - var1) + var1;
  else if (wt < 0.5)
    *var = var1;
  else
    *var = var0;
}
```

Here is the call graph for this function:




#### 5.19.2.15 jsec2time()

```
void jsec2time (
    double jsec,
    int * year,
    int * mon,
    int * day,
    int * hour,
    int * min,
    int * sec,
    double * remain )
```

Convert seconds to date.

Definition at line 1960 of file libtrac.c.

```
                          {

  struct tm t0, *t1;

  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  time_t jsec0 = (time_t) jsec + timegm(&t0);
  t1 = gmtime(&jsec0);

  *year = t1->tm_year + 1900;
  *mon = t1->tm_mon + 1;
  *day = t1->tm_mday;
  *hour = t1->tm_hour;
  *min = t1->tm_min;
  *sec = t1->tm_sec;
  *remain = jsec - floor(jsec);
}
```

#### 5.19.2.16 lapse_rate()

```
double lapse_rate (
    double t,
    double h2o )
```

Calculate moist adiabatic lapse rate.

Definition at line 1993 of file libtrac.c.

```
                 {

  /*
     Calculate moist adiabatic lapse rate [K/km] from temperature [K]
     and water vapor volume mixing ratio [1].

     Reference: https://en.wikipedia.org/wiki/Lapse_rate
   */

  const double a = RA * SQR(t), r = SH(h2o) / (1. - SH(h2o));

  return 1e3 * G0 * (a + LV * r * t) / (CPD * a + SQR(LV) * r * EPS);
}
```

#### 5.19.2.17 locate_irr()

```
int locate_irr (
    double * xx,
    int n,
    double x )
```

Find array index for irregular grid.

Definition at line 2011 of file libtrac.c.

```
               {

  int ilo = 0;
  int ihi = n - 1;
  int i = (ihi + ilo) >> 1;

  if (xx[i] < xx[i + 1])
    while (ihi > ilo + 1) {
      i = (ihi + ilo) >> 1;
      if (xx[i] > x)
        ihi = i;
      else
        ilo = i;
  } else
    while (ihi > ilo + 1) {
      i = (ihi + ilo) >> 1;
      if (xx[i] <= x)
        ihi = i;
      else
        ilo = i;
    }

  return ilo;
}
```

#### 5.19.2.18 locate_reg()

```
int locate_reg (
    double * xx,
    int n,
    double x )
```

Find array index for regular grid.

Definition at line 2041 of file libtrac.c.

```
               {

  /* Calculate index... */
  int i = (int) ((x - xx[0]) / (xx[1] - xx[0]));
```

```
  /* Check range... */
  if (i < 0)
    return 0;
  else if (i > n - 2)
    return n - 2;
  else
    return i;
}
```

### 5.19.2.19 nat_temperature()

```
double nat_temperature (
    double p,
    double h2o,
    double hno3 )
```

Calculate NAT existence temperature.

Definition at line 2060 of file libtrac.c.

```
                {

  /* Check water vapor vmr... */
  h2o = GSL_MAX(h2o, 0.1e-6);

  /* Calculate T_NAT... */
  double p_hno3 = hno3 * p / 1.333224;
  double p_h2o = h2o * p / 1.333224;
  double a = 0.009179 - 0.00088 * log10(p_h2o);
  double b = (38.9855 - log10(p_hno3) - 2.7836 * log10(p_h2o)) / a;
  double c = -11397.0 / a;
  double tnat = (-b + sqrt(b * b - 4. * c)) / 2.;
  double x2 = (-b - sqrt(b * b - 4. * c)) / 2.;
  if (x2 > 0)
    tnat = x2;

  return tnat;
}
```

### 5.19.2.20 read_atm()

```
int read_atm (
    const char * filename,
    ctl_t * ctl,
    atm_t * atm )
```

Read atmospheric data.

Definition at line 2084 of file libtrac.c.

```
                {

  FILE *in;

  double t0;

  int dimid, ncid, varid;

  size_t nparts;

  /* Set timer... */
  SELECT_TIMER("READ_ATM", "INPUT", NVTX_READ);

  /* Init... */
  atm->np = 0;

  /* Write info... */
  LOG(1, "Read atmospheric data: %s", filename);

  /* Read ASCII data... */
  if (ctl->atm_type == 0) {

    /* Open file... */
    if (!(in = fopen(filename, "r"))) {
```

```
      WARN("File not found!");
      return 0;
    }

    /* Read line... */
    char line[LEN];
    while (fgets(line, LEN, in)) {

      /* Read data... */
      char *tok;
      TOK(line, tok, "%lg", atm->time[atm->np]);
      TOK(NULL, tok, "%lg", atm->p[atm->np]);
      TOK(NULL, tok, "%lg", atm->lon[atm->np]);
      TOK(NULL, tok, "%lg", atm->lat[atm->np]);
      for (int iq = 0; iq < ctl->nq; iq++)
        TOK(NULL, tok, "%lg", atm->q[iq][atm->np]);

      /* Convert altitude to pressure... */
      atm->p[atm->np] = P(atm->p[atm->np]);

      /* Increment data point counter... */
      if ((++atm->np) > NP)
        ERRMSG("Too many data points!");
    }

    /* Close file... */
    fclose(in);
  }

  /* Read binary data... */
  else if (ctl->atm_type == 1) {

    /* Open file... */
    if (!(in = fopen(filename, "r")))
      return 0;

    /* Read data... */
    FREAD(&atm->np, int,
          1,
          in);
    FREAD(atm->time, double,
            (size_t) atm->np,
          in);
    FREAD(atm->p, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lon, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lat, double,
            (size_t) atm->np,
          in);
    for (int iq = 0; iq < ctl->nq; iq++)
      FREAD(atm->q[iq], double,
              (size_t) atm->np,
            in);

    /* Close file... */
    fclose(in);
  }

  /* Read netCDF data... */
  else if (ctl->atm_type == 2) {

    /* Open file... */
    if (nc_open(filename, NC_NOWRITE, &ncid) != NC_NOERR)
      return 0;

    /* Get dimensions... */
    NC(nc_inq_dimid(ncid, "NPARTS", &dimid));
    NC(nc_inq_dimlen(ncid, dimid, &nparts));
    atm->np = (int) nparts;
    if (atm->np > NP)
      ERRMSG("Too many particles!");

    /* Get time... */
    NC(nc_inq_varid(ncid, "time", &varid));
    NC(nc_get_var_double(ncid, varid, &t0));
    for (int ip = 0; ip < atm->np; ip++)
      atm->time[ip] = t0;

    /* Read geolocations... */
    NC(nc_inq_varid(ncid, "PRESS", &varid));
    NC(nc_get_var_double(ncid, varid, atm->p));
    NC(nc_inq_varid(ncid, "LON", &varid));
    NC(nc_get_var_double(ncid, varid, atm->lon));
    NC(nc_inq_varid(ncid, "LAT", &varid));
```

```
    NC(nc_get_var_double(ncid, varid, atm->lat));

    /* Read variables... */
    if (ctl->qnt_p >= 0)
      if (nc_inq_varid(ncid, "PRESS", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_p]));
    if (ctl->qnt_t >= 0)
      if (nc_inq_varid(ncid, "TEMP", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_t]));
    if (ctl->qnt_u >= 0)
      if (nc_inq_varid(ncid, "U", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_u]));
    if (ctl->qnt_v >= 0)
      if (nc_inq_varid(ncid, "V", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_v]));
    if (ctl->qnt_w >= 0)
      if (nc_inq_varid(ncid, "W", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_w]));
    if (ctl->qnt_h2o >= 0)
      if (nc_inq_varid(ncid, "SH", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_h2o]));
    if (ctl->qnt_o3 >= 0)
      if (nc_inq_varid(ncid, "O3", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_o3]));
    if (ctl->qnt_theta >= 0)
      if (nc_inq_varid(ncid, "THETA", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_theta]));
    if (ctl->qnt_pv >= 0)
      if (nc_inq_varid(ncid, "PV", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_pv]));

    /* Check data... */
    for (int ip = 0; ip < atm->np; ip++)
      if (fabs(atm->lon[ip]) > 360 || fabs(atm->lat[ip]) > 90
          || (ctl->qnt_t >= 0 && fabs(atm->q[ctl->qnt_t][ip]) > 350)
          || (ctl->qnt_h2o >= 0 && fabs(atm->q[ctl->qnt_h2o][ip]) > 1)
          || (ctl->qnt_theta >= 0 && fabs(atm->q[ctl->qnt_theta][ip]) > 1e10)
          || (ctl->qnt_pv >= 0 && fabs(atm->q[ctl->qnt_pv][ip]) > 1e10)) {
        atm->time[ip] = GSL_NAN;
        atm->p[ip] = GSL_NAN;
        atm->lon[ip] = GSL_NAN;
        atm->lat[ip] = GSL_NAN;
        for (int iq = 0; iq < ctl->nq; iq++)
          atm->q[iq][ip] = GSL_NAN;
      } else {
        if (ctl->qnt_h2o >= 0)
          atm->q[ctl->qnt_h2o][ip] *= 1.608;
        if (ctl->qnt_pv >= 0)
          atm->q[ctl->qnt_pv][ip] *= 1e6;
        if (atm->lon[ip] > 180)
          atm->lon[ip] -= 360;
      }

    /* Close file... */
    NC(nc_close(ncid));
  }

  /* Error... */
  else
    ERRMSG("Atmospheric data type not supported!");

  /* Check number of points... */
  if (atm->np < 1)
    ERRMSG("Can not read any data!");

  /* Write info... */
  double mini, maxi;
  LOG(2, "Number of particles: %d", atm->np);
  gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
  LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
  LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
  LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
  LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
  LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
  for (int iq = 0; iq < ctl->nq; iq++) {
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }

  /* Return success... */
```

```
  return 1;
}
```

#### 5.19.2.21 read_ctl()

```
void read_ctl (
    const char * filename,
    int argc,
    char * argv[],
    ctl_t * ctl )
```

Read control parameters.

Definition at line 2290 of file libtrac.c.

```
                 {

  /* Set timer... */
  SELECT_TIMER("READ_CTL", "INPUT", NVTX_READ);

  /* Write info... */
  LOG(1, "\nMassive-Parallel Trajectory Calculations (MPTRAC)\n"
      "(executable: %s | version: %s | compiled: %s, %s)\n",
      argv[0], VERSION, __DATE__, __TIME__);

  /* Initialize quantity indices... */
  ctl->qnt_ens = -1;
  ctl->qnt_stat = -1;
  ctl->qnt_m = -1;
  ctl->qnt_vmr = -1;
  ctl->qnt_r = -1;
  ctl->qnt_rho = -1;
  ctl->qnt_ps = -1;
  ctl->qnt_ts = -1;
  ctl->qnt_zs = -1;
  ctl->qnt_us = -1;
  ctl->qnt_vs = -1;
  ctl->qnt_pbl = -1;
  ctl->qnt_pt = -1;
  ctl->qnt_tt = -1;
  ctl->qnt_zt = -1;
  ctl->qnt_h2ot = -1;
  ctl->qnt_z = -1;
  ctl->qnt_p = -1;
  ctl->qnt_t = -1;
  ctl->qnt_u = -1;
  ctl->qnt_v = -1;
  ctl->qnt_w = -1;
  ctl->qnt_h2o = -1;
  ctl->qnt_o3 = -1;
  ctl->qnt_lwc = -1;
  ctl->qnt_iwc = -1;
  ctl->qnt_pct = -1;
  ctl->qnt_pcb = -1;
  ctl->qnt_cl = -1;
  ctl->qnt_plcl = -1;
  ctl->qnt_plfc = -1;
  ctl->qnt_pel = -1;
  ctl->qnt_cape = -1;
  ctl->qnt_cin = -1;
  ctl->qnt_hno3 = -1;
  ctl->qnt_oh = -1;
  ctl->qnt_psat = -1;
  ctl->qnt_psice = -1;
  ctl->qnt_pw = -1;
  ctl->qnt_sh = -1;
  ctl->qnt_rh = -1;
  ctl->qnt_rhice = -1;
  ctl->qnt_theta = -1;
  ctl->qnt_zeta = -1;
  ctl->qnt_tvirt = -1;
  ctl->qnt_lapse = -1;
  ctl->qnt_vh = -1;
  ctl->qnt_vz = -1;
  ctl->qnt_pv = -1;
  ctl->qnt_tdew = -1;
  ctl->qnt_tice = -1;
  ctl->qnt_tsts = -1;
  ctl->qnt_tnat = -1;

```

```
/* Read quantities... */
ctl->nq = (int) scan_ctl(filename, argc, argv, "NQ", -1, "0", NULL);
if (ctl->nq > NQ)
  ERRMSG("Too many quantities!");
for (int iq = 0; iq < ctl->nq; iq++) {

  /* Read quantity name and format... */
  scan_ctl(filename, argc, argv, "QNT_NAME", iq, "", ctl->qnt_name[iq]);
  scan_ctl(filename, argc, argv, "QNT_FORMAT", iq, "%g",
           ctl->qnt_format[iq]);

  /* Try to identify quantity... */
  SET_QNT(qnt_ens, "ens", "-")
    SET_QNT(qnt_stat, "stat", "-")
    SET_QNT(qnt_m, "m", "kg")
    SET_QNT(qnt_vmr, "vmr", "ppv")
    SET_QNT(qnt_r, "r", "microns")
    SET_QNT(qnt_rho, "rho", "kg/m^3")
    SET_QNT(qnt_ps, "ps", "hPa")
    SET_QNT(qnt_ts, "ts", "K")
    SET_QNT(qnt_zs, "zs", "km")
    SET_QNT(qnt_us, "us", "m/s")
    SET_QNT(qnt_vs, "vs", "m/s")
    SET_QNT(qnt_pbl, "pbl", "hPa")
    SET_QNT(qnt_pt, "pt", "hPa")
    SET_QNT(qnt_tt, "tt", "K")
    SET_QNT(qnt_zt, "zt", "km")
    SET_QNT(qnt_h2ot, "h2ot", "ppv")
    SET_QNT(qnt_z, "z", "km")
    SET_QNT(qnt_p, "p", "hPa")
    SET_QNT(qnt_t, "t", "K")
    SET_QNT(qnt_u, "u", "m/s")
    SET_QNT(qnt_v, "v", "m/s")
    SET_QNT(qnt_w, "w", "hPa/s")
    SET_QNT(qnt_h2o, "h2o", "ppv")
    SET_QNT(qnt_o3, "o3", "ppv")
    SET_QNT(qnt_lwc, "lwc", "kg/kg")
    SET_QNT(qnt_iwc, "iwc", "kg/kg")
    SET_QNT(qnt_pct, "pct", "hPa")
    SET_QNT(qnt_pcb, "pcb", "hPa")
    SET_QNT(qnt_cl, "cl", "kg/m^2")
    SET_QNT(qnt_plcl, "plcl", "hPa")
    SET_QNT(qnt_plfc, "plfc", "hPa")
    SET_QNT(qnt_pel, "pel", "hPa")
    SET_QNT(qnt_cape, "cape", "J/kg")
    SET_QNT(qnt_cin, "cin", "J/kg")
    SET_QNT(qnt_hno3, "hno3", "ppv")
    SET_QNT(qnt_oh, "oh", "molec/cm^3")
    SET_QNT(qnt_psat, "psat", "hPa")
    SET_QNT(qnt_psice, "psice", "hPa")
    SET_QNT(qnt_pw, "pw", "hPa")
    SET_QNT(qnt_sh, "sh", "kg/kg")
    SET_QNT(qnt_rh, "rh", "%%")
    SET_QNT(qnt_rhice, "rhice", "%%")
    SET_QNT(qnt_theta, "theta", "K")
    SET_QNT(qnt_zeta, "zeta", "K")
    SET_QNT(qnt_tvirt, "tvirt", "K")
    SET_QNT(qnt_lapse, "lapse", "K/km")
    SET_QNT(qnt_vh, "vh", "m/s")
    SET_QNT(qnt_vz, "vz", "m/s")
    SET_QNT(qnt_pv, "pv", "PVU")
    SET_QNT(qnt_tdew, "tdew", "K")
    SET_QNT(qnt_tice, "tice", "K")
    SET_QNT(qnt_tsts, "tsts", "K")
    SET_QNT(qnt_tnat, "tnat", "K")
    scan_ctl(filename, argc, argv, "QNT_UNIT", iq, "", ctl->qnt_unit[iq]);
}

/* netCDF I/O parameters... */
ctl->chunkszhint =
  (size_t) scan_ctl(filename, argc, argv, "CHUNKSZHINT", -1, "163840000",
                    NULL);
ctl->read_mode =
  (int) scan_ctl(filename, argc, argv, "READMODE", -1, "0", NULL);

/* Time steps of simulation... */
ctl->direction =
  (int) scan_ctl(filename, argc, argv, "DIRECTION", -1, "1", NULL);
if (ctl->direction != -1 && ctl->direction != 1)
  ERRMSG("Set DIRECTION to -1 or 1!");
ctl->t_stop = scan_ctl(filename, argc, argv, "T_STOP", -1, "1e100", NULL);
ctl->dt_mod = scan_ctl(filename, argc, argv, "DT_MOD", -1, "180", NULL);

/* Meteorological data... */
scan_ctl(filename, argc, argv, "METBASE", -1, "-", ctl->metbase);
ctl->dt_met = scan_ctl(filename, argc, argv, "DT_MET", -1, "3600", NULL);
ctl->met_dx = (int) scan_ctl(filename, argc, argv, "MET_DX", -1, "1", NULL);
```

```
  ctl->met_dy = (int) scan_ctl(filename, argc, argv, "MET_DY", -1, "1", NULL);
  ctl->met_dp = (int) scan_ctl(filename, argc, argv, "MET_DP", -1, "1", NULL);
  if (ctl->met_dx < 1 || ctl->met_dy < 1 || ctl->met_dp < 1)
    ERRMSG("MET_DX, MET_DY, and MET_DP need to be greater than zero!");
  ctl->met_sx = (int) scan_ctl(filename, argc, argv, "MET_SX", -1, "1", NULL);
  ctl->met_sy = (int) scan_ctl(filename, argc, argv, "MET_SY", -1, "1", NULL);
  ctl->met_sp = (int) scan_ctl(filename, argc, argv, "MET_SP", -1, "1", NULL);
  if (ctl->met_sx < 1 || ctl->met_sy < 1 || ctl->met_sp < 1)
    ERRMSG("MET_SX, MET_SY, and MET_SP need to be greater than zero!");
  ctl->met_detrend =
    scan_ctl(filename, argc, argv, "MET_DETREND", -1, "-999", NULL);
  ctl->met_np = (int) scan_ctl(filename, argc, argv, "MET_NP", -1, "0", NULL);
  if (ctl->met_np > EP)
    ERRMSG("Too many levels!");
  for (int ip = 0; ip < ctl->met_np; ip++)
    ctl->met_p[ip] = scan_ctl(filename, argc, argv, "MET_P", ip, "", NULL);
  ctl->met_geopot_sx
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SX", -1, "-1", NULL);
  ctl->met_geopot_sy
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SY", -1, "-1", NULL);
  ctl->met_tropo =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO", -1, "3", NULL);
  if (ctl->met_tropo < 0 || ctl->met_tropo > 5)
    ERRMSG("Set MET_TROPO = 0 ... 5!");
  ctl->met_tropo_lapse =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE", -1, "2.0", NULL);
  ctl->met_tropo_nlev =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV", -1, "20", NULL);
  ctl->met_tropo_lapse_sep =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE_SEP", -1, "3.0", NULL);
  ctl->met_tropo_nlev_sep =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV_SEP", -1, "10",
                   NULL);
  ctl->met_tropo_pv =
    scan_ctl(filename, argc, argv, "MET_TROPO_PV", -1, "3.5", NULL);
  ctl->met_tropo_theta =
    scan_ctl(filename, argc, argv, "MET_TROPO_THETA", -1, "380", NULL);
  ctl->met_tropo_spline =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_SPLINE", -1, "1", NULL);
  ctl->met_cloud =
    (int) scan_ctl(filename, argc, argv, "MET_CLOUD", -1, "1", NULL);
  if (ctl->met_cloud < 0 || ctl->met_cloud > 3)
    ERRMSG("Set MET_CLOUD = 0 ... 3!");
  ctl->met_dt_out =
    scan_ctl(filename, argc, argv, "MET_DT_OUT", -1, "0.1", NULL);
  ctl->met_cache =
    (int) scan_ctl(filename, argc, argv, "MET_CACHE", -1, "0", NULL);

  /* Isosurface parameters... */
  ctl->isosurf =
    (int) scan_ctl(filename, argc, argv, "ISOSURF", -1, "0", NULL);
  scan_ctl(filename, argc, argv, "BALLOON", -1, "-", ctl->balloon);

  /* Advection parameters... */
  ctl->advect = (int) scan_ctl(filename, argc, argv, "ADVECT", -1, "0", NULL);
  ctl->reflect =
    (int) scan_ctl(filename, argc, argv, "REFLECT", -1, "0", NULL);

  /* Diffusion parameters... */
  ctl->turb_dx_trop =
    scan_ctl(filename, argc, argv, "TURB_DX_TROP", -1, "50", NULL);
  ctl->turb_dx_strat =
    scan_ctl(filename, argc, argv, "TURB_DX_STRAT", -1, "0", NULL);
  ctl->turb_dz_trop =
    scan_ctl(filename, argc, argv, "TURB_DZ_TROP", -1, "0", NULL);
  ctl->turb_dz_strat =
    scan_ctl(filename, argc, argv, "TURB_DZ_STRAT", -1, "0.1", NULL);
  ctl->turb_mesox =
    scan_ctl(filename, argc, argv, "TURB_MESOX", -1, "0.16", NULL);
  ctl->turb_mesoz =
    scan_ctl(filename, argc, argv, "TURB_MESOZ", -1, "0.16", NULL);

  /* Convection... */
  ctl->conv_cape
    = scan_ctl(filename, argc, argv, "CONV_CAPE", -1, "-999", NULL);
  ctl->conv_cin
    = scan_ctl(filename, argc, argv, "CONV_CIN", -1, "-999", NULL);
  ctl->conv_wmax
    = scan_ctl(filename, argc, argv, "CONV_WMAX", -1, "-999", NULL);
  ctl->conv_wcape
    = (int) scan_ctl(filename, argc, argv, "CONV_WCAPE", -1, "0", NULL);
  ctl->conv_dt = scan_ctl(filename, argc, argv, "CONV_DT", -1, "-999", NULL);
  ctl->conv_mix_bot
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_BOT", -1, "1", NULL);
  ctl->conv_mix_top
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_TOP", -1, "1", NULL);

```

```
/* Boundary conditions... */
ctl->bound_mass =
  scan_ctl(filename, argc, argv, "BOUND_MASS", -1, "-999", NULL);
ctl->bound_vmr =
  scan_ctl(filename, argc, argv, "BOUND_VMR", -1, "-999", NULL);
ctl->bound_lat0 =
  scan_ctl(filename, argc, argv, "BOUND_LAT0", -1, "-90", NULL);
ctl->bound_lat1 =
  scan_ctl(filename, argc, argv, "BOUND_LAT1", -1, "90", NULL);
ctl->bound_p0 =
  scan_ctl(filename, argc, argv, "BOUND_P0", -1, "1e10", NULL);
ctl->bound_p1 =
  scan_ctl(filename, argc, argv, "BOUND_P1", -1, "-1e10", NULL);
ctl->bound_dps =
  scan_ctl(filename, argc, argv, "BOUND_DPS", -1, "-999", NULL);

/* Species parameters... */
scan_ctl(filename, argc, argv, "SPECIES", -1, "-", ctl->species);
if (strcasecmp(ctl->species, "CF2Cl2") == 0) {
  ctl->molmass = 120.907;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 3e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 3500.0;
} else if (strcasecmp(ctl->species, "CFCl3") == 0) {
  ctl->molmass = 137.359;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.1e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 3300.0;
} else if (strcasecmp(ctl->species, "CH4") == 0) {
  ctl->molmass = 16.043;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 2.45e-12;
  ctl->oh_chem[1] = 1775;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.4e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
} else if (strcasecmp(ctl->species, "CO") == 0) {
  ctl->molmass = 28.01;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 6.9e-33;
  ctl->oh_chem[1] = 2.1;
  ctl->oh_chem[2] = 1.1e-12;
  ctl->oh_chem[3] = -1.3;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 9.7e-6;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1300.0;
} else if (strcasecmp(ctl->species, "CO2") == 0) {
  ctl->molmass = 44.009;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 3.3e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
} else if (strcasecmp(ctl->species, "N2O") == 0) {
  ctl->molmass = 44.013;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2600.;
} else if (strcasecmp(ctl->species, "NH3") == 0) {
  ctl->molmass = 17.031;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 1.7e-12;
  ctl->oh_chem[1] = 710;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 5.9e-1;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 4200.0;
} else if (strcasecmp(ctl->species, "HNO3") == 0) {
  ctl->molmass = 63.012;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 2.1e3;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 8700.0;
} else if (strcasecmp(ctl->species, "NO") == 0) {
  ctl->molmass = 30.006;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 7.1e-31;
  ctl->oh_chem[1] = 2.6;
  ctl->oh_chem[2] = 3.6e-11;
  ctl->oh_chem[3] = 0.1;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.9e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
} else if (strcasecmp(ctl->species, "NO2") == 0) {
  ctl->molmass = 46.005;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 1.8e-30;
  ctl->oh_chem[1] = 3.0;
  ctl->oh_chem[2] = 2.8e-11;
  ctl->oh_chem[3] = 0.0;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.2e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
} else if (strcasecmp(ctl->species, "O3") == 0) {
  ctl->molmass = 47.997;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 1.7e-12;
  ctl->oh_chem[1] = 940;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2800.0;
} else if (strcasecmp(ctl->species, "SF6") == 0) {
```

```
    ctl->molmass = 146.048;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-6;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 3100.0;
  } else if (strcasecmp(ctl->species, "SO2") == 0) {
    ctl->molmass = 64.066;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 2.9e-31;
    ctl->oh_chem[1] = 4.1;
    ctl->oh_chem[2] = 1.7e-12;
    ctl->oh_chem[3] = -0.2;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.3e-2;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2900.0;
  } else {
    ctl->molmass =
      scan_ctl(filename, argc, argv, "MOLMASS", -1, "-999", NULL);
    ctl->oh_chem_reaction =
      (int) scan_ctl(filename, argc, argv, "OH_CHEM_REACTION", -1, "0", NULL);
    for (int ip = 0; ip < 4; ip++)
      ctl->oh_chem[ip] =
        scan_ctl(filename, argc, argv, "OH_CHEM", ip, "0", NULL);
    for (int ip = 0; ip < 1; ip++)
      ctl->dry_depo[ip] =
        scan_ctl(filename, argc, argv, "DRY_DEPO", ip, "0", NULL);
    for (int ip = 0; ip < 8; ip++)
      ctl->wet_depo[ip] =
        scan_ctl(filename, argc, argv, "WET_DEPO", ip, "0", NULL);
  }
  ctl->tdec_trop = scan_ctl(filename, argc, argv, "TDEC_TROP", -1, "0", NULL);
  ctl->tdec_strat =
    scan_ctl(filename, argc, argv, "TDEC_STRAT", -1, "0", NULL);

  /* PSC analysis... */
  ctl->psc_h2o = scan_ctl(filename, argc, argv, "PSC_H2O", -1, "4e-6", NULL);
  ctl->psc_hno3 =
    scan_ctl(filename, argc, argv, "PSC_HNO3", -1, "9e-9", NULL);

  /* Output of atmospheric data... */
  scan_ctl(filename, argc, argv, "ATM_BASENAME", -1, "-", ctl->atm_basename);
  scan_ctl(filename, argc, argv, "ATM_GPFILE", -1, "-", ctl->atm_gpfile);
  ctl->atm_dt_out =
    scan_ctl(filename, argc, argv, "ATM_DT_OUT", -1, "86400", NULL);
  ctl->atm_filter =
    (int) scan_ctl(filename, argc, argv, "ATM_FILTER", -1, "0", NULL);
  ctl->atm_stride =
    (int) scan_ctl(filename, argc, argv, "ATM_STRIDE", -1, "1", NULL);
  ctl->atm_type =
    (int) scan_ctl(filename, argc, argv, "ATM_TYPE", -1, "0", NULL);

  /* Output of CSI data... */
  scan_ctl(filename, argc, argv, "CSI_BASENAME", -1, "-", ctl->csi_basename);
  ctl->csi_dt_out =
    scan_ctl(filename, argc, argv, "CSI_DT_OUT", -1, "86400", NULL);
  scan_ctl(filename, argc, argv, "CSI_OBSFILE", -1, "-", ctl->csi_obsfile);
  ctl->csi_obsmin =
    scan_ctl(filename, argc, argv, "CSI_OBSMIN", -1, "0", NULL);
  ctl->csi_modmin =
    scan_ctl(filename, argc, argv, "CSI_MODMIN", -1, "0", NULL);
  ctl->csi_z0 = scan_ctl(filename, argc, argv, "CSI_Z0", -1, "0", NULL);
  ctl->csi_z1 = scan_ctl(filename, argc, argv, "CSI_Z1", -1, "100", NULL);
  ctl->csi_nz = (int) scan_ctl(filename, argc, argv, "CSI_NZ", -1, "1", NULL);
  ctl->csi_lon0 =
    scan_ctl(filename, argc, argv, "CSI_LON0", -1, "-180", NULL);
  ctl->csi_lon1 = scan_ctl(filename, argc, argv, "CSI_LON1", -1, "180", NULL);
  ctl->csi_nx =
    (int) scan_ctl(filename, argc, argv, "CSI_NX", -1, "360", NULL);
  ctl->csi_lat0 = scan_ctl(filename, argc, argv, "CSI_LAT0", -1, "-90", NULL);
  ctl->csi_lat1 = scan_ctl(filename, argc, argv, "CSI_LAT1", -1, "90", NULL);
  ctl->csi_ny =
    (int) scan_ctl(filename, argc, argv, "CSI_NY", -1, "180", NULL);

  /* Output of ensemble data... */
  scan_ctl(filename, argc, argv, "ENS_BASENAME", -1, "-", ctl->ens_basename);

  /* Output of grid data... */
  scan_ctl(filename, argc, argv, "GRID_BASENAME", -1, "-",
           ctl->grid_basename);
  scan_ctl(filename, argc, argv, "GRID_GPFILE", -1, "-", ctl->grid_gpfile);
  ctl->grid_dt_out =
    scan_ctl(filename, argc, argv, "GRID_DT_OUT", -1, "86400", NULL);
  ctl->grid_sparse =
    (int) scan_ctl(filename, argc, argv, "GRID_SPARSE", -1, "0", NULL);
  ctl->grid_z0 = scan_ctl(filename, argc, argv, "GRID_Z0", -1, "0", NULL);
  ctl->grid_z1 = scan_ctl(filename, argc, argv, "GRID_Z1", -1, "100", NULL);
  ctl->grid_nz =
    (int) scan_ctl(filename, argc, argv, "GRID_NZ", -1, "1", NULL);
  ctl->grid_lon0 =
    scan_ctl(filename, argc, argv, "GRID_LON0", -1, "-180", NULL);
```

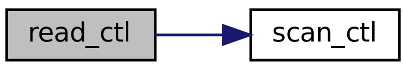
```
  ctl->grid_lon1 =
    scan_ctl(filename, argc, argv, "GRID_LON1", -1, "180", NULL);
  ctl->grid_nx =
    (int) scan_ctl(filename, argc, argv, "GRID_NX", -1, "360", NULL);
  ctl->grid_lat0 =
    scan_ctl(filename, argc, argv, "GRID_LAT0", -1, "-90", NULL);
  ctl->grid_lat1 =
    scan_ctl(filename, argc, argv, "GRID_LAT1", -1, "90", NULL);
  ctl->grid_ny =
    (int) scan_ctl(filename, argc, argv, "GRID_NY", -1, "180", NULL);

  /* Output of profile data... */
  scan_ctl(filename, argc, argv, "PROF_BASENAME", -1, "-",
           ctl->prof_basename);
  scan_ctl(filename, argc, argv, "PROF_OBSFILE", -1, "-", ctl->prof_obsfile);
  ctl->prof_z0 = scan_ctl(filename, argc, argv, "PROF_Z0", -1, "0", NULL);
  ctl->prof_z1 = scan_ctl(filename, argc, argv, "PROF_Z1", -1, "60", NULL);
  ctl->prof_nz =
    (int) scan_ctl(filename, argc, argv, "PROF_NZ", -1, "60", NULL);
  ctl->prof_lon0 =
    scan_ctl(filename, argc, argv, "PROF_LON0", -1, "-180", NULL);
  ctl->prof_lon1 =
    scan_ctl(filename, argc, argv, "PROF_LON1", -1, "180", NULL);
  ctl->prof_nx =
    (int) scan_ctl(filename, argc, argv, "PROF_NX", -1, "360", NULL);
  ctl->prof_lat0 =
    scan_ctl(filename, argc, argv, "PROF_LAT0", -1, "-90", NULL);
  ctl->prof_lat1 =
    scan_ctl(filename, argc, argv, "PROF_LAT1", -1, "90", NULL);
  ctl->prof_ny =
    (int) scan_ctl(filename, argc, argv, "PROF_NY", -1, "180", NULL);

  /* Output of sample data... */
  scan_ctl(filename, argc, argv, "SAMPLE_BASENAME", -1, "-",
           ctl->sample_basename);
  scan_ctl(filename, argc, argv, "SAMPLE_OBSFILE", -1, "-",
           ctl->sample_obsfile);
  ctl->sample_dx =
    scan_ctl(filename, argc, argv, "SAMPLE_DX", -1, "50", NULL);
  ctl->sample_dz =
    scan_ctl(filename, argc, argv, "SAMPLE_DZ", -1, "-999", NULL);

  /* Output of station data... */
  scan_ctl(filename, argc, argv, "STAT_BASENAME", -1, "-",
           ctl->stat_basename);
  ctl->stat_lon = scan_ctl(filename, argc, argv, "STAT_LON", -1, "0", NULL);
  ctl->stat_lat = scan_ctl(filename, argc, argv, "STAT_LAT", -1, "0", NULL);
  ctl->stat_r = scan_ctl(filename, argc, argv, "STAT_R", -1, "50", NULL);
  ctl->stat_t0 =
    scan_ctl(filename, argc, argv, "STAT_T0", -1, "-1e100", NULL);
  ctl->stat_t1 = scan_ctl(filename, argc, argv, "STAT_T1", -1, "1e100", NULL);
}
```

Here is the call graph for this function:




#### 5.19.2.22 read_met()

```
int read_met (
    ctl_t * ctl,
    char * filename,
    met_t * met )
```

Read meteorological data file.

Definition at line 2762 of file libtrac.c.

```
                 {

  int ncid;

  /* Write info... */
  LOG(1, "Read meteorological data: %s", filename);

  /* Open netCDF file... */
  if (nc__open(filename, ctl->read_mode, &ctl->chunkszhint, &ncid) !=
      NC_NOERR) {
    WARN("File not found!");
    return 0;
  }

  /* Read coordinates of meteorological data... */
  read_met_grid(filename, ncid, ctl, met);

  /* Read meteo data on vertical levels... */
  read_met_levels(ncid, ctl, met);

  /* Extrapolate data for lower boundary... */
  read_met_extrapolate(met);

  /* Read surface data... */
  read_met_surface(ncid, met);

  /* Create periodic boundary conditions... */
  read_met_periodic(met);

  /* Downsampling... */
  read_met_sample(ctl, met);

  /* Calculate geopotential heights... */
  read_met_geopot(ctl, met);

  /* Calculate potential vorticity... */
  read_met_pv(met);

  /* Calculate boundary layer data... */
  read_met_pbl(met);

  /* Calculate tropopause data... */
  read_met_tropo(ctl, met);

  /* Calculate cloud properties... */
  read_met_cloud(met);

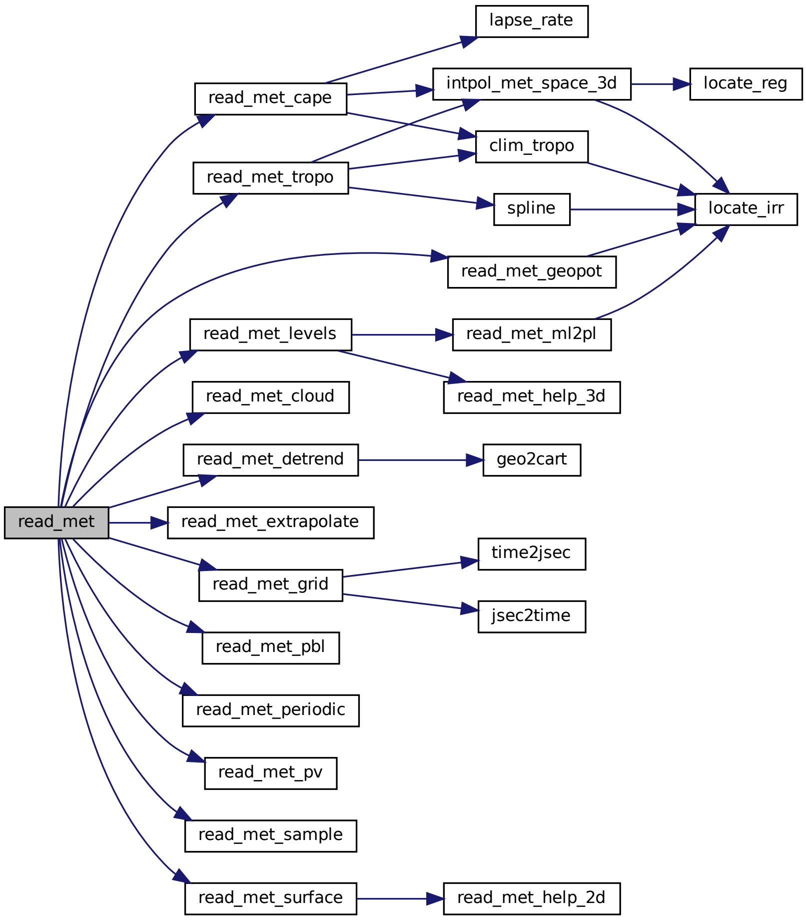
  /* Calculate convective available potential energy... */
  read_met_cape(met);

  /* Detrending... */
  read_met_detrend(ctl, met);

  /* Close file... */
  NC(nc_close(ncid));

  /* Return success... */
  return 1;
}
```

Here is the call graph for this function:




### 5.19.2.23 read_met_cape() `void read_met_cape ( met_t * met )`

Calculate convective available potential energy.

Definition at line 2827 of file libtrac.c.

```
                     {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CAPE", "METPROC", NVTX_READ);
  LOG(2, "Calculate CAPE...");

  /* Vertical spacing (about 100 m)... */
  const double pfac = 1.01439, dz0 = RI / MA / G0 * log(pfac);

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get potential temperature and water vapor vmr at lowest 50 hPa... */
      int n = 0;
      double h2o = 0, t, theta = 0;
```

```
      double pbot = GSL_MIN(met->ps[ix][iy], met->p[0]);
      double ptop = pbot - 50.;
      for (int ip = 0; ip < met->np; ip++) {
        if (met->p[ip] <= pbot) {
          theta += THETA(met->p[ip], met->t[ix][iy][ip]);
          h2o += met->h2o[ix][iy][ip];
          n++;
        }
        if (met->p[ip] < ptop && n > 0)
          break;
      }
      theta /= n;
      h2o /= n;

      /* Cannot compute anything if water vapor is missing... */
      met->plcl[ix][iy] = GSL_NAN;
      met->plfc[ix][iy] = GSL_NAN;
      met->pel[ix][iy] = GSL_NAN;
      met->cape[ix][iy] = GSL_NAN;
      met->cin[ix][iy] = GSL_NAN;
      if (h2o <= 0)
        continue;

      /* Find lifted condensation level (LCL)... */
      ptop = P(20.);
      pbot = met->ps[ix][iy];
      do {
        met->plcl[ix][iy] = (float) (0.5 * (pbot + ptop));
        t = theta / pow(1000. / met->plcl[ix][iy], 0.286);
        if (RH(met->plcl[ix][iy], t, h2o) > 100.)
          ptop = met->plcl[ix][iy];
        else
          pbot = met->plcl[ix][iy];
      } while (pbot - ptop > 0.1);

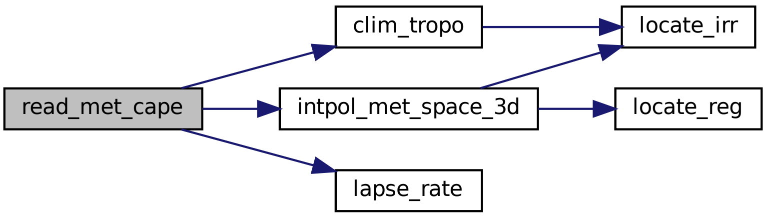
      /* Calculate CIN up to LCL... */
      INTPOL_INIT;
      double dcape, dcape_old, dz, psat, h2o_env, t_env;
      double p = met->ps[ix][iy];
      met->cape[ix][iy] = met->cin[ix][iy] = 0;
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t = theta / pow(1000. / p, 0.286);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape < 0)
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > met->plcl[ix][iy]);

      /* Calculate level of free convection (LFC), equilibrium level (EL),
         and convective available potential energy (CAPE)... */
      dcape = 0;
      p = met->plcl[ix][iy];
      t = theta / pow(1000. / p, 0.286);
      ptop = 0.75 * clim_tropo(met->time, met->lat[iy]);
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t -= lapse_rate(t, h2o) * dz;
        psat = PSAT(t);
        h2o = psat / (p - (1. - EPS) * psat);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape_old = dcape;
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape > 0) {
          met->cape[ix][iy] += (float) dcape;
          if (!isfinite(met->plfc[ix][iy]))
            met->plfc[ix][iy] = (float) p;
        } else if (dcape_old > 0)
          met->pel[ix][iy] = (float) p;
        if (dcape < 0 && !isfinite(met->plfc[ix][iy]))
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > ptop);

      /* Check results... */
      if (!isfinite(met->plfc[ix][iy]))
        met->cin[ix][iy] = GSL_NAN;
    }
```

```
}
```

Here is the call graph for this function:




### 5.19.2.24 read_met_cloud() 

```
void read_met_cloud (
    met_t * met )
```

Calculate cloud properties.

Definition at line 2936 of file libtrac.c.

```
                          {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CLOUD", "METPROC", NVTX_READ);
  LOG(2, "Calculate cloud data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Init... */
      met->pct[ix][iy] = GSL_NAN;
      met->pcb[ix][iy] = GSL_NAN;
      met->cl[ix][iy] = 0;

      /* Loop over pressure levels... */
      for (int ip = 0; ip < met->np - 1; ip++) {

        /* Check pressure... */
        if (met->p[ip] > met->ps[ix][iy] || met->p[ip] < P(20.))
          continue;

        /* Check ice water and liquid water content... */
        if (met->iwc[ix][iy][ip] > 0 || met->lwc[ix][iy][ip] > 0) {

          /* Get cloud top pressure ... */
          met->pct[ix][iy]
            = (float) (0.5 * (met->p[ip] + (float) met->p[ip + 1]));

          /* Get cloud bottom pressure ... */
          if (!isfinite(met->pcb[ix][iy]))
            met->pcb[ix][iy]
              = (float) (0.5 * (met->p[ip] + met->p[GSL_MAX(ip - 1, 0)]));
        }

        /* Get cloud water... */
        met->cl[ix][iy] += (float)
          (0.5 * (met->iwc[ix][iy][ip] + met->iwc[ix][iy][ip + 1]
                  + met->lwc[ix][iy][ip] + met->lwc[ix][iy][ip + 1])
           * 100. * (met->p[ip] - met->p[ip + 1]) / G0);
      }
    }
}
```

#### 5.19.2.25 read_met_detrend() `void read_met_detrend ( ctl_t * ctl, met_t * met )`

Apply detrending method to temperature and winds.

Definition at line 2984 of file libtrac.c.

```
                    {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_detrend <= 0)
    return;

  /* Set timer... */
  SELECT_TIMER("READ_MET_DETREND", "METPROC", NVTX_READ);
  LOG(2, "Detrend meteo data...");

  /* Allocate... */
  ALLOC(help, met_t, 1);

  /* Calculate standard deviation... */
  double sigma = ctl->met_detrend / 2.355;
  double tssq = 2. * SQR(sigma);

  /* Calculate box size in latitude... */
  int sy = (int) (3. * DY2DEG(sigma) / fabs(met->lat[1] - met->lat[0]));
  sy = GSL_MIN(GSL_MAX(1, sy), met->ny / 2);

  /* Calculate background... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++) {
    for (int iy = 0; iy < met->ny; iy++) {

      /* Calculate Cartesian coordinates... */
      double x0[3];
      geo2cart(0.0, met->lon[ix], met->lat[iy], x0);

      /* Calculate box size in longitude... */
      int sx =
        (int) (3. * DX2DEG(sigma, met->lat[iy]) /
               fabs(met->lon[1] - met->lon[0]));
      sx = GSL_MIN(GSL_MAX(1, sx), met->nx / 2);

      /* Init... */
      float wsum = 0;
      for (int ip = 0; ip < met->np; ip++) {
        help->t[ix][iy][ip] = 0;
        help->u[ix][iy][ip] = 0;
        help->v[ix][iy][ip] = 0;
        help->w[ix][iy][ip] = 0;
      }

      /* Loop over neighboring grid points... */
      for (int ix2 = ix - sx; ix2 <= ix + sx; ix2++) {
        int ix3 = ix2;
        if (ix3 < 0)
          ix3 += met->nx;
        else if (ix3 >= met->nx)
          ix3 -= met->nx;
        for (int iy2 = GSL_MAX(iy - sy, 0);
             iy2 <= GSL_MIN(iy + sy, met->ny - 1); iy2++) {

          /* Calculate Cartesian coordinates... */
          double x1[3];
          geo2cart(0.0, met->lon[ix3], met->lat[iy2], x1);

          /* Calculate weighting factor... */
          float w = (float) exp(-DIST2(x0, x1) / tssq);

          /* Add data... */
          wsum += w;
          for (int ip = 0; ip < met->np; ip++) {
            help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip];
            help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip];
            help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip];
            help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip];
          }
        }
      }

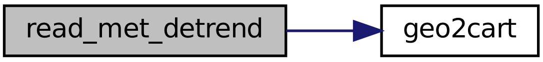
      /* Normalize... */
      for (int ip = 0; ip < met->np; ip++) {
```

```
        help->t[ix][iy][ip] /= wsum;
        help->u[ix][iy][ip] /= wsum;
        help->v[ix][iy][ip] /= wsum;
        help->w[ix][iy][ip] /= wsum;
      }
    }
  }

  /* Subtract background... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++) {
        met->t[ix][iy][ip] -= help->t[ix][iy][ip];
        met->u[ix][iy][ip] -= help->u[ix][iy][ip];
        met->v[ix][iy][ip] -= help->v[ix][iy][ip];
        met->w[ix][iy][ip] -= help->w[ix][iy][ip];
      }

  /* Free... */
  free(help);
}
```

Here is the call graph for this function:




### 5.19.2.26 read_met_extrapolate() `void read_met_extrapolate ( met_t * met )`

Extrapolate meteorological data at lower boundary.

Definition at line 3088 of file libtrac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("READ_MET_EXTRAPOLATE", "METPROC", NVTX_READ);
  LOG(2, "Extrapolate meteo data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Find lowest valid data point... */
      int ip0;
      for (ip0 = met->np - 1; ip0 >= 0; ip0--)
        if (!isfinite(met->t[ix][iy][ip0])
            || !isfinite(met->u[ix][iy][ip0])
            || !isfinite(met->v[ix][iy][ip0])
            || !isfinite(met->w[ix][iy][ip0]))
          break;

      /* Extrapolate... */
      for (int ip = ip0; ip >= 0; ip--) {
        met->t[ix][iy][ip] = met->t[ix][iy][ip + 1];
        met->u[ix][iy][ip] = met->u[ix][iy][ip + 1];
        met->v[ix][iy][ip] = met->v[ix][iy][ip + 1];
        met->w[ix][iy][ip] = met->w[ix][iy][ip + 1];
        met->h2o[ix][iy][ip] = met->h2o[ix][iy][ip + 1];
        met->o3[ix][iy][ip] = met->o3[ix][iy][ip + 1];
        met->lwc[ix][iy][ip] = met->lwc[ix][iy][ip + 1];
        met->iwc[ix][iy][ip] = met->iwc[ix][iy][ip + 1];
      }
    }
}
```

#### 5.19.2.27 read_met_geopot()

```
void read_met_geopot (
    ctl_t * ctl,
    met_t * met )
```

Calculate geopotential heights.

Definition at line 3125 of file libtrac.c.

```
{

  static float help[EP][EX][EY];

  double logp[EP];

  int dx = ctl->met_geopot_sx, dy = ctl->met_geopot_sy;

  /* Set timer... */
  SELECT_TIMER("READ_MET_GEOPOT", "METPROC", NVTX_READ);
  LOG(2, "Calculate geopotential heights...");

  /* Calculate log pressure... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    logp[ip] = log(met->p[ip]);

  /* Apply hydrostatic equation to calculate geopotential heights... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get surface height and pressure... */
      double zs = met->zs[ix][iy];
      double lnps = log(met->ps[ix][iy]);

      /* Get temperature and water vapor vmr at the surface... */
      int ip0 = locate_irr(met->p, met->np, met->ps[ix][iy]);
      double ts = LIN(met->p[ip0], met->t[ix][iy][ip0], met->p[ip0 + 1],
                      met->t[ix][iy][ip0 + 1], met->ps[ix][iy]);
      double h2os = LIN(met->p[ip0], met->h2o[ix][iy][ip0], met->p[ip0 + 1],
                        met->h2o[ix][iy][ip0 + 1], met->ps[ix][iy]);

      /* Upper part of profile... */
      met->z[ix][iy][ip0 + 1]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0 + 1],
                         met->t[ix][iy][ip0 + 1], met->h2o[ix][iy][ip0 + 1]));
      for (int ip = ip0 + 2; ip < met->np; ip++)
        met->z[ix][iy][ip]
          = (float) (met->z[ix][iy][ip - 1] +
                     ZDIFF(logp[ip - 1], met->t[ix][iy][ip - 1],
                           met->h2o[ix][iy][ip - 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));

      /* Lower part of profile... */
      met->z[ix][iy][ip0]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0],
                         met->t[ix][iy][ip0], met->h2o[ix][iy][ip0]));
      for (int ip = ip0 - 1; ip >= 0; ip--)
        met->z[ix][iy][ip]
          = (float) (met->z[ix][iy][ip + 1] +
                     ZDIFF(logp[ip + 1], met->t[ix][iy][ip + 1],
                           met->h2o[ix][iy][ip + 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));
    }

  /* Check control parameters... */
  if (dx == 0 || dy == 0)
    return;

  /* Default smoothing parameters... */
  if (dx < 0 || dy < 0) {
    if (fabs(met->lon[1] - met->lon[0]) < 0.5) {
      dx = 3;
      dy = 2;
    } else {
      dx = 6;
      dy = 4;
    }
  }

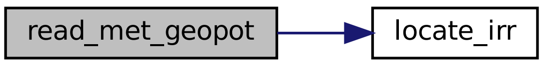
  /* Calculate weights for smoothing... */
  float ws[dx + 1][dy + 1];
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix <= dx; ix++)
```

```
    for (int iy = 0; iy < dy; iy++)
      ws[ix][iy] = (1.0f - (float) ix / (float) dx)
        * (1.0f - (float) iy / (float) dy);

  /* Copy data... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++)
        help[ip][ix][iy] = met->z[ix][iy][ip];

  /* Horizontal smoothing... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ip = 0; ip < met->np; ip++)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        float res = 0, wsum = 0;
        int iy0 = GSL_MAX(iy - dy + 1, 0);
        int iy1 = GSL_MIN(iy + dy - 1, met->ny - 1);
        for (int ix2 = ix - dx + 1; ix2 <= ix + dx - 1; ++ix2) {
          int ix3 = ix2;
          if (ix3 < 0)
            ix3 += met->nx;
          else if (ix3 >= met->nx)
            ix3 -= met->nx;
          for (int iy2 = iy0; iy2 <= iy1; ++iy2)
            if (isfinite(help[ip][ix3][iy2])) {
              float w = ws[abs(ix - ix2)][abs(iy - iy2)];
              res += w * help[ip][ix3][iy2];
              wsum += w;
            }
        }
        if (wsum > 0)
          met->z[ix][iy][ip] = res / wsum;
        else
          met->z[ix][iy][ip] = GSL_NAN;
      }
}
```

Here is the call graph for this function:




#### 5.19.2.28 read_met_grid()

```
void read_met_grid (
    char * filename,
    int ncid,
    ctl_t * ctl,
    met_t * met )
```

Read coordinates of meteorological data.

Definition at line 3245 of file libtrac.c.

```
                 {

  char levname[LEN], tstr[10];

  double rtime, r2;

  int dimid, varid, year2, mon2, day2, hour2, min2, sec2;

  size_t np, nx, ny;

```

```
  /* Set timer... */
  SELECT_TIMER("READ_MET_GRID", "INPUT", NVTX_READ);
  LOG(2, "Read meteo grid information...");

  /* Get time from filename... */
  sprintf(tstr, "%.4s", &filename[strlen(filename) - 16]);
  int year = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 11]);
  int mon = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 8]);
  int day = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 5]);
  int hour = atoi(tstr);
  time2jsec(year, mon, day, hour, 0, 0, 0, &met->time);

  /* Check time... */
  if (year < 1900 || year > 2100 || mon < 1 || mon > 12
      || day < 1 || day > 31 || hour < 0 || hour > 23)
    ERRMSG("Cannot read time from filename!");
  jsec2time(met->time, &year2, &mon2, &day2, &hour2, &min2, &sec2, &r2);
  LOG(2, "Time from filename: %.2f (%d-%02d-%02d, %02d:%02d UTC)",
      met->time, year2, mon2, day2, hour2, min2);

  /* Check time information... */
  if (nc_inq_varid(ncid, "time", &varid) == NC_NOERR) {
    NC(nc_get_var_double(ncid, varid, &rtime));
    if (fabs(year * 10000. + mon * 100. + day + hour / 24. - rtime) > 1.0)
      WARN("Time information in meteo file does not match filename!");
  } else
    WARN("Time information in meteo file is missing!");

  /* Get grid dimensions... */
  NC(nc_inq_dimid(ncid, "lon", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &nx));
  LOG(2, "Number of longitudes: %zu", nx);
  if (nx < 2 || nx > EX)
    ERRMSG("Number of longitudes out of range!");

  NC(nc_inq_dimid(ncid, "lat", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &ny));
  LOG(2, "Number of latitudes: %zu", ny);
  if (ny < 2 || ny > EY)
    ERRMSG("Number of latitudes out of range!");

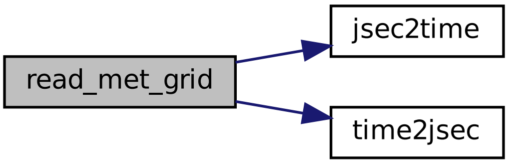
  sprintf(levname, "lev");
  NC(nc_inq_dimid(ncid, levname, &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &np));
  if (np == 1) {
    sprintf(levname, "lev_2");
    if (nc_inq_dimid(ncid, levname, &dimid) != NC_NOERR) {
      sprintf(levname, "plev");
      nc_inq_dimid(ncid, levname, &dimid);
    }
    NC(nc_inq_dimlen(ncid, dimid, &np));
  }
  LOG(2, "Number of levels: %zu", np);
  if (np < 2 || np > EP)
    ERRMSG("Number of levels out of range!");

  /* Store dimensions... */
  met->np = (int) np;
  met->nx = (int) nx;
  met->ny = (int) ny;

  /* Read longitudes and latitudes... */
  NC(nc_inq_varid(ncid, "lon", &varid));
  NC(nc_get_var_double(ncid, varid, met->lon));
  LOG(2, "Longitudes: %g, %g ... %g deg",
      met->lon[0], met->lon[1], met->lon[met->nx - 1]);
  NC(nc_inq_varid(ncid, "lat", &varid));
  NC(nc_get_var_double(ncid, varid, met->lat));
  LOG(2, "Latitudes: %g, %g ... %g deg",
      met->lat[0], met->lat[1], met->lat[met->ny - 1]);

  /* Read pressure levels... */
  if (ctl->met_np <= 0) {
    NC(nc_inq_varid(ncid, levname, &varid));
    NC(nc_get_var_double(ncid, varid, met->p));
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] /= 100.;
    LOG(2, "Altitude levels: %g, %g ... %g km",
        Z(met->p[0]), Z(met->p[1]), Z(met->p[met->np - 1]));
    LOG(2, "Pressure levels: %g, %g ... %g hPa",
        met->p[0], met->p[1], met->p[met->np - 1]);
  }
}
```

Here is the call graph for this function:




### 5.19.2.29 read_met_help_3d()

```
int read_met_help_3d (
    int ncid,
    char * varname,
    char * varname2,
    met_t * met,
    float dest[EX][EY][EP],
    float scl,
    int init )
```

Read and convert 3D variable from meteorological data file.

Definition at line 3348 of file libtrac.c.

```
                  {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
    sprintf(varsel, "%s", varname);

  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s "
        "(FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

```

```
    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
            dest[ix][iy][ip] = 0;
          short aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux * scalfac + offset) < 1e14f)
            dest[ix][iy][ip] += scl * (aux * scalfac + offset);
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY * EP);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
            dest[ix][iy][ip] = 0;
          float aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux) < 1e14f)
            dest[ix][iy][ip] += scl * aux;
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
  }

  /* Return... */
  return 1;
}
```

#### 5.19.2.30 read_met_help_2d()

```
int read_met_help_2d (
    int ncid,
    char * varname,
    char * varname2,
    met_t * met,
    float dest[EX][EY],
    float scl,
    int init )
```

Read and convert 2D variable from meteorological data file.

Definition at line 3466 of file libtrac.c.

```
            {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
    sprintf(varsel, "%s", varname);

  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Write info... */
    LOG(2, "Packed: scale_factor= %g / add_offset= %g", scalfac, offset);

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s"
        " (FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        short aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux * scalfac + offset) < 1e14f)
          dest[ix][iy] += scl * (aux * scalfac + offset);
        else
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);
```

```

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        float aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux) < 1e14f)
          dest[ix][iy] += scl * aux;
        else
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }

  /* Return... */
  return 1;
}
```

#### 5.19.2.31 read_met_levels()

```
void read_met_levels (
    int ncid,
    ctl_t * ctl,
    met_t * met )
```

Read meteorological data on vertical levels.

Definition at line 3585 of file libtrac.c.

```
                    {

  /* Set timer... */
  SELECT_TIMER("READ_MET_LEVELS", "INPUT", NVTX_READ);
  LOG(2, "Read level data...");

  /* Read meteorological data... */
  if (!read_met_help_3d(ncid, "t", "T", met, met->t, 1.0, 1))
    ERRMSG("Cannot read temperature!");
  if (!read_met_help_3d(ncid, "u", "U", met, met->u, 1.0, 1))
    ERRMSG("Cannot read zonal wind!");
  if (!read_met_help_3d(ncid, "v", "V", met, met->v, 1.0, 1))
    ERRMSG("Cannot read meridional wind!");
  if (!read_met_help_3d(ncid, "w", "W", met, met->w, 0.01f, 1))
    WARN("Cannot read vertical velocity!");
  if (!read_met_help_3d
      (ncid, "q", "Q", met, met->h2o, (float) (MA / MH2O), 1))
    WARN("Cannot read specific humidity!");
  if (!read_met_help_3d
      (ncid, "o3", "O3", met, met->o3, (float) (MA / MO3), 1))
    WARN("Cannot read ozone data!");
  if (ctl->met_cloud == 1 || ctl->met_cloud == 3) {
    if (!read_met_help_3d(ncid, "clwc", "CLWC", met, met->lwc, 1.0, 1))
      WARN("Cannot read cloud liquid water content!");
    if (!read_met_help_3d(ncid, "ciwc", "CIWC", met, met->iwc, 1.0, 1))
      WARN("Cannot read cloud ice water content!");
  }
  if (ctl->met_cloud == 2 || ctl->met_cloud == 3) {
    if (!read_met_help_3d
        (ncid, "crwc", "CRWC", met, met->lwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud rain water content!");
    if (!read_met_help_3d
        (ncid, "cswc", "CSWC", met, met->iwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud snow water content!");
  }

  /* Transfer from model levels to pressure levels... */
  if (ctl->met_np > 0) {

    /* Read pressure on model levels... */
    if (!read_met_help_3d(ncid, "pl", "PL", met, met->pl, 0.01f, 1))
      ERRMSG("Cannot read pressure on model levels!");

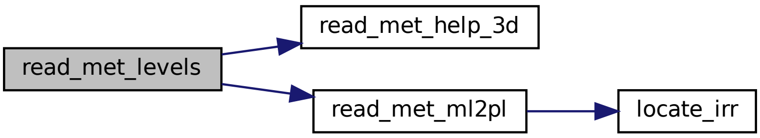
```

```
    /* Vertical interpolation from model to pressure levels... */
    read_met_ml2pl(ctl, met, met->t);
    read_met_ml2pl(ctl, met, met->u);
    read_met_ml2pl(ctl, met, met->v);
    read_met_ml2pl(ctl, met, met->w);
    read_met_ml2pl(ctl, met, met->h2o);
    read_met_ml2pl(ctl, met, met->o3);
    read_met_ml2pl(ctl, met, met->lwc);
    read_met_ml2pl(ctl, met, met->iwc);

    /* Set new pressure levels... */
    met->np = ctl->met_np;
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] = ctl->met_p[ip];
  }

  /* Check ordering of pressure levels... */
  for (int ip = 1; ip < met->np; ip++)
    if (met->p[ip - 1] < met->p[ip])
      ERRMSG("Pressure levels must be descending!");
}
```

Here is the call graph for this function:




#### 5.19.2.32 read_met_ml2pl() void read_met_ml2pl ( ctl_t * *ctl*, met_t * *met*, float *var[EX][EY][EP]* )

Convert meteorological data from model levels to pressure levels.

Definition at line 3655 of file libtrac.c.

```
                          {

  double aux[EP], p[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_ML2PL", "METPROC", NVTX_READ);
  LOG(2, "Interpolate meteo data to pressure levels...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) private(aux,p) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

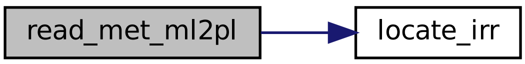
      /* Copy pressure profile... */
      for (int ip = 0; ip < met->np; ip++)
        p[ip] = met->pl[ix][iy][ip];

      /* Interpolate... */
      for (int ip = 0; ip < ctl->met_np; ip++) {
        double pt = ctl->met_p[ip];
        if ((pt > p[0] && p[0] > p[1]) || (pt < p[0] && p[0] < p[1]))
          pt = p[0];
        else if ((pt > p[met->np - 1] && p[1] > p[0])
                 || (pt < p[met->np - 1] && p[1] < p[0]))
          pt = p[met->np - 1];
        int ip2 = locate_irr(p, met->np, pt);
```

```
        aux[ip] = LIN(p[ip2], var[ix][iy][ip2],
                      p[ip2 + 1], var[ix][iy][ip2 + 1], pt);
      }

      /* Copy data... */
      for (int ip = 0; ip < ctl->met_np; ip++)
        var[ix][iy][ip] = (float) aux[ip];
    }
}
```

Here is the call graph for this function:




#### 5.19.2.33 read_met_pbl() `void read_met_pbl ( met_t * met )`

Calculate pressure of the boundary layer.

Definition at line 3696 of file libtrac.c.

```
                 {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PBL", "METPROC", NVTX_READ);
  LOG(2, "Calculate planetary boundary layer...");

  /* Parameters used to estimate the height of the PBL
     (e.g., Vogelezang and Holtslag, 1996; Seidel et al., 2012)... */
  const double rib_crit = 0.25, dz = 0.05, umin = 5.0;

  /* Loop over grid points... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set bottom level of PBL... */
      double pbl_bot = met->ps[ix][iy] + DZ2DP(dz, met->ps[ix][iy]);

      /* Find lowest level near the bottom... */
      int ip;
      for (ip = 1; ip < met->np; ip++)
        if (met->p[ip] < pbl_bot)
          break;

      /* Get near surface data... */
      double zs = LIN(met->p[ip - 1], met->z[ix][iy][ip - 1],
                      met->p[ip], met->z[ix][iy][ip], pbl_bot);
      double ts = LIN(met->p[ip - 1], met->t[ix][iy][ip - 1],
                      met->p[ip], met->t[ix][iy][ip], pbl_bot);
      double us = LIN(met->p[ip - 1], met->u[ix][iy][ip - 1],
                      met->p[ip], met->u[ix][iy][ip], pbl_bot);
      double vs = LIN(met->p[ip - 1], met->v[ix][iy][ip - 1],
                      met->p[ip], met->v[ix][iy][ip], pbl_bot);
      double h2os = LIN(met->p[ip - 1], met->h2o[ix][iy][ip - 1],
                        met->p[ip], met->h2o[ix][iy][ip], pbl_bot);
      double tvs = THETAVIRT(pbl_bot, ts, h2os);

      /* Init... */
      double rib, rib_old = 0;

      /* Loop over levels... */
      for (; ip < met->np; ip++) {

```

```
      /* Get squared horizontal wind speed... */
      double vh2
        = SQR(met->u[ix][iy][ip] - us) + SQR(met->v[ix][iy][ip] - vs);
      vh2 = GSL_MAX(vh2, SQR(umin));

      /* Calculate bulk Richardson number... */
      rib = G0 * 1e3 * (met->z[ix][iy][ip] - zs) / tvs
        * (THETAVIRT(met->p[ip], met->t[ix][iy][ip],
                     met->h2o[ix][iy][ip]) - tvs) / vh2;

      /* Check for critical value... */
      if (rib >= rib_crit) {
        met->pbl[ix][iy] = (float) (LIN(rib_old, met->p[ip - 1],
                                        rib, met->p[ip], rib_crit));
        if (met->pbl[ix][iy] > pbl_bot)
          met->pbl[ix][iy] = (float) pbl_bot;
        break;
      }

      /* Save Richardson number... */
      rib_old = rib;
    }
  }
}
```

#### 5.19.2.34 read_met_periodic()

```
void read_met_periodic (
    met_t * met )
```

Create meteorological data with periodic boundary conditions.

Definition at line 3767 of file libtrac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PERIODIC", "METPROC", NVTX_READ);
  LOG(2, "Apply periodic boundary conditions...");

  /* Check longitudes... */
  if (!(fabs(met->lon[met->nx - 1] - met->lon[0]
             + met->lon[1] - met->lon[0] - 360) < 0.01))
    return;

  /* Increase longitude counter... */
  if ((++met->nx) > EX)
    ERRMSG("Cannot create periodic boundary conditions!");

  /* Set longitude... */
  met->lon[met->nx - 1] = met->lon[met->nx - 2] + met->lon[1] - met->lon[0];

  /* Loop over latitudes and pressure levels... */
#pragma omp parallel for default(shared)
  for (int iy = 0; iy < met->ny; iy++) {
    met->ps[met->nx - 1][iy] = met->ps[0][iy];
    met->zs[met->nx - 1][iy] = met->zs[0][iy];
    met->ts[met->nx - 1][iy] = met->ts[0][iy];
    met->us[met->nx - 1][iy] = met->us[0][iy];
    met->vs[met->nx - 1][iy] = met->vs[0][iy];
    for (int ip = 0; ip < met->np; ip++) {
      met->t[met->nx - 1][iy][ip] = met->t[0][iy][ip];
      met->u[met->nx - 1][iy][ip] = met->u[0][iy][ip];
      met->v[met->nx - 1][iy][ip] = met->v[0][iy][ip];
      met->w[met->nx - 1][iy][ip] = met->w[0][iy][ip];
      met->h2o[met->nx - 1][iy][ip] = met->h2o[0][iy][ip];
      met->o3[met->nx - 1][iy][ip] = met->o3[0][iy][ip];
      met->lwc[met->nx - 1][iy][ip] = met->lwc[0][iy][ip];
      met->iwc[met->nx - 1][iy][ip] = met->iwc[0][iy][ip];
    }
  }
}
```

#### 5.19.2.35 read_met_pv()

```
void read_met_pv (
    met_t * met )
```

Calculate potential vorticity.

Definition at line 3809 of file libtrac.c.

```
                  {

  double pows[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_PV", "METPROC", NVTX_READ);
  LOG(2, "Calculate potential vorticity...");

  /* Set powers... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    pows[ip] = pow(1000. / met->p[ip], 0.286);

  /* Loop over grid points... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++) {

    /* Set indices... */
    int ix0 = GSL_MAX(ix - 1, 0);
    int ix1 = GSL_MIN(ix + 1, met->nx - 1);

    /* Loop over grid points... */
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set indices... */
      int iy0 = GSL_MAX(iy - 1, 0);
      int iy1 = GSL_MIN(iy + 1, met->ny - 1);

      /* Set auxiliary variables... */
      double latr = 0.5 * (met->lat[iy1] + met->lat[iy0]);
      double dx = 1000. * DEG2DX(met->lon[ix1] - met->lon[ix0], latr);
      double dy = 1000. * DEG2DY(met->lat[iy1] - met->lat[iy0]);
      double c0 = cos(met->lat[iy0] / 180. * M_PI);
      double c1 = cos(met->lat[iy1] / 180. * M_PI);
      double cr = cos(latr / 180. * M_PI);
      double vort = 2 * 7.2921e-5 * sin(latr * M_PI / 180.);

      /* Loop over grid points... */
      for (int ip = 0; ip < met->np; ip++) {

        /* Get gradients in longitude... */
        double dtdx
          = (met->t[ix1][iy][ip] - met->t[ix0][iy][ip]) * pows[ip] / dx;
        double dvdx = (met->v[ix1][iy][ip] - met->v[ix0][iy][ip]) / dx;

        /* Get gradients in latitude... */
        double dtdy
          = (met->t[ix][iy1][ip] - met->t[ix][iy0][ip]) * pows[ip] / dy;
        double dudy
          = (met->u[ix][iy1][ip] * c1 - met->u[ix][iy0][ip] * c0) / dy;

        /* Set indices... */
        int ip0 = GSL_MAX(ip - 1, 0);
        int ip1 = GSL_MIN(ip + 1, met->np - 1);

        /* Get gradients in pressure... */
        double dtdp, dudp, dvdp;
        double dp0 = 100. * (met->p[ip] - met->p[ip0]);
        double dp1 = 100. * (met->p[ip1] - met->p[ip]);
        if (ip != ip0 && ip != ip1) {
          double denom = dp0 * dp1 * (dp0 + dp1);
          dtdp = (dp0 * dp0 * met->t[ix][iy][ip1] * pows[ip1]
                  - dp1 * dp1 * met->t[ix][iy][ip0] * pows[ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->t[ix][iy][ip] * pows[ip])
            / denom;
          dudp = (dp0 * dp0 * met->u[ix][iy][ip1]
                  - dp1 * dp1 * met->u[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->u[ix][iy][ip])
            / denom;
          dvdp = (dp0 * dp0 * met->v[ix][iy][ip1]
                  - dp1 * dp1 * met->v[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->v[ix][iy][ip])
            / denom;
        } else {
          double denom = dp0 + dp1;
          dtdp =
            (met->t[ix][iy][ip1] * pows[ip1] -
             met->t[ix][iy][ip0] * pows[ip0]) / denom;
          dudp = (met->u[ix][iy][ip1] - met->u[ix][iy][ip0]) / denom;
```

```
          dvdp = (met->v[ix][iy][ip1] - met->v[ix][iy][ip0]) / denom;
        }

        /* Calculate PV... */
        met->pv[ix][iy][ip] = (float)
          (1e6 * G0 *
           (-dtdp * (dvdx - dudy / cr + vort) + dvdp * dtdx - dudp * dtdy));
      }
    }
  }

  /* Fix for polar regions... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++)
    for (int ip = 0; ip < met->np; ip++) {
      met->pv[ix][0][ip]
        = met->pv[ix][1][ip]
        = met->pv[ix][2][ip];
      met->pv[ix][met->ny - 1][ip]
        = met->pv[ix][met->ny - 2][ip]
        = met->pv[ix][met->ny - 3][ip];
    }
}
```

### 5.19.2.36 read_met_sample()

```
void read_met_sample (
    ctl_t * ctl,
    met_t * met )
```

Downsampling of meteorological data.

Definition at line 3915 of file libtrac.c.

```
                 {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_dp <= 1 && ctl->met_dx <= 1 && ctl->met_dy <= 1
      && ctl->met_sp <= 1 && ctl->met_sx <= 1 && ctl->met_sy <= 1)
    return;

  /* Set timer... */
  SELECT_TIMER("READ_MET_SAMPLE", "METPROC", NVTX_READ);
  LOG(2, "Downsampling of meteo data...");

  /* Allocate... */
  ALLOC(help, met_t, 1);

  /* Copy data... */
  help->nx = met->nx;
  help->ny = met->ny;
  help->np = met->np;
  memcpy(help->lon, met->lon, sizeof(met->lon));
  memcpy(help->lat, met->lat, sizeof(met->lat));
  memcpy(help->p, met->p, sizeof(met->p));

  /* Smoothing... */
  for (int ix = 0; ix < met->nx; ix += ctl->met_dx) {
    for (int iy = 0; iy < met->ny; iy += ctl->met_dy) {
      for (int ip = 0; ip < met->np; ip += ctl->met_dp) {
        help->ps[ix][iy] = 0;
        help->zs[ix][iy] = 0;
        help->ts[ix][iy] = 0;
        help->us[ix][iy] = 0;
        help->vs[ix][iy] = 0;
        help->t[ix][iy][ip] = 0;
        help->u[ix][iy][ip] = 0;
        help->v[ix][iy][ip] = 0;
        help->w[ix][iy][ip] = 0;
        help->h2o[ix][iy][ip] = 0;
        help->o3[ix][iy][ip] = 0;
        help->lwc[ix][iy][ip] = 0;
        help->iwc[ix][iy][ip] = 0;
        float wsum = 0;
        for (int ix2 = ix - ctl->met_sx + 1; ix2 <= ix + ctl->met_sx - 1;
             ix2++) {
          int ix3 = ix2;
          if (ix3 < 0)
            ix3 += met->nx;
```

```
          else if (ix3 >= met->nx)
            ix3 -= met->nx;

          for (int iy2 = GSL_MAX(iy - ctl->met_sy + 1, 0);
               iy2 <= GSL_MIN(iy + ctl->met_sy - 1, met->ny - 1); iy2++)
            for (int ip2 = GSL_MAX(ip - ctl->met_sp + 1, 0);
                 ip2 <= GSL_MIN(ip + ctl->met_sp - 1, met->np - 1); ip2++) {
              float w = (1.0f - (float) abs(ix - ix2) / (float) ctl->met_sx)
                * (1.0f - (float) abs(iy - iy2) / (float) ctl->met_sy)
                * (1.0f - (float) abs(ip - ip2) / (float) ctl->met_sp);
              help->ps[ix][iy] += w * met->ps[ix3][iy2];
              help->zs[ix][iy] += w * met->zs[ix3][iy2];
              help->ts[ix][iy] += w * met->ts[ix3][iy2];
              help->us[ix][iy] += w * met->us[ix3][iy2];
              help->vs[ix][iy] += w * met->vs[ix3][iy2];
              help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip2];
              help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip2];
              help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip2];
              help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip2];
              help->h2o[ix][iy][ip] += w * met->h2o[ix3][iy2][ip2];
              help->o3[ix][iy][ip] += w * met->o3[ix3][iy2][ip2];
              help->lwc[ix][iy][ip] += w * met->lwc[ix3][iy2][ip2];
              help->iwc[ix][iy][ip] += w * met->iwc[ix3][iy2][ip2];
              wsum += w;
            }
        }
        help->ps[ix][iy] /= wsum;
        help->zs[ix][iy] /= wsum;
        help->ts[ix][iy] /= wsum;
        help->us[ix][iy] /= wsum;
        help->vs[ix][iy] /= wsum;
        help->t[ix][iy][ip] /= wsum;
        help->u[ix][iy][ip] /= wsum;
        help->v[ix][iy][ip] /= wsum;
        help->w[ix][iy][ip] /= wsum;
        help->h2o[ix][iy][ip] /= wsum;
        help->o3[ix][iy][ip] /= wsum;
        help->lwc[ix][iy][ip] /= wsum;
        help->iwc[ix][iy][ip] /= wsum;
      }
    }
  }

  /* Downsampling... */
  met->nx = 0;
  for (int ix = 0; ix < help->nx; ix += ctl->met_dx) {
    met->lon[met->nx] = help->lon[ix];
    met->ny = 0;
    for (int iy = 0; iy < help->ny; iy += ctl->met_dy) {
      met->lat[met->ny] = help->lat[iy];
      met->ps[met->nx][met->ny] = help->ps[ix][iy];
      met->zs[met->nx][met->ny] = help->zs[ix][iy];
      met->ts[met->nx][met->ny] = help->ts[ix][iy];
      met->us[met->nx][met->ny] = help->us[ix][iy];
      met->vs[met->nx][met->ny] = help->vs[ix][iy];
      met->np = 0;
      for (int ip = 0; ip < help->np; ip += ctl->met_dp) {
        met->p[met->np] = help->p[ip];
        met->t[met->nx][met->ny][met->np] = help->t[ix][iy][ip];
        met->u[met->nx][met->ny][met->np] = help->u[ix][iy][ip];
        met->v[met->nx][met->ny][met->np] = help->v[ix][iy][ip];
        met->w[met->nx][met->ny][met->np] = help->w[ix][iy][ip];
        met->h2o[met->nx][met->ny][met->np] = help->h2o[ix][iy][ip];
        met->o3[met->nx][met->ny][met->np] = help->o3[ix][iy][ip];
        met->lwc[met->nx][met->ny][met->np] = help->lwc[ix][iy][ip];
        met->iwc[met->nx][met->ny][met->np] = help->iwc[ix][iy][ip];
        met->np++;
      }
      met->ny++;
    }
    met->nx++;
  }

  /* Free... */
  free(help);
}
```

#### 5.19.2.37 read_met_surface()

```
void read_met_surface (
        int ncid,
        met_t * met )
```

Read surface data.

Definition at line 4043 of file libtrac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("READ_MET_SURFACE", "INPUT", NVTX_READ);
  LOG(2, "Read surface data...");

  /* Read surface pressure... */
  if (!read_met_help_2d(ncid, "lnsp", "LNSP", met, met->ps, 1.0f, 1)) {
    if (!read_met_help_2d(ncid, "ps", "PS", met, met->ps, 0.01f, 1)) {
      WARN("Cannot not read surface pressure data (use lowest level)!");
      for (int ix = 0; ix < met->nx; ix++)
        for (int iy = 0; iy < met->ny; iy++)
          met->ps[ix][iy] = (float) met->p[0];
    }
  } else
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->ps[ix][iy] = (float) (exp(met->ps[ix][iy]) / 100.);

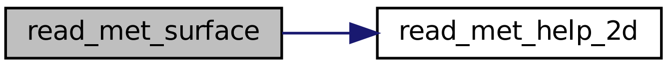
  /* Read geopotential height at the surface... */
  if (!read_met_help_2d
      (ncid, "z", "Z", met, met->zs, (float) (1. / (1000. * G0)), 1))
    if (!read_met_help_2d
        (ncid, "zm", "ZM", met, met->zs, (float) (1. / 1000.), 1))
      WARN("Cannot read surface geopotential height!");

  /* Read temperature at the surface... */
  if (!read_met_help_2d(ncid, "t2m", "T2M", met, met->ts, 1.0, 1))
    WARN("Cannot read surface temperature!");

  /* Read zonal wind at the surface... */
  if (!read_met_help_2d(ncid, "u10m", "U10M", met, met->us, 1.0, 1))
    WARN("Cannot read surface zonal wind!");

  /* Read meridional wind at the surface... */
  if (!read_met_help_2d(ncid, "v10m", "V10M", met, met->vs, 1.0, 1))
    WARN("Cannot read surface meridional wind!");
}
```

Here is the call graph for this function:




### 5.19.2.38 read_met_tropo() `void read_met_tropo ( ctl_t * ctl, met_t * met )`

Calculate tropopause data.

Definition at line 4086 of file libtrac.c.

```
                {

  double p2[200], pv[EP], pv2[200], t[EP], t2[200], th[EP],
    th2[200], z[EP], z2[200];

  /* Set timer... */
  SELECT_TIMER("READ_MET_TROPO", "METPROC", NVTX_READ);
  LOG(2, "Calculate tropopause...");

```

```
  /* Get altitude and pressure profiles... */
#pragma omp parallel for default(shared)
  for (int iz = 0; iz < met->np; iz++)
    z[iz] = Z(met->p[iz]);
#pragma omp parallel for default(shared)
  for (int iz = 0; iz <= 190; iz++) {
    z2[iz] = 4.5 + 0.1 * iz;
    p2[iz] = P(z2[iz]);
  }

  /* Do not calculate tropopause... */
  if (ctl->met_tropo == 0)
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = GSL_NAN;

  /* Use tropopause climatology... */
  else if (ctl->met_tropo == 1) {
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = (float) clim_tropo(met->time, met->lat[iy]);
  }

  /* Use cold point... */
  else if (ctl->met_tropo == 2) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 171, ctl->met_tropo_spline);

        /* Find minimum... */
        int iz = (int) gsl_stats_min_index(t2, 1, 171);
        if (iz > 0 && iz < 170)
          met->pt[ix][iy] = (float) p2[iz];
        else
          met->pt[ix][iy] = GSL_NAN;
      }
  }

  /* Use WMO definition... */
  else if (ctl->met_tropo == 3 || ctl->met_tropo == 4) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        int iz;
        for (iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 191, ctl->met_tropo_spline);

        /* Find 1st tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (iz = 0; iz <= 170; iz++) {
          int found = 1;
          for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
            if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                ctl->met_tropo_lapse) {
              found = 0;
              break;
            }
          if (found) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
        }

        /* Find 2nd tropopause... */
        if (ctl->met_tropo == 4) {
          met->pt[ix][iy] = GSL_NAN;
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev_sep; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) <
                  ctl->met_tropo_lapse_sep) {
                found = 0;
```

```
                break;
              }
            if (found)
              break;
          }
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                  ctl->met_tropo_lapse) {
                found = 0;
                break;
              }
            if (found) {
              if (iz > 0 && iz < 170)
                met->pt[ix][iy] = (float) p2[iz];
              break;
            }
          }
        }
      }
  }

  /* Use dynamical tropopause... */
  else if (ctl->met_tropo == 5) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(pv,pv2,th,th2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate potential vorticity profile... */
        for (int iz = 0; iz < met->np; iz++)
          pv[iz] = met->pv[ix][iy][iz];
        spline(z, pv, met->np, z2, pv2, 171, ctl->met_tropo_spline);

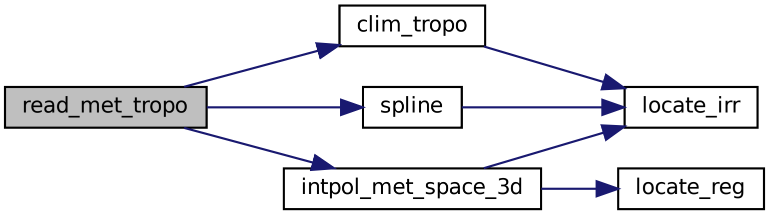
        /* Interpolate potential temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          th[iz] = THETA(met->p[iz], met->t[ix][iy][iz]);
        spline(z, th, met->np, z2, th2, 171, ctl->met_tropo_spline);

        /* Find dynamical tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (int iz = 0; iz <= 170; iz++)
          if (fabs(pv2[iz]) >= ctl->met_tropo_pv
              || th2[iz] >= ctl->met_tropo_theta) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
      }
  }

  else
    ERRMSG("Cannot calculate tropopause!");

  /* Interpolate temperature, geopotential height, and water vapor vmr... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {
      double h2ot, tt, zt;
      INTPOL_INIT;
      intpol_met_space_3d(met, met->t, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &tt, ci, cw, 1);
      intpol_met_space_3d(met, met->z, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &zt, ci, cw, 0);
      intpol_met_space_3d(met, met->h2o, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &h2ot, ci, cw, 0);
      met->tt[ix][iy] = (float) tt;
      met->zt[ix][iy] = (float) zt;
      met->h2ot[ix][iy] = (float) h2ot;
    }
}
```

Here is the call graph for this function:




### 5.19.2.39 scan_ctl()

```
double scan_ctl (
    const char * filename,
    int argc,
    char * argv[],
    const char * varname,
    int arridx,
    const char * defvalue,
    char * value )
```

Read a control parameter from file or command line.

Definition at line 4260 of file libtrac.c.

```
                 {

  FILE *in = NULL;

  char dummy[LEN], fullname1[LEN], fullname2[LEN], line[LEN],
    rvarname[LEN], rval[LEN];

  int contain = 0, i;

  /* Open file... */
  if (filename[strlen(filename) - 1] != '-')
    if (!(in = fopen(filename, "r")))
      ERRMSG("Cannot open file!");

  /* Set full variable name... */
  if (arridx >= 0) {
    sprintf(fullname1, "%s[%d]", varname, arridx);
    sprintf(fullname2, "%s[*]", varname);
  } else {
    sprintf(fullname1, "%s", varname);
    sprintf(fullname2, "%s", varname);
  }

  /* Read data... */
  if (in != NULL)
    while (fgets(line, LEN, in))
      if (sscanf(line, "%s %s %s", rvarname, dummy, rval) == 3)
        if (strcasecmp(rvarname, fullname1) == 0 ||
            strcasecmp(rvarname, fullname2) == 0) {
          contain = 1;
          break;
        }
  for (i = 1; i < argc - 1; i++)
    if (strcasecmp(argv[i], fullname1) == 0 ||
        strcasecmp(argv[i], fullname2) == 0) {
      sprintf(rval, "%s", argv[i + 1]);
      contain = 1;
      break;
    }

```

```
04307   /* Close file... */
04308   if (in != NULL)
04309     fclose(in);
04310
04311   /* Check for missing variables... */
04312   if (!contain) {
04313     if (strlen(defvalue) > 0)
04314       sprintf(rval, "%s", defvalue);
04315     else
04316       ERRMSG("Missing variable %s!\n", fullname1);
04317   }
04318
04319   /* Write info... */
04320   LOG(1, "%s = %s", fullname1, rval);
04321
04322   /* Return values... */
04323   if (value != NULL)
04324     sprintf(value, "%s", rval);
04325   return atof(rval);
04326 }
```

#### 5.19.2.40 sedi()

```
double sedi (
    double p,
    double T,
    double r_p,
    double rho_p )
```

Calculate sedimentation velocity.

Definition at line 4330 of file libtrac.c.

```
04334                   {
04335
04336   double eta, G, K, lambda, rho, v;
04337
04338   /* Convert pressure from hPa to Pa... */
04339   p *= 100.;
04340
04341   /* Convert particle radius from microns to m... */
04342   r_p *= 1e-6;
04343
04344   /* Density of dry air [kg / m^3]... */
04345   rho = p / (RA * T);
04346
04347   /* Dynamic viscosity of air [kg / (m s)]... */
04348   eta = 1.8325e-5 * (416.16 / (T + 120.)) * pow(T / 296.16, 1.5);
04349
04350   /* Thermal velocity of an air molecule [m / s]... */
04351   v = sqrt(8. * KB * T / (M_PI * 4.8096e-26));
04352
04353   /* Mean free path of an air molecule [m]... */
04354   lambda = 2. * eta / (rho * v);
04355
04356   /* Knudsen number for air (dimensionless)... */
04357   K = lambda / r_p;
04358
04359   /* Cunningham slip-flow correction (dimensionless)... */
04360   G = 1. + K * (1.249 + 0.42 * exp(-0.87 / K));
04361
04362   /* Sedimentation velocity [m / s]... */
04363   return 2. * SQR(r_p) * (rho_p - rho) * G0 / (9. * eta) * G;
04364 }
```

#### 5.19.2.41 spline()

```
void spline (
    double * x,
    double * y,
    int n,
    double * x2,
    double * y2,
```

int *n2*,
int *method* )

Spline interpolation.

Definition at line 4368 of file libtrac.c.

```
                  {

  /* Cubic spline interpolation... */
  if (method == 1) {

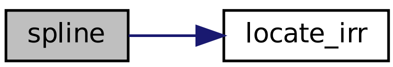
    /* Allocate... */
    gsl_interp_accel *acc;
    gsl_spline *s;
    acc = gsl_interp_accel_alloc();
    s = gsl_spline_alloc(gsl_interp_cspline, (size_t) n);

    /* Interpolate profile... */
    gsl_spline_init(s, x, y, (size_t) n);
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else
        y2[i] = gsl_spline_eval(s, x2[i], acc);

    /* Free... */
    gsl_spline_free(s);
    gsl_interp_accel_free(acc);
  }

  /* Linear interpolation... */
  else {
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else {
        int idx = locate_irr(x, n, x2[i]);
        y2[i] = LIN(x[idx], y[idx], x[idx + 1], y[idx + 1], x2[i]);
      }
  }
}
```

Here is the call graph for this function:




#### 5.19.2.42 stddev() float stddev (

float * *data*,
int *n* )

Calculate standard deviation.

Definition at line 4417 of file libtrac.c.

```
             {

  if (n <= 0)
```

```
    return 0;

  float mean = 0, var = 0;

  for (int i = 0; i < n; ++i) {
    mean += data[i];
    var += SQR(data[i]);
  }

  return sqrtf(var / (float) n - SQR(mean / (float) n));
}
```

#### 5.19.2.43 time2jsec()

```
void time2jsec (
    int year,
    int mon,
    int day,
    int hour,
    int min,
    int sec,
    double remain,
    double * jsec )
```

Convert date to seconds.

Definition at line 4436 of file libtrac.c.

```
                     {

  struct tm t0, t1;

  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  t1.tm_year = year - 1900;
  t1.tm_mon = mon - 1;
  t1.tm_mday = day;
  t1.tm_hour = hour;
  t1.tm_min = min;
  t1.tm_sec = sec;

  *jsec = (double) timegm(&t1) - (double) timegm(&t0) + remain;
}
```

#### 5.19.2.44 timer()

```
void timer (
    const char * name,
    const char * group,
    int output )
```

Measure wall-clock time.

Definition at line 4467 of file libtrac.c.

```
                   {

  static char names[NTIMER][100], groups[NTIMER][100];

  static double rt_name[NTIMER], rt_group[NTIMER], t0, t1;

  static int iname = -1, igroup = -1, nname, ngroup;

  /* Get time... */
  t1 = omp_get_wtime();

  /* Add elapsed time to current timers... */
```

```
  if (iname >= 0)
    rt_name[iname] += t1 - t0;
  if (igroup >= 0)
    rt_group[igroup] += t1 - t0;

  /* Report timers... */
  if (output) {
    for (int i = 0; i < nname; i++)
      LOG(1, "TIMER_%s = %.3f s", names[i], rt_name[i]);
    for (int i = 0; i < ngroup; i++)
      LOG(1, "TIMER_%s = %.3f s", groups[i], rt_group[i]);
    double total = 0.0;
    for (int i = 0; i < nname; i++)
      total += rt_name[i];
    LOG(1, "TIMER_TOTAL = %.3f s", total);
  }

  /* Identify IDs of next timer... */
  for (iname = 0; iname < nname; iname++)
    if (strcasecmp(name, names[iname]) == 0)
      break;
  for (igroup = 0; igroup < ngroup; igroup++)
    if (strcasecmp(group, groups[igroup]) == 0)
      break;

  /* Check whether this is a new timer... */
  if (iname >= nname) {
    sprintf(names[iname], "%s", name);
    if ((++nname) > NTIMER)
      ERRMSG("Too many timers!");
  }

  /* Check whether this is a new group... */
  if (igroup >= ngroup) {
    sprintf(groups[igroup], "%s", group);
    if ((++ngroup) > NTIMER)
      ERRMSG("Too many groups!");
  }

  /* Save starting time... */
  t0 = t1;
}
```

#### 5.19.2.45 tropo_weight()

```
double tropo_weight (
    double t,
    double lat,
    double p )
```

Get weighting factor based on tropopause distance.

Definition at line 4527 of file libtrac.c.

```
                  {

  /* Get tropopause pressure... */
  double pt = clim_tropo(t, lat);

  /* Get pressure range... */
  double p1 = pt * 0.866877899;
  double p0 = pt / 0.866877899;

  /* Get weighting factor... */
  if (p > p0)
    return 1;
  else if (p < p1)
    return 0;
  else
    return LIN(p0, 1.0, p1, 0.0, p);
}
```

Here is the call graph for this function:


### 5.19.2.46 write_atm()

```
void write_atm (
        const char * filename,
        ctl_t * ctl,
        atm_t * atm,
        double t )
```

Write atmospheric data.

Definition at line 4550 of file libtrac.c.

```
                {

  FILE *in, *out;

  char line[LEN];

  double r, t0, t1;

  int year, mon, day, hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_ATM", "OUTPUT", NVTX_WRITE);

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Write info... */
  LOG(1, "Write atmospheric data: %s", filename);

  /* Write ASCII data... */
  if (ctl->atm_type == 0) {

    /* Check if gnuplot output is requested... */
    if (ctl->atm_gpfile[0] != '-') {

      /* Create gnuplot pipe... */
      if (!(out = popen("gnuplot", "w")))
        ERRMSG("Cannot create pipe to gnuplot!");

      /* Set plot filename... */
      fprintf(out, "set out \"%s.png\"\n", filename);

      /* Set time string... */
      jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
      fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
              year, mon, day, hour, min);

      /* Dump gnuplot file to pipe... */
      if (!(in = fopen(ctl->atm_gpfile, "r")))
        ERRMSG("Cannot open file!");
      while (fgets(line, LEN, in))
        fprintf(out, "%s", line);
      fclose(in);
    }

    else {

      /* Create file... */
      if (!(out = fopen(filename, "w")))
```

```
      ERRMSG("Cannot create file!");
  }

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
  for (int iq = 0; iq < ctl->nq; iq++)
    fprintf(out, "# $%i = %s [%s]\n", iq + 5, ctl->qnt_name[iq],
            ctl->qnt_unit[iq]);
  fprintf(out, "\n");

  /* Write data... */
  for (int ip = 0; ip < atm->np; ip += ctl->atm_stride) {

    /* Check time... */
    if (ctl->atm_filter == 2 && (atm->time[ip] < t0 || atm->time[ip] > t1))
      continue;

    /* Write output... */
    fprintf(out, "%.2f %g %g %g", atm->time[ip], Z(atm->p[ip]),
            atm->lon[ip], atm->lat[ip]);
    for (int iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      if (ctl->atm_filter == 1
          && (atm->time[ip] < t0 || atm->time[ip] > t1))
        fprintf(out, ctl->qnt_format[iq], GSL_NAN);
      else
        fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, "\n");
  }

  /* Close file... */
  fclose(out);
}

/* Write binary data... */
else if (ctl->atm_type == 1) {

  /* Create file... */
  if (!(out = fopen(filename, "w")))
    ERRMSG("Cannot create file!");

  /* Write data... */
  FWRITE(&atm->np, int,
         1,
         out);
  FWRITE(atm->time, double,
           (size_t) atm->np,
         out);
  FWRITE(atm->p, double,
           (size_t) atm->np,
         out);
  FWRITE(atm->lon, double,
           (size_t) atm->np,
         out);
  FWRITE(atm->lat, double,
           (size_t) atm->np,
         out);
  for (int iq = 0; iq < ctl->nq; iq++)
    FWRITE(atm->q[iq], double,
             (size_t) atm->np,
           out);

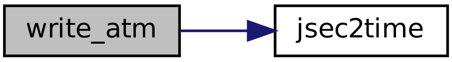
  /* Close file... */
  fclose(out);
}

/* Error... */
else
  ERRMSG("Atmospheric data type not supported!");

/* Write info... */
double mini, maxi;
LOG(2, "Number of particles: %d", atm->np);
gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
for (int iq = 0; iq < ctl->nq; iq++) {
```

```
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }
}
```

Here is the call graph for this function:




#### 5.19.2.47 write_csi()

```
void write_csi (
        const char * filename,
        ctl_t * ctl,
        atm_t * atm,
        double t )
```

Write CSI data.

Definition at line 4702 of file libtrac.c.

```
              {

  static FILE *in, *out;

  static char line[LEN];

  static double modmean[GX][GY][GZ], obsmean[GX][GY][GZ], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dlon, dlat, dz, lat,
    x[1000000], y[1000000], work[2000000];

  static int obscount[GX][GY][GZ], ct, cx, cy, cz, ip, ix, iy, iz, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_CSI", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Open observation data file... */
    LOG(1, "Read CSI observation data: %s", ctl->csi_obsfile);
    if (!(in = fopen(ctl->csi_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new file... */
    LOG(1, "Write CSI data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = number of hits (cx)\n"
            "# $3 = number of misses (cy)\n"
```

```
            "# $4 = number of false alarms (cz)\n"
            "# $5 = number of observations (cx + cy)\n"
            "# $6 = number of forecasts (cx + cz)\n"
            "# $7 = bias (ratio of forecasts and observations) [%%]\n"
            "# $8 = probability of detection (POD) [%%]\n"
            "# $9 = false alarm rate (FAR) [%%]\n"
            "# $10 = critical success index (CSI) [%%]\n");
    fprintf(out,
            "# $11 = hits associated with random chance\n"
            "# $12 = equitable threat score (ETS) [%%]\n"
            "# $13 = Pearson linear correlation coefficient\n"
            "# $14 = Spearman rank-order correlation coefficient\n"
            "# $15 = column density mean error (F - O) [kg/m^2]\n"
            "# $16 = column density root mean square error (RMSE) [kg/m^2]\n"
            "# $17 = column density mean absolute error [kg/m^2]\n"
            "# $18 = number of data points\n\n");

    /* Set grid box size... */
    dz = (ctl->csi_z1 - ctl->csi_z0) / ctl->csi_nz;
    dlon = (ctl->csi_lon1 - ctl->csi_lon0) / ctl->csi_nx;
    dlat = (ctl->csi_lat1 - ctl->csi_lat0) / ctl->csi_ny;

    /* Set horizontal coordinates... */
    for (iy = 0; iy < ctl->csi_ny; iy++) {
      lat = ctl->csi_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.) * cos(lat * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid cells... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++)
        modmean[ix][iy][iz] = obsmean[ix][iy][iz] = obscount[ix][iy][iz] = 0;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->csi_lon0) / dlon);
    iy = (int) ((rlat - ctl->csi_lat0) / dlat);
    iz = (int) ((rz - ctl->csi_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy][iz] += robs;
    obscount[ix][iy][iz]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->csi_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->csi_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->csi_z0) / dz);
```

```
    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get total mass in grid cell... */
    modmean[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Analyze all grid cells... */
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++) {

        /* Calculate mean observation index... */
        if (obscount[ix][iy][iz] > 0)
          obsmean[ix][iy][iz] /= obscount[ix][iy][iz];

        /* Calculate column density... */
        if (modmean[ix][iy][iz] > 0)
          modmean[ix][iy][iz] /= (1e6 * area[iy]);

        /* Calculate CSI... */
        if (obscount[ix][iy][iz] > 0) {
          ct++;
          if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
              modmean[ix][iy][iz] >= ctl->csi_modmin)
            cx++;
          else if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
                   modmean[ix][iy][iz] < ctl->csi_modmin)
            cy++;
          else if (obsmean[ix][iy][iz] < ctl->csi_obsmin &&
                   modmean[ix][iy][iz] >= ctl->csi_modmin)
            cz++;
        }

        /* Save data for other verification statistics... */
        if (obscount[ix][iy][iz] > 0
            && (obsmean[ix][iy][iz] >= ctl->csi_obsmin
                || modmean[ix][iy][iz] >= ctl->csi_modmin)) {
          x[n] = modmean[ix][iy][iz];
          y[n] = obsmean[ix][iy][iz];
          if ((++n) > 1000000)
            ERRMSG("Too many data points to calculate statistics!");
        }
      }

  /* Write output... */
  if (fmod(t, ctl->csi_dt_out) == 0) {

    /* Calculate verification statistics
       (https://www.cawcr.gov.au/projects/verification/) ... */
    int nobs = cx + cy;
    int nfor = cx + cz;
    double bias = (nobs > 0) ? 100. * nfor / nobs : GSL_NAN;
    double pod = (nobs > 0) ? (100. * cx) / nobs : GSL_NAN;
    double far = (nfor > 0) ? (100. * cz) / nfor : GSL_NAN;
    double csi = (cx + cy + cz > 0) ? (100. * cx) / (cx + cy + cz) : GSL_NAN;
    double cx_rd = (ct > 0) ? (1. * nobs * nfor) / ct : GSL_NAN;
    double ets = (cx + cy + cz - cx_rd > 0) ?
      (100. * (cx - cx_rd)) / (cx + cy + cz - cx_rd) : GSL_NAN;
    double rho_p =
      (n > 0) ? gsl_stats_correlation(x, 1, y, 1, (size_t) n) : GSL_NAN;
    double rho_s =
      (n > 0) ? gsl_stats_spearman(x, 1, y, 1, (size_t) n, work) : GSL_NAN;
    for (int i = 0; i < n; i++)
      work[i] = x[i] - y[i];
    double mean = (n > 0) ? gsl_stats_mean(work, 1, (size_t) n) : GSL_NAN;
    double rmse = (n > 0) ? gsl_stats_sd_with_fixed_mean(work, 1, (size_t) n,
                                                          0.0) : GSL_NAN;
    double absdev =
      (n > 0) ? gsl_stats_absdev_m(work, 1, (size_t) n, 0.0) : GSL_NAN;

    /* Write... */
    fprintf(out, "%.2f %d %d %d %d %d %g %g %g %g %g %g %g %g %g %g %g %d\n",
            t, cx, cy, cz, nobs, nfor, bias, pod, far, csi, cx_rd, ets,
            rho_p, rho_s, mean, rmse, absdev, n);

    /* Set counters to zero... */
    n = ct = cx = cy = cz = 0;
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

#### 5.19.2.48 write_ens()

```
void write_ens (
        const char * filename,
        ctl_t * ctl,
        atm_t * atm,
        double t )
```

Write ensemble data.

Definition at line 4923 of file libtrac.c.

```
                {

  static FILE *out;

  static double dummy, ens, lat, lon, p[NENS], q[NQ][NENS],
    t0, t1, x[NENS][3], xm[3];

  static int ip, iq;

  static size_t i, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_ENS", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantities... */
    if (ctl->qnt_ens < 0)
      ERRMSG("Missing ensemble IDs!");

    /* Create new file... */
    LOG(1, "Write ensemble data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (mean) [%s]\n", 5 + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (sigma) [%s]\n", 5 + ctl->nq + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "# $%d = number of members\n\n", 5 + 2 * ctl->nq);
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Init... */
  ens = GSL_NAN;
  n = 0;

  /* Loop over air parcels... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check ensemble id... */
    if (atm->q[ctl->qnt_ens][ip] != ens) {

      /* Write results... */
      if (n > 0) {

        /* Get mean position... */
        xm[0] = xm[1] = xm[2] = 0;
        for (i = 0; i < n; i++) {
          xm[0] += x[i][0] / (double) n;
          xm[1] += x[i][1] / (double) n;
          xm[2] += x[i][2] / (double) n;
        }
        cart2geo(xm, &dummy, &lon, &lat);
```

```
        fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon,
                lat);

        /* Get quantity statistics... */
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
        }
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
        }
        fprintf(out, " %zu\n", n);
      }

      /* Init new ensemble... */
      ens = atm->q[ctl->qnt_ens][ip];
      n = 0;
    }

    /* Save data... */
    p[n] = atm->p[ip];
    geo2cart(0, atm->lon[ip], atm->lat[ip], x[n]);
    for (iq = 0; iq < ctl->nq; iq++)
      q[iq][n] = atm->q[iq][ip];
    if ((++n) >= NENS)
      ERRMSG("Too many data points!");
  }

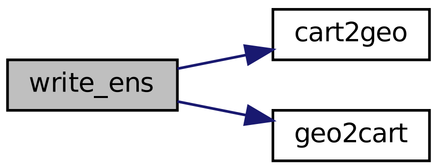
  /* Write results... */
  if (n > 0) {

    /* Get mean position... */
    xm[0] = xm[1] = xm[2] = 0;
    for (i = 0; i < n; i++) {
      xm[0] += x[i][0] / (double) n;
      xm[1] += x[i][1] / (double) n;
      xm[2] += x[i][2] / (double) n;
    }
    cart2geo(xm, &dummy, &lon, &lat);
    fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon, lat);

    /* Get quantity statistics... */
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
    }
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
    }
    fprintf(out, " %zu\n", n);
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

Here is the call graph for this function:



#### 5.19.2.49 write_grid()

```
void write_grid (
        const char * filename,
        ctl_t * ctl,
        met_t * met0,
        met_t * met1,
        atm_t * atm,
        double t )
```

Write gridded data.

Definition at line 5057 of file libtrac.c.

```
                  {

  FILE *in, *out;

  char line[LEN];

  static double mass[GX][GY][GZ], vmr[GX][GY][GZ], vmr_expl, vmr_impl,
    z[GZ], dz, lon[GX], dlon, lat[GY], dlat, area[GY], rho_air,
    press[GZ], temp, cd, t0, t1, r;

  static int ip, ix, *ixs, iy, *iys, iz, *izs, np[GX][GY][GZ], year, mon, day,
    hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_GRID", "OUTPUT", NVTX_WRITE);

  /* Check dimensions... */
  if (ctl->grid_nx > GX || ctl->grid_ny > GY || ctl->grid_nz > GZ)
    ERRMSG("Grid dimensions too large!");

  /* Set grid box size... */
  dz = (ctl->grid_z1 - ctl->grid_z0) / ctl->grid_nz;
  dlon = (ctl->grid_lon1 - ctl->grid_lon0) / ctl->grid_nx;
  dlat = (ctl->grid_lat1 - ctl->grid_lat0) / ctl->grid_ny;

  /* Set vertical coordinates... */
#pragma omp parallel for default(shared) private(iz)
  for (iz = 0; iz < ctl->grid_nz; iz++) {
    z[iz] = ctl->grid_z0 + dz * (iz + 0.5);
    press[iz] = P(z[iz]);
  }

  /* Set horizontal coordinates... */
  for (ix = 0; ix < ctl->grid_nx; ix++)
    lon[ix] = ctl->grid_lon0 + dlon * (ix + 0.5);
#pragma omp parallel for default(shared) private(iy)
  for (iy = 0; iy < ctl->grid_ny; iy++) {
    lat[iy] = ctl->grid_lat0 + dlat * (iy + 0.5);
    area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
      * cos(lat[iy] * M_PI / 180.);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->grid_nx; ix++)
    for (iy = 0; iy < ctl->grid_ny; iy++)
      for (iz = 0; iz < ctl->grid_nz; iz++) {
        mass[ix][iy][iz] = 0;
        vmr[ix][iy][iz] = 0;
        np[ix][iy][iz] = 0;
      }

  /* Allocate... */
  ALLOC(ixs, int,
        atm->np);
  ALLOC(iys, int,
        atm->np);
  ALLOC(izs, int,
        atm->np);

  /* Get indices... */
#pragma omp parallel for default(shared) private(ip)
  for (ip = 0; ip < atm->np; ip++) {
    ixs[ip] = (int) ((atm->lon[ip] - ctl->grid_lon0) / dlon);
    iys[ip] = (int) ((atm->lat[ip] - ctl->grid_lat0) / dlat);
    izs[ip] = (int) ((Z(atm->p[ip]) - ctl->grid_z0) / dz);
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
```

```
        || ixs[ip] < 0 || ixs[ip] >= ctl->grid_nx
        || iys[ip] < 0 || iys[ip] >= ctl->grid_ny
        || izs[ip] < 0 || izs[ip] >= ctl->grid_nz)
      izs[ip] = -1;
  }

  /* Average data... */
  for (ip = 0; ip < atm->np; ip++)
    if (izs[ip] >= 0) {
      np[ixs[ip]][iys[ip]][izs[ip]]++;
      if (ctl->qnt_m >= 0)
        mass[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_m][ip];
      if (ctl->qnt_vmr >= 0)
        vmr[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_vmr][ip];
    }

  /* Free... */
  free(ixs);
  free(iys);
  free(izs);

  /* Check if gnuplot output is requested... */
  if (ctl->grid_gpfile[0] != '-') {

    /* Write info... */
    LOG(1, "Plot grid data: %s.png", filename);

    /* Create gnuplot pipe... */
    if (!(out = popen("gnuplot", "w")))
      ERRMSG("Cannot create pipe to gnuplot!");

    /* Set plot filename... */
    fprintf(out, "set out \"%s.png\"\n", filename);

    /* Set time string... */
    jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
    fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
            year, mon, day, hour, min);

    /* Dump gnuplot file to pipe... */
    if (!(in = fopen(ctl->grid_gpfile, "r")))
      ERRMSG("Cannot open file!");
    while (fgets(line, LEN, in))
      fprintf(out, "%s", line);
    fclose(in);
  }

  else {

    /* Write info... */
    LOG(1, "Write grid data: %s", filename);

    /* Create file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");
  }

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = surface area [km^2]\n"
          "# $6 = layer width [km]\n"
          "# $7 = number of particles [1]\n"
          "# $8 = column density (implicit) [kg/m^2]\n"
          "# $9 = volume mixing ratio (implicit) [ppv]\n"
          "# $10 = volume mixing ratio (explicit) [ppv]\n\n");

  /* Write data... */
  for (ix = 0; ix < ctl->grid_nx; ix++) {
    if (ix > 0 && ctl->grid_ny > 1 && !ctl->grid_sparse)
      fprintf(out, "\n");
    for (iy = 0; iy < ctl->grid_ny; iy++) {
      if (iy > 0 && ctl->grid_nz > 1 && !ctl->grid_sparse)
        fprintf(out, "\n");
      for (iz = 0; iz < ctl->grid_nz; iz++)
        if (!ctl->grid_sparse || mass[ix][iy][iz] > 0 || vmr[ix][iy][iz] > 0) {

          /* Calculate column density... */
          if (ctl->qnt_m >= 0)
            cd = mass[ix][iy][iz] / (1e6 * area[iy]);
          else
            cd = GSL_NAN;

          /* Calculate volume mixing ratio (implicit)... */
```

```
          if (ctl->qnt_m >= 0 && ctl->molmass > 0) {
            vmr_impl = 0;
            if (mass[ix][iy][iz] > 0) {

              /* Get temperature... */
              INTPOL_INIT;
              intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                                 lon[ix], lat[iy], &temp, ci, cw, 1);

              /* Calculate density of air... */
              rho_air = 100. * press[iz] / (RA * temp);

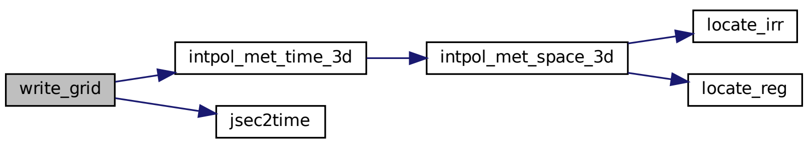
              /* Calculate volume mixing ratio... */
              vmr_impl = MA / ctl->molmass * mass[ix][iy][iz]
                / (rho_air * 1e6 * area[iy] * 1e3 * dz);
            }
          } else
            vmr_impl = GSL_NAN;

          /* Calculate volume mixing ratio (explicit)... */
          if (ctl->qnt_vmr >= 0 && np[ix][iy][iz] > 0)
            vmr_expl = vmr[ix][iy][iz] / np[ix][iy][iz];
          else
            vmr_expl = GSL_NAN;

          /* Write output... */
          fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", t, z[iz],
                  lon[ix], lat[iy], area[iy], dz, np[ix][iy][iz], cd,
                  vmr_impl, vmr_expl);
        }
    }
  }

  /* Close file... */
  fclose(out);
}
```

Here is the call graph for this function:




#### 5.19.2.50 write_prof()

```
void write_prof (
        const char * filename,
        ctl_t * ctl,
        met_t * met0,
        met_t * met1,
        atm_t * atm,
        double t )
```

Write profile data.

Definition at line 5260 of file libtrac.c.

```
                {

  static FILE *in, *out;

  static char line[LEN];

  static double mass[GX][GY][GZ], obsmean[GX][GY], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dz, dlon, dlat,
    lon[GX], lat[GY], z[GZ], press[GZ], temp, rho_air, vmr, h2o, o3;
```

```
  static int obscount[GX][GY], ip, ix, iy, iz, okay;

  /* Set timer... */
  SELECT_TIMER("WRITE_PROF", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Check dimensions... */
    if (ctl->prof_nx > GX || ctl->prof_ny > GY || ctl->prof_nz > GZ)
      ERRMSG("Grid dimensions too large!");

    /* Check molar mass... */
    if (ctl->molmass <= 0)
      ERRMSG("Specify molar mass!");

    /* Open observation data file... */
    LOG(1, "Read profile observation data: %s", ctl->prof_obsfile);
    if (!(in = fopen(ctl->prof_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new output file... */
    LOG(1, "Write profile data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
            "# $4 = latitude [deg]\n"
            "# $5 = pressure [hPa]\n"
            "# $6 = temperature [K]\n"
            "# $7 = volume mixing ratio [ppv]\n"
            "# $8 = H2O volume mixing ratio [ppv]\n"
            "# $9 = O3 volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n"
            "# $11 = number of observations\n");

    /* Set grid box size... */
    dz = (ctl->prof_z1 - ctl->prof_z0) / ctl->prof_nz;
    dlon = (ctl->prof_lon1 - ctl->prof_lon0) / ctl->prof_nx;
    dlat = (ctl->prof_lat1 - ctl->prof_lat0) / ctl->prof_ny;

    /* Set vertical coordinates... */
    for (iz = 0; iz < ctl->prof_nz; iz++) {
      z[iz] = ctl->prof_z0 + dz * (iz + 0.5);
      press[iz] = P(z[iz]);
    }

    /* Set horizontal coordinates... */
    for (ix = 0; ix < ctl->prof_nx; ix++)
      lon[ix] = ctl->prof_lon0 + dlon * (ix + 0.5);
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      lat[iy] = ctl->prof_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
        * cos(lat[iy] * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(2)
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      obsmean[ix][iy] = 0;
      obscount[ix][iy] = 0;
      for (iz = 0; iz < ctl->prof_nz; iz++)
        mass[ix][iy][iz] = 0;
    }

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
```

```
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->prof_lon0) / dlon);
    iy = (int) ((rlat - ctl->prof_lat0) / dlat);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx || iy < 0 || iy >= ctl->prof_ny)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy] += robs;

    /* Count observations... */
    obscount[ix][iy]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->prof_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->prof_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->prof_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx ||
        iy < 0 || iy >= ctl->prof_ny || iz < 0 || iz >= ctl->prof_nz)
      continue;

    /* Get total mass in grid cell... */
    mass[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Extract profiles... */
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++)
      if (obscount[ix][iy] >= 1) {

        /* Check profile... */
        okay = 0;
        for (iz = 0; iz < ctl->prof_nz; iz++)
          if (mass[ix][iy][iz] > 0) {
            okay = 1;
            break;
          }
        if (!okay)
          continue;

        /* Write output... */
        fprintf(out, "\n");

        /* Loop over altitudes... */
        for (iz = 0; iz < ctl->prof_nz; iz++) {

          /* Get pressure and temperature... */
          INTPOL_INIT;
          intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                             lon[ix], lat[iy], &temp, ci, cw, 1);
          intpol_met_time_3d(met0, met0->h2o, met1, met1->h2o, t, press[iz],
                             lon[ix], lat[iy], &h2o, ci, cw, 0);
          intpol_met_time_3d(met0, met0->o3, met1, met1->o3, t, press[iz],
                             lon[ix], lat[iy], &o3, ci, cw, 0);

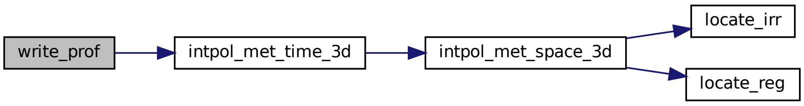
          /* Calculate volume mixing ratio... */
          rho_air = 100. * press[iz] / (RA * temp);
          vmr = MA / ctl->molmass * mass[ix][iy][iz]
            / (rho_air * area[iy] * dz * 1e9);
```

```

          /* Write output... */
          fprintf(out, "%.2f %g %g %g %g %g %g %g %g %g %d\n",
                  t, z[iz], lon[ix], lat[iy], press[iz], temp, vmr, h2o, o3,
                  obsmean[ix][iy] / obscount[ix][iy], obscount[ix][iy]);
        }
      }

  /* Close files... */
  if (t == ctl->t_stop) {
    fclose(in);
    fclose(out);
  }
}
```

Here is the call graph for this function:




### 5.19.2.51 write_sample()

```
void write_sample (
        const char * filename,
        ctl_t * ctl,
        met_t * met0,
        met_t * met1,
        atm_t * atm,
        double t )
```

Write sample data.

Definition at line 5466 of file libtrac.c.

```
                {

  static FILE *in, *out;

  static char line[LEN];

  static double area, dlat, rmax2, t0, t1, rt, rt_old, rz, rlon, rlat, robs;

  /* Set timer... */
  SELECT_TIMER("WRITE_SAMPLE", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Open observation data file... */
    LOG(1, "Read sample observation data: %s", ctl->sample_obsfile);
    if (!(in = fopen(ctl->sample_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new file... */
    LOG(1, "Write sample data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
```

```
            "# $4 = latitude [deg]\n"
            "# $5 = surface area [km^2]\n"
            "# $6 = layer width [km]\n"
            "# $7 = number of particles [1]\n"
            "# $8 = column density [kg/m^2]\n"
            "# $9 = volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n\n");

    /* Set latitude range, squared radius, and area... */
    dlat = DY2DEG(ctl->sample_dx);
    rmax2 = SQR(ctl->sample_dx);
    area = M_PI * rmax2;
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Calculate Cartesian coordinates... */
    double x0[3];
    geo2cart(0, rlon, rlat, x0);

    /* Set pressure range... */
    double rp = P(rz);
    double ptop = P(rz + ctl->sample_dz);
    double pbot = P(rz - ctl->sample_dz);

    /* Init... */
    double mass = 0;
    int np = 0;

    /* Loop over air parcels... */
#pragma omp parallel for default(shared) reduction(+:mass,np)
    for (int ip = 0; ip < atm->np; ip++) {

      /* Check time... */
      if (atm->time[ip] < t0 || atm->time[ip] > t1)
        continue;

      /* Check latitude... */
      if (fabs(rlat - atm->lat[ip]) > dlat)
        continue;

      /* Check horizontal distance... */
      double x1[3];
      geo2cart(0, atm->lon[ip], atm->lat[ip], x1);
      if (DIST2(x0, x1) > rmax2)
        continue;

      /* Check pressure... */
      if (ctl->sample_dz > 0)
        if (atm->p[ip] > pbot || atm->p[ip] < ptop)
          continue;

      /* Add mass... */
      if (ctl->qnt_m >= 0)
        mass += atm->q[ctl->qnt_m][ip];
      np++;
    }

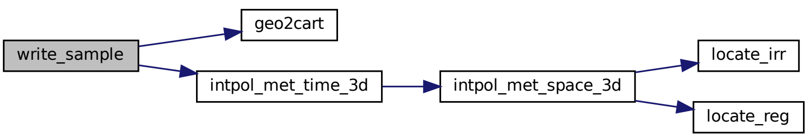
    /* Calculate column density... */
    double cd = mass / (1e6 * area);

    /* Calculate volume mixing ratio... */
    double vmr = 0;
    if (ctl->molmass > 0 && ctl->sample_dz > 0) {
      if (mass > 0) {

        /* Get temperature... */
        double temp;
        INTPOL_INIT;
        intpol_met_time_3d(met0, met0->t, met1, met1->t, rt, rp,
```

```
05591                               rlon, rlat, &temp, ci, cw, 1);
05592
05593           /* Calculate density of air... */
05594           double rho_air = 100. * rp / (RA * temp);
05595
05596           /* Calculate volume mixing ratio... */
05597           vmr = MA / ctl->molmass * mass
05598             / (rho_air * 1e6 * area * 1e3 * ctl->sample_dz);
05599         }
05600       } else
05601         vmr = GSL_NAN;
05602
05603       /* Write output... */
05604       fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", rt, rz, rlon, rlat,
05605               area, ctl->sample_dz, np, cd, vmr, robs);
05606
05607       /* Check time... */
05608       if (rt >= t1)
05609         break;
05610     }
05611
05612     /* Close files... */
05613     if (t == ctl->t_stop) {
05614       fclose(in);
05615       fclose(out);
05616     }
05617 }
```

Here is the call graph for this function:




#### 5.19.2.52 write_station()

```
void write_station (
    const char * filename,
    ctl_t * ctl,
    atm_t * atm,
    double t )
```

Write station data.

Definition at line 5621 of file libtrac.c.

```
05625                   {
05626
05627     static FILE *out;
05628
05629     static double rmax2, t0, t1, x0[3], x1[3];
05630
05631     /* Set timer... */
05632     SELECT_TIMER("WRITE_STATION", "OUTPUT", NVTX_WRITE);
05633
05634     /* Init... */
05635     if (t == ctl->t_start) {
05636
05637       /* Write info... */
05638       LOG(1, "Write station data: %s", filename);
05639
05640       /* Create new file... */
05641       if (!(out = fopen(filename, "w")))
05642         ERRMSG("Cannot create file!");
05643
05644       /* Write header... */
05645       fprintf(out,
```

```
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (int iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%i = %s [%s]\n", (iq + 5),
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "\n");

    /* Set geolocation and search radius... */
    geo2cart(0, ctl->stat_lon, ctl->stat_lat, x0);
    rmax2 = SQR(ctl->stat_r);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Loop over air parcels... */
  for (int ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check time range for station output... */
    if (atm->time[ip] < ctl->stat_t0 || atm->time[ip] > ctl->stat_t1)
      continue;

    /* Check station flag... */
    if (ctl->qnt_stat >= 0)
      if (atm->q[ctl->qnt_stat][ip])
        continue;

    /* Get Cartesian coordinates... */
    geo2cart(0, atm->lon[ip], atm->lat[ip], x1);

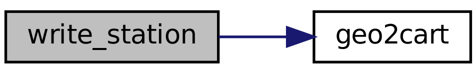
    /* Check horizontal distance... */
    if (DIST2(x0, x1) > rmax2)
      continue;

    /* Set station flag... */
    if (ctl->qnt_stat >= 0)
      atm->q[ctl->qnt_stat][ip] = 1;

    /* Write data... */
    fprintf(out, "%.2f %g %g %g",
            atm->time[ip], Z(atm->p[ip]), atm->lon[ip], atm->lat[ip]);
    for (int iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, "\n");
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

Here is the call graph for this function:




## 5.20 libtrac.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
```

```
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/*****************************************************************************/

void cart2geo(
  double *x,
  double *z,
  double *lon,
  double *lat) {

  double radius = NORM(x);
  *lat = asin(x[2] / radius) * 180. / M_PI;
  *lon = atan2(x[1], x[0]) * 180. / M_PI;
  *z = radius - RE;
}

/*****************************************************************************/

static double clim_hno3_secs[12] = {
  1209600.00, 3888000.00, 6393600.00,
  9072000.00, 11664000.00, 14342400.00,
  16934400.00, 19612800.00, 22291200.00,
  24883200.00, 27561600.00, 30153600.00
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_hno3_secs)
#endif

static double clim_hno3_lats[18] = {
  -85, -75, -65, -55, -45, -35, -25, -15, -5,
  5, 15, 25, 35, 45, 55, 65, 75, 85
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_hno3_lats)
#endif

static double clim_hno3_ps[10] = {
  4.64159, 6.81292, 10, 14.678, 21.5443,
  31.6228, 46.4159, 68.1292, 100, 146.78
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_hno3_ps)
#endif

static double clim_hno3_var[12][18][10] = {
  {{0.782, 1.65, 2.9, 4.59, 6.71, 8.25, 7.16, 5.75, 2.9, 1.74},
   {0.529, 1.64, 2.76, 4.55, 6.58, 8, 6.99, 5.55, 2.68, 1.57},
   {0.723, 1.55, 2.73, 4.48, 6.32, 7.58, 7.05, 5.16, 2.49, 1.54},
   {0.801, 1.56, 2.74, 4.52, 6.23, 7.35, 6.68, 4.4, 1.97, 1.23},
   {0.818, 1.62, 2.77, 4.38, 5.98, 6.84, 5.83, 3.05, 1.15, 0.709},
   {0.901, 1.73, 2.78, 4.21, 5.63, 6.16, 4.68, 1.87, 0.617, 0.37},
   {0.997, 1.8, 2.79, 4.09, 4.88, 4.96, 3.12, 1.22, 0.311, 0.244},
   {1, 1.71, 2.51, 3.4, 3.74, 3.39, 2.25, 0.845, 0.204, 0.222},
   {0.997, 1.7, 2.36, 2.88, 3.01, 2.25, 1.77, 0.608, 0.163, 0.181},
   {0.991, 1.79, 2.57, 3.06, 3.08, 2.15, 1.81, 0.59, 0.168, 0.104},
   {0.974, 1.86, 2.84, 3.8, 3.93, 3.79, 2.91, 1.02, 0.152, 0.0985},
   {0.85, 1.86, 3.3, 5.24, 6.55, 6.86, 5.12, 1.93, 0.378, 0.185},
   {0.783, 1.89, 3.85, 6.6, 8.56, 8.66, 6.95, 3.95, 1.47, 0.745},
   {0.883, 2.05, 4.34, 7.54, 9.68, 9.77, 8.19, 5.72, 3.15, 1.77},
   {1.4, 2.44, 4.72, 8.07, 10.5, 10.9, 9.28, 6.95, 4.47, 2.49},
   {1.7, 2.43, 4.24, 7.43, 10.4, 11.2, 9.72, 8.15, 5.7, 2.97},
   {2.06, 2.27, 3.68, 6.77, 10.3, 10.3, 9.05, 9.1, 6.73, 3.14},
   {2.33, 2.39, 3.51, 6.45, 10.3, 9.88, 8.57, 9.42, 7.22, 3.19}},
  {{0.947, 2.21, 3.81, 5.69, 7.55, 8.63, 7.53, 5.98, 3.03, 1.64},
   {0.642, 2, 3.4, 5.49, 7.5, 8.52, 7.53, 5.83, 2.74, 1.42},
   {0.756, 1.83, 3.18, 5.11, 7.24, 8.63, 7.66, 5.5, 2.45, 1.33},
   {0.837, 1.75, 3.06, 5, 6.79, 8.08, 7.05, 4.42, 1.81, 1.05},
   {0.86, 1.73, 2.96, 4.68, 6.38, 7.38, 6.09, 2.92, 1.06, 0.661},
   {0.926, 1.78, 2.89, 4.37, 5.74, 6.14, 4.59, 1.78, 0.561, 0.332},
   {0.988, 1.78, 2.75, 3.95, 4.64, 4.49, 2.85, 1.13, 0.271, 0.184},
```

```
    {0.999, 1.7, 2.44, 3.27, 3.57, 3.03, 2.06, 0.736, 0.181, 0.189},
    {0.971, 1.67, 2.23, 2.63, 2.83, 2.15, 1.74, 0.554, 0.157, 0.167},
    {0.985, 1.72, 2.34, 2.69, 2.81, 2.11, 1.78, 0.592, 0.152, 0.101},
    {0.95, 1.72, 2.57, 3.44, 3.84, 3.89, 2.91, 0.976, 0.135, 0.114},
    {0.819, 1.64, 2.93, 4.75, 6.02, 6.93, 5.2, 1.83, 0.347, 0.191},
    {0.731, 1.58, 3.3, 5.95, 7.81, 8.32, 6.93, 3.83, 1.47, 0.875},
    {0.77, 1.75, 3.74, 6.67, 8.76, 9.41, 8.19, 5.78, 3.32, 2.11},
    {1.08, 2.17, 4.24, 7.13, 9.2, 10.3, 9.03, 6.87, 4.65, 3.01},
    {1.43, 2.49, 4.31, 7, 9.14, 10.6, 9.34, 7.6, 5.86, 3.64},
    {1.5, 2.68, 4.32, 6.75, 8.78, 10.6, 9.05, 7.65, 6.27, 4.07},
    {1.73, 2.91, 4.33, 6.67, 8.73, 10.6, 8.5, 7.54, 6.63, 4.17}},
   {{1.43, 3.07, 5.22, 7.54, 9.78, 10.4, 10.1, 7.26, 3.61, 1.69},
    {0.989, 2.69, 4.76, 7.19, 9.44, 9.94, 9.5, 6.74, 3.24, 1.52},
    {0.908, 2.23, 4.11, 6.48, 8.74, 9.41, 8.58, 5.8, 2.66, 1.3},
    {0.923, 1.99, 3.61, 5.83, 7.84, 8.6, 7.55, 4.57, 1.87, 0.98},
    {0.933, 1.9, 3.31, 5.28, 7.1, 7.84, 6.44, 3.18, 1.1, 0.642},
    {0.982, 1.88, 3.1, 4.76, 6.16, 6.57, 5.16, 2.04, 0.598, 0.33},
    {1.02, 1.82, 2.88, 4.12, 4.71, 4.54, 3.03, 1.22, 0.268, 0.174},
    {0.992, 1.7, 2.51, 3.33, 3.62, 2.87, 2.05, 0.705, 0.161, 0.169},
    {0.969, 1.69, 2.2, 2.62, 2.84, 2.13, 1.78, 0.529, 0.146, 0.186},
    {0.945, 1.69, 2.27, 2.64, 2.83, 2.2, 1.83, 0.561, 0.139, 0.121},
    {0.922, 1.65, 2.48, 3.33, 3.83, 4.09, 2.92, 0.973, 0.117, 0.135},
    {0.886, 1.59, 2.66, 4.26, 5.51, 6.57, 5.09, 1.79, 0.342, 0.194},
    {0.786, 1.5, 2.78, 5.01, 6.8, 7.83, 6.65, 3.62, 1.45, 1},
    {0.745, 1.55, 3.05, 5.49, 7.44, 8.6, 7.8, 5.28, 2.95, 2.12},
    {0.938, 1.76, 3.4, 5.82, 7.8, 9.04, 8.43, 6.15, 3.85, 2.82},
    {0.999, 2, 3.66, 5.95, 7.94, 9.27, 8.8, 6.93, 4.87, 3.54},
    {1.13, 2.23, 3.86, 5.82, 7.65, 9, 8.82, 7.17, 5.72, 4.08},
    {1.23, 2.33, 3.94, 5.74, 7.48, 8.9, 8.84, 7.35, 6.3, 4.42}},
   {{1.55, 3.2, 6.25, 10, 12.9, 12.9, 11.9, 7.96, 3.96, 1.75},
    {1.32, 3.27, 6.32, 9.99, 12.7, 12.4, 11.3, 7.51, 3.66, 1.58},
    {1.25, 3.08, 5.77, 8.71, 11.2, 11.2, 9.84, 6.52, 3.23, 1.5},
    {1.18, 2.59, 4.76, 7.46, 9.61, 9.66, 8.42, 5.06, 2.25, 1.09},
    {1.09, 2.24, 3.99, 6.4, 8.33, 8.54, 7.08, 3.69, 1.36, 0.727},
    {1.06, 2.07, 3.52, 5.52, 7.06, 7.26, 5.83, 2.46, 0.732, 0.409},
    {1.07, 1.91, 3.09, 4.63, 5.21, 4.9, 3.68, 1.43, 0.326, 0.198},
    {1.03, 1.74, 2.63, 3.54, 3.78, 2.89, 2.09, 0.743, 0.175, 0.12},
    {0.959, 1.71, 2.32, 2.77, 2.99, 2.24, 1.76, 0.519, 0.149, 0.172},
    {0.931, 1.68, 2.32, 2.74, 2.99, 2.46, 1.88, 0.578, 0.156, 0.157},
    {0.933, 1.66, 2.49, 3.42, 3.99, 4.12, 2.93, 1.02, 0.181, 0.138},
    {0.952, 1.64, 2.6, 4, 5.15, 6.07, 4.84, 1.78, 0.407, 0.286},
    {0.84, 1.54, 2.68, 4.47, 5.97, 7.13, 6.23, 3.25, 1.38, 1.02},
    {0.714, 1.44, 2.73, 4.68, 6.28, 7.68, 7.21, 4.82, 2.55, 1.96},
    {0.838, 1.57, 2.96, 4.93, 6.55, 8.08, 7.74, 5.77, 3.32, 2.52},
    {0.823, 1.65, 3.11, 5.09, 6.89, 8.36, 8.31, 6.59, 4.1, 3.04},
    {0.886, 1.83, 3.42, 5.33, 6.92, 8.36, 8.63, 7.21, 4.82, 3.46},
    {1.07, 2.12, 3.74, 5.54, 6.98, 8.41, 8.75, 7.41, 5.16, 3.62}},
   {{1.13, 2.59, 7.49, 13.5, 15.4, 12.9, 11.3, 8.62, 4.18, 1.63},
    {0.973, 2.79, 7.23, 12.8, 15.2, 13.3, 11.6, 8.42, 4.06, 1.57},
    {1.46, 3.44, 6.78, 10.4, 12.7, 12.1, 10.5, 7.04, 3.59, 1.63},
    {1.52, 3.38, 6.04, 9.08, 11, 10.3, 8.9, 5.7, 2.77, 1.37},
    {1.32, 2.65, 4.75, 7.49, 9.32, 8.89, 7.42, 4.27, 1.7, 0.88},
    {1.19, 2.2, 3.88, 6.36, 8.03, 7.81, 6.19, 2.94, 0.948, 0.527},
    {1.14, 1.96, 3.28, 5.26, 6.12, 5.8, 4.47, 1.66, 0.388, 0.229},
    {1.07, 1.82, 2.82, 3.92, 4.03, 3.15, 2.31, 0.871, 0.183, 0.0972},
    {0.978, 1.77, 2.53, 3.04, 3.1, 2.36, 1.76, 0.575, 0.16, 0.126},
    {0.962, 1.72, 2.49, 3.01, 3.22, 2.72, 2, 0.716, 0.162, 0.183},
    {0.968, 1.7, 2.6, 3.57, 4.28, 4.35, 3.09, 1.2, 0.262, 0.18},
    {0.977, 1.68, 2.71, 4.03, 5.17, 6.01, 4.81, 1.81, 0.473, 0.343},
    {0.819, 1.58, 2.75, 4.37, 5.8, 6.9, 5.96, 2.95, 1.19, 0.964},
    {0.672, 1.44, 2.69, 4.42, 5.92, 7.26, 6.79, 4.32, 2.22, 1.83},
    {0.783, 1.42, 2.65, 4.45, 6.04, 7.57, 7.39, 5.4, 2.94, 2.25},
    {0.757, 1.43, 2.7, 4.54, 6.14, 7.65, 7.51, 5.95, 3.42, 2.39},
    {0.758, 1.57, 3.04, 4.88, 6.24, 7.85, 7.58, 6.35, 3.81, 2.52},
    {0.835, 1.72, 3.35, 5.24, 6.5, 8.1, 7.67, 6.51, 4, 2.6}},
   {{1.5, 2.12, 7.64, 10.5, 5.59, 2.14, 2.2, 3.5, 4.71, 3.26},
    {1.32, 2.14, 7.23, 12, 9.3, 5.3, 5.11, 5.37, 5.12, 3.05},
    {1.53, 2.92, 6.9, 11.9, 13.5, 11.3, 9.91, 7.18, 4.75, 2.65},
    {1.66, 3.48, 6.25, 9.53, 11.3, 10.3, 9.01, 5.76, 2.99, 1.67},
    {1.54, 3.03, 5.21, 8.03, 9.66, 8.98, 7.5, 4.64, 2.11, 1.13},
    {1.32, 2.39, 4.03, 6.74, 8.52, 8.05, 6.4, 3.48, 1.2, 0.639},
    {1.17, 2.08, 3.35, 5.52, 6.86, 6.54, 5.08, 1.97, 0.462, 0.217},
    {1.07, 1.92, 3.01, 4.24, 4.47, 3.77, 2.77, 1.07, 0.213, 0.0694},
    {0.992, 1.88, 2.76, 3.39, 3.32, 2.52, 1.8, 0.713, 0.192, 0.136},
    {0.992, 1.8, 2.63, 3.34, 3.46, 2.95, 2.09, 0.9, 0.242, 0.194},
    {0.987, 1.77, 2.67, 3.64, 4.37, 4.36, 3, 1.27, 0.354, 0.229},
    {0.979, 1.74, 2.77, 3.99, 5.12, 5.75, 4.53, 1.75, 0.555, 0.302},
    {0.832, 1.6, 2.78, 4.32, 5.53, 6.67, 5.69, 2.59, 0.982, 0.66},
    {0.696, 1.41, 2.64, 4.31, 5.65, 7.14, 6.56, 3.8, 1.75, 1.41},
    {0.788, 1.36, 2.59, 4.3, 5.73, 7.35, 7.04, 4.82, 2.41, 1.8},
    {0.761, 1.43, 2.61, 4.28, 5.64, 7.37, 7.11, 5.37, 2.68, 1.9},
    {0.701, 1.44, 2.82, 4.64, 5.76, 7.63, 7.07, 5.74, 2.98, 1.88},
    {0.763, 1.5, 2.95, 4.97, 6.08, 7.88, 7.12, 5.98, 3.21, 1.91}},
   {{3.58, 2.59, 6.49, 5.84, 1.63, 0.282, 0.647, 0.371, 1.36, 2.33},
    {3.09, 2.38, 6.37, 7.66, 4.06, 1.23, 1.8, 1.65, 2.32, 2.78},
    {2.31, 2.84, 5.58, 9.63, 11, 9.02, 8.2, 6.23, 4.17, 3.08},
    {1.61, 3.16, 5.72, 9.13, 11.4, 10.4, 9.15, 6.18, 3.52, 2.3},
```

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    {1.32, 2.8, 4.79, 7.44, 9.43, 8.83, 7.41, 4.9, 2.38, 1.38},
    {1.14, 2.36, 3.94, 6.41, 8.38, 8.17, 6.53, 3.76, 1.31, 0.656},
    {1.05, 2.1, 3.36, 5.45, 7.07, 6.98, 5.44, 2.22, 0.52, 0.176},
    {1.02, 2, 3.05, 4.33, 4.74, 4.21, 3.2, 1.26, 0.277, 0.0705},
    {1.01, 1.96, 2.9, 3.53, 3.46, 2.69, 1.89, 0.859, 0.254, 0.12},
    {1.01, 1.86, 2.7, 3.46, 3.59, 3.03, 2.14, 1, 0.34, 0.199},
    {1.02, 1.81, 2.67, 3.68, 4.39, 4.3, 2.93, 1.35, 0.477, 0.25},
    {0.991, 1.79, 2.82, 4.05, 5.08, 5.5, 4.21, 1.74, 0.605, 0.259},
    {0.844, 1.73, 2.87, 4.38, 5.49, 6.47, 5.5, 2.44, 0.85, 0.422},
    {0.729, 1.57, 2.76, 4.43, 5.73, 7.13, 6.43, 3.52, 1.38, 0.913},
    {0.819, 1.46, 2.69, 4.45, 5.92, 7.47, 7.05, 4.52, 2, 1.4},
    {0.783, 1.47, 2.71, 4.48, 5.92, 7.46, 7.16, 5.08, 2.35, 1.56},
    {0.735, 1.51, 2.96, 4.84, 5.92, 7.77, 7.2, 5.54, 2.56, 1.61},
    {0.8, 1.61, 3.14, 5.2, 6.26, 8.08, 7.27, 5.72, 2.75, 1.62}},
   {{5, 4.43, 5.53, 5.35, 2.33, 0.384, 0.663, 0.164, 0.692, 1.4},
    {3.62, 3.79, 4.77, 5.94, 4.12, 1.36, 1.3, 0.973, 1.37, 1.73},
    {2.11, 2.7, 4.12, 7.14, 9.03, 7.74, 7.12, 5.44, 3.73, 2.6},
    {1.13, 2.32, 4.12, 6.97, 9.86, 9.69, 8.85, 6.22, 3.59, 2.14},
    {0.957, 2.28, 4.11, 6.47, 8.66, 8.78, 7.33, 4.94, 2.44, 1.38},
    {0.881, 2.1, 3.65, 5.94, 7.98, 8.29, 6.69, 3.95, 1.36, 0.672},
    {0.867, 1.96, 3.26, 5.23, 6.94, 7.2, 5.63, 2.41, 0.578, 0.19},
    {0.953, 1.94, 2.98, 4.23, 4.83, 4.52, 3.38, 1.34, 0.293, 0.181},
    {1.01, 1.91, 2.77, 3.35, 3.3, 2.62, 1.99, 0.905, 0.245, 0.107},
    {1.03, 1.81, 2.57, 3.29, 3.43, 2.87, 2.13, 0.988, 0.306, 0.185},
    {1.02, 1.78, 2.58, 3.59, 4.19, 4, 2.72, 1.29, 0.389, 0.224},
    {1.01, 1.84, 2.84, 4.06, 4.9, 5.08, 3.71, 1.64, 0.529, 0.232},
    {0.902, 1.84, 2.98, 4.43, 5.5, 6.28, 5.18, 2.35, 0.734, 0.341},
    {0.785, 1.68, 2.93, 4.67, 5.95, 7.3, 6.52, 3.48, 1.24, 0.754},
    {0.847, 1.62, 2.94, 4.86, 6.38, 7.99, 7.5, 4.64, 1.93, 1.23},
    {0.8, 1.6, 2.94, 4.95, 6.62, 8.16, 7.91, 5.43, 2.43, 1.45},
    {0.82, 1.76, 3.37, 5.47, 6.82, 8.24, 7.73, 5.79, 2.69, 1.5},
    {0.988, 2.05, 3.87, 6.01, 7.18, 8.41, 7.7, 5.93, 2.89, 1.55}},
   {{1.52, 2.7, 3.79, 4.95, 3.8, 1.51, 1.11, 0.784, 1.1, 1.56},
    {1.19, 2.16, 3.34, 4.76, 4.61, 2.93, 2.07, 1.65, 1.63, 1.74},
    {0.804, 1.65, 2.79, 4.63, 6.64, 6.95, 6.68, 5.11, 3.3, 2.09},
    {0.86, 1.8, 3.25, 5.3, 7.91, 8.76, 8.28, 6.01, 3.39, 1.83},
    {0.859, 1.95, 3.54, 5.64, 7.88, 8.55, 7.3, 4.88, 2.3, 1.22},
    {0.809, 1.88, 3.38, 5.45, 7.47, 8.02, 6.69, 3.98, 1.35, 0.646},
    {0.822, 1.81, 3.11, 4.9, 6.62, 6.96, 5.63, 2.47, 0.614, 0.169},
    {0.92, 1.83, 2.8, 3.93, 4.56, 4.4, 3.25, 1.31, 0.295, 0.0587},
    {0.986, 1.83, 2.6, 3.13, 3.08, 2.53, 1.94, 0.886, 0.244, 0.0815},
    {0.997, 1.74, 2.5, 3.16, 3.24, 2.67, 2.05, 0.939, 0.281, 0.147},
    {1.01, 1.75, 2.57, 3.55, 4.1, 3.81, 2.53, 1.21, 0.354, 0.197},
    {1.04, 1.88, 2.9, 4.16, 4.95, 4.96, 3.48, 1.63, 0.502, 0.163},
    {0.967, 1.95, 3.17, 4.72, 5.85, 6.5, 5.34, 2.53, 0.748, 0.303},
    {0.846, 1.83, 3.23, 5.15, 6.62, 7.82, 6.85, 3.79, 1.36, 0.714},
    {0.91, 1.81, 3.35, 5.55, 7.32, 8.55, 7.88, 5.03, 2.13, 1.1},
    {0.87, 1.94, 3.6, 5.97, 7.98, 9.14, 8.71, 6.04, 2.73, 1.41},
    {1.04, 2.36, 4.22, 6.57, 8.5, 9.53, 9.22, 6.71, 3.2, 1.56},
    {1.36, 2.84, 4.72, 6.94, 8.81, 9.87, 9.59, 7.1, 3.43, 1.65}},
   {{0.704, 1.4, 2.03, 3.08, 4.64, 4.24, 2.55, 1.57, 1.99, 1.91},
    {0.484, 1.38, 2.08, 3.54, 5.11, 4.98, 3.73, 2.57, 2.29, 1.84},
    {0.749, 1.57, 2.63, 4.17, 6.15, 6.97, 6.64, 5.11, 3.35, 1.97},
    {0.864, 1.69, 3.16, 4.87, 7.13, 8.33, 7.87, 5.9, 3.17, 1.56},
    {0.861, 1.79, 3.28, 5.2, 7.29, 8.32, 7.38, 4.9, 2.23, 1.11},
    {0.835, 1.79, 3.19, 4.99, 6.72, 7.58, 6.45, 3.68, 1.25, 0.616},
    {0.847, 1.8, 3.07, 4.66, 6.12, 6.6, 5.21, 2.18, 0.554, 0.21},
    {0.941, 1.78, 2.68, 3.68, 4.28, 4.18, 2.97, 1.15, 0.238, 0.0968},
    {0.98, 1.78, 2.48, 2.99, 2.96, 2.35, 1.88, 0.747, 0.207, 0.105},
    {0.978, 1.74, 2.51, 3.07, 3.12, 2.36, 1.95, 0.777, 0.216, 0.146},
    {1.01, 1.79, 2.63, 3.53, 3.95, 3.47, 2.38, 1.08, 0.265, 0.178},
    {1.06, 1.94, 3.02, 4.43, 5.19, 5.01, 3.68, 1.71, 0.429, 0.14},
    {0.99, 2.02, 3.38, 5.22, 6.56, 6.91, 5.56, 2.75, 0.816, 0.353},
    {0.923, 2.05, 3.66, 5.98, 7.78, 8.5, 7.23, 4.26, 1.67, 0.802},
    {1.08, 2.27, 4.17, 6.8, 8.89, 9.55, 8.59, 5.64, 2.58, 1.2},
    {1.12, 2.5, 4.52, 7.22, 9.76, 10.3, 9.72, 6.79, 3.32, 1.52},
    {1.2, 2.64, 4.81, 7.64, 10.5, 11.4, 10.6, 7.65, 3.87, 1.73},
    {1.4, 2.91, 5.01, 7.75, 10.7, 11.6, 11.1, 8.02, 4.04, 1.8}},
   {{0.75, 1.49, 2.39, 3.39, 4.93, 5.94, 5.03, 2.75, 2.27, 1.78},
    {0.508, 1.52, 2.38, 3.82, 5.34, 6.13, 5.6, 3.31, 2.42, 1.73},
    {0.715, 1.56, 2.7, 4.39, 6.18, 6.96, 7.1, 5.04, 3.01, 1.75},
    {0.813, 1.62, 2.94, 4.65, 6.53, 7.65, 7.52, 5.49, 2.75, 1.41},
    {0.802, 1.68, 2.97, 4.64, 6.37, 7.53, 7.01, 4.56, 1.9, 0.955},
    {0.816, 1.75, 3.01, 4.59, 6.15, 7.06, 6.15, 3.38, 1.11, 0.61},
    {0.867, 1.78, 2.92, 4.35, 5.69, 6.05, 4.73, 1.91, 0.519, 0.269},
    {0.932, 1.7, 2.55, 3.44, 4.03, 3.98, 2.74, 1.08, 0.247, 0.132},
    {0.937, 1.74, 2.51, 3.09, 3.11, 2.34, 1.84, 0.67, 0.189, 0.121},
    {0.942, 1.75, 2.63, 3.3, 3.27, 2.21, 1.87, 0.663, 0.171, 0.147},
    {0.959, 1.8, 2.82, 3.78, 4.03, 3.37, 2.53, 1.04, 0.199, 0.146},
    {1.01, 1.9, 3.13, 4.76, 5.63, 5.6, 4.31, 1.83, 0.367, 0.172},
    {0.989, 2.04, 3.64, 6, 7.62, 7.6, 6, 3.35, 1.05, 0.448},
    {1.02, 2.28, 4.32, 7.19, 9.21, 9.16, 7.64, 4.97, 2.2, 0.948},
    {1.26, 2.77, 5.2, 8.31, 10.5, 10.4, 9.01, 6.37, 3.46, 1.56},
    {1.31, 2.76, 5.23, 8.49, 11.2, 11.3, 10.1, 7.27, 3.98, 1.76},
    {1.26, 2.5, 5.14, 8.85, 12.3, 12.3, 11.2, 8.13, 4.45, 1.97},
    {1.35, 2.49, 5.26, 9.16, 13, 12.8, 11.8, 8.57, 4.72, 2.05}},
   {{0.759, 1.54, 2.54, 4.22, 6.26, 7.44, 7.14, 4.99, 2.84, 1.89},
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  {0.508, 1.55, 2.5, 4.29, 6.29, 7.29, 7.07, 5.03, 2.77, 1.74},
  {0.699, 1.56, 2.62, 4.17, 6.08, 7.38, 7.04, 5.17, 2.81, 1.65},
  {0.778, 1.5, 2.65, 4.35, 6.07, 7.28, 6.84, 4.8, 2.28, 1.28},
  {0.772, 1.55, 2.71, 4.3, 5.76, 6.91, 6.2, 3.69, 1.45, 0.837},
  {0.836, 1.67, 2.78, 4.21, 5.56, 6.41, 5.33, 2.47, 0.807, 0.488},
  {0.937, 1.79, 2.78, 4.12, 5.17, 5.38, 3.89, 1.47, 0.392, 0.256},
  {0.97, 1.75, 2.52, 3.39, 3.83, 3.63, 2.48, 0.968, 0.212, 0.198},
  {0.968, 1.74, 2.5, 3.11, 3.2, 2.34, 1.79, 0.629, 0.169, 0.173},
  {0.98, 1.8, 2.69, 3.42, 3.4, 2.18, 1.81, 0.606, 0.164, 0.138},
  {0.975, 1.84, 2.96, 4.08, 4.12, 3.5, 2.79, 1.02, 0.145, 0.133},
  {0.96, 1.94, 3.27, 5.17, 6.26, 6.35, 4.88, 1.91, 0.329, 0.189},
  {0.954, 2.06, 3.8, 6.53, 8.46, 8.32, 6.53, 3.83, 1.32, 0.6},
  {1, 2.34, 4.58, 7.71, 9.68, 9.75, 7.96, 5.45, 2.84, 1.39},
  {1.24, 2.65, 5.14, 8.51, 10.7, 10.6, 8.96, 6.51, 3.83, 1.85},
  {1.34, 2.44, 4.99, 8.63, 11.6, 11.4, 10.1, 7.84, 4.77, 2.24},
  {1.33, 2.1, 4.76, 8.78, 12.2, 11.7, 10.8, 8.68, 5.15, 2.35},
  {1.42, 2.04, 4.68, 8.92, 12.7, 12, 11.2, 8.99, 5.32, 2.33}}
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_hno3_var)
#endif

double clim_hno3(
  double t,
  double lat,
  double p) {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Check pressure... */
  if (p < clim_hno3_ps[0])
    p = clim_hno3_ps[0];
  else if (p > clim_hno3_ps[9])
    p = clim_hno3_ps[9];

  /* Check latitude... */
  if (lat < clim_hno3_lats[0])
    lat = clim_hno3_lats[0];
  else if (lat > clim_hno3_lats[17])
    lat = clim_hno3_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_hno3_secs, 12, sec);
  int ilat = locate_reg(clim_hno3_lats, 18, lat);
  int ip = locate_irr(clim_hno3_ps, 10, p);

  /* Interpolate HNO3 climatology (Froidevaux et al., 2015)... */
  double aux00 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat][ip + 1], p);
  double aux11 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_hno3_lats[ilat], aux00,
              clim_hno3_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_hno3_lats[ilat], aux10,
              clim_hno3_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_hno3_secs[isec], aux00,
              clim_hno3_secs[isec + 1], aux11, sec);

  /* Convert from ppb to ppv... */
  return GSL_MAX(1e-9 * aux00, 0.0);
}

/*****************************************************************************/

static double clim_oh_secs[12] = {
  1209600.00, 3888000.00, 6393600.00,
  9072000.00, 11664000.00, 14342400.00,
  16934400.00, 19612800.00, 22291200.00,
  24883200.00, 27561600.00, 30153600.00
};

```

```
#ifdef _OPENACC
#pragma acc declare copyin(clim_oh_secs)
#endif

static double clim_oh_lats[18] = {
  -85, -75, -65, -55, -45, -35, -25, -15, -5,
  5, 15, 25, 35, 45, 55, 65, 75, 85
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_oh_lats)
#endif

static double clim_oh_ps[34] = {
  0.17501, 0.233347, 0.31113, 0.41484, 0.553119, 0.737493, 0.983323,
  1.3111, 1.74813, 2.33084, 3.10779, 4.14372, 5.52496, 7.36661, 9.82214,
  13.0962, 17.4616, 23.2821, 31.0428, 41.3904, 55.1872, 73.583, 98.1107,
  130.814, 174.419, 232.559, 310.078, 413.438, 551.25, 735, 789.809,
  848.705, 911.993, 980
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_oh_ps)
#endif

static double clim_oh_var[12][18][34] = {
  {{6.422, 6.418, 7.221, 8.409, 9.768, 11.22, 12.65, 13.68, 14.03,
    13.06, 11.01, 8.791, 7.096, 6.025, 5.135, 4.057, 2.791, 1.902,
    1.318, 0.9553, 0.7083, 0.5542, 0.5145, 0.5485, 0.6292, 0.5982, 1.716,
    1.111, 0.9802, 0.6707, 0.5235, 0.4476, 0.3783, 0.3091},
   {6.311, 6.394, 7.2, 8.349, 9.664, 11.02, 12.21, 13.06, 13.28,
    12.42, 10.59, 8.552, 6.944, 5.862, 4.948, 3.826, 2.689, 1.873,
    1.302, 0.9316, 0.7053, 0.5634, 0.508, 0.5207, 0.6166, 0.6789, 1.682,
    1.218, 1.079, 0.7621, 0.6662, 0.5778, 0.4875, 0.3997},
   {5.851, 5.827, 6.393, 7.294, 8.322, 9.415, 10.46, 11.24, 11.59,
    11.13, 9.754, 7.97, 6.417, 5.331, 4.468, 3.512, 2.581, 1.855,
    1.336, 0.9811, 0.756, 0.6328, 0.6011, 0.6202, 0.7603, 0.8883, 1.303,
    1.124, 1.118, 0.9428, 0.8655, 0.8156, 0.7602, 0.6805},
   {5.276, 5.158, 5.66, 6.463, 7.419, 8.488, 9.563, 10.45, 10.94,
    10.65, 9.465, 7.762, 6.204, 5.074, 4.209, 3.324, 2.511, 1.865,
    1.386, 1.066, 0.8521, 0.723, 0.6997, 0.7492, 0.8705, 0.8088, 1.22,
    1.192, 1.298, 1.096, 1.037, 0.9589, 0.8856, 0.7726},
   {5.06, 4.919, 5.379, 6.142, 7.095, 8.156, 9.18, 10.09, 10.62,
    10.33, 9.123, 7.479, 5.967, 4.858, 3.987, 3.097, 2.342, 1.743,
    1.323, 1.044, 0.8598, 0.7596, 0.7701, 0.7858, 0.8741, 1.256, 1.266,
    1.418, 1.594, 1.247, 1.169, 1.111, 1.054, 0.9141},
   {4.921, 4.759, 5.188, 5.936, 6.847, 7.871, 8.903, 9.805, 10.31,
    10, 8.818, 7.223, 5.757, 4.66, 3.75, 2.831, 2.1, 1.579,
    1.243, 1.017, 0.8801, 0.8193, 0.9409, 1.131, 0.7313, 1.201, 1.383,
    1.643, 1.751, 1.494, 1.499, 1.647, 1.934, 2.147},
   {4.665, 4.507, 4.947, 5.652, 6.549, 7.573, 8.609, 9.499, 9.985,
    9.664, 8.478, 6.944, 5.519, 4.407, 3.511, 2.595, 1.917, 1.46,
    1.172, 1.009, 0.9372, 0.9439, 1.047, 1.219, 0.5712, 1.032, 1.342,
    1.716, 1.846, 1.551, 1.55, 1.686, 2.006, 2.235},
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    9.264, 8.037, 6.532, 5.141, 4.037, 3.148, 2.319, 1.715, 1.318,
    1.078, 0.9647, 0.9327, 0.9604, 1.023, 0.4157, 0.4762, 1.04, 1.589,
    2.093, 1.957, 1.557, 1.52, 1.565, 1.776, 1.904},
   {4.154, 3.996, 4.347, 5.004, 5.854, 6.869, 7.929, 8.837, 9.23,
    8.708, 7.447, 6.024, 4.761, 3.742, 2.898, 2.096, 1.55, 1.191,
    0.9749, 0.8889, 0.8745, 0.9004, 0.9648, 0.36, 0.4423, 0.973, 1.571,
    2.086, 1.971, 1.569, 1.537, 1.567, 1.74, 1.811},
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    8.07, 6.863, 5.56, 4.438, 3.522, 2.736, 1.971, 1.441, 1.098,
    0.8945, 0.8155, 0.7965, 0.8013, 0.8582, 1.119, 0.4076, 0.8805, 1.446,
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    6.472, 5.463, 4.466, 3.649, 2.997, 2.396, 1.785, 1.289, 0.9304,
    0.7095, 0.5806, 0.5049, 0.4639, 0.4899, 0.5149, 0.5445, 0.5185, 0.7495,
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    0.5514, 0.4313, 0.3505, 0.2957, 0.2688, 0.2455, 0.232, 0.3565, 0.4017,
    0.5063, 0.6618, 0.7621, 0.7915, 0.8372, 0.923, 0.9218},
   {2.548, 2.725, 3.135, 3.637, 4.165, 4.666, 5.013, 5.056, 4.72,
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    0.3748, 0.2897, 0.2303, 0.19, 0.1645, 0.1431, 0.1215, 0.09467, 0.1442,
    0.1847, 0.2368, 0.2463, 0.2387, 0.2459, 0.2706, 0.2751},
   {1.946, 2.135, 2.46, 2.831, 3.203, 3.504, 3.584, 3.37, 2.921,
    2.357, 1.865, 1.551, 1.392, 1.165, 0.8443, 0.5497, 0.3686, 0.2632,
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    3.59e-13}},
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   {3.743, 3.817, 4.311, 4.948, 5.666, 6.417, 7.077, 7.528, 7.551,
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    8.272, 7.179, 5.922, 4.767, 3.814, 2.996, 2.187, 1.599, 1.203,
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   {4.213, 4.111, 4.507, 5.117, 5.882, 6.773, 7.67, 8.464, 8.829,
    8.438, 7.378, 6.088, 4.84, 3.802, 2.915, 2.114, 1.561, 1.195,
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    {1.982, 2.163, 2.522, 2.962, 3.444, 3.894, 4.12, 3.996, 3.538,
     2.915, 2.39, 2.044, 1.761, 1.418, 1.026, 0.6684, 0.4452, 0.3147,
     0.2354, 0.1814, 0.1474, 0.1272, 0.1136, 0.1042, 0.09334, 0.07244, 0.09453,
     0.1067, 0.1323, 0.1309, 0.1255, 0.1235, 0.1251, 0.1207},
    {1.313, 1.48, 1.706, 1.932, 2.113, 2.193, 2.081, 1.804, 1.487,
     1.196, 0.9808, 0.8365, 0.6791, 0.4931, 0.3304, 0.2112, 0.1439, 0.1054,
     0.08052, 0.06314, 0.05248, 0.04667, 0.0419, 0.03731, 0.03192, 0.02135,
     0.01682,
     0.0156, 0.01767, 0.01723, 0.0161, 0.01526, 0.0148, 0.01411},
    {0.242, 0.2311, 0.2162, 0.1962, 0.1752, 0.1604, 0.1387, 0.1112, 0.08183,
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    5.901e-05},
   {0.0001232, 0.0001559, 0.0001539, 0.0001693, 0.0002134, 0.0002031,
    0.0001037, 1.126e-05, 5.382e-06,
    1.867e-06, 5.983e-07, 2.464e-07, 1.576e-07, 1.322e-07, 1.312e-07,
    1.319e-07, 3.921e-07, 3.583e-06,
    3.815e-05, 6.754e-05, 0.0001004, 0.0002135, 0.0004217, 0.0007681,
    0.001524, 0.0004274, 0.000876,
    2.698e-05, 1.328e-12, 1.445e-13, 9.798e-14, 8.583e-14, 9.786e-14,
    1.774e-13}},
  {{6.595, 6.532, 7.313, 8.453, 9.864, 11.47, 13.06, 14.28, 14.67,
    13.68, 11.56, 9.275, 7.452, 6.201, 5.275, 4.16, 2.898, 2.003,
    1.4, 1.04, 0.7754, 0.7071, 0.7598, 0.799, 0.825, 0.9217, 1.851,
    1.254, 1.138, 0.8159, 0.6311, 0.5427, 0.4614, 0.3814},
   {6.516, 6.556, 7.327, 8.526, 9.924, 11.42, 12.85, 13.82, 14.03,
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    1.344, 0.9685, 0.7276, 0.6364, 0.6746, 0.7239, 0.786, 0.9333, 1.793,
    1.344, 1.234, 0.8885, 0.7949, 0.6932, 0.5878, 0.4871},
   {6.179, 6.202, 6.853, 7.807, 8.924, 10.13, 11.21, 12.01, 12.29,
    11.63, 10.05, 8.152, 6.536, 5.386, 4.503, 3.473, 2.521, 1.809,
    1.273, 0.9058, 0.6837, 0.5774, 0.5746, 0.6269, 0.7726, 0.9434, 1.275,
    1.102, 1.148, 0.9922, 0.9195, 0.8713, 0.8162, 0.7358},
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    10.96, 9.696, 7.981, 6.412, 5.281, 4.41, 3.469, 2.606, 1.892,
    1.37, 1.034, 0.8087, 0.6766, 0.6565, 0.6981, 0.7901, 0.6904, 1.01,
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    1.431, 1.09, 0.869, 0.7456, 0.7339, 0.7833, 0.8079, 1.059, 1.104,
    1.303, 1.515, 1.253, 1.185, 1.131, 1.076, 0.9437},
   {4.936, 4.795, 5.272, 5.985, 6.878, 7.91, 8.989, 9.922, 10.53,
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    1.402, 1.087, 0.8859, 0.7846, 0.8226, 0.8854, 0.9635, 1.037, 1.251,
    1.527, 1.706, 1.5, 1.503, 1.644, 1.914, 2.113},
   {4.796, 4.617, 5.024, 5.703, 6.591, 7.617, 8.632, 9.544, 10.07,
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    1.216, 1.017, 0.9039, 0.8702, 0.9836, 1.21, 0.6125, 1.009, 1.311,
    1.688, 1.862, 1.575, 1.568, 1.696, 2.001, 2.214},
   {4.522, 4.356, 4.742, 5.465, 6.36, 7.357, 8.359, 9.269, 9.706,
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    0.9637, 0.8579, 0.8414, 0.8686, 0.8189, 1.154, 0.4693, 0.9934, 1.568,
    2.075, 1.962, 1.563, 1.524, 1.545, 1.704, 1.786},
   {3.87, 3.761, 4.135, 4.74, 5.547, 6.523, 7.533, 8.287, 8.542,
    7.978, 6.743, 5.463, 4.36, 3.491, 2.739, 1.993, 1.453, 1.095,
    0.8767, 0.7822, 0.7664, 0.777, 0.8145, 1.109, 0.4094, 0.8854, 1.413,
    1.91, 1.872, 1.47, 1.421, 1.428, 1.538, 1.583},
   {3.565, 3.517, 3.908, 4.525, 5.299, 6.159, 6.982, 7.581, 7.734,
    7.15, 6.028, 4.918, 3.993, 3.242, 2.541, 1.833, 1.321, 0.9862,
    0.7851, 0.6877, 0.6504, 0.6409, 0.6657, 0.7916, 0.3852, 0.627, 0.8774,
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   {3.27, 3.307, 3.718, 4.324, 5.008, 5.72, 6.391, 6.82, 6.844,
    6.25, 5.256, 4.321, 3.562, 2.929, 2.309, 1.67, 1.183, 0.8581,
    0.6613, 0.5437, 0.4817, 0.4549, 0.4828, 0.4971, 0.343, 0.4517, 0.5928,
    0.7482, 1.114, 1.156, 1.127, 1.142, 1.266, 1.325},
   {2.881, 2.972, 3.365, 3.885, 4.479, 5.095, 5.612, 5.869, 5.739,
    5.109, 4.233, 3.497, 2.928, 2.45, 1.923, 1.37, 0.937, 0.6588,
    0.4974, 0.3913, 0.3216, 0.2799, 0.263, 0.2476, 0.2702, 0.3664, 0.3897,
    0.4754, 0.6181, 0.6968, 0.7144, 0.7507, 0.8199, 0.8256},
   {2.352, 2.522, 2.914, 3.377, 3.888, 4.391, 4.73, 4.773, 4.456,
    3.814, 3.103, 2.576, 2.19, 1.824, 1.372, 0.9129, 0.606, 0.4281,
    0.3241, 0.25, 0.1992, 0.1685, 0.1489, 0.1316, 0.116, 0.1598, 0.1448,
    0.1805, 0.2224, 0.2379, 0.2369, 0.2454, 0.2679, 0.2718},
   {1.666, 1.833, 2.135, 2.486, 2.847, 3.14, 3.202, 3.006, 2.612,
    2.127, 1.726, 1.486, 1.277, 0.9733, 0.6654, 0.4233, 0.2852, 0.2051,
    0.1537, 0.1174, 0.09422, 0.08017, 0.06975, 0.06009, 0.04775, 0.03319,
    0.03371,
    0.03896, 0.04544, 0.04203, 0.03927, 0.03814, 0.03917, 0.04012},
   {0.8975, 0.9719, 1.03, 1.066, 1.034, 0.9374, 0.7957, 0.662, 0.5656,
    0.4856, 0.4141, 0.3239, 0.2283, 0.1478, 0.09439, 0.06056, 0.04188,
    0.03179,
    0.02625, 0.02293, 0.02134, 0.01999, 0.01796, 0.01508, 0.01136, 0.006243,
    0.005399,
    0.002554, 0.002671, 0.002877, 0.002693, 0.002456, 0.002169, 0.001592},
   {0.005568, 0.003081, 0.001936, 0.001388, 0.001138, 0.0009141, 0.0003913,
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    9.014e-06, 5.819e-06, 3.047e-06, 1.303e-06, 5.602e-07, 2.183e-07,
    1.757e-07, 3.825e-07, 2.566e-06,
    1.334e-05, 1.436e-05, 1.976e-05, 7.261e-05, 0.0002657, 0.0005962,
    0.001653, 0.0002773, 0.0008521,
    1.309e-06, 3.72e-14, 2.315e-16, 2.404e-15, 7.283e-17, 5.816e-17,
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    1.165e-16},
   {5.606e-05, 7.174e-05, 7.065e-05, 8.779e-05, 0.0001175, 0.0001418,
    6.181e-05, 7.462e-06, 8.135e-06,
    6.922e-06, 3.21e-06, 1.063e-06, 3.185e-07, 7.307e-08, 1.298e-08,
    1.751e-08, 6.792e-08, 5.277e-07,
    7.612e-06, 1.832e-05, 4.78e-05, 0.0001019, 0.0001703, 0.0003801, 0.001213,
    0.0002105, 0.0006011,
    2.875e-06, 7.798e-13, 1.214e-13, 8.329e-14, 7.553e-14, 1.014e-13,
    1.901e-13}}
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_oh_var)
#endif

double clim_oh(
  double t,
  double lat,
  double p) {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Check pressure... */
  if (p < clim_oh_ps[0])
    p = clim_oh_ps[0];
  else if (p > clim_oh_ps[33])
    p = clim_oh_ps[33];

  /* Check latitude... */
  if (lat < clim_oh_lats[0])
    lat = clim_oh_lats[0];
  else if (lat > clim_oh_lats[17])
    lat = clim_oh_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_oh_secs, 12, sec);
  int ilat = locate_reg(clim_oh_lats, 18, lat);
  int ip = locate_irr(clim_oh_ps, 34, p);

  /* Interpolate OH climatology (Pommrich et al., 2014)... */
  double aux00 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat][ip + 1], p);
  double aux11 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_oh_lats[ilat], aux00, clim_oh_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_oh_lats[ilat], aux10, clim_oh_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_oh_secs[isec], aux00, clim_oh_secs[isec + 1], aux11, sec);
  return GSL_MAX(1e6 * aux00, 0.0);
}

/*****************************************************************************/

static double clim_tropo_secs[12] = {
  1209600.00, 3888000.00, 6393600.00,
  9072000.00, 11664000.00, 14342400.00,
  16934400.00, 19612800.00, 22291200.00,
  24883200.00, 27561600.00, 30153600.00
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_tropo_secs)
#endif

static double clim_tropo_lats[73]
  = { -90, -87.5, -85, -82.5, -80, -77.5, -75, -72.5, -70, -67.5,
  -65, -62.5, -60, -57.5, -55, -52.5, -50, -47.5, -45, -42.5,
  -40, -37.5, -35, -32.5, -30, -27.5, -25, -22.5, -20, -17.5,
  -15, -12.5, -10, -7.5, -5, -2.5, 0, 2.5, 5, 7.5, 10, 12.5,
  15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5, 40, 42.5,
  45, 47.5, 50, 52.5, 55, 57.5, 60, 62.5, 65, 67.5, 70, 72.5,
  75, 77.5, 80, 82.5, 85, 87.5, 90
};
```

```
#ifdef _OPENACC
#pragma acc declare copyin(clim_tropo_lats)
#endif

static double clim_tropo_tps[12][73]
  = { {324.1, 325.6, 325, 324.3, 322.5, 319.7, 314, 307.2, 301.8, 299.6,
       297.1, 292.2, 285.6, 276.1, 264, 248.9, 231.9, 213.5, 194.4,
       175.3, 157, 140.4, 126.7, 116.3, 109.5, 105.4, 103, 101.4, 100.4,
       99.69, 99.19, 98.84, 98.56, 98.39, 98.39, 98.42, 98.44, 98.54,
       98.68, 98.81, 98.89, 98.96, 99.12, 99.65, 101.4, 105.4, 113.5, 128,
       152.1, 184.7, 214, 234.1, 247.3, 255.8, 262.6, 267.7, 271.7, 275,
       277.2, 279, 280.1, 280.4, 280.6, 280.1, 279.3, 278.3, 276.8, 275.8,
       275.3, 275.6, 275.4, 274.1, 273.5},
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 150.3, 135, 122.8, 113.9, 108.2, 104.7, 102.5, 101.1, 100.2, 99.42,
 98.88, 98.52, 98.25, 98.09, 98.07, 98.1, 98.12, 98.2, 98.25, 98.27,
 98.26, 98.27, 98.36, 98.79, 100.2, 104.2, 113.7, 131.2, 159.5, 193,
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 287.5, 286.2, 285.8},
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 161.7, 146.4, 132.2, 120.6, 112.3, 107.2, 104.3, 102.4, 101.3,
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 195.5, 183.3, 169.7, 154.7, 138.7, 124.1, 113.6, 107.8, 104.7,
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 99.94, 100.2, 100.5, 100.9, 101.4, 102.1, 103.4, 107, 115.2, 129.1,
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 102.4, 103, 103.8, 104.9, 106.8, 110.1, 115.6, 124, 135.2, 148.9,
 165.2, 181.3, 198, 211.8, 223.5, 233.8, 242.9, 251.5, 259, 266.2,
 273.1, 279.2, 286.2, 292.8, 299.6, 306, 311.1, 315.5, 318.8, 322.6,
 325.3, 325.8, 325.8},
{220.1, 218.1, 210.8, 207.2, 207.6, 210.5, 211.4, 213.5, 217.3,
 222.4, 227.9, 232.8, 237.4, 240.8, 242.8, 243, 241.5, 238.6, 234.2,
 228.5, 221, 210.7, 195.1, 172.9, 147.8, 127.6, 115.6, 109.9, 107.1,
 105.7, 105, 104.8, 104.8, 104.9, 105, 105.1, 105.3, 105.5, 105.8,
 106.4, 107, 107.6, 108.1, 108.8, 110, 111.8, 114.2, 117.4, 121.6,
 127.9, 137.3, 151.2, 169.5, 189, 205.8, 218.9, 229.1, 237.8, 245,
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 233.9, 222.6, 203.7, 177, 149.5, 129.7, 119, 114, 111.7, 110.7,
 110.3, 110.3, 110.6, 110.9, 111.1, 111.3, 111.5, 111.6, 111.9,
 112.2, 112.5, 112.6, 112.8, 113, 113.4, 114, 115.1, 116.5, 118.3,
 120.9, 124.4, 130.2, 139.4, 154.6, 173.8, 193.1, 208.1, 220.4,
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 112.4, 114.2, 116.9, 121.1, 127.9, 139.3, 155.2, 173.6, 190.7,
 206.1, 220.1, 232.3, 243, 251.8, 259.2, 265.7, 270.6, 275.3,
 279.3, 283.3, 286.9, 289.7, 292.8, 296.1, 300.5, 303.9, 304.8,
 305.1},
```

```
{241.5, 239.6, 236.8, 237.4, 239.4, 242.3, 244.2, 246.4, 249.2,
 253.6, 258.6, 262.7, 264.8, 264.2, 260.6, 254.1, 245.5, 235.3,
 223.9, 211.7, 198.3, 183.1, 165.6, 147.1, 130.5, 118.7, 111.9,
 108.1, 105.8, 104.3, 103.4, 102.8, 102.5, 102.4, 102.5, 102.5,
 102.5, 102.7, 103.1, 103.8, 104.6, 105.4, 106.1, 107, 108.2,
 109.9, 112.8, 117.5, 126, 140.4, 161, 181.9, 201.2, 216.8, 230.4,
 241.8, 251.4, 259.9, 266.9, 272.8, 277.4, 280.4, 282.9, 284.6,
 286.1, 287.4, 288.3, 289.5, 290.9, 294.2, 296.9, 297.5, 297.6},
{301.2, 300.3, 296.6, 295.4, 295, 294.3, 291.2, 287.4, 284.9, 284.7,
 284.1, 281.5, 277.1, 270.4, 261.7, 250.6, 237.6, 223.1, 207.9, 192,
 175.8, 158.8, 142.1, 127.6, 116.8, 109.9, 106, 103.6, 102.1, 101.1,
 100.4, 99.96, 99.6, 99.37, 99.32, 99.32, 99.31, 99.46, 99.77, 100.2,
 100.7, 101.3, 101.8, 102.7, 104.1, 106.8, 111.9, 121, 136.7, 160,
 186.9, 209.9, 228.1, 241.2, 251.5, 259.5, 265.7, 270.9, 274.8, 278,
 280.3, 281.8, 283, 283.3, 283.7, 283.8, 283, 282.2, 281.2, 281.4,
 281.7, 281.1, 281.2}
};

#ifdef _OPENACC
#pragma acc declare copyin(clim_tropo_tps)
#endif

double clim_tropo(
  double t,
  double lat) {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Get indices... */
  int isec = locate_irr(clim_tropo_secs, 12, sec);
  int ilat = locate_reg(clim_tropo_lats, 73, lat);

  /* Interpolate tropopause data (NCEP/NCAR Reanalysis 1)... */
  double p0 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec][ilat + 1], lat);
  double p1 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec + 1][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec + 1][ilat + 1], lat);
  return LIN(clim_tropo_secs[isec], p0, clim_tropo_secs[isec + 1], p1, sec);
}

/*****************************************************************************/

void day2doy(
  int year,
  int mon,
  int day,
  int *doy) {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d0l[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  /* Get day of year... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0))
    *doy = d0l[mon - 1] + day - 1;
  else
    *doy = d0[mon - 1] + day - 1;
}

/*****************************************************************************/

void doy2day(
  int year,
  int doy,
  int *mon,
  int *day) {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d0l[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  int i;

  /* Get month and day... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0)) {
    for (i = 11; i > 0; i--)
      if (d0l[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d0l[i] + 1;
```

```
  } else {
    for (i = 11; i > 0; i--)
      if (d0[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d0[i] + 1;
  }
}

/*****************************************************************************/

void geo2cart(
  double z,
  double lon,
  double lat,
  double *x) {

  double radius = z + RE;
  x[0] = radius * cos(lat / 180. * M_PI) * cos(lon / 180. * M_PI);
  x[1] = radius * cos(lat / 180. * M_PI) * sin(lon / 180. * M_PI);
  x[2] = radius * sin(lat / 180. * M_PI);
}

/*****************************************************************************/

void get_met(
  ctl_t * ctl,
  double t,
  met_t ** met0,
  met_t ** met1) {

  static int init;

  met_t *mets;

  char cachefile[LEN], cmd[2 * LEN], filename[LEN];

  /* Set timer... */
  SELECT_TIMER("GET_MET", "INPUT", NVTX_READ);

  /* Init... */
  if (t == ctl->t_start || !init) {
    init = 1;

    /* Read meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    get_met_help(t + 1.0 * ctl->direction, 1, ctl->metbase, ctl->dt_met,
                 filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
    met_t *met1up = *met1;
#pragma acc update device(met0up[:1],met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + 1.1 * ctl->dt_met * ctl->direction, ctl->direction,
                   ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for forward trajectories... */
  if (t > (*met1)->time) {

    /* Pointer swap... */
    mets = *met1;
    *met1 = *met0;
    *met0 = mets;

    /* Read new meteo data... */
    get_met_help(t, 1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
```

```
    met_t *met1up = *met1;
#pragma acc update device(met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + ctl->dt_met, 1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for backward trajectories... */
  if (t < (*met0)->time) {

    /* Pointer swap... */
    mets = *met1;
    *met1 = *met0;
    *met0 = mets;

    /* Read new meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
#pragma acc update device(met0up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t - ctl->dt_met, -1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Check that grids are consistent... */
  if ((*met0)->nx != (*met1)->nx
      || (*met0)->ny != (*met1)->ny || (*met0)->np != (*met1)->np)
    ERRMSG("Meteo grid dimensions do not match!");
  for (int ix = 0; ix < (*met0)->nx; ix++)
    if (fabs((*met0)->lon[ix] - (*met1)->lon[ix]) > 0.001)
      ERRMSG("Meteo grid longitudes do not match!");
  for (int iy = 0; iy < (*met0)->ny; iy++)
    if (fabs((*met0)->lat[iy] - (*met1)->lat[iy]) > 0.001)
      ERRMSG("Meteo grid latitudes do not match!");
  for (int ip = 0; ip < (*met0)->np; ip++)
    if (fabs((*met0)->p[ip] - (*met1)->p[ip]) > 0.001)
      ERRMSG("Meteo grid pressure levels do not match!");
}

/*****************************************************************************/

void get_met_help(
  double t,
  int direct,
  char *metbase,
  double dt_met,
  char *filename) {

  char repl[LEN];

  double t6, r;

  int year, mon, day, hour, min, sec;

  /* Round time to fixed intervals... */
  if (direct == -1)
    t6 = floor(t / dt_met) * dt_met;
  else
    t6 = ceil(t / dt_met) * dt_met;

  /* Decode time... */
  jsec2time(t6, &year, &mon, &day, &hour, &min, &sec, &r);

  /* Set filename... */
  sprintf(filename, "%s_YYYY_MM_DD_HH.nc", metbase);
  sprintf(repl, "%d", year);
  get_met_replace(filename, "YYYY", repl);
  sprintf(repl, "%02d", mon);
```

```
  get_met_replace(filename, "MM", repl);
  sprintf(repl, "%02d", day);
  get_met_replace(filename, "DD", repl);
  sprintf(repl, "%02d", hour);
  get_met_replace(filename, "HH", repl);
}

/*****************************************************************************/

void get_met_replace(
  char *orig,
  char *search,
  char *repl) {

  char buffer[LEN], *ch;

  /* Iterate... */
  for (int i = 0; i < 3; i++) {

    /* Replace sub-string... */
    if (!(ch = strstr(orig, search)))
      return;
    strncpy(buffer, orig, (size_t) (ch - orig));
    buffer[ch - orig] = 0;
    sprintf(buffer + (ch - orig), "%s%s", repl, ch + strlen(search));
    orig[0] = 0;
    strcpy(orig, buffer);
  }
}

/*****************************************************************************/

void intpol_met_space_3d(
  met_t * met,
  float array[EX][EY][EP],
  double p,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init) {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

    /* Get interpolation indices... */
    ci[0] = locate_irr(met->p, met->np, p);
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[0] = (met->p[ci[0] + 1] - p)
      / (met->p[ci[0] + 1] - met->p[ci[0]]);
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Interpolate vertically... */
  double aux00 =
    cw[0] * (array[ci[1]][ci[2]][ci[0]] - array[ci[1]][ci[2]][ci[0] + 1])
    + array[ci[1]][ci[2]][ci[0] + 1];
  double aux01 =
    cw[0] * (array[ci[1]][ci[2] + 1][ci[0]] -
             array[ci[1]][ci[2] + 1][ci[0] + 1])
    + array[ci[1]][ci[2] + 1][ci[0] + 1];
  double aux10 =
    cw[0] * (array[ci[1] + 1][ci[2]][ci[0]] -
             array[ci[1] + 1][ci[2]][ci[0] + 1])
    + array[ci[1] + 1][ci[2]][ci[0] + 1];
  double aux11 =
    cw[0] * (array[ci[1] + 1][ci[2] + 1][ci[0]] -
             array[ci[1] + 1][ci[2] + 1][ci[0] + 1])
    + array[ci[1] + 1][ci[2] + 1][ci[0] + 1];

  /* Interpolate horizontally... */
  aux00 = cw[2] * (aux00 - aux01) + aux01;
  aux11 = cw[2] * (aux10 - aux11) + aux11;
  *var = cw[1] * (aux00 - aux11) + aux11;
}
```

```c

/*****************************************************************************/

void intpol_met_space_2d(
  met_t * met,
  float array[EX][EY],
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init) {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

    /* Get interpolation indices... */
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Set variables... */
  double aux00 = array[ci[1]][ci[2]];
  double aux01 = array[ci[1]][ci[2] + 1];
  double aux10 = array[ci[1] + 1][ci[2]];
  double aux11 = array[ci[1] + 1][ci[2] + 1];

  /* Interpolate horizontally... */
  if (isfinite(aux00) && isfinite(aux01)
      && isfinite(aux10) && isfinite(aux11)) {
    aux00 = cw[2] * (aux00 - aux01) + aux01;
    aux11 = cw[2] * (aux10 - aux11) + aux11;
    *var = cw[1] * (aux00 - aux11) + aux11;
  } else {
    if (cw[2] < 0.5) {
      if (cw[1] < 0.5)
        *var = aux11;
      else
        *var = aux01;
    } else {
      if (cw[1] < 0.5)
        *var = aux10;
      else
        *var = aux00;
    }
  }
}

/*****************************************************************************/

void intpol_met_time_3d(
  met_t * met0,
  float array0[EX][EY][EP],
  met_t * met1,
  float array1[EX][EY][EP],
  double ts,
  double p,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init) {

  double var0, var1, wt;

  /* Spatial interpolation... */
  intpol_met_space_3d(met0, array0, p, lon, lat, &var0, ci, cw, init);
  intpol_met_space_3d(met1, array1, p, lon, lat, &var1, ci, cw, 0);

  /* Get weighting factor... */
  wt = (met1->time - ts) / (met1->time - met0->time);

  /* Interpolate... */
  *var = wt * (var0 - var1) + var1;
}

```

```
/*****************************************************************************/

void intpol_met_time_2d(
  met_t * met0,
  float array0[EX][EY],
  met_t * met1,
  float array1[EX][EY],
  double ts,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init) {

  double var0, var1, wt;

  /* Spatial interpolation... */
  intpol_met_space_2d(met0, array0, lon, lat, &var0, ci, cw, init);
  intpol_met_space_2d(met1, array1, lon, lat, &var1, ci, cw, 0);

  /* Get weighting factor... */
  wt = (met1->time - ts) / (met1->time - met0->time);

  /* Interpolate... */
  if (isfinite(var0) && isfinite(var1))
    *var = wt * (var0 - var1) + var1;
  else if (wt < 0.5)
    *var = var1;
  else
    *var = var0;
}

/*****************************************************************************/

void jsec2time(
  double jsec,
  int *year,
  int *mon,
  int *day,
  int *hour,
  int *min,
  int *sec,
  double *remain) {

  struct tm t0, *t1;

  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  time_t jsec0 = (time_t) jsec + timegm(&t0);
  t1 = gmtime(&jsec0);

  *year = t1->tm_year + 1900;
  *mon = t1->tm_mon + 1;
  *day = t1->tm_mday;
  *hour = t1->tm_hour;
  *min = t1->tm_min;
  *sec = t1->tm_sec;
  *remain = jsec - floor(jsec);
}

/*****************************************************************************/

double lapse_rate(
  double t,
  double h2o) {

  /*
     Calculate moist adiabatic lapse rate [K/km] from temperature [K]
     and water vapor volume mixing ratio [1].

     Reference: https://en.wikipedia.org/wiki/Lapse_rate
   */

  const double a = RA * SQR(t), r = SH(h2o) / (1. - SH(h2o));

  return 1e3 * G0 * (a + LV * r * t) / (CPD * a + SQR(LV) * r * EPS);
}

/*****************************************************************************/

int locate_irr(
```

```c
  double *xx,
  int n,
  double x) {

  int ilo = 0;
  int ihi = n - 1;
  int i = (ihi + ilo) >> 1;

  if (xx[i] < xx[i + 1])
    while (ihi > ilo + 1) {
      i = (ihi + ilo) >> 1;
      if (xx[i] > x)
        ihi = i;
      else
        ilo = i;
  } else
    while (ihi > ilo + 1) {
      i = (ihi + ilo) >> 1;
      if (xx[i] <= x)
        ihi = i;
      else
        ilo = i;
    }

  return ilo;
}

/*****************************************************************************/

int locate_reg(
  double *xx,
  int n,
  double x) {

  /* Calculate index... */
  int i = (int) ((x - xx[0]) / (xx[1] - xx[0]));

  /* Check range... */
  if (i < 0)
    return 0;
  else if (i > n - 2)
    return n - 2;
  else
    return i;
}

/*****************************************************************************/

double nat_temperature(
  double p,
  double h2o,
  double hno3) {

  /* Check water vapor vmr... */
  h2o = GSL_MAX(h2o, 0.1e-6);

  /* Calculate T_NAT... */
  double p_hno3 = hno3 * p / 1.333224;
  double p_h2o = h2o * p / 1.333224;
  double a = 0.009179 - 0.00088 * log10(p_h2o);
  double b = (38.9855 - log10(p_hno3) - 2.7836 * log10(p_h2o)) / a;
  double c = -11397.0 / a;
  double tnat = (-b + sqrt(b * b - 4. * c)) / 2.;
  double x2 = (-b - sqrt(b * b - 4. * c)) / 2.;
  if (x2 > 0)
    tnat = x2;

  return tnat;
}

/*****************************************************************************/

int read_atm(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm) {

  FILE *in;

  double t0;

  int dimid, ncid, varid;

  size_t nparts;

  /* Set timer... */
  SELECT_TIMER("READ_ATM", "INPUT", NVTX_READ);
```

```

  /* Init... */
  atm->np = 0;

  /* Write info... */
  LOG(1, "Read atmospheric data: %s", filename);

  /* Read ASCII data... */
  if (ctl->atm_type == 0) {

    /* Open file... */
    if (!(in = fopen(filename, "r"))) {
      WARN("File not found!");
      return 0;
    }

    /* Read line... */
    char line[LEN];
    while (fgets(line, LEN, in)) {

      /* Read data... */
      char *tok;
      TOK(line, tok, "%lg", atm->time[atm->np]);
      TOK(NULL, tok, "%lg", atm->p[atm->np]);
      TOK(NULL, tok, "%lg", atm->lon[atm->np]);
      TOK(NULL, tok, "%lg", atm->lat[atm->np]);
      for (int iq = 0; iq < ctl->nq; iq++)
        TOK(NULL, tok, "%lg", atm->q[iq][atm->np]);

      /* Convert altitude to pressure... */
      atm->p[atm->np] = P(atm->p[atm->np]);

      /* Increment data point counter... */
      if ((++atm->np) > NP)
        ERRMSG("Too many data points!");
    }

    /* Close file... */
    fclose(in);
  }

  /* Read binary data... */
  else if (ctl->atm_type == 1) {

    /* Open file... */
    if (!(in = fopen(filename, "r")))
      return 0;

    /* Read data... */
    FREAD(&atm->np, int,
          1,
          in);
    FREAD(atm->time, double,
            (size_t) atm->np,
          in);
    FREAD(atm->p, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lon, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lat, double,
            (size_t) atm->np,
          in);
    for (int iq = 0; iq < ctl->nq; iq++)
      FREAD(atm->q[iq], double,
              (size_t) atm->np,
            in);

    /* Close file... */
    fclose(in);
  }

  /* Read netCDF data... */
  else if (ctl->atm_type == 2) {

    /* Open file... */
    if (nc_open(filename, NC_NOWRITE, &ncid) != NC_NOERR)
      return 0;

    /* Get dimensions... */
    NC(nc_inq_dimid(ncid, "NPARTS", &dimid));
    NC(nc_inq_dimlen(ncid, dimid, &nparts));
    atm->np = (int) nparts;
    if (atm->np > NP)
      ERRMSG("Too many particles!");

```

```
    /* Get time... */
    NC(nc_inq_varid(ncid, "time", &varid));
    NC(nc_get_var_double(ncid, varid, &t0));
    for (int ip = 0; ip < atm->np; ip++)
      atm->time[ip] = t0;

    /* Read geolocations... */
    NC(nc_inq_varid(ncid, "PRESS", &varid));
    NC(nc_get_var_double(ncid, varid, atm->p));
    NC(nc_inq_varid(ncid, "LON", &varid));
    NC(nc_get_var_double(ncid, varid, atm->lon));
    NC(nc_inq_varid(ncid, "LAT", &varid));
    NC(nc_get_var_double(ncid, varid, atm->lat));

    /* Read variables... */
    if (ctl->qnt_p >= 0)
      if (nc_inq_varid(ncid, "PRESS", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_p]));
    if (ctl->qnt_t >= 0)
      if (nc_inq_varid(ncid, "TEMP", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_t]));
    if (ctl->qnt_u >= 0)
      if (nc_inq_varid(ncid, "U", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_u]));
    if (ctl->qnt_v >= 0)
      if (nc_inq_varid(ncid, "V", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_v]));
    if (ctl->qnt_w >= 0)
      if (nc_inq_varid(ncid, "W", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_w]));
    if (ctl->qnt_h2o >= 0)
      if (nc_inq_varid(ncid, "SH", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_h2o]));
    if (ctl->qnt_o3 >= 0)
      if (nc_inq_varid(ncid, "O3", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_o3]));
    if (ctl->qnt_theta >= 0)
      if (nc_inq_varid(ncid, "THETA", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_theta]));
    if (ctl->qnt_pv >= 0)
      if (nc_inq_varid(ncid, "PV", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_pv]));

    /* Check data... */
    for (int ip = 0; ip < atm->np; ip++)
      if (fabs(atm->lon[ip]) > 360 || fabs(atm->lat[ip]) > 90
          || (ctl->qnt_t >= 0 && fabs(atm->q[ctl->qnt_t][ip]) > 350)
          || (ctl->qnt_h2o >= 0 && fabs(atm->q[ctl->qnt_h2o][ip]) > 1)
          || (ctl->qnt_theta >= 0 && fabs(atm->q[ctl->qnt_theta][ip]) > 1e10)
          || (ctl->qnt_pv >= 0 && fabs(atm->q[ctl->qnt_pv][ip]) > 1e10)) {
        atm->time[ip] = GSL_NAN;
        atm->p[ip] = GSL_NAN;
        atm->lon[ip] = GSL_NAN;
        atm->lat[ip] = GSL_NAN;
        for (int iq = 0; iq < ctl->nq; iq++)
          atm->q[iq][ip] = GSL_NAN;
      } else {
        if (ctl->qnt_h2o >= 0)
          atm->q[ctl->qnt_h2o][ip] *= 1.608;
        if (ctl->qnt_pv >= 0)
          atm->q[ctl->qnt_pv][ip] *= 1e6;
        if (atm->lon[ip] > 180)
          atm->lon[ip] -= 360;
      }

    /* Close file... */
    NC(nc_close(ncid));
  }

  /* Error... */
  else
    ERRMSG("Atmospheric data type not supported!");

  /* Check number of points... */
  if (atm->np < 1)
    ERRMSG("Can not read any data!");

  /* Write info... */
  double mini, maxi;
  LOG(2, "Number of particles: %d", atm->np);
  gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
  LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
  LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
  LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
  LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
```

```
  gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
  LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
  for (int iq = 0; iq < ctl->nq; iq++) {
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }

  /* Return success... */
  return 1;
}

/*****************************************************************************/

void read_ctl(
  const char *filename,
  int argc,
  char *argv[],
  ctl_t * ctl) {

  /* Set timer... */
  SELECT_TIMER("READ_CTL", "INPUT", NVTX_READ);

  /* Write info... */
  LOG(1, "\nMassive-Parallel Trajectory Calculations (MPTRAC)\n"
      "(executable: %s | version: %s | compiled: %s, %s)\n",
      argv[0], VERSION, __DATE__, __TIME__);

  /* Initialize quantity indices... */
  ctl->qnt_ens = -1;
  ctl->qnt_stat = -1;
  ctl->qnt_m = -1;
  ctl->qnt_vmr = -1;
  ctl->qnt_r = -1;
  ctl->qnt_rho = -1;
  ctl->qnt_ps = -1;
  ctl->qnt_ts = -1;
  ctl->qnt_zs = -1;
  ctl->qnt_us = -1;
  ctl->qnt_vs = -1;
  ctl->qnt_pbl = -1;
  ctl->qnt_pt = -1;
  ctl->qnt_tt = -1;
  ctl->qnt_zt = -1;
  ctl->qnt_h2ot = -1;
  ctl->qnt_z = -1;
  ctl->qnt_p = -1;
  ctl->qnt_t = -1;
  ctl->qnt_u = -1;
  ctl->qnt_v = -1;
  ctl->qnt_w = -1;
  ctl->qnt_h2o = -1;
  ctl->qnt_o3 = -1;
  ctl->qnt_lwc = -1;
  ctl->qnt_iwc = -1;
  ctl->qnt_pct = -1;
  ctl->qnt_pcb = -1;
  ctl->qnt_cl = -1;
  ctl->qnt_plcl = -1;
  ctl->qnt_plfc = -1;
  ctl->qnt_pel = -1;
  ctl->qnt_cape = -1;
  ctl->qnt_cin = -1;
  ctl->qnt_hno3 = -1;
  ctl->qnt_oh = -1;
  ctl->qnt_psat = -1;
  ctl->qnt_psice = -1;
  ctl->qnt_pw = -1;
  ctl->qnt_sh = -1;
  ctl->qnt_rh = -1;
  ctl->qnt_rhice = -1;
  ctl->qnt_theta = -1;
  ctl->qnt_zeta = -1;
  ctl->qnt_tvirt = -1;
  ctl->qnt_lapse = -1;
  ctl->qnt_vh = -1;
  ctl->qnt_vz = -1;
  ctl->qnt_pv = -1;
  ctl->qnt_tdew = -1;
  ctl->qnt_tice = -1;
  ctl->qnt_tsts = -1;
  ctl->qnt_tnat = -1;

  /* Read quantities... */
```

```
  ctl->nq = (int) scan_ctl(filename, argc, argv, "NQ", -1, "0", NULL);
  if (ctl->nq > NQ)
    ERRMSG("Too many quantities!");
  for (int iq = 0; iq < ctl->nq; iq++) {

    /* Read quantity name and format... */
    scan_ctl(filename, argc, argv, "QNT_NAME", iq, "", ctl->qnt_name[iq]);
    scan_ctl(filename, argc, argv, "QNT_FORMAT", iq, "%g",
             ctl->qnt_format[iq]);

    /* Try to identify quantity... */
    SET_QNT(qnt_ens, "ens", "-")
      SET_QNT(qnt_stat, "stat", "-")
      SET_QNT(qnt_m, "m", "kg")
      SET_QNT(qnt_vmr, "vmr", "ppv")
      SET_QNT(qnt_r, "r", "microns")
      SET_QNT(qnt_rho, "rho", "kg/m^3")
      SET_QNT(qnt_ps, "ps", "hPa")
      SET_QNT(qnt_ts, "ts", "K")
      SET_QNT(qnt_zs, "zs", "km")
      SET_QNT(qnt_us, "us", "m/s")
      SET_QNT(qnt_vs, "vs", "m/s")
      SET_QNT(qnt_pbl, "pbl", "hPa")
      SET_QNT(qnt_pt, "pt", "hPa")
      SET_QNT(qnt_tt, "tt", "K")
      SET_QNT(qnt_zt, "zt", "km")
      SET_QNT(qnt_h2ot, "h2ot", "ppv")
      SET_QNT(qnt_z, "z", "km")
      SET_QNT(qnt_p, "p", "hPa")
      SET_QNT(qnt_t, "t", "K")
      SET_QNT(qnt_u, "u", "m/s")
      SET_QNT(qnt_v, "v", "m/s")
      SET_QNT(qnt_w, "w", "hPa/s")
      SET_QNT(qnt_h2o, "h2o", "ppv")
      SET_QNT(qnt_o3, "o3", "ppv")
      SET_QNT(qnt_lwc, "lwc", "kg/kg")
      SET_QNT(qnt_iwc, "iwc", "kg/kg")
      SET_QNT(qnt_pct, "pct", "hPa")
      SET_QNT(qnt_pcb, "pcb", "hPa")
      SET_QNT(qnt_cl, "cl", "kg/m^2")
      SET_QNT(qnt_plcl, "plcl", "hPa")
      SET_QNT(qnt_plfc, "plfc", "hPa")
      SET_QNT(qnt_pel, "pel", "hPa")
      SET_QNT(qnt_cape, "cape", "J/kg")
      SET_QNT(qnt_cin, "cin", "J/kg")
      SET_QNT(qnt_hno3, "hno3", "ppv")
      SET_QNT(qnt_oh, "oh", "molec/cm^3")
      SET_QNT(qnt_psat, "psat", "hPa")
      SET_QNT(qnt_psice, "psice", "hPa")
      SET_QNT(qnt_pw, "pw", "hPa")
      SET_QNT(qnt_sh, "sh", "kg/kg")
      SET_QNT(qnt_rh, "rh", "%%")
      SET_QNT(qnt_rhice, "rhice", "%%")
      SET_QNT(qnt_theta, "theta", "K")
      SET_QNT(qnt_zeta, "zeta", "K")
      SET_QNT(qnt_tvirt, "tvirt", "K")
      SET_QNT(qnt_lapse, "lapse", "K/km")
      SET_QNT(qnt_vh, "vh", "m/s")
      SET_QNT(qnt_vz, "vz", "m/s")
      SET_QNT(qnt_pv, "pv", "PVU")
      SET_QNT(qnt_tdew, "tdew", "K")
      SET_QNT(qnt_tice, "tice", "K")
      SET_QNT(qnt_tsts, "tsts", "K")
      SET_QNT(qnt_tnat, "tnat", "K")
      scan_ctl(filename, argc, argv, "QNT_UNIT", iq, "", ctl->qnt_unit[iq]);
  }

  /* netCDF I/O parameters... */
  ctl->chunkszhint =
    (size_t) scan_ctl(filename, argc, argv, "CHUNKSZHINT", -1, "163840000",
                      NULL);
  ctl->read_mode =
    (int) scan_ctl(filename, argc, argv, "READMODE", -1, "0", NULL);

  /* Time steps of simulation... */
  ctl->direction =
    (int) scan_ctl(filename, argc, argv, "DIRECTION", -1, "1", NULL);
  if (ctl->direction != -1 && ctl->direction != 1)
    ERRMSG("Set DIRECTION to -1 or 1!");
  ctl->t_stop = scan_ctl(filename, argc, argv, "T_STOP", -1, "1e100", NULL);
  ctl->dt_mod = scan_ctl(filename, argc, argv, "DT_MOD", -1, "180", NULL);

  /* Meteorological data... */
  scan_ctl(filename, argc, argv, "METBASE", -1, "-", ctl->metbase);
  ctl->dt_met = scan_ctl(filename, argc, argv, "DT_MET", -1, "3600", NULL);
  ctl->met_dx = (int) scan_ctl(filename, argc, argv, "MET_DX", -1, "1", NULL);
  ctl->met_dy = (int) scan_ctl(filename, argc, argv, "MET_DY", -1, "1", NULL);
```

```
  ctl->met_dp = (int) scan_ctl(filename, argc, argv, "MET_DP", -1, "1", NULL);
  if (ctl->met_dx < 1 || ctl->met_dy < 1 || ctl->met_dp < 1)
    ERRMSG("MET_DX, MET_DY, and MET_DP need to be greater than zero!");
  ctl->met_sx = (int) scan_ctl(filename, argc, argv, "MET_SX", -1, "1", NULL);
  ctl->met_sy = (int) scan_ctl(filename, argc, argv, "MET_SY", -1, "1", NULL);
  ctl->met_sp = (int) scan_ctl(filename, argc, argv, "MET_SP", -1, "1", NULL);
  if (ctl->met_sx < 1 || ctl->met_sy < 1 || ctl->met_sp < 1)
    ERRMSG("MET_SX, MET_SY, and MET_SP need to be greater than zero!");
  ctl->met_detrend =
    scan_ctl(filename, argc, argv, "MET_DETREND", -1, "-999", NULL);
  ctl->met_np = (int) scan_ctl(filename, argc, argv, "MET_NP", -1, "0", NULL);
  if (ctl->met_np > EP)
    ERRMSG("Too many levels!");
  for (int ip = 0; ip < ctl->met_np; ip++)
    ctl->met_p[ip] = scan_ctl(filename, argc, argv, "MET_P", ip, "", NULL);
  ctl->met_geopot_sx
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SX", -1, "-1", NULL);
  ctl->met_geopot_sy
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SY", -1, "-1", NULL);
  ctl->met_tropo =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO", -1, "3", NULL);
  if (ctl->met_tropo < 0 || ctl->met_tropo > 5)
    ERRMSG("Set MET_TROPO = 0 ... 5!");
  ctl->met_tropo_lapse =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE", -1, "2.0", NULL);
  ctl->met_tropo_nlev =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV", -1, "20", NULL);
  ctl->met_tropo_lapse_sep =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE_SEP", -1, "3.0", NULL);
  ctl->met_tropo_nlev_sep =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV_SEP", -1, "10",
                   NULL);
  ctl->met_tropo_pv =
    scan_ctl(filename, argc, argv, "MET_TROPO_PV", -1, "3.5", NULL);
  ctl->met_tropo_theta =
    scan_ctl(filename, argc, argv, "MET_TROPO_THETA", -1, "380", NULL);
  ctl->met_tropo_spline =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_SPLINE", -1, "1", NULL);
  ctl->met_cloud =
    (int) scan_ctl(filename, argc, argv, "MET_CLOUD", -1, "1", NULL);
  if (ctl->met_cloud < 0 || ctl->met_cloud > 3)
    ERRMSG("Set MET_CLOUD = 0 ... 3!");
  ctl->met_dt_out =
    scan_ctl(filename, argc, argv, "MET_DT_OUT", -1, "0.1", NULL);
  ctl->met_cache =
    (int) scan_ctl(filename, argc, argv, "MET_CACHE", -1, "0", NULL);

  /* Isosurface parameters... */
  ctl->isosurf =
    (int) scan_ctl(filename, argc, argv, "ISOSURF", -1, "0", NULL);
  scan_ctl(filename, argc, argv, "BALLOON", -1, "-", ctl->balloon);

  /* Advection parameters... */
  ctl->advect = (int) scan_ctl(filename, argc, argv, "ADVECT", -1, "0", NULL);
  ctl->reflect =
    (int) scan_ctl(filename, argc, argv, "REFLECT", -1, "0", NULL);

  /* Diffusion parameters... */
  ctl->turb_dx_trop =
    scan_ctl(filename, argc, argv, "TURB_DX_TROP", -1, "50", NULL);
  ctl->turb_dx_strat =
    scan_ctl(filename, argc, argv, "TURB_DX_STRAT", -1, "0", NULL);
  ctl->turb_dz_trop =
    scan_ctl(filename, argc, argv, "TURB_DZ_TROP", -1, "0", NULL);
  ctl->turb_dz_strat =
    scan_ctl(filename, argc, argv, "TURB_DZ_STRAT", -1, "0.1", NULL);
  ctl->turb_mesox =
    scan_ctl(filename, argc, argv, "TURB_MESOX", -1, "0.16", NULL);
  ctl->turb_mesoz =
    scan_ctl(filename, argc, argv, "TURB_MESOZ", -1, "0.16", NULL);

  /* Convection... */
  ctl->conv_cape
    = scan_ctl(filename, argc, argv, "CONV_CAPE", -1, "-999", NULL);
  ctl->conv_cin
    = scan_ctl(filename, argc, argv, "CONV_CIN", -1, "-999", NULL);
  ctl->conv_wmax
    = scan_ctl(filename, argc, argv, "CONV_WMAX", -1, "-999", NULL);
  ctl->conv_wcape
    = (int) scan_ctl(filename, argc, argv, "CONV_WCAPE", -1, "0", NULL);
  ctl->conv_dt = scan_ctl(filename, argc, argv, "CONV_DT", -1, "-999", NULL);
  ctl->conv_mix_bot
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_BOT", -1, "1", NULL);
  ctl->conv_mix_top
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_TOP", -1, "1", NULL);

  /* Boundary conditions... */
```

```
ctl->bound_mass =
  scan_ctl(filename, argc, argv, "BOUND_MASS", -1, "-999", NULL);
ctl->bound_vmr =
  scan_ctl(filename, argc, argv, "BOUND_VMR", -1, "-999", NULL);
ctl->bound_lat0 =
  scan_ctl(filename, argc, argv, "BOUND_LAT0", -1, "-90", NULL);
ctl->bound_lat1 =
  scan_ctl(filename, argc, argv, "BOUND_LAT1", -1, "90", NULL);
ctl->bound_p0 =
  scan_ctl(filename, argc, argv, "BOUND_P0", -1, "1e10", NULL);
ctl->bound_p1 =
  scan_ctl(filename, argc, argv, "BOUND_P1", -1, "-1e10", NULL);
ctl->bound_dps =
  scan_ctl(filename, argc, argv, "BOUND_DPS", -1, "-999", NULL);

/* Species parameters... */
scan_ctl(filename, argc, argv, "SPECIES", -1, "-", ctl->species);
if (strcasecmp(ctl->species, "CF2Cl2") == 0) {
  ctl->molmass = 120.907;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 3e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 3500.0;
} else if (strcasecmp(ctl->species, "CFCl3") == 0) {
  ctl->molmass = 137.359;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.1e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 3300.0;
} else if (strcasecmp(ctl->species, "CH4") == 0) {
  ctl->molmass = 16.043;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 2.45e-12;
  ctl->oh_chem[1] = 1775;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.4e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
} else if (strcasecmp(ctl->species, "CO") == 0) {
  ctl->molmass = 28.01;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 6.9e-33;
  ctl->oh_chem[1] = 2.1;
  ctl->oh_chem[2] = 1.1e-12;
  ctl->oh_chem[3] = -1.3;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 9.7e-6;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1300.0;
} else if (strcasecmp(ctl->species, "CO2") == 0) {
  ctl->molmass = 44.009;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 3.3e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
} else if (strcasecmp(ctl->species, "N2O") == 0) {
  ctl->molmass = 44.013;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2600.;
} else if (strcasecmp(ctl->species, "NH3") == 0) {
  ctl->molmass = 17.031;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 1.7e-12;
  ctl->oh_chem[1] = 710;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 5.9e-1;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 4200.0;
} else if (strcasecmp(ctl->species, "HNO3") == 0) {
  ctl->molmass = 63.012;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 2.1e3;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 8700.0;
} else if (strcasecmp(ctl->species, "NO") == 0) {
  ctl->molmass = 30.006;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 7.1e-31;
  ctl->oh_chem[1] = 2.6;
  ctl->oh_chem[2] = 3.6e-11;
  ctl->oh_chem[3] = 0.1;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.9e-5;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
} else if (strcasecmp(ctl->species, "NO2") == 0) {
  ctl->molmass = 46.005;
  ctl->oh_chem_reaction = 3;
  ctl->oh_chem[0] = 1.8e-30;
  ctl->oh_chem[1] = 3.0;
  ctl->oh_chem[2] = 2.8e-11;
  ctl->oh_chem[3] = 0.0;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1.2e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
} else if (strcasecmp(ctl->species, "O3") == 0) {
  ctl->molmass = 47.997;
  ctl->oh_chem_reaction = 2;
  ctl->oh_chem[0] = 1.7e-12;
  ctl->oh_chem[1] = 940;
  ctl->wet_depo[2] = ctl->wet_depo[6] = 1e-4;
  ctl->wet_depo[3] = ctl->wet_depo[7] = 2800.0;
} else if (strcasecmp(ctl->species, "SF6") == 0) {
  ctl->molmass = 146.048;
```

```
    ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-6;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 3100.0;
  } else if (strcasecmp(ctl->species, "SO2") == 0) {
    ctl->molmass = 64.066;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 2.9e-31;
    ctl->oh_chem[1] = 4.1;
    ctl->oh_chem[2] = 1.7e-12;
    ctl->oh_chem[3] = -0.2;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.3e-2;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2900.0;
  } else {
    ctl->molmass =
      scan_ctl(filename, argc, argv, "MOLMASS", -1, "-999", NULL);
    ctl->oh_chem_reaction =
      (int) scan_ctl(filename, argc, argv, "OH_CHEM_REACTION", -1, "0", NULL);
    for (int ip = 0; ip < 4; ip++)
      ctl->oh_chem[ip] =
        scan_ctl(filename, argc, argv, "OH_CHEM", ip, "0", NULL);
    for (int ip = 0; ip < 1; ip++)
      ctl->dry_depo[ip] =
        scan_ctl(filename, argc, argv, "DRY_DEPO", ip, "0", NULL);
    for (int ip = 0; ip < 8; ip++)
      ctl->wet_depo[ip] =
        scan_ctl(filename, argc, argv, "WET_DEPO", ip, "0", NULL);
  }
  ctl->tdec_trop = scan_ctl(filename, argc, argv, "TDEC_TROP", -1, "0", NULL);
  ctl->tdec_strat =
    scan_ctl(filename, argc, argv, "TDEC_STRAT", -1, "0", NULL);

  /* PSC analysis... */
  ctl->psc_h2o = scan_ctl(filename, argc, argv, "PSC_H2O", -1, "4e-6", NULL);
  ctl->psc_hno3 =
    scan_ctl(filename, argc, argv, "PSC_HNO3", -1, "9e-9", NULL);

  /* Output of atmospheric data... */
  scan_ctl(filename, argc, argv, "ATM_BASENAME", -1, "-", ctl->atm_basename);
  scan_ctl(filename, argc, argv, "ATM_GPFILE", -1, "-", ctl->atm_gpfile);
  ctl->atm_dt_out =
    scan_ctl(filename, argc, argv, "ATM_DT_OUT", -1, "86400", NULL);
  ctl->atm_filter =
    (int) scan_ctl(filename, argc, argv, "ATM_FILTER", -1, "0", NULL);
  ctl->atm_stride =
    (int) scan_ctl(filename, argc, argv, "ATM_STRIDE", -1, "1", NULL);
  ctl->atm_type =
    (int) scan_ctl(filename, argc, argv, "ATM_TYPE", -1, "0", NULL);

  /* Output of CSI data... */
  scan_ctl(filename, argc, argv, "CSI_BASENAME", -1, "-", ctl->csi_basename);
  ctl->csi_dt_out =
    scan_ctl(filename, argc, argv, "CSI_DT_OUT", -1, "86400", NULL);
  scan_ctl(filename, argc, argv, "CSI_OBSFILE", -1, "-", ctl->csi_obsfile);
  ctl->csi_obsmin =
    scan_ctl(filename, argc, argv, "CSI_OBSMIN", -1, "0", NULL);
  ctl->csi_modmin =
    scan_ctl(filename, argc, argv, "CSI_MODMIN", -1, "0", NULL);
  ctl->csi_z0 = scan_ctl(filename, argc, argv, "CSI_Z0", -1, "0", NULL);
  ctl->csi_z1 = scan_ctl(filename, argc, argv, "CSI_Z1", -1, "100", NULL);
  ctl->csi_nz = (int) scan_ctl(filename, argc, argv, "CSI_NZ", -1, "1", NULL);
  ctl->csi_lon0 =
    scan_ctl(filename, argc, argv, "CSI_LON0", -1, "-180", NULL);
  ctl->csi_lon1 = scan_ctl(filename, argc, argv, "CSI_LON1", -1, "180", NULL);
  ctl->csi_nx =
    (int) scan_ctl(filename, argc, argv, "CSI_NX", -1, "360", NULL);
  ctl->csi_lat0 = scan_ctl(filename, argc, argv, "CSI_LAT0", -1, "-90", NULL);
  ctl->csi_lat1 = scan_ctl(filename, argc, argv, "CSI_LAT1", -1, "90", NULL);
  ctl->csi_ny =
    (int) scan_ctl(filename, argc, argv, "CSI_NY", -1, "180", NULL);

  /* Output of ensemble data... */
  scan_ctl(filename, argc, argv, "ENS_BASENAME", -1, "-", ctl->ens_basename);

  /* Output of grid data... */
  scan_ctl(filename, argc, argv, "GRID_BASENAME", -1, "-",
           ctl->grid_basename);
  scan_ctl(filename, argc, argv, "GRID_GPFILE", -1, "-", ctl->grid_gpfile);
  ctl->grid_dt_out =
    scan_ctl(filename, argc, argv, "GRID_DT_OUT", -1, "86400", NULL);
  ctl->grid_sparse =
    (int) scan_ctl(filename, argc, argv, "GRID_SPARSE", -1, "0", NULL);
  ctl->grid_z0 = scan_ctl(filename, argc, argv, "GRID_Z0", -1, "0", NULL);
  ctl->grid_z1 = scan_ctl(filename, argc, argv, "GRID_Z1", -1, "100", NULL);
  ctl->grid_nz =
    (int) scan_ctl(filename, argc, argv, "GRID_NZ", -1, "1", NULL);
  ctl->grid_lon0 =
    scan_ctl(filename, argc, argv, "GRID_LON0", -1, "-180", NULL);
  ctl->grid_lon1 =
```

```
    scan_ctl(filename, argc, argv, "GRID_LON1", -1, "180", NULL);
  ctl->grid_nx =
    (int) scan_ctl(filename, argc, argv, "GRID_NX", -1, "360", NULL);
  ctl->grid_lat0 =
    scan_ctl(filename, argc, argv, "GRID_LAT0", -1, "-90", NULL);
  ctl->grid_lat1 =
    scan_ctl(filename, argc, argv, "GRID_LAT1", -1, "90", NULL);
  ctl->grid_ny =
    (int) scan_ctl(filename, argc, argv, "GRID_NY", -1, "180", NULL);

  /* Output of profile data... */
  scan_ctl(filename, argc, argv, "PROF_BASENAME", -1, "-",
           ctl->prof_basename);
  scan_ctl(filename, argc, argv, "PROF_OBSFILE", -1, "-", ctl->prof_obsfile);
  ctl->prof_z0 = scan_ctl(filename, argc, argv, "PROF_Z0", -1, "0", NULL);
  ctl->prof_z1 = scan_ctl(filename, argc, argv, "PROF_Z1", -1, "60", NULL);
  ctl->prof_nz =
    (int) scan_ctl(filename, argc, argv, "PROF_NZ", -1, "60", NULL);
  ctl->prof_lon0 =
    scan_ctl(filename, argc, argv, "PROF_LON0", -1, "-180", NULL);
  ctl->prof_lon1 =
    scan_ctl(filename, argc, argv, "PROF_LON1", -1, "180", NULL);
  ctl->prof_nx =
    (int) scan_ctl(filename, argc, argv, "PROF_NX", -1, "360", NULL);
  ctl->prof_lat0 =
    scan_ctl(filename, argc, argv, "PROF_LAT0", -1, "-90", NULL);
  ctl->prof_lat1 =
    scan_ctl(filename, argc, argv, "PROF_LAT1", -1, "90", NULL);
  ctl->prof_ny =
    (int) scan_ctl(filename, argc, argv, "PROF_NY", -1, "180", NULL);

  /* Output of sample data... */
  scan_ctl(filename, argc, argv, "SAMPLE_BASENAME", -1, "-",
           ctl->sample_basename);
  scan_ctl(filename, argc, argv, "SAMPLE_OBSFILE", -1, "-",
           ctl->sample_obsfile);
  ctl->sample_dx =
    scan_ctl(filename, argc, argv, "SAMPLE_DX", -1, "50", NULL);
  ctl->sample_dz =
    scan_ctl(filename, argc, argv, "SAMPLE_DZ", -1, "-999", NULL);

  /* Output of station data... */
  scan_ctl(filename, argc, argv, "STAT_BASENAME", -1, "-",
           ctl->stat_basename);
  ctl->stat_lon = scan_ctl(filename, argc, argv, "STAT_LON", -1, "0", NULL);
  ctl->stat_lat = scan_ctl(filename, argc, argv, "STAT_LAT", -1, "0", NULL);
  ctl->stat_r = scan_ctl(filename, argc, argv, "STAT_R", -1, "50", NULL);
  ctl->stat_t0 =
    scan_ctl(filename, argc, argv, "STAT_T0", -1, "-1e100", NULL);
  ctl->stat_t1 = scan_ctl(filename, argc, argv, "STAT_T1", -1, "1e100", NULL);
}

/*****************************************************************************/

int read_met(
  ctl_t * ctl,
  char *filename,
  met_t * met) {

  int ncid;

  /* Write info... */
  LOG(1, "Read meteorological data: %s", filename);

  /* Open netCDF file... */
  if (nc__open(filename, ctl->read_mode, &ctl->chunkszhint, &ncid) !=
      NC_NOERR) {
    WARN("File not found!");
    return 0;
  }

  /* Read coordinates of meteorological data... */
  read_met_grid(filename, ncid, ctl, met);

  /* Read meteo data on vertical levels... */
  read_met_levels(ncid, ctl, met);

  /* Extrapolate data for lower boundary... */
  read_met_extrapolate(met);

  /* Read surface data... */
  read_met_surface(ncid, met);

  /* Create periodic boundary conditions... */
  read_met_periodic(met);

  /* Downsampling... */
```

```
  read_met_sample(ctl, met);

  /* Calculate geopotential heights... */
  read_met_geopot(ctl, met);

  /* Calculate potential vorticity... */
  read_met_pv(met);

  /* Calculate boundary layer data... */
  read_met_pbl(met);

  /* Calculate tropopause data... */
  read_met_tropo(ctl, met);

  /* Calculate cloud properties... */
  read_met_cloud(met);

  /* Calculate convective available potential energy... */
  read_met_cape(met);

  /* Detrending... */
  read_met_detrend(ctl, met);

  /* Close file... */
  NC(nc_close(ncid));

  /* Return success... */
  return 1;
}

/*****************************************************************************/

void read_met_cape(
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CAPE", "METPROC", NVTX_READ);
  LOG(2, "Calculate CAPE...");

  /* Vertical spacing (about 100 m)... */
  const double pfac = 1.01439, dz0 = RI / MA / G0 * log(pfac);

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get potential temperature and water vapor vmr at lowest 50 hPa... */
      int n = 0;
      double h2o = 0, t, theta = 0;
      double pbot = GSL_MIN(met->ps[ix][iy], met->p[0]);
      double ptop = pbot - 50.;
      for (int ip = 0; ip < met->np; ip++) {
        if (met->p[ip] <= pbot) {
          theta += THETA(met->p[ip], met->t[ix][iy][ip]);
          h2o += met->h2o[ix][iy][ip];
          n++;
        }
        if (met->p[ip] < ptop && n > 0)
          break;
      }
      theta /= n;
      h2o /= n;

      /* Cannot compute anything if water vapor is missing... */
      met->plcl[ix][iy] = GSL_NAN;
      met->plfc[ix][iy] = GSL_NAN;
      met->pel[ix][iy] = GSL_NAN;
      met->cape[ix][iy] = GSL_NAN;
      met->cin[ix][iy] = GSL_NAN;
      if (h2o <= 0)
        continue;

      /* Find lifted condensation level (LCL)... */
      ptop = P(20.);
      pbot = met->ps[ix][iy];
      do {
        met->plcl[ix][iy] = (float) (0.5 * (pbot + ptop));
        t = theta / pow(1000. / met->plcl[ix][iy], 0.286);
        if (RH(met->plcl[ix][iy], t, h2o) > 100.)
          ptop = met->plcl[ix][iy];
        else
          pbot = met->plcl[ix][iy];
      } while (pbot - ptop > 0.1);

      /* Calculate CIN up to LCL... */
      INTPOL_INIT;
```

```
      double dcape, dcape_old, dz, psat, h2o_env, t_env;
      double p = met->ps[ix][iy];
      met->cape[ix][iy] = met->cin[ix][iy] = 0;
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t = theta / pow(1000. / p, 0.286);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape < 0)
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > met->plcl[ix][iy]);

      /* Calculate level of free convection (LFC), equilibrium level (EL),
         and convective available potential energy (CAPE)... */
      dcape = 0;
      p = met->plcl[ix][iy];
      t = theta / pow(1000. / p, 0.286);
      ptop = 0.75 * clim_tropo(met->time, met->lat[iy]);
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t -= lapse_rate(t, h2o) * dz;
        psat = PSAT(t);
        h2o = psat / (p - (1. - EPS) * psat);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape_old = dcape;
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape > 0) {
          met->cape[ix][iy] += (float) dcape;
          if (!isfinite(met->plfc[ix][iy]))
            met->plfc[ix][iy] = (float) p;
        } else if (dcape_old > 0)
          met->pel[ix][iy] = (float) p;
        if (dcape < 0 && !isfinite(met->plfc[ix][iy]))
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > ptop);

      /* Check results... */
      if (!isfinite(met->plfc[ix][iy]))
        met->cin[ix][iy] = GSL_NAN;
    }
}

/*****************************************************************************/

void read_met_cloud(
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CLOUD", "METPROC", NVTX_READ);
  LOG(2, "Calculate cloud data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Init... */
      met->pct[ix][iy] = GSL_NAN;
      met->pcb[ix][iy] = GSL_NAN;
      met->cl[ix][iy] = 0;

      /* Loop over pressure levels... */
      for (int ip = 0; ip < met->np - 1; ip++) {

        /* Check pressure... */
        if (met->p[ip] > met->ps[ix][iy] || met->p[ip] < P(20.))
          continue;

        /* Check ice water and liquid water content... */
        if (met->iwc[ix][iy][ip] > 0 || met->lwc[ix][iy][ip] > 0) {

          /* Get cloud top pressure ... */
          met->pct[ix][iy]
            = (float) (0.5 * (met->p[ip] + (float) met->p[ip + 1]));

          /* Get cloud bottom pressure ... */
          if (!isfinite(met->pcb[ix][iy]))
```

```
          met->pcb[ix][iy]
            = (float) (0.5 * (met->p[ip] + met->p[GSL_MAX(ip - 1, 0)]));
      }

      /* Get cloud water... */
      met->cl[ix][iy] += (float)
        (0.5 * (met->iwc[ix][iy][ip] + met->iwc[ix][iy][ip + 1]
                + met->lwc[ix][iy][ip] + met->lwc[ix][iy][ip + 1])
         * 100. * (met->p[ip] - met->p[ip + 1]) / G0);
    }
  }
}

/*****************************************************************************/

void read_met_detrend(
  ctl_t * ctl,
  met_t * met) {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_detrend <= 0)
    return;

  /* Set timer... */
  SELECT_TIMER("READ_MET_DETREND", "METPROC", NVTX_READ);
  LOG(2, "Detrend meteo data...");

  /* Allocate... */
  ALLOC(help, met_t, 1);

  /* Calculate standard deviation... */
  double sigma = ctl->met_detrend / 2.355;
  double tssq = 2. * SQR(sigma);

  /* Calculate box size in latitude... */
  int sy = (int) (3. * DY2DEG(sigma) / fabs(met->lat[1] - met->lat[0]));
  sy = GSL_MIN(GSL_MAX(1, sy), met->ny / 2);

  /* Calculate background... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++) {
    for (int iy = 0; iy < met->ny; iy++) {

      /* Calculate Cartesian coordinates... */
      double x0[3];
      geo2cart(0.0, met->lon[ix], met->lat[iy], x0);

      /* Calculate box size in longitude... */
      int sx =
        (int) (3. * DX2DEG(sigma, met->lat[iy]) /
               fabs(met->lon[1] - met->lon[0]));
      sx = GSL_MIN(GSL_MAX(1, sx), met->nx / 2);

      /* Init... */
      float wsum = 0;
      for (int ip = 0; ip < met->np; ip++) {
        help->t[ix][iy][ip] = 0;
        help->u[ix][iy][ip] = 0;
        help->v[ix][iy][ip] = 0;
        help->w[ix][iy][ip] = 0;
      }

      /* Loop over neighboring grid points... */
      for (int ix2 = ix - sx; ix2 <= ix + sx; ix2++) {
        int ix3 = ix2;
        if (ix3 < 0)
          ix3 += met->nx;
        else if (ix3 >= met->nx)
          ix3 -= met->nx;
        for (int iy2 = GSL_MAX(iy - sy, 0);
             iy2 <= GSL_MIN(iy + sy, met->ny - 1); iy2++) {

          /* Calculate Cartesian coordinates... */
          double x1[3];
          geo2cart(0.0, met->lon[ix3], met->lat[iy2], x1);

          /* Calculate weighting factor... */
          float w = (float) exp(-DIST2(x0, x1) / tssq);

          /* Add data... */
          wsum += w;
          for (int ip = 0; ip < met->np; ip++) {
            help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip];
            help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip];
            help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip];
```

```
            help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip];
          }
        }
      }

      /* Normalize... */
      for (int ip = 0; ip < met->np; ip++) {
        help->t[ix][iy][ip] /= wsum;
        help->u[ix][iy][ip] /= wsum;
        help->v[ix][iy][ip] /= wsum;
        help->w[ix][iy][ip] /= wsum;
      }
    }
  }

  /* Subtract background... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++) {
        met->t[ix][iy][ip] -= help->t[ix][iy][ip];
        met->u[ix][iy][ip] -= help->u[ix][iy][ip];
        met->v[ix][iy][ip] -= help->v[ix][iy][ip];
        met->w[ix][iy][ip] -= help->w[ix][iy][ip];
      }

  /* Free... */
  free(help);
}

/*****************************************************************************/

void read_met_extrapolate(
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_EXTRAPOLATE", "METPROC", NVTX_READ);
  LOG(2, "Extrapolate meteo data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Find lowest valid data point... */
      int ip0;
      for (ip0 = met->np - 1; ip0 >= 0; ip0--)
        if (!isfinite(met->t[ix][iy][ip0])
            || !isfinite(met->u[ix][iy][ip0])
            || !isfinite(met->v[ix][iy][ip0])
            || !isfinite(met->w[ix][iy][ip0]))
          break;

      /* Extrapolate... */
      for (int ip = ip0; ip >= 0; ip--) {
        met->t[ix][iy][ip] = met->t[ix][iy][ip + 1];
        met->u[ix][iy][ip] = met->u[ix][iy][ip + 1];
        met->v[ix][iy][ip] = met->v[ix][iy][ip + 1];
        met->w[ix][iy][ip] = met->w[ix][iy][ip + 1];
        met->h2o[ix][iy][ip] = met->h2o[ix][iy][ip + 1];
        met->o3[ix][iy][ip] = met->o3[ix][iy][ip + 1];
        met->lwc[ix][iy][ip] = met->lwc[ix][iy][ip + 1];
        met->iwc[ix][iy][ip] = met->iwc[ix][iy][ip + 1];
      }
    }
}

/*****************************************************************************/

void read_met_geopot(
  ctl_t * ctl,
  met_t * met) {

  static float help[EP][EX][EY];

  double logp[EP];

  int dx = ctl->met_geopot_sx, dy = ctl->met_geopot_sy;

  /* Set timer... */
  SELECT_TIMER("READ_MET_GEOPOT", "METPROC", NVTX_READ);
  LOG(2, "Calculate geopotential heights...");

  /* Calculate log pressure... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    logp[ip] = log(met->p[ip]);
```

```

  /* Apply hydrostatic equation to calculate geopotential heights... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get surface height and pressure... */
      double zs = met->zs[ix][iy];
      double lnps = log(met->ps[ix][iy]);

      /* Get temperature and water vapor vmr at the surface... */
      int ip0 = locate_irr(met->p, met->np, met->ps[ix][iy]);
      double ts = LIN(met->p[ip0], met->t[ix][iy][ip0], met->p[ip0 + 1],
                      met->t[ix][iy][ip0 + 1], met->ps[ix][iy]);
      double h2os = LIN(met->p[ip0], met->h2o[ix][iy][ip0], met->p[ip0 + 1],
                        met->h2o[ix][iy][ip0 + 1], met->ps[ix][iy]);

      /* Upper part of profile... */
      met->z[ix][iy][ip0 + 1]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0 + 1],
                         met->t[ix][iy][ip0 + 1], met->h2o[ix][iy][ip0 + 1]));
      for (int ip = ip0 + 2; ip < met->np; ip++)
        met->z[ix][iy][ip]
          = (float) (met->z[ix][iy][ip - 1] +
                     ZDIFF(logp[ip - 1], met->t[ix][iy][ip - 1],
                           met->h2o[ix][iy][ip - 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));

      /* Lower part of profile... */
      met->z[ix][iy][ip0]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0],
                         met->t[ix][iy][ip0], met->h2o[ix][iy][ip0]));
      for (int ip = ip0 - 1; ip >= 0; ip--)
        met->z[ix][iy][ip]
          = (float) (met->z[ix][iy][ip + 1] +
                     ZDIFF(logp[ip + 1], met->t[ix][iy][ip + 1],
                           met->h2o[ix][iy][ip + 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));
    }

  /* Check control parameters... */
  if (dx == 0 || dy == 0)
    return;

  /* Default smoothing parameters... */
  if (dx < 0 || dy < 0) {
    if (fabs(met->lon[1] - met->lon[0]) < 0.5) {
      dx = 3;
      dy = 2;
    } else {
      dx = 6;
      dy = 4;
    }
  }

  /* Calculate weights for smoothing... */
  float ws[dx + 1][dy + 1];
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix <= dx; ix++)
    for (int iy = 0; iy < dy; iy++)
      ws[ix][iy] = (1.0f - (float) ix / (float) dx)
        * (1.0f - (float) iy / (float) dy);

  /* Copy data... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++)
        help[ip][ix][iy] = met->z[ix][iy][ip];

  /* Horizontal smoothing... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ip = 0; ip < met->np; ip++)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        float res = 0, wsum = 0;
        int iy0 = GSL_MAX(iy - dy + 1, 0);
        int iy1 = GSL_MIN(iy + dy - 1, met->ny - 1);
        for (int ix2 = ix - dx + 1; ix2 <= ix + dx - 1; ++ix2) {
          int ix3 = ix2;
          if (ix3 < 0)
            ix3 += met->nx;
          else if (ix3 >= met->nx)
            ix3 -= met->nx;
          for (int iy2 = iy0; iy2 <= iy1; ++iy2)
```

```
            if (isfinite(help[ip][ix3][iy2])) {
              float w = ws[abs(ix - ix2)][abs(iy - iy2)];
              res += w * help[ip][ix3][iy2];
              wsum += w;
            }
        }
        if (wsum > 0)
          met->z[ix][iy][ip] = res / wsum;
        else
          met->z[ix][iy][ip] = GSL_NAN;
      }
}

/*****************************************************************************/

void read_met_grid(
  char *filename,
  int ncid,
  ctl_t * ctl,
  met_t * met) {

  char levname[LEN], tstr[10];

  double rtime, r2;

  int dimid, varid, year2, mon2, day2, hour2, min2, sec2;

  size_t np, nx, ny;

  /* Set timer... */
  SELECT_TIMER("READ_MET_GRID", "INPUT", NVTX_READ);
  LOG(2, "Read meteo grid information...");

  /* Get time from filename... */
  sprintf(tstr, "%.4s", &filename[strlen(filename) - 16]);
  int year = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 11]);
  int mon = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 8]);
  int day = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 5]);
  int hour = atoi(tstr);
  time2jsec(year, mon, day, hour, 0, 0, 0, &met->time);

  /* Check time... */
  if (year < 1900 || year > 2100 || mon < 1 || mon > 12
      || day < 1 || day > 31 || hour < 0 || hour > 23)
    ERRMSG("Cannot read time from filename!");
  jsec2time(met->time, &year2, &mon2, &day2, &hour2, &min2, &sec2, &r2);
  LOG(2, "Time from filename: %.2f (%d-%02d-%02d, %02d:%02d UTC)",
      met->time, year2, mon2, day2, hour2, min2);

  /* Check time information... */
  if (nc_inq_varid(ncid, "time", &varid) == NC_NOERR) {
    NC(nc_get_var_double(ncid, varid, &rtime));
    if (fabs(year * 10000. + mon * 100. + day + hour / 24. - rtime) > 1.0)
      WARN("Time information in meteo file does not match filename!");
  } else
    WARN("Time information in meteo file is missing!");

  /* Get grid dimensions... */
  NC(nc_inq_dimid(ncid, "lon", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &nx));
  LOG(2, "Number of longitudes: %zu", nx);
  if (nx < 2 || nx > EX)
    ERRMSG("Number of longitudes out of range!");

  NC(nc_inq_dimid(ncid, "lat", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &ny));
  LOG(2, "Number of latitudes: %zu", ny);
  if (ny < 2 || ny > EY)
    ERRMSG("Number of latitudes out of range!");

  sprintf(levname, "lev");
  NC(nc_inq_dimid(ncid, levname, &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &np));
  if (np == 1) {
    sprintf(levname, "lev_2");
    if (nc_inq_dimid(ncid, levname, &dimid) != NC_NOERR) {
      sprintf(levname, "plev");
      nc_inq_dimid(ncid, levname, &dimid);
    }
    NC(nc_inq_dimlen(ncid, dimid, &np));
  }
  LOG(2, "Number of levels: %zu", np);
  if (np < 2 || np > EP)
    ERRMSG("Number of levels out of range!");
```

```

  /* Store dimensions... */
  met->np = (int) np;
  met->nx = (int) nx;
  met->ny = (int) ny;

  /* Read longitudes and latitudes... */
  NC(nc_inq_varid(ncid, "lon", &varid));
  NC(nc_get_var_double(ncid, varid, met->lon));
  LOG(2, "Longitudes: %g, %g ... %g deg",
      met->lon[0], met->lon[1], met->lon[met->nx - 1]);
  NC(nc_inq_varid(ncid, "lat", &varid));
  NC(nc_get_var_double(ncid, varid, met->lat));
  LOG(2, "Latitudes: %g, %g ... %g deg",
      met->lat[0], met->lat[1], met->lat[met->ny - 1]);

  /* Read pressure levels... */
  if (ctl->met_np <= 0) {
    NC(nc_inq_varid(ncid, levname, &varid));
    NC(nc_get_var_double(ncid, varid, met->p));
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] /= 100.;
    LOG(2, "Altitude levels: %g, %g ... %g km",
        Z(met->p[0]), Z(met->p[1]), Z(met->p[met->np - 1]));
    LOG(2, "Pressure levels: %g, %g ... %g hPa",
        met->p[0], met->p[1], met->p[met->np - 1]);
  }
}

/*****************************************************************************/

int read_met_help_3d(
  int ncid,
  char *varname,
  char *varname2,
  met_t * met,
  float dest[EX][EY][EP],
  float scl,
  int init) {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
    sprintf(varsel, "%s", varname);

  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s "
        "(FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
```

```
            dest[ix][iy][ip] = 0;
          short aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux * scalfac + offset) < 1e14f)
            dest[ix][iy][ip] += scl * (aux * scalfac + offset);
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY * EP);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
            dest[ix][iy][ip] = 0;
          float aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux) < 1e14f)
            dest[ix][iy][ip] += scl * aux;
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
  }

  /* Return... */
  return 1;
}

/*****************************************************************************/

int read_met_help_2d(
  int ncid,
  char *varname,
  char *varname2,
  met_t * met,
  float dest[EX][EY],
  float scl,
  int init) {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
    sprintf(varsel, "%s", varname);

```

```
  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Write info... */
    LOG(2, "Packed: scale_factor= %g / add_offset= %g", scalfac, offset);

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s"
        " (FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        short aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux * scalfac + offset) < 1e14f)
          dest[ix][iy] += scl * (aux * scalfac + offset);
        else
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        float aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux) < 1e14f)
          dest[ix][iy] += scl * aux;
        else
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }
```

```
  /* Return... */
  return 1;
}

/*****************************************************************************/

void read_met_levels(
  int ncid,
  ctl_t * ctl,
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_LEVELS", "INPUT", NVTX_READ);
  LOG(2, "Read level data...");

  /* Read meteorological data... */
  if (!read_met_help_3d(ncid, "t", "T", met, met->t, 1.0, 1))
    ERRMSG("Cannot read temperature!");
  if (!read_met_help_3d(ncid, "u", "U", met, met->u, 1.0, 1))
    ERRMSG("Cannot read zonal wind!");
  if (!read_met_help_3d(ncid, "v", "V", met, met->v, 1.0, 1))
    ERRMSG("Cannot read meridional wind!");
  if (!read_met_help_3d(ncid, "w", "W", met, met->w, 0.01f, 1))
    WARN("Cannot read vertical velocity!");
  if (!read_met_help_3d
      (ncid, "q", "Q", met, met->h2o, (float) (MA / MH2O), 1))
    WARN("Cannot read specific humidity!");
  if (!read_met_help_3d
      (ncid, "o3", "O3", met, met->o3, (float) (MA / MO3), 1))
    WARN("Cannot read ozone data!");
  if (ctl->met_cloud == 1 || ctl->met_cloud == 3) {
    if (!read_met_help_3d(ncid, "clwc", "CLWC", met, met->lwc, 1.0, 1))
      WARN("Cannot read cloud liquid water content!");
    if (!read_met_help_3d(ncid, "ciwc", "CIWC", met, met->iwc, 1.0, 1))
      WARN("Cannot read cloud ice water content!");
  }
  if (ctl->met_cloud == 2 || ctl->met_cloud == 3) {
    if (!read_met_help_3d
        (ncid, "crwc", "CRWC", met, met->lwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud rain water content!");
    if (!read_met_help_3d
        (ncid, "cswc", "CSWC", met, met->iwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud snow water content!");
  }

  /* Transfer from model levels to pressure levels... */
  if (ctl->met_np > 0) {

    /* Read pressure on model levels... */
    if (!read_met_help_3d(ncid, "pl", "PL", met, met->pl, 0.01f, 1))
      ERRMSG("Cannot read pressure on model levels!");

    /* Vertical interpolation from model to pressure levels... */
    read_met_ml2pl(ctl, met, met->t);
    read_met_ml2pl(ctl, met, met->u);
    read_met_ml2pl(ctl, met, met->v);
    read_met_ml2pl(ctl, met, met->w);
    read_met_ml2pl(ctl, met, met->h2o);
    read_met_ml2pl(ctl, met, met->o3);
    read_met_ml2pl(ctl, met, met->lwc);
    read_met_ml2pl(ctl, met, met->iwc);

    /* Set new pressure levels... */
    met->np = ctl->met_np;
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] = ctl->met_p[ip];
  }

  /* Check ordering of pressure levels... */
  for (int ip = 1; ip < met->np; ip++)
    if (met->p[ip - 1] < met->p[ip])
      ERRMSG("Pressure levels must be descending!");
}

/*****************************************************************************/

void read_met_ml2pl(
  ctl_t * ctl,
  met_t * met,
  float var[EX][EY][EP]) {

  double aux[EP], p[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_ML2PL", "METPROC", NVTX_READ);
  LOG(2, "Interpolate meteo data to pressure levels...");
```

```

  /* Loop over columns... */
#pragma omp parallel for default(shared) private(aux,p) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Copy pressure profile... */
      for (int ip = 0; ip < met->np; ip++)
        p[ip] = met->pl[ix][iy][ip];

      /* Interpolate... */
      for (int ip = 0; ip < ctl->met_np; ip++) {
        double pt = ctl->met_p[ip];
        if ((pt > p[0] && p[0] > p[1]) || (pt < p[0] && p[0] < p[1]))
          pt = p[0];
        else if ((pt > p[met->np - 1] && p[1] > p[0])
                 || (pt < p[met->np - 1] && p[1] < p[0]))
          pt = p[met->np - 1];
        int ip2 = locate_irr(p, met->np, pt);
        aux[ip] = LIN(p[ip2], var[ix][iy][ip2],
                      p[ip2 + 1], var[ix][iy][ip2 + 1], pt);
      }

      /* Copy data... */
      for (int ip = 0; ip < ctl->met_np; ip++)
        var[ix][iy][ip] = (float) aux[ip];
    }
}

/*****************************************************************************/

void read_met_pbl(
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PBL", "METPROC", NVTX_READ);
  LOG(2, "Calculate planetary boundary layer...");

  /* Parameters used to estimate the height of the PBL
     (e.g., Vogelezang and Holtslag, 1996; Seidel et al., 2012)... */
  const double rib_crit = 0.25, dz = 0.05, umin = 5.0;

  /* Loop over grid points... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set bottom level of PBL... */
      double pbl_bot = met->ps[ix][iy] + DZ2DP(dz, met->ps[ix][iy]);

      /* Find lowest level near the bottom... */
      int ip;
      for (ip = 1; ip < met->np; ip++)
        if (met->p[ip] < pbl_bot)
          break;

      /* Get near surface data... */
      double zs = LIN(met->p[ip - 1], met->z[ix][iy][ip - 1],
                      met->p[ip], met->z[ix][iy][ip], pbl_bot);
      double ts = LIN(met->p[ip - 1], met->t[ix][iy][ip - 1],
                      met->p[ip], met->t[ix][iy][ip], pbl_bot);
      double us = LIN(met->p[ip - 1], met->u[ix][iy][ip - 1],
                      met->p[ip], met->u[ix][iy][ip], pbl_bot);
      double vs = LIN(met->p[ip - 1], met->v[ix][iy][ip - 1],
                      met->p[ip], met->v[ix][iy][ip], pbl_bot);
      double h2os = LIN(met->p[ip - 1], met->h2o[ix][iy][ip - 1],
                        met->p[ip], met->h2o[ix][iy][ip], pbl_bot);
      double tvs = THETAVIRT(pbl_bot, ts, h2os);

      /* Init... */
      double rib, rib_old = 0;

      /* Loop over levels... */
      for (; ip < met->np; ip++) {

        /* Get squared horizontal wind speed... */
        double vh2
          = SQR(met->u[ix][iy][ip] - us) + SQR(met->v[ix][iy][ip] - vs);
        vh2 = GSL_MAX(vh2, SQR(umin));

        /* Calculate bulk Richardson number... */
        rib = G0 * 1e3 * (met->z[ix][iy][ip] - zs) / tvs
          * (THETAVIRT(met->p[ip], met->t[ix][iy][ip],
                       met->h2o[ix][iy][ip]) - tvs) / vh2;

        /* Check for critical value... */
        if (rib >= rib_crit) {
```

```
          met->pbl[ix][iy] = (float) (LIN(rib_old, met->p[ip - 1],
                                          rib, met->p[ip], rib_crit));
          if (met->pbl[ix][iy] > pbl_bot)
            met->pbl[ix][iy] = (float) pbl_bot;
          break;
        }

        /* Save Richardson number... */
        rib_old = rib;
      }
    }
}

/*****************************************************************************/

void read_met_periodic(
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PERIODIC", "METPROC", NVTX_READ);
  LOG(2, "Apply periodic boundary conditions...");

  /* Check longitudes... */
  if (!(fabs(met->lon[met->nx - 1] - met->lon[0]
             + met->lon[1] - met->lon[0] - 360) < 0.01))
    return;

  /* Increase longitude counter... */
  if ((++met->nx) > EX)
    ERRMSG("Cannot create periodic boundary conditions!");

  /* Set longitude... */
  met->lon[met->nx - 1] = met->lon[met->nx - 2] + met->lon[1] - met->lon[0];

  /* Loop over latitudes and pressure levels... */
#pragma omp parallel for default(shared)
  for (int iy = 0; iy < met->ny; iy++) {
    met->ps[met->nx - 1][iy] = met->ps[0][iy];
    met->zs[met->nx - 1][iy] = met->zs[0][iy];
    met->ts[met->nx - 1][iy] = met->ts[0][iy];
    met->us[met->nx - 1][iy] = met->us[0][iy];
    met->vs[met->nx - 1][iy] = met->vs[0][iy];
    for (int ip = 0; ip < met->np; ip++) {
      met->t[met->nx - 1][iy][ip] = met->t[0][iy][ip];
      met->u[met->nx - 1][iy][ip] = met->u[0][iy][ip];
      met->v[met->nx - 1][iy][ip] = met->v[0][iy][ip];
      met->w[met->nx - 1][iy][ip] = met->w[0][iy][ip];
      met->h2o[met->nx - 1][iy][ip] = met->h2o[0][iy][ip];
      met->o3[met->nx - 1][iy][ip] = met->o3[0][iy][ip];
      met->lwc[met->nx - 1][iy][ip] = met->lwc[0][iy][ip];
      met->iwc[met->nx - 1][iy][ip] = met->iwc[0][iy][ip];
    }
  }
}

/*****************************************************************************/

void read_met_pv(
  met_t * met) {

  double pows[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_PV", "METPROC", NVTX_READ);
  LOG(2, "Calculate potential vorticity...");

  /* Set powers... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    pows[ip] = pow(1000. / met->p[ip], 0.286);

  /* Loop over grid points... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++) {

    /* Set indices... */
    int ix0 = GSL_MAX(ix - 1, 0);
    int ix1 = GSL_MIN(ix + 1, met->nx - 1);

    /* Loop over grid points... */
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set indices... */
      int iy0 = GSL_MAX(iy - 1, 0);
      int iy1 = GSL_MIN(iy + 1, met->ny - 1);

      /* Set auxiliary variables... */
```

```
      double latr = 0.5 * (met->lat[iy1] + met->lat[iy0]);
      double dx = 1000. * DEG2DX(met->lon[ix1] - met->lon[ix0], latr);
      double dy = 1000. * DEG2DY(met->lat[iy1] - met->lat[iy0]);
      double c0 = cos(met->lat[iy0] / 180. * M_PI);
      double c1 = cos(met->lat[iy1] / 180. * M_PI);
      double cr = cos(latr / 180. * M_PI);
      double vort = 2 * 7.2921e-5 * sin(latr * M_PI / 180.);

      /* Loop over grid points... */
      for (int ip = 0; ip < met->np; ip++) {

        /* Get gradients in longitude... */
        double dtdx
          = (met->t[ix1][iy][ip] - met->t[ix0][iy][ip]) * pows[ip] / dx;
        double dvdx = (met->v[ix1][iy][ip] - met->v[ix0][iy][ip]) / dx;

        /* Get gradients in latitude... */
        double dtdy
          = (met->t[ix][iy1][ip] - met->t[ix][iy0][ip]) * pows[ip] / dy;
        double dudy
          = (met->u[ix][iy1][ip] * c1 - met->u[ix][iy0][ip] * c0) / dy;

        /* Set indices... */
        int ip0 = GSL_MAX(ip - 1, 0);
        int ip1 = GSL_MIN(ip + 1, met->np - 1);

        /* Get gradients in pressure... */
        double dtdp, dudp, dvdp;
        double dp0 = 100. * (met->p[ip] - met->p[ip0]);
        double dp1 = 100. * (met->p[ip1] - met->p[ip]);
        if (ip != ip0 && ip != ip1) {
          double denom = dp0 * dp1 * (dp0 + dp1);
          dtdp = (dp0 * dp0 * met->t[ix][iy][ip1] * pows[ip1]
                  - dp1 * dp1 * met->t[ix][iy][ip0] * pows[ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->t[ix][iy][ip] * pows[ip])
            / denom;
          dudp = (dp0 * dp0 * met->u[ix][iy][ip1]
                  - dp1 * dp1 * met->u[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->u[ix][iy][ip])
            / denom;
          dvdp = (dp0 * dp0 * met->v[ix][iy][ip1]
                  - dp1 * dp1 * met->v[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->v[ix][iy][ip])
            / denom;
        } else {
          double denom = dp0 + dp1;
          dtdp =
            (met->t[ix][iy][ip1] * pows[ip1] -
             met->t[ix][iy][ip0] * pows[ip0]) / denom;
          dudp = (met->u[ix][iy][ip1] - met->u[ix][iy][ip0]) / denom;
          dvdp = (met->v[ix][iy][ip1] - met->v[ix][iy][ip0]) / denom;
        }

        /* Calculate PV... */
        met->pv[ix][iy][ip] = (float)
          (1e6 * G0 *
           (-dtdp * (dvdx - dudy / cr + vort) + dvdp * dtdx - dudp * dtdy));
      }
    }
  }

  /* Fix for polar regions... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++)
    for (int ip = 0; ip < met->np; ip++) {
      met->pv[ix][0][ip]
        = met->pv[ix][1][ip]
        = met->pv[ix][2][ip];
      met->pv[ix][met->ny - 1][ip]
        = met->pv[ix][met->ny - 2][ip]
        = met->pv[ix][met->ny - 3][ip];
    }
}

/*****************************************************************************/

void read_met_sample(
  ctl_t * ctl,
  met_t * met) {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_dp <= 1 && ctl->met_dx <= 1 && ctl->met_dy <= 1
      && ctl->met_sp <= 1 && ctl->met_sx <= 1 && ctl->met_sy <= 1)
    return;

```

```
/* Set timer... */
SELECT_TIMER("READ_MET_SAMPLE", "METPROC", NVTX_READ);
LOG(2, "Downsampling of meteo data...");

/* Allocate... */
ALLOC(help, met_t, 1);

/* Copy data... */
help->nx = met->nx;
help->ny = met->ny;
help->np = met->np;
memcpy(help->lon, met->lon, sizeof(met->lon));
memcpy(help->lat, met->lat, sizeof(met->lat));
memcpy(help->p, met->p, sizeof(met->p));

/* Smoothing... */
for (int ix = 0; ix < met->nx; ix += ctl->met_dx) {
  for (int iy = 0; iy < met->ny; iy += ctl->met_dy) {
    for (int ip = 0; ip < met->np; ip += ctl->met_dp) {
      help->ps[ix][iy] = 0;
      help->zs[ix][iy] = 0;
      help->ts[ix][iy] = 0;
      help->us[ix][iy] = 0;
      help->vs[ix][iy] = 0;
      help->t[ix][iy][ip] = 0;
      help->u[ix][iy][ip] = 0;
      help->v[ix][iy][ip] = 0;
      help->w[ix][iy][ip] = 0;
      help->h2o[ix][iy][ip] = 0;
      help->o3[ix][iy][ip] = 0;
      help->lwc[ix][iy][ip] = 0;
      help->iwc[ix][iy][ip] = 0;
      float wsum = 0;
      for (int ix2 = ix - ctl->met_sx + 1; ix2 <= ix + ctl->met_sx - 1;
           ix2++) {
        int ix3 = ix2;
        if (ix3 < 0)
          ix3 += met->nx;
        else if (ix3 >= met->nx)
          ix3 -= met->nx;

        for (int iy2 = GSL_MAX(iy - ctl->met_sy + 1, 0);
             iy2 <= GSL_MIN(iy + ctl->met_sy - 1, met->ny - 1); iy2++)
          for (int ip2 = GSL_MAX(ip - ctl->met_sp + 1, 0);
               ip2 <= GSL_MIN(ip + ctl->met_sp - 1, met->np - 1); ip2++) {
            float w = (1.0f - (float) abs(ix - ix2) / (float) ctl->met_sx)
              * (1.0f - (float) abs(iy - iy2) / (float) ctl->met_sy)
              * (1.0f - (float) abs(ip - ip2) / (float) ctl->met_sp);
            help->ps[ix][iy] += w * met->ps[ix3][iy2];
            help->zs[ix][iy] += w * met->zs[ix3][iy2];
            help->ts[ix][iy] += w * met->ts[ix3][iy2];
            help->us[ix][iy] += w * met->us[ix3][iy2];
            help->vs[ix][iy] += w * met->vs[ix3][iy2];
            help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip2];
            help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip2];
            help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip2];
            help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip2];
            help->h2o[ix][iy][ip] += w * met->h2o[ix3][iy2][ip2];
            help->o3[ix][iy][ip] += w * met->o3[ix3][iy2][ip2];
            help->lwc[ix][iy][ip] += w * met->lwc[ix3][iy2][ip2];
            help->iwc[ix][iy][ip] += w * met->iwc[ix3][iy2][ip2];
            wsum += w;
          }
      }
      help->ps[ix][iy] /= wsum;
      help->zs[ix][iy] /= wsum;
      help->ts[ix][iy] /= wsum;
      help->us[ix][iy] /= wsum;
      help->vs[ix][iy] /= wsum;
      help->t[ix][iy][ip] /= wsum;
      help->u[ix][iy][ip] /= wsum;
      help->v[ix][iy][ip] /= wsum;
      help->w[ix][iy][ip] /= wsum;
      help->h2o[ix][iy][ip] /= wsum;
      help->o3[ix][iy][ip] /= wsum;
      help->lwc[ix][iy][ip] /= wsum;
      help->iwc[ix][iy][ip] /= wsum;
    }
  }
}

/* Downsampling... */
met->nx = 0;
for (int ix = 0; ix < help->nx; ix += ctl->met_dx) {
  met->lon[met->nx] = help->lon[ix];
  met->ny = 0;
  for (int iy = 0; iy < help->ny; iy += ctl->met_dy) {
```

```
      met->lat[met->ny] = help->lat[iy];
      met->ps[met->nx][met->ny] = help->ps[ix][iy];
      met->zs[met->nx][met->ny] = help->zs[ix][iy];
      met->ts[met->nx][met->ny] = help->ts[ix][iy];
      met->us[met->nx][met->ny] = help->us[ix][iy];
      met->vs[met->nx][met->ny] = help->vs[ix][iy];
      met->np = 0;
      for (int ip = 0; ip < help->np; ip += ctl->met_dp) {
        met->p[met->np] = help->p[ip];
        met->t[met->nx][met->ny][met->np] = help->t[ix][iy][ip];
        met->u[met->nx][met->ny][met->np] = help->u[ix][iy][ip];
        met->v[met->nx][met->ny][met->np] = help->v[ix][iy][ip];
        met->w[met->nx][met->ny][met->np] = help->w[ix][iy][ip];
        met->h2o[met->nx][met->ny][met->np] = help->h2o[ix][iy][ip];
        met->o3[met->nx][met->ny][met->np] = help->o3[ix][iy][ip];
        met->lwc[met->nx][met->ny][met->np] = help->lwc[ix][iy][ip];
        met->iwc[met->nx][met->ny][met->np] = help->iwc[ix][iy][ip];
        met->np++;
      }
      met->ny++;
    }
    met->nx++;
  }

  /* Free... */
  free(help);
}

/*****************************************************************************/

void read_met_surface(
  int ncid,
  met_t * met) {

  /* Set timer... */
  SELECT_TIMER("READ_MET_SURFACE", "INPUT", NVTX_READ);
  LOG(2, "Read surface data...");

  /* Read surface pressure... */
  if (!read_met_help_2d(ncid, "lnsp", "LNSP", met, met->ps, 1.0f, 1)) {
    if (!read_met_help_2d(ncid, "ps", "PS", met, met->ps, 0.01f, 1)) {
      WARN("Cannot not read surface pressure data (use lowest level)!");
      for (int ix = 0; ix < met->nx; ix++)
        for (int iy = 0; iy < met->ny; iy++)
          met->ps[ix][iy] = (float) met->p[0];
    }
  } else
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->ps[ix][iy] = (float) (exp(met->ps[ix][iy]) / 100.);

  /* Read geopotential height at the surface... */
  if (!read_met_help_2d
      (ncid, "z", "Z", met, met->zs, (float) (1. / (1000. * G0)), 1))
    if (!read_met_help_2d
        (ncid, "zm", "ZM", met, met->zs, (float) (1. / 1000.), 1))
      WARN("Cannot read surface geopotential height!");

  /* Read temperature at the surface... */
  if (!read_met_help_2d(ncid, "t2m", "T2M", met, met->ts, 1.0, 1))
    WARN("Cannot read surface temperature!");

  /* Read zonal wind at the surface... */
  if (!read_met_help_2d(ncid, "u10m", "U10M", met, met->us, 1.0, 1))
    WARN("Cannot read surface zonal wind!");

  /* Read meridional wind at the surface... */
  if (!read_met_help_2d(ncid, "v10m", "V10M", met, met->vs, 1.0, 1))
    WARN("Cannot read surface meridional wind!");
}

/*****************************************************************************/

void read_met_tropo(
  ctl_t * ctl,
  met_t * met) {

  double p2[200], pv[EP], pv2[200], t[EP], t2[200], th[EP],
    th2[200], z[EP], z2[200];

  /* Set timer... */
  SELECT_TIMER("READ_MET_TROPO", "METPROC", NVTX_READ);
  LOG(2, "Calculate tropopause...");

  /* Get altitude and pressure profiles... */
#pragma omp parallel for default(shared)
  for (int iz = 0; iz < met->np; iz++)
```

```
    z[iz] = Z(met->p[iz]);
#pragma omp parallel for default(shared)
  for (int iz = 0; iz <= 190; iz++) {
    z2[iz] = 4.5 + 0.1 * iz;
    p2[iz] = P(z2[iz]);
  }

  /* Do not calculate tropopause... */
  if (ctl->met_tropo == 0)
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = GSL_NAN;

  /* Use tropopause climatology... */
  else if (ctl->met_tropo == 1) {
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = (float) clim_tropo(met->time, met->lat[iy]);
  }

  /* Use cold point... */
  else if (ctl->met_tropo == 2) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 171, ctl->met_tropo_spline);

        /* Find minimum... */
        int iz = (int) gsl_stats_min_index(t2, 1, 171);
        if (iz > 0 && iz < 170)
          met->pt[ix][iy] = (float) p2[iz];
        else
          met->pt[ix][iy] = GSL_NAN;
      }
  }

  /* Use WMO definition... */
  else if (ctl->met_tropo == 3 || ctl->met_tropo == 4) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        int iz;
        for (iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 191, ctl->met_tropo_spline);

        /* Find 1st tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (iz = 0; iz <= 170; iz++) {
          int found = 1;
          for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
            if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                ctl->met_tropo_lapse) {
              found = 0;
              break;
            }
          if (found) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
        }

        /* Find 2nd tropopause... */
        if (ctl->met_tropo == 4) {
          met->pt[ix][iy] = GSL_NAN;
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev_sep; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) <
                  ctl->met_tropo_lapse_sep) {
                found = 0;
                break;
              }
            if (found)
```

```
              break;
          }
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                  ctl->met_tropo_lapse) {
                found = 0;
                break;
              }
            if (found) {
              if (iz > 0 && iz < 170)
                met->pt[ix][iy] = (float) p2[iz];
              break;
            }
          }
        }
      }
  }

  /* Use dynamical tropopause... */
  else if (ctl->met_tropo == 5) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(pv,pv2,th,th2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate potential vorticity profile... */
        for (int iz = 0; iz < met->np; iz++)
          pv[iz] = met->pv[ix][iy][iz];
        spline(z, pv, met->np, z2, pv2, 171, ctl->met_tropo_spline);

        /* Interpolate potential temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          th[iz] = THETA(met->p[iz], met->t[ix][iy][iz]);
        spline(z, th, met->np, z2, th2, 171, ctl->met_tropo_spline);

        /* Find dynamical tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (int iz = 0; iz <= 170; iz++)
          if (fabs(pv2[iz]) >= ctl->met_tropo_pv
              || th2[iz] >= ctl->met_tropo_theta) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
      }
  }

  else
    ERRMSG("Cannot calculate tropopause!");

  /* Interpolate temperature, geopotential height, and water vapor vmr... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {
      double h2ot, tt, zt;
      INTPOL_INIT;
      intpol_met_space_3d(met, met->t, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &tt, ci, cw, 1);
      intpol_met_space_3d(met, met->z, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &zt, ci, cw, 0);
      intpol_met_space_3d(met, met->h2o, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &h2ot, ci, cw, 0);
      met->tt[ix][iy] = (float) tt;
      met->zt[ix][iy] = (float) zt;
      met->h2ot[ix][iy] = (float) h2ot;
    }
}

/*****************************************************************************/

double scan_ctl(
  const char *filename,
  int argc,
  char *argv[],
  const char *varname,
  int arridx,
  const char *defvalue,
  char *value) {

  FILE *in = NULL;

  char dummy[LEN], fullname1[LEN], fullname2[LEN], line[LEN],
    rvarname[LEN], rval[LEN];

```

```
  int contain = 0, i;

  /* Open file... */
  if (filename[strlen(filename) - 1] != '-')
    if (!(in = fopen(filename, "r")))
      ERRMSG("Cannot open file!");

  /* Set full variable name... */
  if (arridx >= 0) {
    sprintf(fullname1, "%s[%d]", varname, arridx);
    sprintf(fullname2, "%s[*]", varname);
  } else {
    sprintf(fullname1, "%s", varname);
    sprintf(fullname2, "%s", varname);
  }

  /* Read data... */
  if (in != NULL)
    while (fgets(line, LEN, in))
      if (sscanf(line, "%s %s %s", rvarname, dummy, rval) == 3)
        if (strcasecmp(rvarname, fullname1) == 0 ||
            strcasecmp(rvarname, fullname2) == 0) {
          contain = 1;
          break;
        }
  for (i = 1; i < argc - 1; i++)
    if (strcasecmp(argv[i], fullname1) == 0 ||
        strcasecmp(argv[i], fullname2) == 0) {
      sprintf(rval, "%s", argv[i + 1]);
      contain = 1;
      break;
    }

  /* Close file... */
  if (in != NULL)
    fclose(in);

  /* Check for missing variables... */
  if (!contain) {
    if (strlen(defvalue) > 0)
      sprintf(rval, "%s", defvalue);
    else
      ERRMSG("Missing variable %s!\n", fullname1);
  }

  /* Write info... */
  LOG(1, "%s = %s", fullname1, rval);

  /* Return values... */
  if (value != NULL)
    sprintf(value, "%s", rval);
  return atof(rval);
}

/*****************************************************************************/

double sedi(
  double p,
  double T,
  double r_p,
  double rho_p) {

  double eta, G, K, lambda, rho, v;

  /* Convert pressure from hPa to Pa... */
  p *= 100.;

  /* Convert particle radius from microns to m... */
  r_p *= 1e-6;

  /* Density of dry air [kg / m^3]... */
  rho = p / (RA * T);

  /* Dynamic viscosity of air [kg / (m s)]... */
  eta = 1.8325e-5 * (416.16 / (T + 120.)) * pow(T / 296.16, 1.5);

  /* Thermal velocity of an air molecule [m / s]... */
  v = sqrt(8. * KB * T / (M_PI * 4.8096e-26));

  /* Mean free path of an air molecule [m]... */
  lambda = 2. * eta / (rho * v);

  /* Knudsen number for air (dimensionless)... */
  K = lambda / r_p;

  /* Cunningham slip-flow correction (dimensionless)... */
  G = 1. + K * (1.249 + 0.42 * exp(-0.87 / K));
```

```
  /* Sedimentation velocity [m / s]... */
  return 2. * SQR(r_p) * (rho_p - rho) * G0 / (9. * eta) * G;
}

/*****************************************************************************/

void spline(
  double *x,
  double *y,
  int n,
  double *x2,
  double *y2,
  int n2,
  int method) {

  /* Cubic spline interpolation... */
  if (method == 1) {

    /* Allocate... */
    gsl_interp_accel *acc;
    gsl_spline *s;
    acc = gsl_interp_accel_alloc();
    s = gsl_spline_alloc(gsl_interp_cspline, (size_t) n);

    /* Interpolate profile... */
    gsl_spline_init(s, x, y, (size_t) n);
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else
        y2[i] = gsl_spline_eval(s, x2[i], acc);

    /* Free... */
    gsl_spline_free(s);
    gsl_interp_accel_free(acc);
  }

  /* Linear interpolation... */
  else {
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else {
        int idx = locate_irr(x, n, x2[i]);
        y2[i] = LIN(x[idx], y[idx], x[idx + 1], y[idx + 1], x2[i]);
      }
  }
}

/*****************************************************************************/

float stddev(
  float *data,
  int n) {

  if (n <= 0)
    return 0;

  float mean = 0, var = 0;

  for (int i = 0; i < n; ++i) {
    mean += data[i];
    var += SQR(data[i]);
  }

  return sqrtf(var / (float) n - SQR(mean / (float) n));
}

/*****************************************************************************/

void time2jsec(
  int year,
  int mon,
  int day,
  int hour,
  int min,
  int sec,
  double remain,
  double *jsec) {

  struct tm t0, t1;

```

```
  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  t1.tm_year = year - 1900;
  t1.tm_mon = mon - 1;
  t1.tm_mday = day;
  t1.tm_hour = hour;
  t1.tm_min = min;
  t1.tm_sec = sec;

  *jsec = (double) timegm(&t1) - (double) timegm(&t0) + remain;
}

/*****************************************************************************/

void timer(
  const char *name,
  const char *group,
  int output) {

  static char names[NTIMER][100], groups[NTIMER][100];

  static double rt_name[NTIMER], rt_group[NTIMER], t0, t1;

  static int iname = -1, igroup = -1, nname, ngroup;

  /* Get time... */
  t1 = omp_get_wtime();

  /* Add elapsed time to current timers... */
  if (iname >= 0)
    rt_name[iname] += t1 - t0;
  if (igroup >= 0)
    rt_group[igroup] += t1 - t0;

  /* Report timers... */
  if (output) {
    for (int i = 0; i < nname; i++)
      LOG(1, "TIMER_%s = %.3f s", names[i], rt_name[i]);
    for (int i = 0; i < ngroup; i++)
      LOG(1, "TIMER_%s = %.3f s", groups[i], rt_group[i]);
    double total = 0.0;
    for (int i = 0; i < nname; i++)
      total += rt_name[i];
    LOG(1, "TIMER_TOTAL = %.3f s", total);
  }

  /* Identify IDs of next timer... */
  for (iname = 0; iname < nname; iname++)
    if (strcasecmp(name, names[iname]) == 0)
      break;
  for (igroup = 0; igroup < ngroup; igroup++)
    if (strcasecmp(group, groups[igroup]) == 0)
      break;

  /* Check whether this is a new timer... */
  if (iname >= nname) {
    sprintf(names[iname], "%s", name);
    if ((++nname) > NTIMER)
      ERRMSG("Too many timers!");
  }

  /* Check whether this is a new group... */
  if (igroup >= ngroup) {
    sprintf(groups[igroup], "%s", group);
    if ((++ngroup) > NTIMER)
      ERRMSG("Too many groups!");
  }

  /* Save starting time... */
  t0 = t1;
}

/*****************************************************************************/

double tropo_weight(
  double t,
  double lat,
  double p) {

  /* Get tropopause pressure... */
  double pt = clim_tropo(t, lat);

```

```
  /* Get pressure range... */
  double p1 = pt * 0.866877899;
  double p0 = pt / 0.866877899;

  /* Get weighting factor... */
  if (p > p0)
    return 1;
  else if (p < p1)
    return 0;
  else
    return LIN(p0, 1.0, p1, 0.0, p);
}

/*****************************************************************************/

void write_atm(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t) {

  FILE *in, *out;

  char line[LEN];

  double r, t0, t1;

  int year, mon, day, hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_ATM", "OUTPUT", NVTX_WRITE);

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Write info... */
  LOG(1, "Write atmospheric data: %s", filename);

  /* Write ASCII data... */
  if (ctl->atm_type == 0) {

    /* Check if gnuplot output is requested... */
    if (ctl->atm_gpfile[0] != '-') {

      /* Create gnuplot pipe... */
      if (!(out = popen("gnuplot", "w")))
        ERRMSG("Cannot create pipe to gnuplot!");

      /* Set plot filename... */
      fprintf(out, "set out \"%s.png\"\n", filename);

      /* Set time string... */
      jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
      fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
              year, mon, day, hour, min);

      /* Dump gnuplot file to pipe... */
      if (!(in = fopen(ctl->atm_gpfile, "r")))
        ERRMSG("Cannot open file!");
      while (fgets(line, LEN, in))
        fprintf(out, "%s", line);
      fclose(in);
    }

    else {

      /* Create file... */
      if (!(out = fopen(filename, "w")))
        ERRMSG("Cannot create file!");
    }

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (int iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%i = %s [%s]\n", iq + 5, ctl->qnt_name[iq],
              ctl->qnt_unit[iq]);
    fprintf(out, "\n");

    /* Write data... */
    for (int ip = 0; ip < atm->np; ip += ctl->atm_stride) {

      /* Check time... */
      if (ctl->atm_filter == 2 && (atm->time[ip] < t0 || atm->time[ip] > t1))
```

```
        continue;

      /* Write output... */
      fprintf(out, "%.2f %g %g %g", atm->time[ip], Z(atm->p[ip]),
              atm->lon[ip], atm->lat[ip]);
      for (int iq = 0; iq < ctl->nq; iq++) {
        fprintf(out, " ");
        if (ctl->atm_filter == 1
            && (atm->time[ip] < t0 || atm->time[ip] > t1))
          fprintf(out, ctl->qnt_format[iq], GSL_NAN);
        else
          fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
      }
      fprintf(out, "\n");
    }

    /* Close file... */
    fclose(out);
  }

  /* Write binary data... */
  else if (ctl->atm_type == 1) {

    /* Create file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write data... */
    FWRITE(&atm->np, int,
           1,
           out);
    FWRITE(atm->time, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->p, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->lon, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->lat, double,
             (size_t) atm->np,
           out);
    for (int iq = 0; iq < ctl->nq; iq++)
      FWRITE(atm->q[iq], double,
               (size_t) atm->np,
             out);

    /* Close file... */
    fclose(out);
  }

  /* Error... */
  else
    ERRMSG("Atmospheric data type not supported!");

  /* Write info... */
  double mini, maxi;
  LOG(2, "Number of particles: %d", atm->np);
  gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
  LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
  LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
  LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
  LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
  LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
  for (int iq = 0; iq < ctl->nq; iq++) {
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }
}

/*****************************************************************************/

void write_csi(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t) {

  static FILE *in, *out;
```

```
  static char line[LEN];

  static double modmean[GX][GY][GZ], obsmean[GX][GY][GZ], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dlon, dlat, dz, lat,
    x[1000000], y[1000000], work[2000000];

  static int obscount[GX][GY][GZ], ct, cx, cy, cz, ip, ix, iy, iz, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_CSI", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Open observation data file... */
    LOG(1, "Read CSI observation data: %s", ctl->csi_obsfile);
    if (!(in = fopen(ctl->csi_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new file... */
    LOG(1, "Write CSI data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = number of hits (cx)\n"
            "# $3 = number of misses (cy)\n"
            "# $4 = number of false alarms (cz)\n"
            "# $5 = number of observations (cx + cy)\n"
            "# $6 = number of forecasts (cx + cz)\n"
            "# $7 = bias (ratio of forecasts and observations) [%%]\n"
            "# $8 = probability of detection (POD) [%%]\n"
            "# $9 = false alarm rate (FAR) [%%]\n"
            "# $10 = critical success index (CSI) [%%]\n");
    fprintf(out,
            "# $11 = hits associated with random chance\n"
            "# $12 = equitable threat score (ETS) [%%]\n"
            "# $13 = Pearson linear correlation coefficient\n"
            "# $14 = Spearman rank-order correlation coefficient\n"
            "# $15 = column density mean error (F - O) [kg/m^2]\n"
            "# $16 = column density root mean square error (RMSE) [kg/m^2]\n"
            "# $17 = column density mean absolute error [kg/m^2]\n"
            "# $18 = number of data points\n\n");

    /* Set grid box size... */
    dz = (ctl->csi_z1 - ctl->csi_z0) / ctl->csi_nz;
    dlon = (ctl->csi_lon1 - ctl->csi_lon0) / ctl->csi_nx;
    dlat = (ctl->csi_lat1 - ctl->csi_lat0) / ctl->csi_ny;

    /* Set horizontal coordinates... */
    for (iy = 0; iy < ctl->csi_ny; iy++) {
      lat = ctl->csi_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.) * cos(lat * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid cells... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++)
        modmean[ix][iy][iz] = obsmean[ix][iy][iz] = obscount[ix][iy][iz] = 0;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
```

```
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->csi_lon0) / dlon);
    iy = (int) ((rlat - ctl->csi_lat0) / dlat);
    iz = (int) ((rz - ctl->csi_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy][iz] += robs;
    obscount[ix][iy][iz]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->csi_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->csi_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->csi_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get total mass in grid cell... */
    modmean[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Analyze all grid cells... */
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++) {

        /* Calculate mean observation index... */
        if (obscount[ix][iy][iz] > 0)
          obsmean[ix][iy][iz] /= obscount[ix][iy][iz];

        /* Calculate column density... */
        if (modmean[ix][iy][iz] > 0)
          modmean[ix][iy][iz] /= (1e6 * area[iy]);

        /* Calculate CSI... */
        if (obscount[ix][iy][iz] > 0) {
          ct++;
          if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
              modmean[ix][iy][iz] >= ctl->csi_modmin)
            cx++;
          else if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
                   modmean[ix][iy][iz] < ctl->csi_modmin)
            cy++;
          else if (obsmean[ix][iy][iz] < ctl->csi_obsmin &&
                   modmean[ix][iy][iz] >= ctl->csi_modmin)
            cz++;
        }

        /* Save data for other verification statistics... */
        if (obscount[ix][iy][iz] > 0
            && (obsmean[ix][iy][iz] >= ctl->csi_obsmin
                || modmean[ix][iy][iz] >= ctl->csi_modmin)) {
          x[n] = modmean[ix][iy][iz];
          y[n] = obsmean[ix][iy][iz];
          if ((++n) > 1000000)
            ERRMSG("Too many data points to calculate statistics!");
        }
      }

  /* Write output... */
  if (fmod(t, ctl->csi_dt_out) == 0) {
```

```
    /* Calculate verification statistics
       (https://www.cawcr.gov.au/projects/verification/) ... */
    int nobs = cx + cy;
    int nfor = cx + cz;
    double bias = (nobs > 0) ? 100. * nfor / nobs : GSL_NAN;
    double pod = (nobs > 0) ? (100. * cx) / nobs : GSL_NAN;
    double far = (nfor > 0) ? (100. * cz) / nfor : GSL_NAN;
    double csi = (cx + cy + cz > 0) ? (100. * cx) / (cx + cy + cz) : GSL_NAN;
    double cx_rd = (ct > 0) ? (1. * nobs * nfor) / ct : GSL_NAN;
    double ets = (cx + cy + cz - cx_rd > 0) ?
      (100. * (cx - cx_rd)) / (cx + cy + cz - cx_rd) : GSL_NAN;
    double rho_p =
      (n > 0) ? gsl_stats_correlation(x, 1, y, 1, (size_t) n) : GSL_NAN;
    double rho_s =
      (n > 0) ? gsl_stats_spearman(x, 1, y, 1, (size_t) n, work) : GSL_NAN;
    for (int i = 0; i < n; i++)
      work[i] = x[i] - y[i];
    double mean = (n > 0) ? gsl_stats_mean(work, 1, (size_t) n) : GSL_NAN;
    double rmse = (n > 0) ? gsl_stats_sd_with_fixed_mean(work, 1, (size_t) n,
                                                         0.0) : GSL_NAN;
    double absdev =
      (n > 0) ? gsl_stats_absdev_m(work, 1, (size_t) n, 0.0) : GSL_NAN;

    /* Write... */
    fprintf(out, "%.2f %d %d %d %d %d %g %g %g %g %g %g %g %g %g %g %g %d\n",
            t, cx, cy, cz, nobs, nfor, bias, pod, far, csi, cx_rd, ets,
            rho_p, rho_s, mean, rmse, absdev, n);

    /* Set counters to zero... */
    n = ct = cx = cy = cz = 0;
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}

/*****************************************************************************/

void write_ens(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t) {

  static FILE *out;

  static double dummy, ens, lat, lon, p[NENS], q[NQ][NENS],
    t0, t1, x[NENS][3], xm[3];

  static int ip, iq;

  static size_t i, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_ENS", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantities... */
    if (ctl->qnt_ens < 0)
      ERRMSG("Missing ensemble IDs!");

    /* Create new file... */
    LOG(1, "Write ensemble data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (mean) [%s]\n", 5 + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (sigma) [%s]\n", 5 + ctl->nq + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "# $%d = number of members\n\n", 5 + 2 * ctl->nq);
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;
```

```

  /* Init... */
  ens = GSL_NAN;
  n = 0;

  /* Loop over air parcels... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check ensemble id... */
    if (atm->q[ctl->qnt_ens][ip] != ens) {

      /* Write results... */
      if (n > 0) {

        /* Get mean position... */
        xm[0] = xm[1] = xm[2] = 0;
        for (i = 0; i < n; i++) {
          xm[0] += x[i][0] / (double) n;
          xm[1] += x[i][1] / (double) n;
          xm[2] += x[i][2] / (double) n;
        }
        cart2geo(xm, &dummy, &lon, &lat);
        fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon,
                lat);

        /* Get quantity statistics... */
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
        }
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
        }
        fprintf(out, " %zu\n", n);
      }

      /* Init new ensemble... */
      ens = atm->q[ctl->qnt_ens][ip];
      n = 0;
    }

    /* Save data... */
    p[n] = atm->p[ip];
    geo2cart(0, atm->lon[ip], atm->lat[ip], x[n]);
    for (iq = 0; iq < ctl->nq; iq++)
      q[iq][n] = atm->q[iq][ip];
    if ((++n) >= NENS)
      ERRMSG("Too many data points!");
  }

  /* Write results... */
  if (n > 0) {

    /* Get mean position... */
    xm[0] = xm[1] = xm[2] = 0;
    for (i = 0; i < n; i++) {
      xm[0] += x[i][0] / (double) n;
      xm[1] += x[i][1] / (double) n;
      xm[2] += x[i][2] / (double) n;
    }
    cart2geo(xm, &dummy, &lon, &lat);
    fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon, lat);

    /* Get quantity statistics... */
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
    }
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
    }
    fprintf(out, " %zu\n", n);
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}

/*****************************************************************************/

```

```
void write_grid(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t) {

  FILE *in, *out;

  char line[LEN];

  static double mass[GX][GY][GZ], vmr[GX][GY][GZ], vmr_expl, vmr_impl,
    z[GZ], dz, lon[GX], dlon, lat[GY], dlat, area[GY], rho_air,
    press[GZ], temp, cd, t0, t1, r;

  static int ip, ix, *ixs, iy, *iys, iz, *izs, np[GX][GY][GZ], year, mon, day,
    hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_GRID", "OUTPUT", NVTX_WRITE);

  /* Check dimensions... */
  if (ctl->grid_nx > GX || ctl->grid_ny > GY || ctl->grid_nz > GZ)
    ERRMSG("Grid dimensions too large!");

  /* Set grid box size... */
  dz = (ctl->grid_z1 - ctl->grid_z0) / ctl->grid_nz;
  dlon = (ctl->grid_lon1 - ctl->grid_lon0) / ctl->grid_nx;
  dlat = (ctl->grid_lat1 - ctl->grid_lat0) / ctl->grid_ny;

  /* Set vertical coordinates... */
#pragma omp parallel for default(shared) private(iz)
  for (iz = 0; iz < ctl->grid_nz; iz++) {
    z[iz] = ctl->grid_z0 + dz * (iz + 0.5);
    press[iz] = P(z[iz]);
  }

  /* Set horizontal coordinates... */
  for (ix = 0; ix < ctl->grid_nx; ix++)
    lon[ix] = ctl->grid_lon0 + dlon * (ix + 0.5);
#pragma omp parallel for default(shared) private(iy)
  for (iy = 0; iy < ctl->grid_ny; iy++) {
    lat[iy] = ctl->grid_lat0 + dlat * (iy + 0.5);
    area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
      * cos(lat[iy] * M_PI / 180.);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->grid_nx; ix++)
    for (iy = 0; iy < ctl->grid_ny; iy++)
      for (iz = 0; iz < ctl->grid_nz; iz++) {
        mass[ix][iy][iz] = 0;
        vmr[ix][iy][iz] = 0;
        np[ix][iy][iz] = 0;
      }

  /* Allocate... */
  ALLOC(ixs, int,
        atm->np);
  ALLOC(iys, int,
        atm->np);
  ALLOC(izs, int,
        atm->np);

  /* Get indices... */
#pragma omp parallel for default(shared) private(ip)
  for (ip = 0; ip < atm->np; ip++) {
    ixs[ip] = (int) ((atm->lon[ip] - ctl->grid_lon0) / dlon);
    iys[ip] = (int) ((atm->lat[ip] - ctl->grid_lat0) / dlat);
    izs[ip] = (int) ((Z(atm->p[ip]) - ctl->grid_z0) / dz);
    if (atm->time[ip] < t0 || atm->time[ip] > t1
        || ixs[ip] < 0 || ixs[ip] >= ctl->grid_nx
        || iys[ip] < 0 || iys[ip] >= ctl->grid_ny
        || izs[ip] < 0 || izs[ip] >= ctl->grid_nz)
      izs[ip] = -1;
  }

  /* Average data... */
  for (ip = 0; ip < atm->np; ip++)
    if (izs[ip] >= 0) {
      np[ixs[ip]][iys[ip]][izs[ip]]++;
```

```
      if (ctl->qnt_m >= 0)
        mass[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_m][ip];
      if (ctl->qnt_vmr >= 0)
        vmr[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_vmr][ip];
    }

  /* Free... */
  free(ixs);
  free(iys);
  free(izs);

  /* Check if gnuplot output is requested... */
  if (ctl->grid_gpfile[0] != '-') {

    /* Write info... */
    LOG(1, "Plot grid data: %s.png", filename);

    /* Create gnuplot pipe... */
    if (!(out = popen("gnuplot", "w")))
      ERRMSG("Cannot create pipe to gnuplot!");

    /* Set plot filename... */
    fprintf(out, "set out \"%s.png\"\n", filename);

    /* Set time string... */
    jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
    fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
            year, mon, day, hour, min);

    /* Dump gnuplot file to pipe... */
    if (!(in = fopen(ctl->grid_gpfile, "r")))
      ERRMSG("Cannot open file!");
    while (fgets(line, LEN, in))
      fprintf(out, "%s", line);
    fclose(in);
  }

  else {

    /* Write info... */
    LOG(1, "Write grid data: %s", filename);

    /* Create file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");
  }

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = surface area [km^2]\n"
          "# $6 = layer width [km]\n"
          "# $7 = number of particles [1]\n"
          "# $8 = column density (implicit) [kg/m^2]\n"
          "# $9 = volume mixing ratio (implicit) [ppv]\n"
          "# $10 = volume mixing ratio (explicit) [ppv]\n\n");

  /* Write data... */
  for (ix = 0; ix < ctl->grid_nx; ix++) {
    if (ix > 0 && ctl->grid_ny > 1 && !ctl->grid_sparse)
      fprintf(out, "\n");
    for (iy = 0; iy < ctl->grid_ny; iy++) {
      if (iy > 0 && ctl->grid_nz > 1 && !ctl->grid_sparse)
        fprintf(out, "\n");
      for (iz = 0; iz < ctl->grid_nz; iz++)
        if (!ctl->grid_sparse || mass[ix][iy][iz] > 0 || vmr[ix][iy][iz] > 0) {

          /* Calculate column density... */
          if (ctl->qnt_m >= 0)
            cd = mass[ix][iy][iz] / (1e6 * area[iy]);
          else
            cd = GSL_NAN;

          /* Calculate volume mixing ratio (implicit)... */
          if (ctl->qnt_m >= 0 && ctl->molmass > 0) {
            vmr_impl = 0;
            if (mass[ix][iy][iz] > 0) {

              /* Get temperature... */
              INTPOL_INIT;
              intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                                 lon[ix], lat[iy], &temp, ci, cw, 1);

              /* Calculate density of air... */
```

```
              rho_air = 100. * press[iz] / (RA * temp);

              /* Calculate volume mixing ratio... */
              vmr_impl = MA / ctl->molmass * mass[ix][iy][iz]
                / (rho_air * 1e6 * area[iy] * 1e3 * dz);
            }
          } else
            vmr_impl = GSL_NAN;

          /* Calculate volume mixing ratio (explicit)... */
          if (ctl->qnt_vmr >= 0 && np[ix][iy][iz] > 0)
            vmr_expl = vmr[ix][iy][iz] / np[ix][iy][iz];
          else
            vmr_expl = GSL_NAN;

          /* Write output... */
          fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", t, z[iz],
                  lon[ix], lat[iy], area[iy], dz, np[ix][iy][iz], cd,
                  vmr_impl, vmr_expl);
        }
    }
  }

  /* Close file... */
  fclose(out);
}

/*****************************************************************************/

void write_prof(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t) {

  static FILE *in, *out;

  static char line[LEN];

  static double mass[GX][GY][GZ], obsmean[GX][GY], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dz, dlon, dlat,
    lon[GX], lat[GY], z[GZ], press[GZ], temp, rho_air, vmr, h2o, o3;

  static int obscount[GX][GY], ip, ix, iy, iz, okay;

  /* Set timer... */
  SELECT_TIMER("WRITE_PROF", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Check dimensions... */
    if (ctl->prof_nx > GX || ctl->prof_ny > GY || ctl->prof_nz > GZ)
      ERRMSG("Grid dimensions too large!");

    /* Check molar mass... */
    if (ctl->molmass <= 0)
      ERRMSG("Specify molar mass!");

    /* Open observation data file... */
    LOG(1, "Read profile observation data: %s", ctl->prof_obsfile);
    if (!(in = fopen(ctl->prof_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new output file... */
    LOG(1, "Write profile data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
            "# $4 = latitude [deg]\n"
            "# $5 = pressure [hPa]\n"
            "# $6 = temperature [K]\n"
            "# $7 = volume mixing ratio [ppv]\n"
```

```
            "# $8 = H2O volume mixing ratio [ppv]\n"
            "# $9 = O3 volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n"
            "# $11 = number of observations\n");

    /* Set grid box size... */
    dz = (ctl->prof_z1 - ctl->prof_z0) / ctl->prof_nz;
    dlon = (ctl->prof_lon1 - ctl->prof_lon0) / ctl->prof_nx;
    dlat = (ctl->prof_lat1 - ctl->prof_lat0) / ctl->prof_ny;

    /* Set vertical coordinates... */
    for (iz = 0; iz < ctl->prof_nz; iz++) {
      z[iz] = ctl->prof_z0 + dz * (iz + 0.5);
      press[iz] = P(z[iz]);
    }

    /* Set horizontal coordinates... */
    for (ix = 0; ix < ctl->prof_nx; ix++)
      lon[ix] = ctl->prof_lon0 + dlon * (ix + 0.5);
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      lat[iy] = ctl->prof_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
        * cos(lat[iy] * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(2)
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      obsmean[ix][iy] = 0;
      obscount[ix][iy] = 0;
      for (iz = 0; iz < ctl->prof_nz; iz++)
        mass[ix][iy][iz] = 0;
    }

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->prof_lon0) / dlon);
    iy = (int) ((rlat - ctl->prof_lat0) / dlat);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx || iy < 0 || iy >= ctl->prof_ny)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy] += robs;

    /* Count observations... */
    obscount[ix][iy]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->prof_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->prof_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->prof_z0) / dz);
```

```
    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx ||
        iy < 0 || iy >= ctl->prof_ny || iz < 0 || iz >= ctl->prof_nz)
      continue;

    /* Get total mass in grid cell... */
    mass[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Extract profiles... */
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++)
      if (obscount[ix][iy] >= 1) {

        /* Check profile... */
        okay = 0;
        for (iz = 0; iz < ctl->prof_nz; iz++)
          if (mass[ix][iy][iz] > 0) {
            okay = 1;
            break;
          }
        if (!okay)
          continue;

        /* Write output... */
        fprintf(out, "\n");

        /* Loop over altitudes... */
        for (iz = 0; iz < ctl->prof_nz; iz++) {

          /* Get pressure and temperature... */
          INTPOL_INIT;
          intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                             lon[ix], lat[iy], &temp, ci, cw, 1);
          intpol_met_time_3d(met0, met0->h2o, met1, met1->h2o, t, press[iz],
                             lon[ix], lat[iy], &h2o, ci, cw, 0);
          intpol_met_time_3d(met0, met0->o3, met1, met1->o3, t, press[iz],
                             lon[ix], lat[iy], &o3, ci, cw, 0);

          /* Calculate volume mixing ratio... */
          rho_air = 100. * press[iz] / (RA * temp);
          vmr = MA / ctl->molmass * mass[ix][iy][iz]
            / (rho_air * area[iy] * dz * 1e9);

          /* Write output... */
          fprintf(out, "%.2f %g %g %g %g %g %g %g %g %g %d\n",
                  t, z[iz], lon[ix], lat[iy], press[iz], temp, vmr, h2o, o3,
                  obsmean[ix][iy] / obscount[ix][iy], obscount[ix][iy]);
        }
      }

  /* Close files... */
  if (t == ctl->t_stop) {
    fclose(in);
    fclose(out);
  }
}

/*****************************************************************************/

void write_sample(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t) {

  static FILE *in, *out;

  static char line[LEN];

  static double area, dlat, rmax2, t0, t1, rt, rt_old, rz, rlon, rlat, robs;

  /* Set timer... */
  SELECT_TIMER("WRITE_SAMPLE", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Open observation data file... */
    LOG(1, "Read sample observation data: %s", ctl->sample_obsfile);
    if (!(in = fopen(ctl->sample_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
```

```
    rt_old = -1e99;

    /* Create new file... */
    LOG(1, "Write sample data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
            "# $4 = latitude [deg]\n"
            "# $5 = surface area [km^2]\n"
            "# $6 = layer width [km]\n"
            "# $7 = number of particles [1]\n"
            "# $8 = column density [kg/m^2]\n"
            "# $9 = volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n\n");

    /* Set latitude range, squared radius, and area... */
    dlat = DY2DEG(ctl->sample_dx);
    rmax2 = SQR(ctl->sample_dx);
    area = M_PI * rmax2;
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Calculate Cartesian coordinates... */
    double x0[3];
    geo2cart(0, rlon, rlat, x0);

    /* Set pressure range... */
    double rp = P(rz);
    double ptop = P(rz + ctl->sample_dz);
    double pbot = P(rz - ctl->sample_dz);

    /* Init... */
    double mass = 0;
    int np = 0;

    /* Loop over air parcels... */
#pragma omp parallel for default(shared) reduction(+:mass,np)
    for (int ip = 0; ip < atm->np; ip++) {

      /* Check time... */
      if (atm->time[ip] < t0 || atm->time[ip] > t1)
        continue;

      /* Check latitude... */
      if (fabs(rlat - atm->lat[ip]) > dlat)
        continue;

      /* Check horizontal distance... */
      double x1[3];
      geo2cart(0, atm->lon[ip], atm->lat[ip], x1);
      if (DIST2(x0, x1) > rmax2)
        continue;

      /* Check pressure... */
      if (ctl->sample_dz > 0)
        if (atm->p[ip] > pbot || atm->p[ip] < ptop)
          continue;

      /* Add mass... */
      if (ctl->qnt_m >= 0)
        mass += atm->q[ctl->qnt_m][ip];
      np++;
    }

```

```
    /* Calculate column density... */
    double cd = mass / (1e6 * area);

    /* Calculate volume mixing ratio... */
    double vmr = 0;
    if (ctl->molmass > 0 && ctl->sample_dz > 0) {
      if (mass > 0) {

        /* Get temperature... */
        double temp;
        INTPOL_INIT;
        intpol_met_time_3d(met0, met0->t, met1, met1->t, rt, rp,
                           rlon, rlat, &temp, ci, cw, 1);

        /* Calculate density of air... */
        double rho_air = 100. * rp / (RA * temp);

        /* Calculate volume mixing ratio... */
        vmr = MA / ctl->molmass * mass
          / (rho_air * 1e6 * area * 1e3 * ctl->sample_dz);
      }
    } else
      vmr = GSL_NAN;

    /* Write output... */
    fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", rt, rz, rlon, rlat,
            area, ctl->sample_dz, np, cd, vmr, robs);

    /* Check time... */
    if (rt >= t1)
      break;
  }

  /* Close files... */
  if (t == ctl->t_stop) {
    fclose(in);
    fclose(out);
  }
}

/*****************************************************************************/

void write_station(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t) {

  static FILE *out;

  static double rmax2, t0, t1, x0[3], x1[3];

  /* Set timer... */
  SELECT_TIMER("WRITE_STATION", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Write info... */
    LOG(1, "Write station data: %s", filename);

    /* Create new file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (int iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%i = %s [%s]\n", (iq + 5),
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "\n");

    /* Set geolocation and search radius... */
    geo2cart(0, ctl->stat_lon, ctl->stat_lat, x0);
    rmax2 = SQR(ctl->stat_r);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Loop over air parcels... */
  for (int ip = 0; ip < atm->np; ip++) {

```

```
    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check time range for station output... */
    if (atm->time[ip] < ctl->stat_t0 || atm->time[ip] > ctl->stat_t1)
      continue;

    /* Check station flag... */
    if (ctl->qnt_stat >= 0)
      if (atm->q[ctl->qnt_stat][ip])
        continue;

    /* Get Cartesian coordinates... */
    geo2cart(0, atm->lon[ip], atm->lat[ip], x1);

    /* Check horizontal distance... */
    if (DIST2(x0, x1) > rmax2)
      continue;

    /* Set station flag... */
    if (ctl->qnt_stat >= 0)
      atm->q[ctl->qnt_stat][ip] = 1;

    /* Write data... */
    fprintf(out, "%.2f %g %g %g",
            atm->time[ip], Z(atm->p[ip]), atm->lon[ip], atm->lat[ip]);
    for (int iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, "\n");
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

## 5.21 libtrac.h File Reference

```
#include <ctype.h>
#include <gsl/gsl_fft_complex.h>
#include <gsl/gsl_math.h>
#include <gsl/gsl_randist.h>
#include <gsl/gsl_rng.h>
#include <gsl/gsl_sort.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_statistics.h>
#include <math.h>
#include <netcdf.h>
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>
#include <sys/time.h>
```

### Data Structures

- struct ctl_t

  *Control parameters.*
- struct atm_t

  *Atmospheric data.*
- struct cache_t

  *Cache data.*
- struct met_t

  *Meteorological data.*

## Macros

- #define CPD 1003.5

  *Specific heat of dry air at constant pressure [J/(kg K)].*
- #define EPS (MH2O / MA)

  *Ratio of the specific gas constant of dry air and water vapor [1].*
- #define G0 9.80665

  *Standard gravity [m/s^2].*
- #define H0 7.0

  *Scale height [km].*
- #define LV 2501000.

  *Latent heat of vaporization of water [J/kg].*
- #define KB 1.3806504e-23

  *Boltzmann constant [kg m^2/(K s^2)].*
- #define MA 28.9644

  *Molar mass of dry air [g/mol].*
- #define MH2O 18.01528

  *Molar mass of water vapor [g/mol].*
- #define MO3 48.00

  *Molar mass of ozone [g/mol].*
- #define P0 1013.25

  *Standard pressure [hPa].*
- #define RA (1e3 * RI / MA)

  *Specific gas constant of dry air [J/(kg K)].*
- #define RE 6367.421

  *Mean radius of Earth [km].*
- #define RI 8.3144598

  *Ideal gas constant [J/(mol K)].*
- #define T0 273.15

  *Standard temperature [K].*
- #define LEN 5000

  *Maximum length of ASCII data lines.*
- #define NP 10000000

  *Maximum number of atmospheric data points.*
- #define NQ 15

  *Maximum number of quantities per data point.*
- #define EP 140

  *Maximum number of pressure levels for meteorological data.*
- #define EX 1201

  *Maximum number of longitudes for meteorological data.*
- #define EY 601

  *Maximum number of latitudes for meteorological data.*
- #define GX 720

  *Maximum number of longitudes for gridded data.*
- #define GY 360

  *Maximum number of latitudes for gridded data.*
- #define GZ 100

  *Maximum number of altitudes for gridded data.*
- #define NENS 2000

  *Maximum number of data points for ensemble analysis.*
- #define NTHREADS 512

*Maximum number of OpenMP threads.*
- #define ALLOC(ptr, type, n)

  *Allocate and clear memory.*
- #define DEG2DX(dlon, lat) ((dlon) ∗ M_PI ∗ RE / 180. ∗ cos((lat) / 180. ∗ M_PI))

  *Convert degrees to zonal distance.*
- #define DEG2DY(dlat) ((dlat) ∗ M_PI ∗ RE / 180.)

  *Convert degrees to meridional distance.*
- #define DP2DZ(dp, p) (- (dp) ∗ H0 / (p))

  *Convert pressure change to vertical distance.*
- #define DX2DEG(dx, lat)

  *Convert zonal distance to degrees.*
- #define DY2DEG(dy) ((dy) ∗ 180. / (M_PI ∗ RE))

  *Convert meridional distance to degrees.*
- #define DZ2DP(dz, p) (-(dz) ∗ (p) / H0)

  *Convert vertical distance to pressure change.*
- #define DIST(a, b) sqrt(DIST2(a, b))

  *Compute Cartesian distance between two vectors.*
- #define DIST2(a, b) ((a[0]-b[0])∗(a[0]-b[0])+(a[1]-b[1])∗(a[1]-b[1])+(a[2]-b[2])∗(a[2]-b[2]))

  *Compute squared distance between two vectors.*
- #define DOTP(a, b) (a[0]∗b[0]+a[1]∗b[1]+a[2]∗b[2])

  *Compute dot product of two vectors.*
- #define FMOD(x, y) ((x) - (int) ((x) / (y)) ∗ (y))

  *Compute floating point modulo.*
- #define FREAD(ptr, type, size, out)

  *Read binary data.*
- #define FWRITE(ptr, type, size, out)

  *Write binary data.*
- #define INTPOL_INIT double cw[3] = {0.0, 0.0, 0.0}; int ci[3] = {0, 0, 0};

  *Initialize cache variables for interpolation.*
- #define INTPOL_2D(var, init)

  *2-D interpolation of a meteo variable.*
- #define INTPOL_3D(var, init)

  *3-D interpolation of a meteo variable.*
- #define INTPOL_SPACE_ALL(p, lon, lat)

  *Spatial interpolation of all meteo data.*
- #define INTPOL_TIME_ALL(time, p, lon, lat)

  *Temporal interpolation of all meteo data.*
- #define LAPSE(p1, t1, p2, t2)

  *Calculate lapse rate between pressure levels.*
- #define LIN(x0, y0, x1, y1, x) ((y0)+((y1)-(y0))/((x1)-(x0))∗((x)-(x0)))

  *Compute linear interpolation.*
- #define NC(cmd)

  *Execute netCDF library command and check result.*
- #define NN(x0, y0, x1, y1, x) (fabs((x) - (x0)) <= fabs((x) - (x1)) ? (y0) : (y1))

  *Compute nearest neighbor interpolation.*
- #define NORM(a) sqrt(DOTP(a, a))

  *Compute norm of a vector.*
- #define P(z) (P0 ∗ exp(-(z) / H0))

  *Convert altitude to pressure.*
- #define PSAT(t) (6.112 ∗ exp(17.62 ∗ ((t) - T0) / (243.12 + (t) - T0)))

  *Compute saturation pressure over water (WMO, 2018).*

- #define PSICE(t) (0.01 ∗ pow(10., -2663.5 / (t) + 12.537))

    *Compute saturation pressure over ice (Marti and Mauersberger, 1993).*
- #define PW(p, h2o)

    *Calculate partial water vapor pressure.*
- #define RH(p, t, h2o) (PW(p, h2o) / PSAT(t) ∗ 100.)

    *Compute relative humidity over water.*
- #define RHICE(p, t, h2o) (PW(p, h2o) / PSICE(t) ∗ 100.)

    *Compute relative humidity over ice.*
- #define SET_ATM(qnt, val)

    *Set atmospheric quantity value.*
- #define SET_QNT(qnt, name, unit)

    *Set atmospheric quantity index.*
- #define SH(h2o) (EPS ∗ GSL_MAX((h2o), 0.1e-6))

    *Compute specific humidity from water vapor volume mixing ratio.*
- #define SQR(x) ((x)∗(x))

    *Compute square.*
- #define TDEW(p, h2o)

    *Calculate dew point temperature (WMO, 2018).*
- #define TICE(p, h2o) (-2663.5 / (log10(100. ∗ PW((p), (h2o))) - 12.537))

    *Calculate frost point temperature (Marti and Mauersberger, 1993).*
- #define THETA(p, t) ((t) ∗ pow(1000. / (p), 0.286))

    *Compute potential temperature.*
- #define THETAVIRT(p, t, h2o) (TVIRT(THETA((p), (t)), GSL_MAX((h2o), 0.1e-6)))

    *Compute virtual potential temperature.*
- #define TOK(line, tok, format, var)

    *Get string tokens.*
- #define TVIRT(t, h2o) ((t) ∗ (1. + (1. - EPS) ∗ GSL_MAX((h2o), 0.1e-6)))

    *Compute virtual temperature.*
- #define Z(p) (H0 ∗ log(P0 / (p)))

    *Convert pressure to altitude.*
- #define ZDIFF(lnp0, t0, h2o0, lnp1, t1, h2o1)

    *Calculate geopotential height difference.*
- #define ZETA(ps, p, t)

    *Calculate zeta vertical coordinate.*
- #define LOGLEV 2

    *Level of log messages (0=none, 1=basic, 2=detailed, 3=debug).*
- #define LOG(level, ...)

    *Print log message.*
- #define WARN(...)

    *Print warning message.*
- #define ERRMSG(...)

    *Print error message and quit program.*
- #define PRINT(format, var)

    *Print macro for debugging.*
- #define NTIMER 100

    *Maximum number of timers.*
- #define PRINT_TIMERS timer("END", "END", 1);

    *Print timers.*
- #define SELECT_TIMER(id, group, color)

    *Select timer.*
- #define START_TIMERS NVTX_PUSH("START", NVTX_CPU);

*Start timers.*
- #define STOP_TIMERS NVTX_POP;

  *Stop timers.*
- #define NVTX_PUSH(range_title, range_color) {}
- #define NVTX_POP {}

## Functions

- void cart2geo (double ∗x, double ∗z, double ∗lon, double ∗lat)

  *Convert Cartesian coordinates to geolocation.*
- int check_finite (const double x)

  *Check if x is finite.*
- double clim_hno3 (double t, double lat, double p)

  *Climatology of HNO3 volume mixing ratios.*
- double clim_oh (double t, double lat, double p)

  *Climatology of OH number concentrations.*
- double clim_tropo (double t, double lat)

  *Climatology of tropopause pressure.*
- void day2doy (int year, int mon, int day, int ∗doy)

  *Get day of year from date.*
- void doy2day (int year, int doy, int ∗mon, int ∗day)

  *Get date from day of year.*
- void geo2cart (double z, double lon, double lat, double ∗x)

  *Convert geolocation to Cartesian coordinates.*
- void get_met (ctl_t ∗ctl, double t, met_t ∗∗met0, met_t ∗∗met1)

  *Get meteorological data for given time step.*
- void get_met_help (double t, int direct, char ∗metbase, double dt_met, char ∗filename)

  *Get meteorological data for time step.*
- void get_met_replace (char ∗orig, char ∗search, char ∗repl)

  *Replace template strings in filename.*
- void intpol_met_space_3d (met_t ∗met, float array[EX][EY][EP], double p, double lon, double lat, double ∗var, int ∗ci, double ∗cw, int init)

  *Spatial interpolation of meteorological data.*
- void intpol_met_space_2d (met_t ∗met, float array[EX][EY], double lon, double lat, double ∗var, int ∗ci, double ∗cw, int init)

  *Spatial interpolation of meteorological data.*
- void intpol_met_time_3d (met_t ∗met0, float array0[EX][EY][EP], met_t ∗met1, float array1[EX][EY][EP], double ts, double p, double lon, double lat, double ∗var, int ∗ci, double ∗cw, int init)

  *Temporal interpolation of meteorological data.*
- void intpol_met_time_2d (met_t ∗met0, float array0[EX][EY], met_t ∗met1, float array1[EX][EY], double ts, double lon, double lat, double ∗var, int ∗ci, double ∗cw, int init)

  *Temporal interpolation of meteorological data.*
- void jsec2time (double jsec, int ∗year, int ∗mon, int ∗day, int ∗hour, int ∗min, int ∗sec, double ∗remain)

  *Convert seconds to date.*
- double lapse_rate (double t, double h2o)

  *Calculate moist adiabatic lapse rate.*
- int locate_irr (double ∗xx, int n, double x)

  *Find array index for irregular grid.*
- int locate_reg (double ∗xx, int n, double x)

  *Find array index for regular grid.*
- double nat_temperature (double p, double h2o, double hno3)

*Calculate NAT existence temperature.*
- int read_atm (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm)

    *Read atmospheric data.*
- void read_ctl (const char ∗filename, int argc, char ∗argv[ ], ctl_t ∗ctl)

    *Read control parameters.*
- int read_met (ctl_t ∗ctl, char ∗filename, met_t ∗met)

    *Read meteorological data file.*
- void read_met_cape (met_t ∗met)

    *Calculate convective available potential energy.*
- void read_met_cloud (met_t ∗met)

    *Calculate cloud properties.*
- void read_met_detrend (ctl_t ∗ctl, met_t ∗met)

    *Apply detrending method to temperature and winds.*
- void read_met_extrapolate (met_t ∗met)

    *Extrapolate meteorological data at lower boundary.*
- void read_met_geopot (ctl_t ∗ctl, met_t ∗met)

    *Calculate geopotential heights.*
- void read_met_grid (char ∗filename, int ncid, ctl_t ∗ctl, met_t ∗met)

    *Read coordinates of meteorological data.*
- int read_met_help_3d (int ncid, char ∗varname, char ∗varname2, met_t ∗met, float dest[EX][EY][EP], float scl, int init)

    *Read and convert 3D variable from meteorological data file.*
- int read_met_help_2d (int ncid, char ∗varname, char ∗varname2, met_t ∗met, float dest[EX][EY], float scl, int init)

    *Read and convert 2D variable from meteorological data file.*
- void read_met_levels (int ncid, ctl_t ∗ctl, met_t ∗met)

    *Read meteorological data on vertical levels.*
- void read_met_ml2pl (ctl_t ∗ctl, met_t ∗met, float var[EX][EY][EP])

    *Convert meteorological data from model levels to pressure levels.*
- void read_met_pbl (met_t ∗met)

    *Calculate pressure of the boundary layer.*
- void read_met_periodic (met_t ∗met)

    *Create meteorological data with periodic boundary conditions.*
- void read_met_pv (met_t ∗met)

    *Calculate potential vorticity.*
- void read_met_sample (ctl_t ∗ctl, met_t ∗met)

    *Downsampling of meteorological data.*
- void read_met_surface (int ncid, met_t ∗met)

    *Read surface data.*
- void read_met_tropo (ctl_t ∗ctl, met_t ∗met)

    *Calculate tropopause data.*
- double scan_ctl (const char ∗filename, int argc, char ∗argv[ ], const char ∗varname, int arridx, const char ∗defvalue, char ∗value)

    *Read a control parameter from file or command line.*
- double sedi (double p, double T, double r_p, double rho_p)

    *Calculate sedimentation velocity.*
- void spline (double ∗x, double ∗y, int n, double ∗x2, double ∗y2, int n2, int method)

    *Spline interpolation.*
- float stddev (float ∗data, int n)

    *Calculate standard deviation.*
- void time2jsec (int year, int mon, int day, int hour, int min, int sec, double remain, double ∗jsec)

*Convert date to seconds.*

- void timer (const char ∗name, const char ∗group, int output)

  *Measure wall-clock time.*
- double tropo_weight (double t, double lat, double p)

  *Get weighting factor based on tropopause distance.*
- void write_atm (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm, double t)

  *Write atmospheric data.*
- void write_csi (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm, double t)

  *Write CSI data.*
- void write_ens (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm, double t)

  *Write ensemble data.*
- void write_grid (const char ∗filename, ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double t)

  *Write gridded data.*
- void write_prof (const char ∗filename, ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double t)

  *Write profile data.*
- void write_sample (const char ∗filename, ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double t)

  *Write sample data.*
- void write_station (const char ∗filename, ctl_t ∗ctl, atm_t ∗atm, double t)

  *Write station data.*

### 5.21.1 Detailed Description

MPTRAC library declarations.

Definition in file libtrac.h.

### 5.21.2 Macro Definition Documentation

#### 5.21.2.1 CPD `#define CPD 1003.5`

Specific heat of dry air at constant pressure [J/(kg K)].

Definition at line 74 of file libtrac.h.

#### 5.21.2.2 EPS `#define EPS (MH2O / MA)`

Ratio of the specific gas constant of dry air and water vapor [1].

Definition at line 77 of file libtrac.h.

#### 5.21.2.3 G0 `#define G0 9.80665`

Standard gravity [m/s^2].

Definition at line 80 of file libtrac.h.

#### 5.21.2.4 H0 `#define H0 7.0`

Scale height [km].

Definition at line 83 of file libtrac.h.

#### 5.21.2.5 LV `#define LV 2501000.`

Latent heat of vaporization of water [J/kg].

Definition at line 86 of file libtrac.h.

#### 5.21.2.6 KB `#define KB 1.3806504e-23`

Boltzmann constant [kg m^2/(K s^2)].

Definition at line 89 of file libtrac.h.

#### 5.21.2.7 MA `#define MA 28.9644`

Molar mass of dry air [g/mol].

Definition at line 92 of file libtrac.h.

#### 5.21.2.8 MH2O `#define MH2O 18.01528`

Molar mass of water vapor [g/mol].

Definition at line 95 of file libtrac.h.

#### 5.21.2.9 MO3 `#define MO3 48.00`

Molar mass of ozone [g/mol].

Definition at line 98 of file libtrac.h.

#### 5.21.2.10 P0 `#define P0 1013.25`

Standard pressure [hPa].

Definition at line 101 of file libtrac.h.

#### 5.21.2.11 RA `#define RA (1e3 * RI / MA)`

Specific gas constant of dry air [J/(kg K)].

Definition at line 104 of file libtrac.h.

#### 5.21.2.12 RE `#define RE 6367.421`

Mean radius of Earth [km].

Definition at line 107 of file libtrac.h.

#### 5.21.2.13 RI `#define RI 8.3144598`

Ideal gas constant [J/(mol K)].

Definition at line 110 of file libtrac.h.

#### 5.21.2.14 T0 `#define T0 273.15`

Standard temperature [K].

Definition at line 113 of file libtrac.h.

#### 5.21.2.15 LEN `#define LEN 5000`

Maximum length of ASCII data lines.

Definition at line 121 of file libtrac.h.

#### 5.21.2.16 NP `#define NP 10000000`

Maximum number of atmospheric data points.

Definition at line 126 of file libtrac.h.

#### 5.21.2.17 NQ `#define NQ 15`

Maximum number of quantities per data point.

Definition at line 131 of file libtrac.h.

#### 5.21.2.18 EP `#define EP 140`

Maximum number of pressure levels for meteorological data.

Definition at line 136 of file libtrac.h.

#### 5.21.2.19 EX `#define EX 1201`

Maximum number of longitudes for meteorological data.

Definition at line 141 of file libtrac.h.

#### 5.21.2.20 EY `#define EY 601`

Maximum number of latitudes for meteorological data.

Definition at line 146 of file libtrac.h.

#### 5.21.2.21 GX `#define GX 720`

Maximum number of longitudes for gridded data.

Definition at line 151 of file libtrac.h.

#### 5.21.2.22 GY `#define GY 360`

Maximum number of latitudes for gridded data.

Definition at line 156 of file libtrac.h.

#### 5.21.2.23 GZ `#define GZ 100`

Maximum number of altitudes for gridded data.

Definition at line 161 of file libtrac.h.

#### 5.21.2.24 NENS `#define NENS 2000`

Maximum number of data points for ensemble analysis.

Definition at line 166 of file libtrac.h.

#### 5.21.2.25 NTHREADS `#define NTHREADS 512`

Maximum number of OpenMP threads.

Definition at line 171 of file libtrac.h.

#### 5.21.2.26 ALLOC

```
#define ALLOC(
            ptr,
            type,
            n )
```

**Value:**

```
if((ptr=calloc((size_t)(n), sizeof(type)))==NULL)       \
  ERRMSG("Out of memory!");
```

Allocate and clear memory.

Definition at line 186 of file libtrac.h.

#### 5.21.2.27 DEG2DX

```
#define DEG2DX(
        dlon,
        lat ) ((dlon) * M_PI * RE / 180. * cos((lat) / 180. * M_PI))
```

Convert degrees to zonal distance.

Definition at line 192 of file libtrac.h.

#### 5.21.2.28 DEG2DY

```
#define DEG2DY(
        dlat ) ((dlat) * M_PI * RE / 180.)
```

Convert degrees to meridional distance.

Definition at line 196 of file libtrac.h.

#### 5.21.2.29 DP2DZ

```
#define DP2DZ(
        dp,
        p ) (- (dp) * H0 / (p))
```

Convert pressure change to vertical distance.

Definition at line 200 of file libtrac.h.

#### 5.21.2.30 DX2DEG

```
#define DX2DEG(
        dx,
        lat )
```

**Value:**

```
(((lat) < -89.999 || (lat) > 89.999) ? 0                    \
 : (dx) * 180. / (M_PI * RE * cos((lat) / 180. * M_PI)))
```

Convert zonal distance to degrees.

Definition at line 204 of file libtrac.h.

#### 5.21.2.31 DY2DEG

```
#define DY2DEG(
        dy ) ((dy) * 180. / (M_PI * RE))
```

Convert meridional distance to degrees.

Definition at line 209 of file libtrac.h.

#### 5.21.2.32 DZ2DP

```
#define DZ2DP(
    dz,
    p ) (-(dz) * (p) / H0)
```

Convert vertical distance to pressure change.

Definition at line 213 of file libtrac.h.

#### 5.21.2.33 DIST

```
#define DIST(
    a,
    b ) sqrt(DIST2(a, b))
```

Compute Cartesian distance between two vectors.

Definition at line 217 of file libtrac.h.

#### 5.21.2.34 DIST2

```
#define DIST2(
    a,
    b ) ((a[0]-b[0])*(a[0]-b[0])+(a[1]-b[1])*(a[1]-b[1])+(a[2]-b[2])*(a[2]-b[2]))
```

Compute squared distance between two vectors.

Definition at line 221 of file libtrac.h.

#### 5.21.2.35 DOTP

```
#define DOTP(
    a,
    b ) (a[0]*b[0]+a[1]*b[1]+a[2]*b[2])
```

Compute dot product of two vectors.

Definition at line 225 of file libtrac.h.

#### 5.21.2.36 FMOD

```
#define FMOD(
    x,
    y ) ((x) - (int) ((x) / (y)) * (y))
```

Compute floating point modulo.

Definition at line 229 of file libtrac.h.

#### 5.21.2.37 FREAD `#define FREAD(`
    ptr,
    type,
    size,
    out )

**Value:**
```
{                                                                    \
  if(fread(ptr, sizeof(type), size, out)!=size)                     \
    ERRMSG("Error while reading!");                                 \
}
```

Read binary data.

Definition at line 233 of file libtrac.h.

#### 5.21.2.38 FWRITE `#define FWRITE(`
    ptr,
    type,
    size,
    out )

**Value:**
```
{                                                                    \
  if(fwrite(ptr, sizeof(type), size, out)!=size)                    \
    ERRMSG("Error while writing!");                                 \
}
```

Write binary data.

Definition at line 239 of file libtrac.h.

#### 5.21.2.39 INTPOL_INIT `#define INTPOL_INIT double cw[3] = {0.0, 0.0, 0.0}; int ci[3] = {0, 0, 0};`

Initialize cache variables for interpolation.

Definition at line 245 of file libtrac.h.

#### 5.21.2.40 INTPOL_2D `#define INTPOL_2D(`
    var,
    init )

**Value:**
```
intpol_met_time_2d(met0, met0->var, met1, met1->var,                          \
                   atm->time[ip], atm->lon[ip], atm->lat[ip],          \
                   &var, ci, cw, init);
```

2-D interpolation of a meteo variable.

Definition at line 249 of file libtrac.h.

#### 5.21.2.41 INTPOL_3D

```
#define INTPOL_3D(
    var,
    init )
```

**Value:**
```
intpol_met_time_3d(met0, met0->var, met1, met1->var,                       \
                   atm->time[ip], atm->p[ip],                         \
                   atm->lon[ip], atm->lat[ip],                        \
                   &var, ci, cw, init);
```

3-D interpolation of a meteo variable.

Definition at line 255 of file libtrac.h.

#### 5.21.2.42 INTPOL_SPACE_ALL

```
#define INTPOL_SPACE_ALL(
    p,
    lon,
    lat )
```

**Value:**
```
{                                                                  \
intpol_met_space_3d(met, met->z, p, lon, lat, &z, ci, cw, 1);          \
intpol_met_space_3d(met, met->t, p, lon, lat, &t, ci, cw, 0);          \
intpol_met_space_3d(met, met->u, p, lon, lat, &u, ci, cw, 0);          \
intpol_met_space_3d(met, met->v, p, lon, lat, &v, ci, cw, 0);          \
intpol_met_space_3d(met, met->w, p, lon, lat, &w, ci, cw, 0);          \
intpol_met_space_3d(met, met->pv, p, lon, lat, &pv, ci, cw, 0);        \
intpol_met_space_3d(met, met->h2o, p, lon, lat, &h2o, ci, cw, 0);      \
intpol_met_space_3d(met, met->o3, p, lon, lat, &o3, ci, cw, 0);        \
intpol_met_space_3d(met, met->lwc, p, lon, lat, &lwc, ci, cw, 0);      \
intpol_met_space_3d(met, met->iwc, p, lon, lat, &iwc, ci, cw, 0);      \
intpol_met_space_2d(met, met->ps, lon, lat, &ps, ci, cw, 0);           \
intpol_met_space_2d(met, met->ts, lon, lat, &ts, ci, cw, 0);           \
intpol_met_space_2d(met, met->zs, lon, lat, &zs, ci, cw, 0);           \
intpol_met_space_2d(met, met->us, lon, lat, &us, ci, cw, 0);           \
intpol_met_space_2d(met, met->vs, lon, lat, &vs, ci, cw, 0);           \
intpol_met_space_2d(met, met->pbl, lon, lat, &pbl, ci, cw, 0);         \
intpol_met_space_2d(met, met->pt, lon, lat, &pt, ci, cw, 0);           \
intpol_met_space_2d(met, met->tt, lon, lat, &tt, ci, cw, 0);           \
intpol_met_space_2d(met, met->zt, lon, lat, &zt, ci, cw, 0);           \
intpol_met_space_2d(met, met->h2ot, lon, lat, &h2ot, ci, cw, 0);       \
intpol_met_space_2d(met, met->pct, lon, lat, &pct, ci, cw, 0);         \
intpol_met_space_2d(met, met->pcb, lon, lat, &pcb, ci, cw, 0);         \
intpol_met_space_2d(met, met->cl, lon, lat, &cl, ci, cw, 0);           \
intpol_met_space_2d(met, met->plcl, lon, lat, &plcl, ci, cw, 0);       \
intpol_met_space_2d(met, met->plfc, lon, lat, &plfc, ci, cw, 0);       \
intpol_met_space_2d(met, met->pel, lon, lat, &pel, ci, cw, 0);         \
intpol_met_space_2d(met, met->cape, lon, lat, &cape, ci, cw, 0);       \
intpol_met_space_2d(met, met->cin, lon, lat, &cin, ci, cw, 0);         \
}
```

Spatial interpolation of all meteo data.

Definition at line 262 of file libtrac.h.

#### 5.21.2.43 INTPOL_TIME_ALL

```
#define INTPOL_TIME_ALL(
    time,
    p,
    lon,
    lat )
```

**Value:**
```
{                                                       \
intpol_met_time_3d(met0, met0->z, met1, met1->z, time, p, lon, lat, &z, ci, cw, 1); \
intpol_met_time_3d(met0, met0->t, met1, met1->t, time, p, lon, lat, &t, ci, cw, 0); \
```

```
intpol_met_time_3d(met0, met0->u, met1, met1->u, time, p, lon, lat, &u, ci, cw, 0); \
intpol_met_time_3d(met0, met0->v, met1, met1->v, time, p, lon, lat, &v, ci, cw, 0); \
intpol_met_time_3d(met0, met0->w, met1, met1->w, time, p, lon, lat, &w, ci, cw, 0); \
intpol_met_time_3d(met0, met0->pv, met1, met1->pv, time, p, lon, lat, &pv, ci, cw, 0); \
intpol_met_time_3d(met0, met0->h2o, met1, met1->h2o, time, p, lon, lat, &h2o, ci, cw, 0); \
intpol_met_time_3d(met0, met0->o3, met1, met1->o3, time, p, lon, lat, &o3, ci, cw, 0); \
intpol_met_time_3d(met0, met0->lwc, met1, met1->lwc, time, p, lon, lat, &lwc, ci, cw, 0); \
intpol_met_time_3d(met0, met0->iwc, met1, met1->iwc, time, p, lon, lat, &iwc, ci, cw, 0); \
intpol_met_time_2d(met0, met0->ps, met1, met1->ps, time, lon, lat, &ps, ci, cw, 0); \
intpol_met_time_2d(met0, met0->ts, met1, met1->ts, time, lon, lat, &ts, ci, cw, 0); \
intpol_met_time_2d(met0, met0->zs, met1, met1->zs, time, lon, lat, &zs, ci, cw, 0); \
intpol_met_time_2d(met0, met0->us, met1, met1->us, time, lon, lat, &us, ci, cw, 0); \
intpol_met_time_2d(met0, met0->vs, met1, met1->vs, time, lon, lat, &vs, ci, cw, 0); \
intpol_met_time_2d(met0, met0->pbl, met1, met1->pbl, time, lon, lat, &pbl, ci, cw, 0); \
intpol_met_time_2d(met0, met0->pt, met1, met1->pt, time, lon, lat, &pt, ci, cw, 0); \
intpol_met_time_2d(met0, met0->tt, met1, met1->tt, time, lon, lat, &tt, ci, cw, 0); \
intpol_met_time_2d(met0, met0->zt, met1, met1->zt, time, lon, lat, &zt, ci, cw, 0); \
intpol_met_time_2d(met0, met0->h2ot, met1, met1->h2ot, time, lon, lat, &h2ot, ci, cw, 0); \
intpol_met_time_2d(met0, met0->pct, met1, met1->pct, time, lon, lat, &pct, ci, cw, 0); \
intpol_met_time_2d(met0, met0->pcb, met1, met1->pcb, time, lon, lat, &pcb, ci, cw, 0); \
intpol_met_time_2d(met0, met0->cl, met1, met1->cl, time, lon, lat, &cl, ci, cw, 0); \
intpol_met_time_2d(met0, met0->plcl, met1, met1->plcl, time, lon, lat, &plcl, ci, cw, 0); \
intpol_met_time_2d(met0, met0->plfc, met1, met1->plfc, time, lon, lat, &plfc, ci, cw, 0); \
intpol_met_time_2d(met0, met0->pel, met1, met1->pel, time, lon, lat, &pel, ci, cw, 0); \
intpol_met_time_2d(met0, met0->cape, met1, met1->cape, time, lon, lat, &cape, ci, cw, 0); \
intpol_met_time_2d(met0, met0->cin, met1, met1->cin, time, lon, lat, &cin, ci, cw, 0); \
}
```

Temporal interpolation of all meteo data.

Definition at line 294 of file libtrac.h.

### 5.21.2.44 LAPSE

```
#define LAPSE(
    p1,
    t1,
    p2,
    t2 )
```

**Value:**

```
(1e3 * G0 / RA * ((t2) - (t1)) / ((t2) + (t1))                    \
 * ((p2) + (p1)) / ((p2) - (p1)))
```

Calculate lapse rate between pressure levels.

Definition at line 326 of file libtrac.h.

### 5.21.2.45 LIN

```
#define LIN(
    x0,
    y0,
    x1,
    y1,
    x ) ((y0)+((y1)-(y0))/((x1)-(x0))*((x)-(x0)))
```

Compute linear interpolation.

Definition at line 331 of file libtrac.h.

#### 5.21.2.46 NC

```
#define NC(
    cmd )
```

**Value:**

```
  {                                   \
  int nc_result=(cmd);                                \
  if(nc_result!=NC_NOERR)                             \
    ERRMSG("%s", nc_strerror(nc_result));             \
}
```

Execute netCDF library command and check result.

Definition at line 335 of file libtrac.h.

#### 5.21.2.47 NN

```
#define NN(
    x0,
    y0,
    x1,
    y1,
    x ) (fabs((x) - (x0)) <= fabs((x) - (x1)) ? (y0) : (y1))
```

Compute nearest neighbor interpolation.

Definition at line 342 of file libtrac.h.

#### 5.21.2.48 NORM

```
#define NORM(
    a ) sqrt(DOTP(a, a))
```

Compute norm of a vector.

Definition at line 346 of file libtrac.h.

#### 5.21.2.49 P

```
#define P(
    z ) (P0 * exp(-(z) / H0))
```

Convert altitude to pressure.

Definition at line 350 of file libtrac.h.

#### 5.21.2.50 PSAT

```
#define PSAT(
    t ) (6.112 * exp(17.62 * ((t) - T0) / (243.12 + (t) - T0)))
```

Compute saturation pressure over water (WMO, 2018).

Definition at line 354 of file libtrac.h.

#### 5.21.2.51 PSICE `#define PSICE( t ) (0.01 * pow(10., -2663.5 / (t) + 12.537))`

Compute saturation pressure over ice (Marti and Mauersberger, 1993).

Definition at line 358 of file libtrac.h.

#### 5.21.2.52 PW `#define PW( p, h2o )`

**Value:**
```
((p) * GSL_MAX((h2o), 0.1e-6)                           \
 / (1. + (1. - EPS) * GSL_MAX((h2o), 0.1e-6)))
```

Calculate partial water vapor pressure.

Definition at line 362 of file libtrac.h.

#### 5.21.2.53 RH `#define RH( p, t, h2o ) (PW(p, h2o) / PSAT(t) * 100.)`

Compute relative humidity over water.

Definition at line 367 of file libtrac.h.

#### 5.21.2.54 RHICE `#define RHICE( p, t, h2o ) (PW(p, h2o) / PSICE(t) * 100.)`

Compute relative humidity over ice.

Definition at line 371 of file libtrac.h.

#### 5.21.2.55 SET_ATM `#define SET_ATM( qnt, val )`

**Value:**
```
if (ctl->qnt >= 0)                               \
  atm->q[ctl->qnt][ip] = val;
```

Set atmospheric quantity value.

Definition at line 375 of file libtrac.h.

#### 5.21.2.56 SET_QNT

```
#define SET_QNT(
    qnt,
    name,
    unit )
```

**Value:**
```
if (strcasecmp(ctl->qnt_name[iq], name) == 0) {        \
  ctl->qnt = iq;                                        \
  sprintf(ctl->qnt_unit[iq], unit);                     \
} else
```

Set atmospheric quantity index.

Definition at line 380 of file libtrac.h.

#### 5.21.2.57 SH

```
#define SH(
    h2o ) (EPS * GSL_MAX((h2o), 0.1e-6))
```

Compute specific humidity from water vapor volume mixing ratio.

Definition at line 387 of file libtrac.h.

#### 5.21.2.58 SQR

```
#define SQR(
    x ) ((x)*(x))
```

Compute square.

Definition at line 391 of file libtrac.h.

#### 5.21.2.59 TDEW

```
#define TDEW(
    p,
    h2o )
```

**Value:**
```
(T0 + 243.12 * log(PW((p), (h2o)) / 6.112)        \
 / (17.62 - log(PW((p), (h2o)) / 6.112)))
```

Calculate dew point temperature (WMO, 2018).

Definition at line 395 of file libtrac.h.

#### 5.21.2.60 TICE

```
#define TICE(
    p,
    h2o ) (-2663.5 / (log10(100. * PW((p), (h2o))) - 12.537))
```

Calculate frost point temperature (Marti and Mauersberger, 1993).

Definition at line 400 of file libtrac.h.

#### 5.21.2.61 THETA `#define THETA(`

```
p,
t ) ((t) * pow(1000. / (p), 0.286))
```

Compute potential temperature.

Definition at line 404 of file libtrac.h.

#### 5.21.2.62 THETAVIRT `#define THETAVIRT(`

```
p,
t,
h2o ) (TVIRT(THETA((p), (t)), GSL_MAX((h2o), 0.1e-6)))
```

Compute virtual potential temperature.

Definition at line 408 of file libtrac.h.

#### 5.21.2.63 TOK `#define TOK(`

```
line,
tok,
format,
var )
```

**Value:**

```
{                                                         \
    if(((tok)=strtok((line), " \t"))) {                              \
      if(sscanf(tok, format, &(var))!=1) continue;                   \
    } else ERRMSG("Error while reading!");                             \
  }
```

Get string tokens.

Definition at line 412 of file libtrac.h.

#### 5.21.2.64 TVIRT `#define TVIRT(`

```
t,
h2o ) ((t) * (1. + (1. - EPS) * GSL_MAX((h2o), 0.1e-6)))
```

Compute virtual temperature.

Definition at line 419 of file libtrac.h.

#### 5.21.2.65 Z `#define Z(`

```
p ) (H0 * log(P0 / (p)))
```

Convert pressure to altitude.

Definition at line 423 of file libtrac.h.

#### 5.21.2.66 ZDIFF

```
#define ZDIFF(
            lnp0,
            t0,
            h2o0,
            lnp1,
            t1,
            h2o1 )
```

**Value:**

```
(RI / MA / G0 * 0.5 * (TVIRT((t0), (h2o0)) + TVIRT((t1), (h2o1)))      \
 * ((lnp0) - (lnp1)))
```

Calculate geopotential height difference.

Definition at line 427 of file libtrac.h.

#### 5.21.2.67 ZETA

```
#define ZETA(
            ps,
            p,
            t )
```

**Value:**

```
(((p) / (ps) <= 0.3 ? 1. :                                             \
  sin(M_PI / 2. * (1. - (p) / (ps)) / (1. - 0.3)))                     \
 * THETA((p), (t)))
```

Calculate zeta vertical coordinate.

Definition at line 432 of file libtrac.h.

#### 5.21.2.68 LOGLEV

```
#define LOGLEV 2
```

Level of log messages (0=none, 1=basic, 2=detailed, 3=debug).

Definition at line 443 of file libtrac.h.

#### 5.21.2.69 LOG

```
#define LOG(
            level,
            ... )
```

**Value:**

```
  {                                         \
  if(level >= 2)                                                       \
    printf("  ");                                                      \
  if(level <= LOGLEV) {                                      \
    printf(__VA_ARGS__);                                               \
    printf("\n");                                                      \
  }                                                                    \
}
```

Print log message.

Definition at line 447 of file libtrac.h.

#### 5.21.2.70 WARN

```
#define WARN(
    ... )
```

**Value:**

```
    {                                                          \
    printf("\nWarning (%s, %s, l%d): ", __FILE__, __func__, __LINE__);  \
    LOG(0, __VA_ARGS__);                                             \
  }
```

Print warning message.

Definition at line 457 of file libtrac.h.

#### 5.21.2.71 ERRMSG

```
#define ERRMSG(
    ... )
```

**Value:**

```
    {                                                          \
    printf("\nError (%s, %s, l%d): ", __FILE__, __func__, __LINE__);    \
    LOG(0, __VA_ARGS__);                                             \
    exit(EXIT_FAILURE);                                              \
  }
```

Print error message and quit program.

Definition at line 463 of file libtrac.h.

#### 5.21.2.72 PRINT

```
#define PRINT(
    format,
    var )
```

**Value:**

```
  printf("Print (%s, %s, l%d): %s= "format"\n",                      \
         __FILE__, __func__, __LINE__, #var, var);
```

Print macro for debugging.

Definition at line 470 of file libtrac.h.

#### 5.21.2.73 NTIMER

```
#define NTIMER 100
```

Maximum number of timers.

Definition at line 479 of file libtrac.h.

#### 5.21.2.74 PRINT_TIMERS

```
#define PRINT_TIMERS timer("END", "END", 1);
```

Print timers.

Definition at line 482 of file libtrac.h.

#### 5.21.2.75 SELECT_TIMER

```
#define SELECT_TIMER(
        id,
        group,
        color )
```

**Value:**

```
{                            \
  NVTX_POP;                                                  \
  NVTX_PUSH(id, color);                                      \
  timer(id, group, 0);                                       \
}
```

Select timer.

Definition at line 486 of file libtrac.h.

#### 5.21.2.76 START_TIMERS

```
#define START_TIMERS NVTX_PUSH("START", NVTX_CPU);
```

Start timers.

Definition at line 493 of file libtrac.h.

#### 5.21.2.77 STOP_TIMERS

```
#define STOP_TIMERS NVTX_POP;
```

Stop timers.

Definition at line 497 of file libtrac.h.

#### 5.21.2.78 NVTX_PUSH

```
#define NVTX_PUSH(
        range_title,
        range_color ) {}
```

Definition at line 544 of file libtrac.h.

#### 5.21.2.79 NVTX_POP

```
#define NVTX_POP {}
```

Definition at line 545 of file libtrac.h.

### 5.21.3 Function Documentation

#### 5.21.3.1 cart2geo()

```
void cart2geo (
        double * x,
        double * z,
        double * lon,
        double * lat )
```

Convert Cartesian coordinates to geolocation.

Definition at line 29 of file libtrac.c.

```
                {

  double radius = NORM(x);
  *lat = asin(x[2] / radius) * 180. / M_PI;
  *lon = atan2(x[1], x[0]) * 180. / M_PI;
  *z = radius - RE;
}
```

#### 5.21.3.2 check_finite()

```
int check_finite (
        const double x )
```

Check if x is finite.

#### 5.21.3.3 clim_hno3()

```
double clim_hno3 (
        double t,
        double lat,
        double p )
```

Climatology of HNO3 volume mixing ratios.

Definition at line 295 of file libtrac.c.

```
             {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Check pressure... */
  if (p < clim_hno3_ps[0])
    p = clim_hno3_ps[0];
  else if (p > clim_hno3_ps[9])
    p = clim_hno3_ps[9];

  /* Check latitude... */
  if (lat < clim_hno3_lats[0])
    lat = clim_hno3_lats[0];
  else if (lat > clim_hno3_lats[17])
    lat = clim_hno3_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_hno3_secs, 12, sec);
  int ilat = locate_reg(clim_hno3_lats, 18, lat);
  int ip = locate_irr(clim_hno3_ps, 10, p);

  /* Interpolate HNO3 climatology (Froidevaux et al., 2015)... */
  double aux00 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat][ip + 1], p);
```

```
  double aux11 = LIN(clim_hno3_ps[ip],
                     clim_hno3_var[isec + 1][ilat + 1][ip],
                     clim_hno3_ps[ip + 1],
                     clim_hno3_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_hno3_lats[ilat], aux00,
              clim_hno3_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_hno3_lats[ilat], aux10,
              clim_hno3_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_hno3_secs[isec], aux00,
              clim_hno3_secs[isec + 1], aux11, sec);

  /* Convert from ppb to ppv... */
  return GSL_MAX(1e-9 * aux00, 0.0);
}
```

#### 5.21.3.4 clim_oh()

```
double clim_oh (
    double t,
    double lat,
    double p )
```

Climatology of OH number concentrations.

Definition at line 1331 of file libtrac.c.

```
            {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Check pressure... */
  if (p < clim_oh_ps[0])
    p = clim_oh_ps[0];
  else if (p > clim_oh_ps[33])
    p = clim_oh_ps[33];

  /* Check latitude... */
  if (lat < clim_oh_lats[0])
    lat = clim_oh_lats[0];
  else if (lat > clim_oh_lats[17])
    lat = clim_oh_lats[17];

  /* Get indices... */
  int isec = locate_irr(clim_oh_secs, 12, sec);
  int ilat = locate_reg(clim_oh_lats, 18, lat);
  int ip = locate_irr(clim_oh_ps, 34, p);

  /* Interpolate OH climatology (Pommrich et al., 2014)... */
  double aux00 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat][ip + 1], p);
  double aux01 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec][ilat + 1][ip + 1], p);
  double aux10 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat][ip + 1], p);
  double aux11 = LIN(clim_oh_ps[ip],
                     clim_oh_var[isec + 1][ilat + 1][ip],
                     clim_oh_ps[ip + 1],
                     clim_oh_var[isec + 1][ilat + 1][ip + 1], p);
  aux00 = LIN(clim_oh_lats[ilat], aux00, clim_oh_lats[ilat + 1], aux01, lat);
  aux11 = LIN(clim_oh_lats[ilat], aux10, clim_oh_lats[ilat + 1], aux11, lat);
  aux00 = LIN(clim_oh_secs[isec], aux00, clim_oh_secs[isec + 1], aux11, sec);
  return GSL_MAX(1e6 * aux00, 0.0);
}
```

#### 5.21.3.5 clim_tropo()

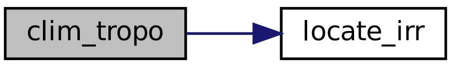
```
double clim_tropo (
    double t,
    double lat )
```

Climatology of tropopause pressure.

Definition at line 1512 of file libtrac.c.

```
                  {

  /* Get seconds since begin of year... */
  double sec = FMOD(t, 365.25 * 86400.);
  while (sec < 0)
    sec += 365.25 * 86400.;

  /* Get indices... */
  int isec = locate_irr(clim_tropo_secs, 12, sec);
  int ilat = locate_reg(clim_tropo_lats, 73, lat);

  /* Interpolate tropopause data (NCEP/NCAR Reanalysis 1)... */
  double p0 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec][ilat + 1], lat);
  double p1 = LIN(clim_tropo_lats[ilat],
                  clim_tropo_tps[isec + 1][ilat],
                  clim_tropo_lats[ilat + 1],
                  clim_tropo_tps[isec + 1][ilat + 1], lat);
  return LIN(clim_tropo_secs[isec], p0, clim_tropo_secs[isec + 1], p1, sec);
}
```

Here is the call graph for this function:




#### 5.21.3.6 day2doy()

```
void day2doy (
    int year,
    int mon,
    int day,
    int * doy )
```

Get day of year from date.

Definition at line 1539 of file libtrac.c.

```
                {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d0l[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  /* Get day of year... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0))
    *doy = d0l[mon - 1] + day - 1;
  else
    *doy = d0[mon - 1] + day - 1;
}
```

#### 5.21.3.7 doy2day()

```
void doy2day (
    int year,
    int doy,
    int * mon,
    int * day )
```

Get date from day of year.

Definition at line 1558 of file libtrac.c.

```
            {

  const int
    d0[12] = { 1, 32, 60, 91, 121, 152, 182, 213, 244, 274, 305, 335 },
    d01[12] = { 1, 32, 61, 92, 122, 153, 183, 214, 245, 275, 306, 336 };

  int i;

  /* Get month and day... */
  if (year % 400 == 0 || (year % 100 != 0 && year % 4 == 0)) {
    for (i = 11; i > 0; i--)
      if (d01[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d01[i] + 1;
  } else {
    for (i = 11; i > 0; i--)
      if (d0[i] <= doy)
        break;
    *mon = i + 1;
    *day = doy - d0[i] + 1;
  }
}
```

#### 5.21.3.8 geo2cart()

```
void geo2cart (
    double z,
    double lon,
    double lat,
    double * x )
```

Convert geolocation to Cartesian coordinates.

Definition at line 1588 of file libtrac.c.

```
             {

  double radius = z + RE;
  x[0] = radius * cos(lat / 180. * M_PI) * cos(lon / 180. * M_PI);
  x[1] = radius * cos(lat / 180. * M_PI) * sin(lon / 180. * M_PI);
  x[2] = radius * sin(lat / 180. * M_PI);
}
```

#### 5.21.3.9 get_met()

```
void get_met (
    ctl_t * ctl,
    double t,
    met_t ** met0,
    met_t ** met1 )
```

Get meteorological data for given time step.

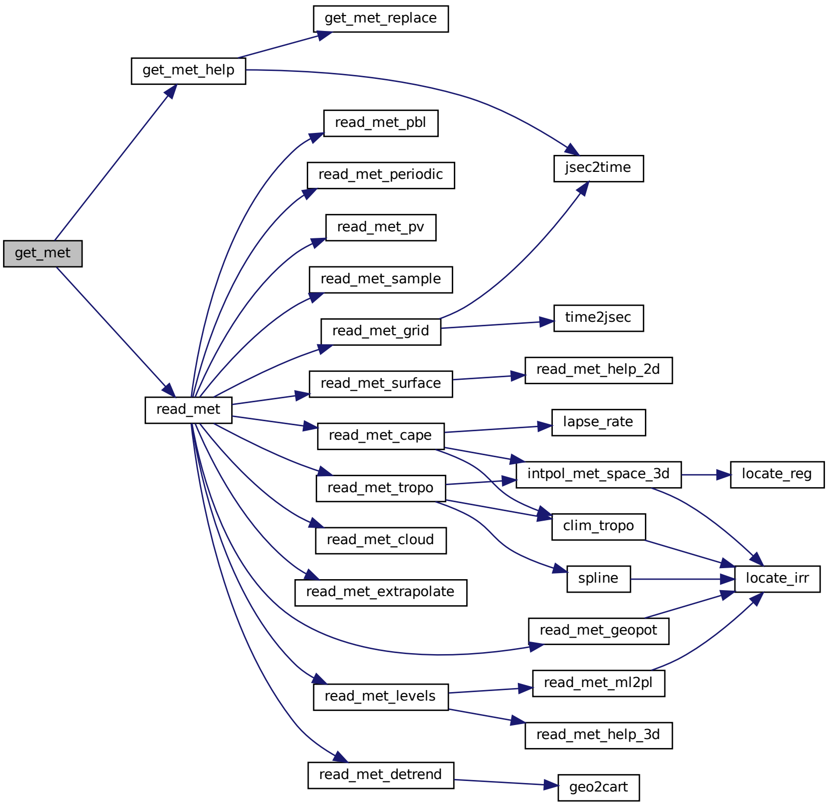
Definition at line 1602 of file libtrac.c.

```
                  {

  static int init;

  met_t *mets;
```

```

  char cachefile[LEN], cmd[2 * LEN], filename[LEN];

  /* Set timer... */
  SELECT_TIMER("GET_MET", "INPUT", NVTX_READ);

  /* Init... */
  if (t == ctl->t_start || !init) {
    init = 1;

    /* Read meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    get_met_help(t + 1.0 * ctl->direction, 1, ctl->metbase, ctl->dt_met,
                 filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
    met_t *met1up = *met1;
#pragma acc update device(met0up[:1],met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + 1.1 * ctl->dt_met * ctl->direction, ctl->direction,
                   ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for forward trajectories... */
  if (t > (*met1)->time) {

    /* Pointer swap... */
    mets = *met1;
    *met1 = *met0;
    *met0 = mets;

    /* Read new meteo data... */
    get_met_help(t, 1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met1))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met1up = *met1;
#pragma acc update device(met1up[:1])
#endif

    /* Caching... */
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t + ctl->dt_met, 1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Read new data for backward trajectories... */
  if (t < (*met0)->time) {

    /* Pointer swap... */
    mets = *met1;
    *met1 = *met0;
    *met0 = mets;

    /* Read new meteo data... */
    get_met_help(t, -1, ctl->metbase, ctl->dt_met, filename);
    if (!read_met(ctl, filename, *met0))
      ERRMSG("Cannot open file!");

    /* Update GPU... */
#ifdef _OPENACC
    met_t *met0up = *met0;
#pragma acc update device(met0up[:1])
#endif

    /* Caching... */
```

```
    if (ctl->met_cache && t != ctl->t_stop) {
      get_met_help(t - ctl->dt_met, -1, ctl->metbase, ctl->dt_met, cachefile);
      sprintf(cmd, "cat %s > /dev/null &", cachefile);
      LOG(1, "Caching: %s", cachefile);
      if (system(cmd) != 0)
        WARN("Caching command failed!");
    }
  }

  /* Check that grids are consistent... */
  if ((*met0)->nx != (*met1)->nx
      || (*met0)->ny != (*met1)->ny || (*met0)->np != (*met1)->np)
    ERRMSG("Meteo grid dimensions do not match!");
  for (int ix = 0; ix < (*met0)->nx; ix++)
    if (fabs((*met0)->lon[ix] - (*met1)->lon[ix]) > 0.001)
      ERRMSG("Meteo grid longitudes do not match!");
  for (int iy = 0; iy < (*met0)->ny; iy++)
    if (fabs((*met0)->lat[iy] - (*met1)->lat[iy]) > 0.001)
      ERRMSG("Meteo grid latitudes do not match!");
  for (int ip = 0; ip < (*met0)->np; ip++)
    if (fabs((*met0)->p[ip] - (*met1)->p[ip]) > 0.001)
      ERRMSG("Meteo grid pressure levels do not match!");
}
```

Here is the call graph for this function:




### 5.21.3.10 get_met_help()

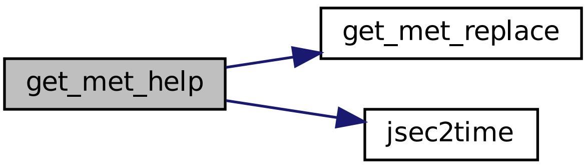
```
void get_met_help (
    double t,
    int direct,
    char * metbase,
    double dt_met,
    char * filename )
```

Get meteorological data for time step.

Definition at line 1724 of file libtrac.c.

```
                      {

  char repl[LEN];

  double t6, r;

  int year, mon, day, hour, min, sec;

  /* Round time to fixed intervals... */
  if (direct == -1)
    t6 = floor(t / dt_met) * dt_met;
  else
    t6 = ceil(t / dt_met) * dt_met;

  /* Decode time... */
  jsec2time(t6, &year, &mon, &day, &hour, &min, &sec, &r);

  /* Set filename... */
  sprintf(filename, "%s_YYYY_MM_DD_HH.nc", metbase);
  sprintf(repl, "%d", year);
  get_met_replace(filename, "YYYY", repl);
  sprintf(repl, "%02d", mon);
  get_met_replace(filename, "MM", repl);
  sprintf(repl, "%02d", day);
  get_met_replace(filename, "DD", repl);
  sprintf(repl, "%02d", hour);
  get_met_replace(filename, "HH", repl);
}
```

Here is the call graph for this function:




### 5.21.3.11 get_met_replace() `void get_met_replace ( char * orig, char * search, char * repl )`

Replace template strings in filename.

Definition at line 1760 of file libtrac.c.

```
                  {

  char buffer[LEN], *ch;

  /* Iterate... */
  for (int i = 0; i < 3; i++) {

    /* Replace sub-string... */
    if (!(ch = strstr(orig, search)))
      return;
    strncpy(buffer, orig, (size_t) (ch - orig));
    buffer[ch - orig] = 0;
```

```
    sprintf(buffer + (ch - orig), "%s%s", repl, ch + strlen(search));
    orig[0] = 0;
    strcpy(orig, buffer);
  }
}
```

#### 5.21.3.12 intpol_met_space_3d()

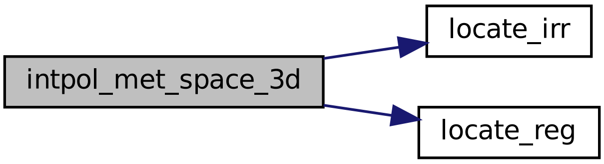
```
void intpol_met_space_3d (
    met_t * met,
    float array[EX][EY][EP],
    double p,
    double lon,
    double lat,
    double * var,
    int * ci,
    double * cw,
    int init )
```

Spatial interpolation of meteorological data.

Definition at line 1783 of file libtrac.c.

```
                {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

    /* Get interpolation indices... */
    ci[0] = locate_irr(met->p, met->np, p);
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[0] = (met->p[ci[0] + 1] - p)
      / (met->p[ci[0] + 1] - met->p[ci[0]]);
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Interpolate vertically... */
  double aux00 =
    cw[0] * (array[ci[1]][ci[2]][ci[0]] - array[ci[1]][ci[2]][ci[0] + 1])
    + array[ci[1]][ci[2]][ci[0] + 1];
  double aux01 =
    cw[0] * (array[ci[1]][ci[2] + 1][ci[0]] -
             array[ci[1]][ci[2] + 1][ci[0] + 1])
    + array[ci[1]][ci[2] + 1][ci[0] + 1];
  double aux10 =
    cw[0] * (array[ci[1] + 1][ci[2]][ci[0]] -
             array[ci[1] + 1][ci[2]][ci[0] + 1])
    + array[ci[1] + 1][ci[2]][ci[0] + 1];
  double aux11 =
    cw[0] * (array[ci[1] + 1][ci[2] + 1][ci[0]] -
             array[ci[1] + 1][ci[2] + 1][ci[0] + 1])
    + array[ci[1] + 1][ci[2] + 1][ci[0] + 1];

  /* Interpolate horizontally... */
  aux00 = cw[2] * (aux00 - aux01) + aux01;
  aux11 = cw[2] * (aux10 - aux11) + aux11;
  *var = cw[1] * (aux00 - aux11) + aux11;
}
```

Here is the call graph for this function:




#### 5.21.3.13 intpol_met_space_2d()

```
void intpol_met_space_2d (
    met_t * met,
    float array[EX][EY],
    double lon,
    double lat,
    double * var,
    int * ci,
    double * cw,
    int init )
```

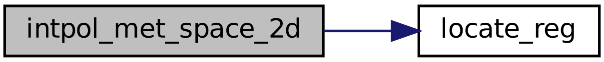
Spatial interpolation of meteorological data.

Definition at line 1841 of file libtrac.c.

```
               {

  /* Initialize interpolation... */
  if (init) {

    /* Check longitude... */
    if (met->lon[met->nx - 1] > 180 && lon < 0)
      lon += 360;

    /* Get interpolation indices... */
    ci[1] = locate_reg(met->lon, met->nx, lon);
    ci[2] = locate_reg(met->lat, met->ny, lat);

    /* Get interpolation weights... */
    cw[1] = (met->lon[ci[1] + 1] - lon)
      / (met->lon[ci[1] + 1] - met->lon[ci[1]]);
    cw[2] = (met->lat[ci[2] + 1] - lat)
      / (met->lat[ci[2] + 1] - met->lat[ci[2]]);
  }

  /* Set variables... */
  double aux00 = array[ci[1]][ci[2]];
  double aux01 = array[ci[1]][ci[2] + 1];
  double aux10 = array[ci[1] + 1][ci[2]];
  double aux11 = array[ci[1] + 1][ci[2] + 1];

  /* Interpolate horizontally... */
  if (isfinite(aux00) && isfinite(aux01)
      && isfinite(aux10) && isfinite(aux11)) {
    aux00 = cw[2] * (aux00 - aux01) + aux01;
    aux11 = cw[2] * (aux10 - aux11) + aux11;
    *var = cw[1] * (aux00 - aux11) + aux11;
  } else {
    if (cw[2] < 0.5) {
      if (cw[1] < 0.5)
        *var = aux11;
      else
        *var = aux01;
    } else {
```

```
01888       if (cw[1] < 0.5)
01889         *var = aux10;
01890       else
01891         *var = aux00;
01892     }
01893   }
01894 }
```

Here is the call graph for this function:




#### 5.21.3.14 intpol_met_time_3d()

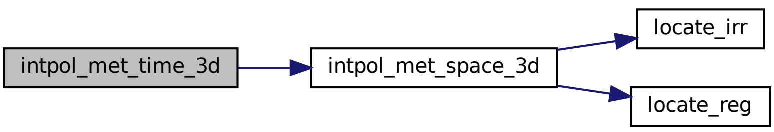
```
void intpol_met_time_3d (
    met_t * met0,
    float array0[EX][EY][EP],
    met_t * met1,
    float array1[EX][EY][EP],
    double ts,
    double p,
    double lon,
    double lat,
    double * var,
    int * ci,
    double * cw,
    int init )
```

Temporal interpolation of meteorological data.

Definition at line 1898 of file libtrac.c.

```
01910             {
01911
01912   double var0, var1, wt;
01913
01914   /* Spatial interpolation... */
01915   intpol_met_space_3d(met0, array0, p, lon, lat, &var0, ci, cw, init);
01916   intpol_met_space_3d(met1, array1, p, lon, lat, &var1, ci, cw, 0);
01917
01918   /* Get weighting factor... */
01919   wt = (met1->time - ts) / (met1->time - met0->time);
01920
01921   /* Interpolate... */
01922   *var = wt * (var0 - var1) + var1;
01923 }
```

Here is the call graph for this function:



#### 5.21.3.15 intpol_met_time_2d()

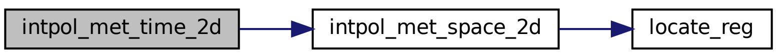
```
void intpol_met_time_2d (
        met_t * met0,
        float array0[EX][EY],
        met_t * met1,
        float array1[EX][EY],
        double ts,
        double lon,
        double lat,
        double * var,
        int * ci,
        double * cw,
        int init )
```

Temporal interpolation of meteorological data.

Definition at line 1927 of file libtrac.c.

```
                {

  double var0, var1, wt;

  /* Spatial interpolation... */
  intpol_met_space_2d(met0, array0, lon, lat, &var0, ci, cw, init);
  intpol_met_space_2d(met1, array1, lon, lat, &var1, ci, cw, 0);

  /* Get weighting factor... */
  wt = (met1->time - ts) / (met1->time - met0->time);

  /* Interpolate... */
  if (isfinite(var0) && isfinite(var1))
    *var = wt * (var0 - var1) + var1;
  else if (wt < 0.5)
    *var = var1;
  else
    *var = var0;
}
```

Here is the call graph for this function:




#### 5.21.3.16 jsec2time()

```
void jsec2time (
        double jsec,
        int * year,
        int * mon,
        int * day,
        int * hour,
        int * min,
        int * sec,
        double * remain )
```

Convert seconds to date.

Definition at line 1960 of file libtrac.c.

```
                      {

  struct tm t0, *t1;

  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  time_t jsec0 = (time_t) jsec + timegm(&t0);
  t1 = gmtime(&jsec0);

  *year = t1->tm_year + 1900;
  *mon = t1->tm_mon + 1;
  *day = t1->tm_mday;
  *hour = t1->tm_hour;
  *min = t1->tm_min;
  *sec = t1->tm_sec;
  *remain = jsec - floor(jsec);
}
```

#### 5.21.3.17 lapse_rate() `double lapse_rate (`

```
double t,
double h2o )
```

Calculate moist adiabatic lapse rate.

Definition at line 1993 of file libtrac.c.

```
                  {

  /*
     Calculate moist adiabatic lapse rate [K/km] from temperature [K]
     and water vapor volume mixing ratio [1].

     Reference: https://en.wikipedia.org/wiki/Lapse_rate
   */

  const double a = RA * SQR(t), r = SH(h2o) / (1. - SH(h2o));

  return 1e3 * G0 * (a + LV * r * t) / (CPD * a + SQR(LV) * r * EPS);
}
```

#### 5.21.3.18 locate_irr() `int locate_irr (`

```
double * xx,
int n,
double x )
```

Find array index for irregular grid.

Definition at line 2011 of file libtrac.c.

```
                 {

  int ilo = 0;
  int ihi = n - 1;
  int i = (ihi + ilo) » 1;

  if (xx[i] < xx[i + 1])
    while (ihi > ilo + 1) {
      i = (ihi + ilo) » 1;
      if (xx[i] > x)
        ihi = i;
      else
        ilo = i;
  } else
    while (ihi > ilo + 1) {
      i = (ihi + ilo) » 1;
```

```
      if (xx[i] <= x)
        ihi = i;
      else
        ilo = i;
    }

  return ilo;
}
```

#### 5.21.3.19 locate_reg()

```
int locate_reg (
        double * xx,
        int n,
        double x )
```

Find array index for regular grid.

Definition at line 2041 of file libtrac.c.

```
               {

  /* Calculate index... */
  int i = (int) ((x - xx[0]) / (xx[1] - xx[0]));

  /* Check range... */
  if (i < 0)
    return 0;
  else if (i > n - 2)
    return n - 2;
  else
    return i;
}
```

#### 5.21.3.20 nat_temperature()

```
double nat_temperature (
        double p,
        double h2o,
        double hno3 )
```

Calculate NAT existence temperature.

Definition at line 2060 of file libtrac.c.

```
                 {

  /* Check water vapor vmr... */
  h2o = GSL_MAX(h2o, 0.1e-6);

  /* Calculate T_NAT... */
  double p_hno3 = hno3 * p / 1.333224;
  double p_h2o = h2o * p / 1.333224;
  double a = 0.009179 - 0.00088 * log10(p_h2o);
  double b = (38.9855 - log10(p_hno3) - 2.7836 * log10(p_h2o)) / a;
  double c = -11397.0 / a;
  double tnat = (-b + sqrt(b * b - 4. * c)) / 2.;
  double x2 = (-b - sqrt(b * b - 4. * c)) / 2.;
  if (x2 > 0)
    tnat = x2;

  return tnat;
}
```

#### 5.21.3.21 read_atm()

```
int read_atm (
    const char * filename,
    ctl_t * ctl,
    atm_t * atm )
```

Read atmospheric data.

Definition at line 2084 of file libtrac.c.

```
                 {

  FILE *in;

  double t0;

  int dimid, ncid, varid;

  size_t nparts;

  /* Set timer... */
  SELECT_TIMER("READ_ATM", "INPUT", NVTX_READ);

  /* Init... */
  atm->np = 0;

  /* Write info... */
  LOG(1, "Read atmospheric data: %s", filename);

  /* Read ASCII data... */
  if (ctl->atm_type == 0) {

    /* Open file... */
    if (!(in = fopen(filename, "r"))) {
      WARN("File not found!");
      return 0;
    }

    /* Read line... */
    char line[LEN];
    while (fgets(line, LEN, in)) {

      /* Read data... */
      char *tok;
      TOK(line, tok, "%lg", atm->time[atm->np]);
      TOK(NULL, tok, "%lg", atm->p[atm->np]);
      TOK(NULL, tok, "%lg", atm->lon[atm->np]);
      TOK(NULL, tok, "%lg", atm->lat[atm->np]);
      for (int iq = 0; iq < ctl->nq; iq++)
        TOK(NULL, tok, "%lg", atm->q[iq][atm->np]);

      /* Convert altitude to pressure... */
      atm->p[atm->np] = P(atm->p[atm->np]);

      /* Increment data point counter... */
      if ((++atm->np) > NP)
        ERRMSG("Too many data points!");
    }

    /* Close file... */
    fclose(in);
  }

  /* Read binary data... */
  else if (ctl->atm_type == 1) {

    /* Open file... */
    if (!(in = fopen(filename, "r")))
      return 0;

    /* Read data... */
    FREAD(&atm->np, int,
          1,
          in);
    FREAD(atm->time, double,
            (size_t) atm->np,
          in);
    FREAD(atm->p, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lon, double,
            (size_t) atm->np,
          in);
    FREAD(atm->lat, double,
            (size_t) atm->np,
          in);
```

```
    for (int iq = 0; iq < ctl->nq; iq++)
      FREAD(atm->q[iq], double,
            (size_t) atm->np,
            in);

    /* Close file... */
    fclose(in);
  }

  /* Read netCDF data... */
  else if (ctl->atm_type == 2) {

    /* Open file... */
    if (nc_open(filename, NC_NOWRITE, &ncid) != NC_NOERR)
      return 0;

    /* Get dimensions... */
    NC(nc_inq_dimid(ncid, "NPARTS", &dimid));
    NC(nc_inq_dimlen(ncid, dimid, &nparts));
    atm->np = (int) nparts;
    if (atm->np > NP)
      ERRMSG("Too many particles!");

    /* Get time... */
    NC(nc_inq_varid(ncid, "time", &varid));
    NC(nc_get_var_double(ncid, varid, &t0));
    for (int ip = 0; ip < atm->np; ip++)
      atm->time[ip] = t0;

    /* Read geolocations... */
    NC(nc_inq_varid(ncid, "PRESS", &varid));
    NC(nc_get_var_double(ncid, varid, atm->p));
    NC(nc_inq_varid(ncid, "LON", &varid));
    NC(nc_get_var_double(ncid, varid, atm->lon));
    NC(nc_inq_varid(ncid, "LAT", &varid));
    NC(nc_get_var_double(ncid, varid, atm->lat));

    /* Read variables... */
    if (ctl->qnt_p >= 0)
      if (nc_inq_varid(ncid, "PRESS", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_p]));
    if (ctl->qnt_t >= 0)
      if (nc_inq_varid(ncid, "TEMP", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_t]));
    if (ctl->qnt_u >= 0)
      if (nc_inq_varid(ncid, "U", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_u]));
    if (ctl->qnt_v >= 0)
      if (nc_inq_varid(ncid, "V", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_v]));
    if (ctl->qnt_w >= 0)
      if (nc_inq_varid(ncid, "W", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_w]));
    if (ctl->qnt_h2o >= 0)
      if (nc_inq_varid(ncid, "SH", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_h2o]));
    if (ctl->qnt_o3 >= 0)
      if (nc_inq_varid(ncid, "O3", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_o3]));
    if (ctl->qnt_theta >= 0)
      if (nc_inq_varid(ncid, "THETA", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_theta]));
    if (ctl->qnt_pv >= 0)
      if (nc_inq_varid(ncid, "PV", &varid) == NC_NOERR)
        NC(nc_get_var_double(ncid, varid, atm->q[ctl->qnt_pv]));

    /* Check data... */
    for (int ip = 0; ip < atm->np; ip++)
      if (fabs(atm->lon[ip]) > 360 || fabs(atm->lat[ip]) > 90
          || (ctl->qnt_t >= 0 && fabs(atm->q[ctl->qnt_t][ip]) > 350)
          || (ctl->qnt_h2o >= 0 && fabs(atm->q[ctl->qnt_h2o][ip]) > 1)
          || (ctl->qnt_theta >= 0 && fabs(atm->q[ctl->qnt_theta][ip]) > 1e10)
          || (ctl->qnt_pv >= 0 && fabs(atm->q[ctl->qnt_pv][ip]) > 1e10)) {
        atm->time[ip] = GSL_NAN;
        atm->p[ip] = GSL_NAN;
        atm->lon[ip] = GSL_NAN;
        atm->lat[ip] = GSL_NAN;
        for (int iq = 0; iq < ctl->nq; iq++)
          atm->q[iq][ip] = GSL_NAN;
      } else {
        if (ctl->qnt_h2o >= 0)
          atm->q[ctl->qnt_h2o][ip] *= 1.608;
        if (ctl->qnt_pv >= 0)
          atm->q[ctl->qnt_pv][ip] *= 1e6;
        if (atm->lon[ip] > 180)
          atm->lon[ip] -= 360;
      }
```

```
    /* Close file... */
    NC(nc_close(ncid));
  }

  /* Error... */
  else
    ERRMSG("Atmospheric data type not supported!");

  /* Check number of points... */
  if (atm->np < 1)
    ERRMSG("Can not read any data!");

  /* Write info... */
  double mini, maxi;
  LOG(2, "Number of particles: %d", atm->np);
  gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
  LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
  LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
  LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
  LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
  LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
  for (int iq = 0; iq < ctl->nq; iq++) {
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }

  /* Return success... */
  return 1;
}
```

#### 5.21.3.22 read_ctl()

```
void read_ctl (
    const char * filename,
    int argc,
    char * argv[],
    ctl_t * ctl )
```

Read control parameters.

Definition at line 2290 of file libtrac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("READ_CTL", "INPUT", NVTX_READ);

  /* Write info... */
  LOG(1, "\nMassive-Parallel Trajectory Calculations (MPTRAC)\n"
      "(executable: %s | version: %s | compiled: %s, %s)\n",
      argv[0], VERSION, __DATE__, __TIME__);

  /* Initialize quantity indices... */
  ctl->qnt_ens = -1;
  ctl->qnt_stat = -1;
  ctl->qnt_m = -1;
  ctl->qnt_vmr = -1;
  ctl->qnt_r = -1;
  ctl->qnt_rho = -1;
  ctl->qnt_ps = -1;
  ctl->qnt_ts = -1;
  ctl->qnt_zs = -1;
  ctl->qnt_us = -1;
  ctl->qnt_vs = -1;
  ctl->qnt_pbl = -1;
  ctl->qnt_pt = -1;
  ctl->qnt_tt = -1;
  ctl->qnt_zt = -1;
  ctl->qnt_h2ot = -1;
  ctl->qnt_z = -1;
  ctl->qnt_p = -1;
  ctl->qnt_t = -1;
```

```
ctl->qnt_u = -1;
ctl->qnt_v = -1;
ctl->qnt_w = -1;
ctl->qnt_h2o = -1;
ctl->qnt_o3 = -1;
ctl->qnt_lwc = -1;
ctl->qnt_iwc = -1;
ctl->qnt_pct = -1;
ctl->qnt_pcb = -1;
ctl->qnt_cl = -1;
ctl->qnt_plcl = -1;
ctl->qnt_plfc = -1;
ctl->qnt_pel = -1;
ctl->qnt_cape = -1;
ctl->qnt_cin = -1;
ctl->qnt_hno3 = -1;
ctl->qnt_oh = -1;
ctl->qnt_psat = -1;
ctl->qnt_psice = -1;
ctl->qnt_pw = -1;
ctl->qnt_sh = -1;
ctl->qnt_rh = -1;
ctl->qnt_rhice = -1;
ctl->qnt_theta = -1;
ctl->qnt_zeta = -1;
ctl->qnt_tvirt = -1;
ctl->qnt_lapse = -1;
ctl->qnt_vh = -1;
ctl->qnt_vz = -1;
ctl->qnt_pv = -1;
ctl->qnt_tdew = -1;
ctl->qnt_tice = -1;
ctl->qnt_tsts = -1;
ctl->qnt_tnat = -1;

/* Read quantities... */
ctl->nq = (int) scan_ctl(filename, argc, argv, "NQ", -1, "0", NULL);
if (ctl->nq > NQ)
  ERRMSG("Too many quantities!");
for (int iq = 0; iq < ctl->nq; iq++) {

  /* Read quantity name and format... */
  scan_ctl(filename, argc, argv, "QNT_NAME", iq, "", ctl->qnt_name[iq]);
  scan_ctl(filename, argc, argv, "QNT_FORMAT", iq, "%g",
           ctl->qnt_format[iq]);

  /* Try to identify quantity... */
  SET_QNT(qnt_ens, "ens", "-")
    SET_QNT(qnt_stat, "stat", "-")
    SET_QNT(qnt_m, "m", "kg")
    SET_QNT(qnt_vmr, "vmr", "ppv")
    SET_QNT(qnt_r, "r", "microns")
    SET_QNT(qnt_rho, "rho", "kg/m^3")
    SET_QNT(qnt_ps, "ps", "hPa")
    SET_QNT(qnt_ts, "ts", "K")
    SET_QNT(qnt_zs, "zs", "km")
    SET_QNT(qnt_us, "us", "m/s")
    SET_QNT(qnt_vs, "vs", "m/s")
    SET_QNT(qnt_pbl, "pbl", "hPa")
    SET_QNT(qnt_pt, "pt", "hPa")
    SET_QNT(qnt_tt, "tt", "K")
    SET_QNT(qnt_zt, "zt", "km")
    SET_QNT(qnt_h2ot, "h2ot", "ppv")
    SET_QNT(qnt_z, "z", "km")
    SET_QNT(qnt_p, "p", "hPa")
    SET_QNT(qnt_t, "t", "K")
    SET_QNT(qnt_u, "u", "m/s")
    SET_QNT(qnt_v, "v", "m/s")
    SET_QNT(qnt_w, "w", "hPa/s")
    SET_QNT(qnt_h2o, "h2o", "ppv")
    SET_QNT(qnt_o3, "o3", "ppv")
    SET_QNT(qnt_lwc, "lwc", "kg/kg")
    SET_QNT(qnt_iwc, "iwc", "kg/kg")
    SET_QNT(qnt_pct, "pct", "hPa")
    SET_QNT(qnt_pcb, "pcb", "hPa")
    SET_QNT(qnt_cl, "cl", "kg/m^2")
    SET_QNT(qnt_plcl, "plcl", "hPa")
    SET_QNT(qnt_plfc, "plfc", "hPa")
    SET_QNT(qnt_pel, "pel", "hPa")
    SET_QNT(qnt_cape, "cape", "J/kg")
    SET_QNT(qnt_cin, "cin", "J/kg")
    SET_QNT(qnt_hno3, "hno3", "ppv")
    SET_QNT(qnt_oh, "oh", "molec/cm^3")
    SET_QNT(qnt_psat, "psat", "hPa")
    SET_QNT(qnt_psice, "psice", "hPa")
    SET_QNT(qnt_pw, "pw", "hPa")
    SET_QNT(qnt_sh, "sh", "kg/kg")
```

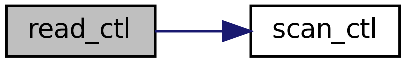
```
      SET_QNT(qnt_rh, "rh", "%%")
      SET_QNT(qnt_rhice, "rhice", "%%")
      SET_QNT(qnt_theta, "theta", "K")
      SET_QNT(qnt_zeta, "zeta", "K")
      SET_QNT(qnt_tvirt, "tvirt", "K")
      SET_QNT(qnt_lapse, "lapse", "K/km")
      SET_QNT(qnt_vh, "vh", "m/s")
      SET_QNT(qnt_vz, "vz", "m/s")
      SET_QNT(qnt_pv, "pv", "PVU")
      SET_QNT(qnt_tdew, "tdew", "K")
      SET_QNT(qnt_tice, "tice", "K")
      SET_QNT(qnt_tsts, "tsts", "K")
      SET_QNT(qnt_tnat, "tnat", "K")
      scan_ctl(filename, argc, argv, "QNT_UNIT", iq, "", ctl->qnt_unit[iq]);
  }

  /* netCDF I/O parameters... */
  ctl->chunkszhint =
    (size_t) scan_ctl(filename, argc, argv, "CHUNKSZHINT", -1, "163840000",
                      NULL);
  ctl->read_mode =
    (int) scan_ctl(filename, argc, argv, "READMODE", -1, "0", NULL);

  /* Time steps of simulation... */
  ctl->direction =
    (int) scan_ctl(filename, argc, argv, "DIRECTION", -1, "1", NULL);
  if (ctl->direction != -1 && ctl->direction != 1)
    ERRMSG("Set DIRECTION to -1 or 1!");
  ctl->t_stop = scan_ctl(filename, argc, argv, "T_STOP", -1, "1e100", NULL);
  ctl->dt_mod = scan_ctl(filename, argc, argv, "DT_MOD", -1, "180", NULL);

  /* Meteorological data... */
  scan_ctl(filename, argc, argv, "METBASE", -1, "-", ctl->metbase);
  ctl->dt_met = scan_ctl(filename, argc, argv, "DT_MET", -1, "3600", NULL);
  ctl->met_dx = (int) scan_ctl(filename, argc, argv, "MET_DX", -1, "1", NULL);
  ctl->met_dy = (int) scan_ctl(filename, argc, argv, "MET_DY", -1, "1", NULL);
  ctl->met_dp = (int) scan_ctl(filename, argc, argv, "MET_DP", -1, "1", NULL);
  if (ctl->met_dx < 1 || ctl->met_dy < 1 || ctl->met_dp < 1)
    ERRMSG("MET_DX, MET_DY, and MET_DP need to be greater than zero!");
  ctl->met_sx = (int) scan_ctl(filename, argc, argv, "MET_SX", -1, "1", NULL);
  ctl->met_sy = (int) scan_ctl(filename, argc, argv, "MET_SY", -1, "1", NULL);
  ctl->met_sp = (int) scan_ctl(filename, argc, argv, "MET_SP", -1, "1", NULL);
  if (ctl->met_sx < 1 || ctl->met_sy < 1 || ctl->met_sp < 1)
    ERRMSG("MET_SX, MET_SY, and MET_SP need to be greater than zero!");
  ctl->met_detrend =
    scan_ctl(filename, argc, argv, "MET_DETREND", -1, "-999", NULL);
  ctl->met_np = (int) scan_ctl(filename, argc, argv, "MET_NP", -1, "0", NULL);
  if (ctl->met_np > EP)
    ERRMSG("Too many levels!");
  for (int ip = 0; ip < ctl->met_np; ip++)
    ctl->met_p[ip] = scan_ctl(filename, argc, argv, "MET_P", ip, "", NULL);
  ctl->met_geopot_sx
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SX", -1, "-1", NULL);
  ctl->met_geopot_sy
    = (int) scan_ctl(filename, argc, argv, "MET_GEOPOT_SY", -1, "-1", NULL);
  ctl->met_tropo =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO", -1, "3", NULL);
  if (ctl->met_tropo < 0 || ctl->met_tropo > 5)
    ERRMSG("Set MET_TROPO = 0 ... 5!");
  ctl->met_tropo_lapse =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE", -1, "2.0", NULL);
  ctl->met_tropo_nlev =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV", -1, "20", NULL);
  ctl->met_tropo_lapse_sep =
    scan_ctl(filename, argc, argv, "MET_TROPO_LAPSE_SEP", -1, "3.0", NULL);
  ctl->met_tropo_nlev_sep =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_NLEV_SEP", -1, "10",
                   NULL);
  ctl->met_tropo_pv =
    scan_ctl(filename, argc, argv, "MET_TROPO_PV", -1, "3.5", NULL);
  ctl->met_tropo_theta =
    scan_ctl(filename, argc, argv, "MET_TROPO_THETA", -1, "380", NULL);
  ctl->met_tropo_spline =
    (int) scan_ctl(filename, argc, argv, "MET_TROPO_SPLINE", -1, "1", NULL);
  ctl->met_cloud =
    (int) scan_ctl(filename, argc, argv, "MET_CLOUD", -1, "1", NULL);
  if (ctl->met_cloud < 0 || ctl->met_cloud > 3)
    ERRMSG("Set MET_CLOUD = 0 ... 3!");
  ctl->met_dt_out =
    scan_ctl(filename, argc, argv, "MET_DT_OUT", -1, "0.1", NULL);
  ctl->met_cache =
    (int) scan_ctl(filename, argc, argv, "MET_CACHE", -1, "0", NULL);

  /* Isosurface parameters... */
  ctl->isosurf =
    (int) scan_ctl(filename, argc, argv, "ISOSURF", -1, "0", NULL);
  scan_ctl(filename, argc, argv, "BALLOON", -1, "-", ctl->balloon);
```

```

  /* Advection parameters... */
  ctl->advect = (int) scan_ctl(filename, argc, argv, "ADVECT", -1, "0", NULL);
  ctl->reflect =
    (int) scan_ctl(filename, argc, argv, "REFLECT", -1, "0", NULL);

  /* Diffusion parameters... */
  ctl->turb_dx_trop =
    scan_ctl(filename, argc, argv, "TURB_DX_TROP", -1, "50", NULL);
  ctl->turb_dx_strat =
    scan_ctl(filename, argc, argv, "TURB_DX_STRAT", -1, "0", NULL);
  ctl->turb_dz_trop =
    scan_ctl(filename, argc, argv, "TURB_DZ_TROP", -1, "0", NULL);
  ctl->turb_dz_strat =
    scan_ctl(filename, argc, argv, "TURB_DZ_STRAT", -1, "0.1", NULL);
  ctl->turb_mesox =
    scan_ctl(filename, argc, argv, "TURB_MESOX", -1, "0.16", NULL);
  ctl->turb_mesoz =
    scan_ctl(filename, argc, argv, "TURB_MESOZ", -1, "0.16", NULL);

  /* Convection... */
  ctl->conv_cape
    = scan_ctl(filename, argc, argv, "CONV_CAPE", -1, "-999", NULL);
  ctl->conv_cin
    = scan_ctl(filename, argc, argv, "CONV_CIN", -1, "-999", NULL);
  ctl->conv_wmax
    = scan_ctl(filename, argc, argv, "CONV_WMAX", -1, "-999", NULL);
  ctl->conv_wcape
    = (int) scan_ctl(filename, argc, argv, "CONV_WCAPE", -1, "0", NULL);
  ctl->conv_dt = scan_ctl(filename, argc, argv, "CONV_DT", -1, "-999", NULL);
  ctl->conv_mix_bot
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_BOT", -1, "1", NULL);
  ctl->conv_mix_top
    = (int) scan_ctl(filename, argc, argv, "CONV_MIX_TOP", -1, "1", NULL);

  /* Boundary conditions... */
  ctl->bound_mass =
    scan_ctl(filename, argc, argv, "BOUND_MASS", -1, "-999", NULL);
  ctl->bound_vmr =
    scan_ctl(filename, argc, argv, "BOUND_VMR", -1, "-999", NULL);
  ctl->bound_lat0 =
    scan_ctl(filename, argc, argv, "BOUND_LAT0", -1, "-90", NULL);
  ctl->bound_lat1 =
    scan_ctl(filename, argc, argv, "BOUND_LAT1", -1, "90", NULL);
  ctl->bound_p0 =
    scan_ctl(filename, argc, argv, "BOUND_P0", -1, "1e10", NULL);
  ctl->bound_p1 =
    scan_ctl(filename, argc, argv, "BOUND_P1", -1, "-1e10", NULL);
  ctl->bound_dps =
    scan_ctl(filename, argc, argv, "BOUND_DPS", -1, "-999", NULL);

  /* Species parameters... */
  scan_ctl(filename, argc, argv, "SPECIES", -1, "-", ctl->species);
  if (strcasecmp(ctl->species, "CF2Cl2") == 0) {
    ctl->molmass = 120.907;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 3e-5;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 3500.0;
  } else if (strcasecmp(ctl->species, "CFCl3") == 0) {
    ctl->molmass = 137.359;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.1e-4;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 3300.0;
  } else if (strcasecmp(ctl->species, "CH4") == 0) {
    ctl->molmass = 16.043;
    ctl->oh_chem_reaction = 2;
    ctl->oh_chem[0] = 2.45e-12;
    ctl->oh_chem[1] = 1775;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.4e-5;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
  } else if (strcasecmp(ctl->species, "CO") == 0) {
    ctl->molmass = 28.01;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 6.9e-33;
    ctl->oh_chem[1] = 2.1;
    ctl->oh_chem[2] = 1.1e-12;
    ctl->oh_chem[3] = -1.3;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 9.7e-6;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 1300.0;
  } else if (strcasecmp(ctl->species, "CO2") == 0) {
    ctl->molmass = 44.009;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 3.3e-4;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
  } else if (strcasecmp(ctl->species, "N2O") == 0) {
    ctl->molmass = 44.013;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-4;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2600.;
  } else if (strcasecmp(ctl->species, "NH3") == 0) {
    ctl->molmass = 17.031;
```

```
    ctl->oh_chem_reaction = 2;
    ctl->oh_chem[0] = 1.7e-12;
    ctl->oh_chem[1] = 710;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 5.9e-1;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 4200.0;
  } else if (strcasecmp(ctl->species, "HNO3") == 0) {
    ctl->molmass = 63.012;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 2.1e3;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 8700.0;
  } else if (strcasecmp(ctl->species, "NO") == 0) {
    ctl->molmass = 30.006;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 7.1e-31;
    ctl->oh_chem[1] = 2.6;
    ctl->oh_chem[2] = 3.6e-11;
    ctl->oh_chem[3] = 0.1;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.9e-5;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 1600.0;
  } else if (strcasecmp(ctl->species, "NO2") == 0) {
    ctl->molmass = 46.005;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 1.8e-30;
    ctl->oh_chem[1] = 3.0;
    ctl->oh_chem[2] = 2.8e-11;
    ctl->oh_chem[3] = 0.0;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.2e-4;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2400.0;
  } else if (strcasecmp(ctl->species, "O3") == 0) {
    ctl->molmass = 47.997;
    ctl->oh_chem_reaction = 2;
    ctl->oh_chem[0] = 1.7e-12;
    ctl->oh_chem[1] = 940;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1e-4;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2800.0;
  } else if (strcasecmp(ctl->species, "SF6") == 0) {
    ctl->molmass = 146.048;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 2.4e-6;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 3100.0;
  } else if (strcasecmp(ctl->species, "SO2") == 0) {
    ctl->molmass = 64.066;
    ctl->oh_chem_reaction = 3;
    ctl->oh_chem[0] = 2.9e-31;
    ctl->oh_chem[1] = 4.1;
    ctl->oh_chem[2] = 1.7e-12;
    ctl->oh_chem[3] = -0.2;
    ctl->wet_depo[2] = ctl->wet_depo[6] = 1.3e-2;
    ctl->wet_depo[3] = ctl->wet_depo[7] = 2900.0;
  } else {
    ctl->molmass =
      scan_ctl(filename, argc, argv, "MOLMASS", -1, "-999", NULL);
    ctl->oh_chem_reaction =
      (int) scan_ctl(filename, argc, argv, "OH_CHEM_REACTION", -1, "0", NULL);
    for (int ip = 0; ip < 4; ip++)
      ctl->oh_chem[ip] =
        scan_ctl(filename, argc, argv, "OH_CHEM", ip, "0", NULL);
    for (int ip = 0; ip < 1; ip++)
      ctl->dry_depo[ip] =
        scan_ctl(filename, argc, argv, "DRY_DEPO", ip, "0", NULL);
    for (int ip = 0; ip < 8; ip++)
      ctl->wet_depo[ip] =
        scan_ctl(filename, argc, argv, "WET_DEPO", ip, "0", NULL);
  }
  ctl->tdec_trop = scan_ctl(filename, argc, argv, "TDEC_TROP", -1, "0", NULL);
  ctl->tdec_strat =
    scan_ctl(filename, argc, argv, "TDEC_STRAT", -1, "0", NULL);

  /* PSC analysis... */
  ctl->psc_h2o = scan_ctl(filename, argc, argv, "PSC_H2O", -1, "4e-6", NULL);
  ctl->psc_hno3 =
    scan_ctl(filename, argc, argv, "PSC_HNO3", -1, "9e-9", NULL);

  /* Output of atmospheric data... */
  scan_ctl(filename, argc, argv, "ATM_BASENAME", -1, "-", ctl->atm_basename);
  scan_ctl(filename, argc, argv, "ATM_GPFILE", -1, "-", ctl->atm_gpfile);
  ctl->atm_dt_out =
    scan_ctl(filename, argc, argv, "ATM_DT_OUT", -1, "86400", NULL);
  ctl->atm_filter =
    (int) scan_ctl(filename, argc, argv, "ATM_FILTER", -1, "0", NULL);
  ctl->atm_stride =
    (int) scan_ctl(filename, argc, argv, "ATM_STRIDE", -1, "1", NULL);
  ctl->atm_type =
    (int) scan_ctl(filename, argc, argv, "ATM_TYPE", -1, "0", NULL);

  /* Output of CSI data... */
  scan_ctl(filename, argc, argv, "CSI_BASENAME", -1, "-", ctl->csi_basename);
  ctl->csi_dt_out =
    scan_ctl(filename, argc, argv, "CSI_DT_OUT", -1, "86400", NULL);
```

```
  scan_ctl(filename, argc, argv, "CSI_OBSFILE", -1, "-", ctl->csi_obsfile);
  ctl->csi_obsmin =
    scan_ctl(filename, argc, argv, "CSI_OBSMIN", -1, "0", NULL);
  ctl->csi_modmin =
    scan_ctl(filename, argc, argv, "CSI_MODMIN", -1, "0", NULL);
  ctl->csi_z0 = scan_ctl(filename, argc, argv, "CSI_Z0", -1, "0", NULL);
  ctl->csi_z1 = scan_ctl(filename, argc, argv, "CSI_Z1", -1, "100", NULL);
  ctl->csi_nz = (int) scan_ctl(filename, argc, argv, "CSI_NZ", -1, "1", NULL);
  ctl->csi_lon0 =
    scan_ctl(filename, argc, argv, "CSI_LON0", -1, "-180", NULL);
  ctl->csi_lon1 = scan_ctl(filename, argc, argv, "CSI_LON1", -1, "180", NULL);
  ctl->csi_nx =
    (int) scan_ctl(filename, argc, argv, "CSI_NX", -1, "360", NULL);
  ctl->csi_lat0 = scan_ctl(filename, argc, argv, "CSI_LAT0", -1, "-90", NULL);
  ctl->csi_lat1 = scan_ctl(filename, argc, argv, "CSI_LAT1", -1, "90", NULL);
  ctl->csi_ny =
    (int) scan_ctl(filename, argc, argv, "CSI_NY", -1, "180", NULL);

  /* Output of ensemble data... */
  scan_ctl(filename, argc, argv, "ENS_BASENAME", -1, "-", ctl->ens_basename);

  /* Output of grid data... */
  scan_ctl(filename, argc, argv, "GRID_BASENAME", -1, "-",
           ctl->grid_basename);
  scan_ctl(filename, argc, argv, "GRID_GPFILE", -1, "-", ctl->grid_gpfile);
  ctl->grid_dt_out =
    scan_ctl(filename, argc, argv, "GRID_DT_OUT", -1, "86400", NULL);
  ctl->grid_sparse =
    (int) scan_ctl(filename, argc, argv, "GRID_SPARSE", -1, "0", NULL);
  ctl->grid_z0 = scan_ctl(filename, argc, argv, "GRID_Z0", -1, "0", NULL);
  ctl->grid_z1 = scan_ctl(filename, argc, argv, "GRID_Z1", -1, "100", NULL);
  ctl->grid_nz =
    (int) scan_ctl(filename, argc, argv, "GRID_NZ", -1, "1", NULL);
  ctl->grid_lon0 =
    scan_ctl(filename, argc, argv, "GRID_LON0", -1, "-180", NULL);
  ctl->grid_lon1 =
    scan_ctl(filename, argc, argv, "GRID_LON1", -1, "180", NULL);
  ctl->grid_nx =
    (int) scan_ctl(filename, argc, argv, "GRID_NX", -1, "360", NULL);
  ctl->grid_lat0 =
    scan_ctl(filename, argc, argv, "GRID_LAT0", -1, "-90", NULL);
  ctl->grid_lat1 =
    scan_ctl(filename, argc, argv, "GRID_LAT1", -1, "90", NULL);
  ctl->grid_ny =
    (int) scan_ctl(filename, argc, argv, "GRID_NY", -1, "180", NULL);

  /* Output of profile data... */
  scan_ctl(filename, argc, argv, "PROF_BASENAME", -1, "-",
           ctl->prof_basename);
  scan_ctl(filename, argc, argv, "PROF_OBSFILE", -1, "-", ctl->prof_obsfile);
  ctl->prof_z0 = scan_ctl(filename, argc, argv, "PROF_Z0", -1, "0", NULL);
  ctl->prof_z1 = scan_ctl(filename, argc, argv, "PROF_Z1", -1, "60", NULL);
  ctl->prof_nz =
    (int) scan_ctl(filename, argc, argv, "PROF_NZ", -1, "60", NULL);
  ctl->prof_lon0 =
    scan_ctl(filename, argc, argv, "PROF_LON0", -1, "-180", NULL);
  ctl->prof_lon1 =
    scan_ctl(filename, argc, argv, "PROF_LON1", -1, "180", NULL);
  ctl->prof_nx =
    (int) scan_ctl(filename, argc, argv, "PROF_NX", -1, "360", NULL);
  ctl->prof_lat0 =
    scan_ctl(filename, argc, argv, "PROF_LAT0", -1, "-90", NULL);
  ctl->prof_lat1 =
    scan_ctl(filename, argc, argv, "PROF_LAT1", -1, "90", NULL);
  ctl->prof_ny =
    (int) scan_ctl(filename, argc, argv, "PROF_NY", -1, "180", NULL);

  /* Output of sample data... */
  scan_ctl(filename, argc, argv, "SAMPLE_BASENAME", -1, "-",
           ctl->sample_basename);
  scan_ctl(filename, argc, argv, "SAMPLE_OBSFILE", -1, "-",
           ctl->sample_obsfile);
  ctl->sample_dx =
    scan_ctl(filename, argc, argv, "SAMPLE_DX", -1, "50", NULL);
  ctl->sample_dz =
    scan_ctl(filename, argc, argv, "SAMPLE_DZ", -1, "-999", NULL);

  /* Output of station data... */
  scan_ctl(filename, argc, argv, "STAT_BASENAME", -1, "-",
           ctl->stat_basename);
  ctl->stat_lon = scan_ctl(filename, argc, argv, "STAT_LON", -1, "0", NULL);
  ctl->stat_lat = scan_ctl(filename, argc, argv, "STAT_LAT", -1, "0", NULL);
  ctl->stat_r = scan_ctl(filename, argc, argv, "STAT_R", -1, "50", NULL);
  ctl->stat_t0 =
    scan_ctl(filename, argc, argv, "STAT_T0", -1, "-1e100", NULL);
  ctl->stat_t1 = scan_ctl(filename, argc, argv, "STAT_T1", -1, "1e100", NULL);
}
```

Here is the call graph for this function:




#### 5.21.3.23 read_met()

```
int read_met (
    ctl_t * ctl,
    char * filename,
    met_t * met )
```

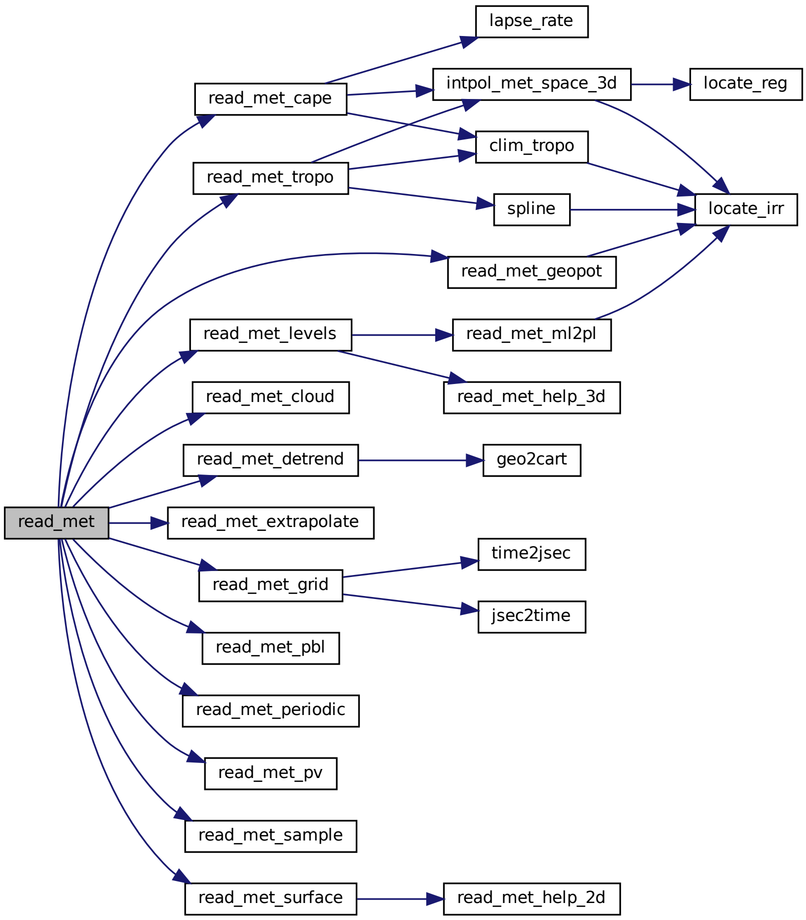
Read meteorological data file.

Definition at line 2762 of file libtrac.c.

```
                  {

  int ncid;

  /* Write info... */
  LOG(1, "Read meteorological data: %s", filename);

  /* Open netCDF file... */
  if (nc__open(filename, ctl->read_mode, &ctl->chunkszhint, &ncid) !=
      NC_NOERR) {
    WARN("File not found!");
    return 0;
  }

  /* Read coordinates of meteorological data... */
  read_met_grid(filename, ncid, ctl, met);

  /* Read meteo data on vertical levels... */
  read_met_levels(ncid, ctl, met);

  /* Extrapolate data for lower boundary... */
  read_met_extrapolate(met);

  /* Read surface data... */
  read_met_surface(ncid, met);

  /* Create periodic boundary conditions... */
  read_met_periodic(met);

  /* Downsampling... */
  read_met_sample(ctl, met);

  /* Calculate geopotential heights... */
  read_met_geopot(ctl, met);

  /* Calculate potential vorticity... */
  read_met_pv(met);

  /* Calculate boundary layer data... */
  read_met_pbl(met);

  /* Calculate tropopause data... */
  read_met_tropo(ctl, met);

  /* Calculate cloud properties... */
  read_met_cloud(met);

  /* Calculate convective available potential energy... */
  read_met_cape(met);

  /* Detrending... */
```

```
  read_met_detrend(ctl, met);

  /* Close file... */
  NC(nc_close(ncid));

  /* Return success... */
  return 1;
}
```

Here is the call graph for this function:




### 5.21.3.24 read_met_cape() `void read_met_cape ( met_t * met )`

Calculate convective available potential energy.

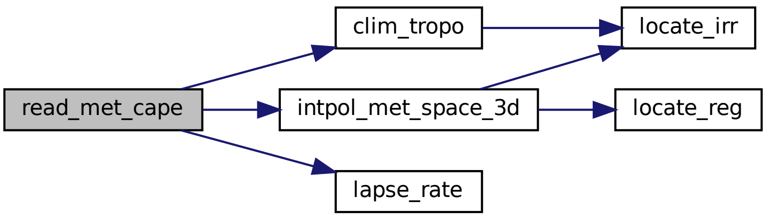
Definition at line 2827 of file libtrac.c.

```
              {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CAPE", "METPROC", NVTX_READ);
  LOG(2, "Calculate CAPE...");

  /* Vertical spacing (about 100 m)... */
```

```
  const double pfac = 1.01439, dz0 = RI / MA / G0 * log(pfac);

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get potential temperature and water vapor vmr at lowest 50 hPa... */
      int n = 0;
      double h2o = 0, t, theta = 0;
      double pbot = GSL_MIN(met->ps[ix][iy], met->p[0]);
      double ptop = pbot - 50.;
      for (int ip = 0; ip < met->np; ip++) {
        if (met->p[ip] <= pbot) {
          theta += THETA(met->p[ip], met->t[ix][iy][ip]);
          h2o += met->h2o[ix][iy][ip];
          n++;
        }
        if (met->p[ip] < ptop && n > 0)
          break;
      }
      theta /= n;
      h2o /= n;

      /* Cannot compute anything if water vapor is missing... */
      met->plcl[ix][iy] = GSL_NAN;
      met->plfc[ix][iy] = GSL_NAN;
      met->pel[ix][iy] = GSL_NAN;
      met->cape[ix][iy] = GSL_NAN;
      met->cin[ix][iy] = GSL_NAN;
      if (h2o <= 0)
        continue;

      /* Find lifted condensation level (LCL)... */
      ptop = P(20.);
      pbot = met->ps[ix][iy];
      do {
        met->plcl[ix][iy] = (float) (0.5 * (pbot + ptop));
        t = theta / pow(1000. / met->plcl[ix][iy], 0.286);
        if (RH(met->plcl[ix][iy], t, h2o) > 100.)
          ptop = met->plcl[ix][iy];
        else
          pbot = met->plcl[ix][iy];
      } while (pbot - ptop > 0.1);

      /* Calculate CIN up to LCL... */
      INTPOL_INIT;
      double dcape, dcape_old, dz, psat, h2o_env, t_env;
      double p = met->ps[ix][iy];
      met->cape[ix][iy] = met->cin[ix][iy] = 0;
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t = theta / pow(1000. / p, 0.286);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape < 0)
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > met->plcl[ix][iy]);

      /* Calculate level of free convection (LFC), equilibrium level (EL),
         and convective available potential energy (CAPE)... */
      dcape = 0;
      p = met->plcl[ix][iy];
      t = theta / pow(1000. / p, 0.286);
      ptop = 0.75 * clim_tropo(met->time, met->lat[iy]);
      do {
        dz = dz0 * TVIRT(t, h2o);
        p /= pfac;
        t -= lapse_rate(t, h2o) * dz;
        psat = PSAT(t);
        h2o = psat / (p - (1. - EPS) * psat);
        intpol_met_space_3d(met, met->t, p, met->lon[ix], met->lat[iy],
                            &t_env, ci, cw, 1);
        intpol_met_space_3d(met, met->h2o, p, met->lon[ix], met->lat[iy],
                            &h2o_env, ci, cw, 0);
        dcape_old = dcape;
        dcape = 1e3 * G0 * (TVIRT(t, h2o) - TVIRT(t_env, h2o_env)) /
          TVIRT(t_env, h2o_env) * dz;
        if (dcape > 0) {
          met->cape[ix][iy] += (float) dcape;
          if (!isfinite(met->plfc[ix][iy]))
            met->plfc[ix][iy] = (float) p;
```

```
        } else if (dcape_old > 0)
          met->pel[ix][iy] = (float) p;
        if (dcape < 0 && !isfinite(met->plfc[ix][iy]))
          met->cin[ix][iy] += fabsf((float) dcape);
      } while (p > ptop);

      /* Check results... */
      if (!isfinite(met->plfc[ix][iy]))
        met->cin[ix][iy] = GSL_NAN;
    }
}
```

Here is the call graph for this function:




### 5.21.3.25 read_met_cloud() void read_met_cloud ( met_t * met )

Calculate cloud properties.

Definition at line 2936 of file libtrac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("READ_MET_CLOUD", "METPROC", NVTX_READ);
  LOG(2, "Calculate cloud data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Init... */
      met->pct[ix][iy] = GSL_NAN;
      met->pcb[ix][iy] = GSL_NAN;
      met->cl[ix][iy] = 0;

      /* Loop over pressure levels... */
      for (int ip = 0; ip < met->np - 1; ip++) {

        /* Check pressure... */
        if (met->p[ip] > met->ps[ix][iy] || met->p[ip] < P(20.))
          continue;

        /* Check ice water and liquid water content... */
        if (met->iwc[ix][iy][ip] > 0 || met->lwc[ix][iy][ip] > 0) {

          /* Get cloud top pressure ... */
          met->pct[ix][iy]
            = (float) (0.5 * (met->p[ip] + (float) met->p[ip + 1]));

          /* Get cloud bottom pressure ... */
          if (!isfinite(met->pcb[ix][iy]))
            met->pcb[ix][iy]
              = (float) (0.5 * (met->p[ip] + met->p[GSL_MAX(ip - 1, 0)]));
        }

```

```
        /* Get cloud water... */
        met->cl[ix][iy] += (float)
          (0.5 * (met->iwc[ix][iy][ip] + met->iwc[ix][iy][ip + 1]
                  + met->lwc[ix][iy][ip] + met->lwc[ix][iy][ip + 1])
           * 100. * (met->p[ip] - met->p[ip + 1]) / G0);
      }
    }
}
```

#### 5.21.3.26 read_met_detrend() void read_met_detrend (

ctl_t * *ctl*,

met_t * *met* )

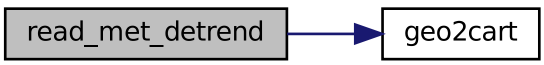
Apply detrending method to temperature and winds.

Definition at line 2984 of file libtrac.c.

```
                 {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_detrend <= 0)
    return;

  /* Set timer... */
  SELECT_TIMER("READ_MET_DETREND", "METPROC", NVTX_READ);
  LOG(2, "Detrend meteo data...");

  /* Allocate... */
  ALLOC(help, met_t, 1);

  /* Calculate standard deviation... */
  double sigma = ctl->met_detrend / 2.355;
  double tssq = 2. * SQR(sigma);

  /* Calculate box size in latitude... */
  int sy = (int) (3. * DY2DEG(sigma) / fabs(met->lat[1] - met->lat[0]));
  sy = GSL_MIN(GSL_MAX(1, sy), met->ny / 2);

  /* Calculate background... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++) {
    for (int iy = 0; iy < met->ny; iy++) {

      /* Calculate Cartesian coordinates... */
      double x0[3];
      geo2cart(0.0, met->lon[ix], met->lat[iy], x0);

      /* Calculate box size in longitude... */
      int sx =
        (int) (3. * DX2DEG(sigma, met->lat[iy]) /
               fabs(met->lon[1] - met->lon[0]));
      sx = GSL_MIN(GSL_MAX(1, sx), met->nx / 2);

      /* Init... */
      float wsum = 0;
      for (int ip = 0; ip < met->np; ip++) {
        help->t[ix][iy][ip] = 0;
        help->u[ix][iy][ip] = 0;
        help->v[ix][iy][ip] = 0;
        help->w[ix][iy][ip] = 0;
      }

      /* Loop over neighboring grid points... */
      for (int ix2 = ix - sx; ix2 <= ix + sx; ix2++) {
        int ix3 = ix2;
        if (ix3 < 0)
          ix3 += met->nx;
        else if (ix3 >= met->nx)
          ix3 -= met->nx;
        for (int iy2 = GSL_MAX(iy - sy, 0);
             iy2 <= GSL_MIN(iy + sy, met->ny - 1); iy2++) {

          /* Calculate Cartesian coordinates... */
          double x1[3];
          geo2cart(0.0, met->lon[ix3], met->lat[iy2], x1);

          /* Calculate weighting factor... */
```

```
          float w = (float) exp(-DIST2(x0, x1) / tssq);

          /* Add data... */
          wsum += w;
          for (int ip = 0; ip < met->np; ip++) {
            help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip];
            help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip];
            help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip];
            help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip];
          }
        }
      }

      /* Normalize... */
      for (int ip = 0; ip < met->np; ip++) {
        help->t[ix][iy][ip] /= wsum;
        help->u[ix][iy][ip] /= wsum;
        help->v[ix][iy][ip] /= wsum;
        help->w[ix][iy][ip] /= wsum;
      }
    }
  }

  /* Subtract background... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++) {
        met->t[ix][iy][ip] -= help->t[ix][iy][ip];
        met->u[ix][iy][ip] -= help->u[ix][iy][ip];
        met->v[ix][iy][ip] -= help->v[ix][iy][ip];
        met->w[ix][iy][ip] -= help->w[ix][iy][ip];
      }

  /* Free... */
  free(help);
}
```

Here is the call graph for this function:




### 5.21.3.27 read_met_extrapolate() `void read_met_extrapolate ( met_t * met )`

Extrapolate meteorological data at lower boundary.

Definition at line 3088 of file libtrac.c.

```
               {

  /* Set timer... */
  SELECT_TIMER("READ_MET_EXTRAPOLATE", "METPROC", NVTX_READ);
  LOG(2, "Extrapolate meteo data...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Find lowest valid data point... */
      int ip0;
      for (ip0 = met->np - 1; ip0 >= 0; ip0--)
        if (!isfinite(met->t[ix][iy][ip0])
```

```
            || !isfinite(met->u[ix][iy][ip0])
            || !isfinite(met->v[ix][iy][ip0])
            || !isfinite(met->w[ix][iy][ip0]))
          break;

      /* Extrapolate... */
      for (int ip = ip0; ip >= 0; ip--) {
        met->t[ix][iy][ip] = met->t[ix][iy][ip + 1];
        met->u[ix][iy][ip] = met->u[ix][iy][ip + 1];
        met->v[ix][iy][ip] = met->v[ix][iy][ip + 1];
        met->w[ix][iy][ip] = met->w[ix][iy][ip + 1];
        met->h2o[ix][iy][ip] = met->h2o[ix][iy][ip + 1];
        met->o3[ix][iy][ip] = met->o3[ix][iy][ip + 1];
        met->lwc[ix][iy][ip] = met->lwc[ix][iy][ip + 1];
        met->iwc[ix][iy][ip] = met->iwc[ix][iy][ip + 1];
      }
    }
}
```

#### 5.21.3.28 read_met_geopot()

```
void read_met_geopot (
        ctl_t * ctl,
        met_t * met )
```

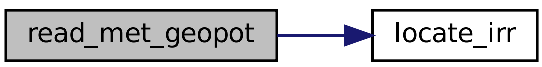
Calculate geopotential heights.

Definition at line 3125 of file libtrac.c.

```
                  {

  static float help[EP][EX][EY];

  double logp[EP];

  int dx = ctl->met_geopot_sx, dy = ctl->met_geopot_sy;

  /* Set timer... */
  SELECT_TIMER("READ_MET_GEOPOT", "METPROC", NVTX_READ);
  LOG(2, "Calculate geopotential heights...");

  /* Calculate log pressure... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    logp[ip] = log(met->p[ip]);

  /* Apply hydrostatic equation to calculate geopotential heights... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Get surface height and pressure... */
      double zs = met->zs[ix][iy];
      double lnps = log(met->ps[ix][iy]);

      /* Get temperature and water vapor vmr at the surface... */
      int ip0 = locate_irr(met->p, met->np, met->ps[ix][iy]);
      double ts = LIN(met->p[ip0], met->t[ix][iy][ip0], met->p[ip0 + 1],
                      met->t[ix][iy][ip0 + 1], met->ps[ix][iy]);
      double h2os = LIN(met->p[ip0], met->h2o[ix][iy][ip0], met->p[ip0 + 1],
                        met->h2o[ix][iy][ip0 + 1], met->ps[ix][iy]);

      /* Upper part of profile... */
      met->z[ix][iy][ip0 + 1]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0 + 1],
                         met->t[ix][iy][ip0 + 1], met->h2o[ix][iy][ip0 + 1]));
      for (int ip = ip0 + 2; ip < met->np; ip++)
        met->z[ix][iy][ip]
          = (float) (met->z[ix][iy][ip - 1] +
                     ZDIFF(logp[ip - 1], met->t[ix][iy][ip - 1],
                           met->h2o[ix][iy][ip - 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));

      /* Lower part of profile... */
      met->z[ix][iy][ip0]
        = (float) (zs +
                   ZDIFF(lnps, ts, h2os, logp[ip0],
                         met->t[ix][iy][ip0], met->h2o[ix][iy][ip0]));
      for (int ip = ip0 - 1; ip >= 0; ip--)
        met->z[ix][iy][ip]
```

```
          = (float) (met->z[ix][iy][ip + 1] +
                     ZDIFF(logp[ip + 1], met->t[ix][iy][ip + 1],
                           met->h2o[ix][iy][ip + 1], logp[ip],
                           met->t[ix][iy][ip], met->h2o[ix][iy][ip]));
    }

  /* Check control parameters... */
  if (dx == 0 || dy == 0)
    return;

  /* Default smoothing parameters... */
  if (dx < 0 || dy < 0) {
    if (fabs(met->lon[1] - met->lon[0]) < 0.5) {
      dx = 3;
      dy = 2;
    } else {
      dx = 6;
      dy = 4;
    }
  }

  /* Calculate weights for smoothing... */
  float ws[dx + 1][dy + 1];
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix <= dx; ix++)
    for (int iy = 0; iy < dy; iy++)
      ws[ix][iy] = (1.0f - (float) ix / (float) dx)
        * (1.0f - (float) iy / (float) dy);

  /* Copy data... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++)
      for (int ip = 0; ip < met->np; ip++)
        help[ip][ix][iy] = met->z[ix][iy][ip];

  /* Horizontal smoothing... */
#pragma omp parallel for default(shared) collapse(3)
  for (int ip = 0; ip < met->np; ip++)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        float res = 0, wsum = 0;
        int iy0 = GSL_MAX(iy - dy + 1, 0);
        int iy1 = GSL_MIN(iy + dy - 1, met->ny - 1);
        for (int ix2 = ix - dx + 1; ix2 <= ix + dx - 1; ++ix2) {
          int ix3 = ix2;
          if (ix3 < 0)
            ix3 += met->nx;
          else if (ix3 >= met->nx)
            ix3 -= met->nx;
          for (int iy2 = iy0; iy2 <= iy1; ++iy2)
            if (isfinite(help[ip][ix3][iy2])) {
              float w = ws[abs(ix - ix2)][abs(iy - iy2)];
              res += w * help[ip][ix3][iy2];
              wsum += w;
            }
        }
        if (wsum > 0)
          met->z[ix][iy][ip] = res / wsum;
        else
          met->z[ix][iy][ip] = GSL_NAN;
      }
}
```

Here is the call graph for this function:



#### 5.21.3.29 read_met_grid()

```
void read_met_grid (
            char * filename,
            int ncid,
            ctl_t * ctl,
            met_t * met )
```

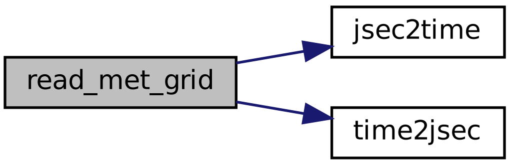
Read coordinates of meteorological data.

Definition at line 3245 of file libtrac.c.

```
                 {

  char levname[LEN], tstr[10];

  double rtime, r2;

  int dimid, varid, year2, mon2, day2, hour2, min2, sec2;

  size_t np, nx, ny;

  /* Set timer... */
  SELECT_TIMER("READ_MET_GRID", "INPUT", NVTX_READ);
  LOG(2, "Read meteo grid information...");

  /* Get time from filename... */
  sprintf(tstr, "%.4s", &filename[strlen(filename) - 16]);
  int year = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 11]);
  int mon = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 8]);
  int day = atoi(tstr);
  sprintf(tstr, "%.2s", &filename[strlen(filename) - 5]);
  int hour = atoi(tstr);
  time2jsec(year, mon, day, hour, 0, 0, 0, &met->time);

  /* Check time... */
  if (year < 1900 || year > 2100 || mon < 1 || mon > 12
      || day < 1 || day > 31 || hour < 0 || hour > 23)
    ERRMSG("Cannot read time from filename!");
  jsec2time(met->time, &year2, &mon2, &day2, &hour2, &min2, &sec2, &r2);
  LOG(2, "Time from filename: %.2f (%d-%02d-%02d, %02d:%02d UTC)",
      met->time, year2, mon2, day2, hour2, min2);

  /* Check time information... */
  if (nc_inq_varid(ncid, "time", &varid) == NC_NOERR) {
    NC(nc_get_var_double(ncid, varid, &rtime));
    if (fabs(year * 10000. + mon * 100. + day + hour / 24. - rtime) > 1.0)
      WARN("Time information in meteo file does not match filename!");
  } else
    WARN("Time information in meteo file is missing!");

  /* Get grid dimensions... */
  NC(nc_inq_dimid(ncid, "lon", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &nx));
  LOG(2, "Number of longitudes: %zu", nx);
  if (nx < 2 || nx > EX)
    ERRMSG("Number of longitudes out of range!");

  NC(nc_inq_dimid(ncid, "lat", &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &ny));
  LOG(2, "Number of latitudes: %zu", ny);
  if (ny < 2 || ny > EY)
    ERRMSG("Number of latitudes out of range!");

  sprintf(levname, "lev");
  NC(nc_inq_dimid(ncid, levname, &dimid));
  NC(nc_inq_dimlen(ncid, dimid, &np));
  if (np == 1) {
    sprintf(levname, "lev_2");
    if (nc_inq_dimid(ncid, levname, &dimid) != NC_NOERR) {
      sprintf(levname, "plev");
      nc_inq_dimid(ncid, levname, &dimid);
    }
    NC(nc_inq_dimlen(ncid, dimid, &np));
  }
  LOG(2, "Number of levels: %zu", np);
  if (np < 2 || np > EP)
    ERRMSG("Number of levels out of range!");

  /* Store dimensions... */
  met->np = (int) np;
  met->nx = (int) nx;
  met->ny = (int) ny;

```

```
  /* Read longitudes and latitudes... */
  NC(nc_inq_varid(ncid, "lon", &varid));
  NC(nc_get_var_double(ncid, varid, met->lon));
  LOG(2, "Longitudes: %g, %g ... %g deg",
      met->lon[0], met->lon[1], met->lon[met->nx - 1]);
  NC(nc_inq_varid(ncid, "lat", &varid));
  NC(nc_get_var_double(ncid, varid, met->lat));
  LOG(2, "Latitudes: %g, %g ... %g deg",
      met->lat[0], met->lat[1], met->lat[met->ny - 1]);

  /* Read pressure levels... */
  if (ctl->met_np <= 0) {
    NC(nc_inq_varid(ncid, levname, &varid));
    NC(nc_get_var_double(ncid, varid, met->p));
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] /= 100.;
    LOG(2, "Altitude levels: %g, %g ... %g km",
        Z(met->p[0]), Z(met->p[1]), Z(met->p[met->np - 1]));
    LOG(2, "Pressure levels: %g, %g ... %g hPa",
        met->p[0], met->p[1], met->p[met->np - 1]);
  }
}
```

Here is the call graph for this function:




#### 5.21.3.30 read_met_help_3d()

```
int read_met_help_3d (
    int ncid,
    char * varname,
    char * varname2,
    met_t * met,
    float dest[EX][EY][EP],
    float scl,
    int init )
```

Read and convert 3D variable from meteorological data file.

Definition at line 3348 of file libtrac.c.

```
            {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
```

```
    sprintf(varsel, "%s", varname);

  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s "
        "(FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
            dest[ix][iy][ip] = 0;
          short aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux * scalfac + offset) < 1e14f)
            dest[ix][iy][ip] += scl * (aux * scalfac + offset);
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY * EP);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 3-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        for (int ip = 0; ip < met->np; ip++) {
          if (init)
            dest[ix][iy][ip] = 0;
          float aux = help[(ip * met->ny + iy) * met->nx + ix];
          if ((fillval == 0 || aux != fillval)
              && (missval == 0 || aux != missval)
              && fabsf(aux) < 1e14f)
            dest[ix][iy][ip] += scl * aux;
          else
            dest[ix][iy][ip] = GSL_NAN;
        }

    /* Free... */
    free(help);
```

```
  }

  /* Return... */
  return 1;
}
```

#### 5.21.3.31 read_met_help_2d()

```
int read_met_help_2d (
        int ncid,
        char * varname,
        char * varname2,
        met_t * met,
        float dest[EX][EY],
        float scl,
        int init )
```

Read and convert 2D variable from meteorological data file.

Definition at line 3466 of file libtrac.c.

```
                {

  char varsel[LEN];

  float offset, scalfac;

  int varid;

  /* Check if variable exists... */
  if (nc_inq_varid(ncid, varname, &varid) != NC_NOERR)
    if (nc_inq_varid(ncid, varname2, &varid) != NC_NOERR) {
      WARN("Cannot read 3-D variable: %s or %s", varname, varname2);
      return 0;
    } else {
      sprintf(varsel, "%s", varname2);
  } else
    sprintf(varsel, "%s", varname);

  /* Read packed data... */
  if (nc_get_att_float(ncid, varid, "add_offset", &offset) == NC_NOERR
      && nc_get_att_float(ncid, varid, "scale_factor",
                          &scalfac) == NC_NOERR) {

    /* Write info... */
    LOG(2, "Packed: scale_factor= %g / add_offset= %g", scalfac, offset);

    /* Allocate... */
    short *help;
    ALLOC(help, short,
          EX * EY * EP);

    /* Read fill value and missing value... */
    short fillval, missval;
    if (nc_get_att_short(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_short(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s"
        " (FILL = %d, MISS = %d, SCALE = %g, OFFSET = %g)",
        varsel, fillval, missval, scalfac, offset);

    /* Read data... */
    NC(nc_get_var_short(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        short aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux * scalfac + offset) < 1e14f)
          dest[ix][iy] += scl * (aux * scalfac + offset);
        else
```

```
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }

  /* Unpacked data... */
  else {

    /* Allocate... */
    float *help;
    ALLOC(help, float,
          EX * EY);

    /* Read fill value and missing value... */
    float fillval, missval;
    if (nc_get_att_float(ncid, varid, "_FillValue", &fillval) != NC_NOERR)
      fillval = 0;
    if (nc_get_att_float(ncid, varid, "missing_value", &missval) != NC_NOERR)
      missval = 0;

    /* Write info... */
    LOG(2, "Read 2-D variable: %s (FILL = %g, MISS = %g)",
        varsel, fillval, missval);

    /* Read data... */
    NC(nc_get_var_float(ncid, varid, help));

    /* Copy and check data... */
#pragma omp parallel for default(shared) num_threads(12)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {
        if (init)
          dest[ix][iy] = 0;
        float aux = help[iy * met->nx + ix];
        if ((fillval == 0 || aux != fillval)
            && (missval == 0 || aux != missval)
            && fabsf(aux) < 1e14f)
          dest[ix][iy] += scl * aux;
        else
          dest[ix][iy] = GSL_NAN;
      }

    /* Free... */
    free(help);
  }

  /* Return... */
  return 1;
}
```

#### 5.21.3.32 read_met_levels()

```
void read_met_levels (
    int ncid,
    ctl_t * ctl,
    met_t * met )
```

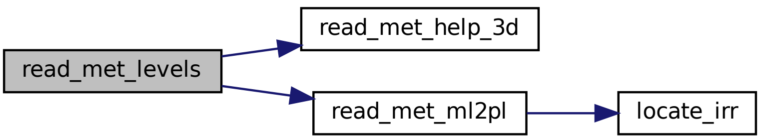
Read meteorological data on vertical levels.

Definition at line 3585 of file libtrac.c.

```
               {

  /* Set timer... */
  SELECT_TIMER("READ_MET_LEVELS", "INPUT", NVTX_READ);
  LOG(2, "Read level data...");

  /* Read meteorological data... */
  if (!read_met_help_3d(ncid, "t", "T", met, met->t, 1.0, 1))
    ERRMSG("Cannot read temperature!");
  if (!read_met_help_3d(ncid, "u", "U", met, met->u, 1.0, 1))
    ERRMSG("Cannot read zonal wind!");
  if (!read_met_help_3d(ncid, "v", "V", met, met->v, 1.0, 1))
    ERRMSG("Cannot read meridional wind!");
  if (!read_met_help_3d(ncid, "w", "W", met, met->w, 0.01f, 1))
    WARN("Cannot read vertical velocity!");
  if (!read_met_help_3d
      (ncid, "q", "Q", met, met->h2o, (float) (MA / MH2O), 1))
    WARN("Cannot read specific humidity!");
```

```
  if (!read_met_help_3d
      (ncid, "o3", "O3", met, met->o3, (float) (MA / MO3), 1))
    WARN("Cannot read ozone data!");
  if (ctl->met_cloud == 1 || ctl->met_cloud == 3) {
    if (!read_met_help_3d(ncid, "clwc", "CLWC", met, met->lwc, 1.0, 1))
      WARN("Cannot read cloud liquid water content!");
    if (!read_met_help_3d(ncid, "ciwc", "CIWC", met, met->iwc, 1.0, 1))
      WARN("Cannot read cloud ice water content!");
  }
  if (ctl->met_cloud == 2 || ctl->met_cloud == 3) {
    if (!read_met_help_3d
        (ncid, "crwc", "CRWC", met, met->lwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud rain water content!");
    if (!read_met_help_3d
        (ncid, "cswc", "CSWC", met, met->iwc, 1.0, ctl->met_cloud == 2))
      WARN("Cannot read cloud snow water content!");
  }

  /* Transfer from model levels to pressure levels... */
  if (ctl->met_np > 0) {

    /* Read pressure on model levels... */
    if (!read_met_help_3d(ncid, "pl", "PL", met, met->pl, 0.01f, 1))
      ERRMSG("Cannot read pressure on model levels!");

    /* Vertical interpolation from model to pressure levels... */
    read_met_ml2pl(ctl, met, met->t);
    read_met_ml2pl(ctl, met, met->u);
    read_met_ml2pl(ctl, met, met->v);
    read_met_ml2pl(ctl, met, met->w);
    read_met_ml2pl(ctl, met, met->h2o);
    read_met_ml2pl(ctl, met, met->o3);
    read_met_ml2pl(ctl, met, met->lwc);
    read_met_ml2pl(ctl, met, met->iwc);

    /* Set new pressure levels... */
    met->np = ctl->met_np;
    for (int ip = 0; ip < met->np; ip++)
      met->p[ip] = ctl->met_p[ip];
  }

  /* Check ordering of pressure levels... */
  for (int ip = 1; ip < met->np; ip++)
    if (met->p[ip - 1] < met->p[ip])
      ERRMSG("Pressure levels must be descending!");
}
```

Here is the call graph for this function:




#### 5.21.3.33 read_met_ml2pl()

```
void read_met_ml2pl (
    ctl_t * ctl,
    met_t * met,
    float var[EX][EY][EP] )
```

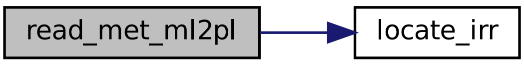
Convert meteorological data from model levels to pressure levels.

Definition at line 3655 of file libtrac.c.

```
{
```

```
  double aux[EP], p[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_ML2PL", "METPROC", NVTX_READ);
  LOG(2, "Interpolate meteo data to pressure levels...");

  /* Loop over columns... */
#pragma omp parallel for default(shared) private(aux,p) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Copy pressure profile... */
      for (int ip = 0; ip < met->np; ip++)
        p[ip] = met->pl[ix][iy][ip];

      /* Interpolate... */
      for (int ip = 0; ip < ctl->met_np; ip++) {
        double pt = ctl->met_p[ip];
        if ((pt > p[0] && p[0] > p[1]) || (pt < p[0] && p[0] < p[1]))
          pt = p[0];
        else if ((pt > p[met->np - 1] && p[1] > p[0])
                 || (pt < p[met->np - 1] && p[1] < p[0]))
          pt = p[met->np - 1];
        int ip2 = locate_irr(p, met->np, pt);
        aux[ip] = LIN(p[ip2], var[ix][iy][ip2],
                      p[ip2 + 1], var[ix][iy][ip2 + 1], pt);
      }

      /* Copy data... */
      for (int ip = 0; ip < ctl->met_np; ip++)
        var[ix][iy][ip] = (float) aux[ip];
    }
}
```

Here is the call graph for this function:




### 5.21.3.34 read_met_pbl() `void read_met_pbl ( met_t * met )`

Calculate pressure of the boundary layer.

Definition at line 3696 of file libtrac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PBL", "METPROC", NVTX_READ);
  LOG(2, "Calculate planetary boundary layer...");

  /* Parameters used to estimate the height of the PBL
     (e.g., Vogelezang and Holtslag, 1996; Seidel et al., 2012)... */
  const double rib_crit = 0.25, dz = 0.05, umin = 5.0;

  /* Loop over grid points... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set bottom level of PBL... */
      double pbl_bot = met->ps[ix][iy] + DZ2DP(dz, met->ps[ix][iy]);

```

```
      /* Find lowest level near the bottom... */
      int ip;
      for (ip = 1; ip < met->np; ip++)
        if (met->p[ip] < pbl_bot)
          break;

      /* Get near surface data... */
      double zs = LIN(met->p[ip - 1], met->z[ix][iy][ip - 1],
                      met->p[ip], met->z[ix][iy][ip], pbl_bot);
      double ts = LIN(met->p[ip - 1], met->t[ix][iy][ip - 1],
                      met->p[ip], met->t[ix][iy][ip], pbl_bot);
      double us = LIN(met->p[ip - 1], met->u[ix][iy][ip - 1],
                      met->p[ip], met->u[ix][iy][ip], pbl_bot);
      double vs = LIN(met->p[ip - 1], met->v[ix][iy][ip - 1],
                      met->p[ip], met->v[ix][iy][ip], pbl_bot);
      double h2os = LIN(met->p[ip - 1], met->h2o[ix][iy][ip - 1],
                        met->p[ip], met->h2o[ix][iy][ip], pbl_bot);
      double tvs = THETAVIRT(pbl_bot, ts, h2os);

      /* Init... */
      double rib, rib_old = 0;

      /* Loop over levels... */
      for (; ip < met->np; ip++) {

        /* Get squared horizontal wind speed... */
        double vh2
          = SQR(met->u[ix][iy][ip] - us) + SQR(met->v[ix][iy][ip] - vs);
        vh2 = GSL_MAX(vh2, SQR(umin));

        /* Calculate bulk Richardson number... */
        rib = G0 * 1e3 * (met->z[ix][iy][ip] - zs) / tvs
          * (THETAVIRT(met->p[ip], met->t[ix][iy][ip],
                       met->h2o[ix][iy][ip]) - tvs) / vh2;

        /* Check for critical value... */
        if (rib >= rib_crit) {
          met->pbl[ix][iy] = (float) (LIN(rib_old, met->p[ip - 1],
                                          rib, met->p[ip], rib_crit));
          if (met->pbl[ix][iy] > pbl_bot)
            met->pbl[ix][iy] = (float) pbl_bot;
          break;
        }

        /* Save Richardson number... */
        rib_old = rib;
      }
    }
}
```

### 5.21.3.35 read_met_periodic() `void read_met_periodic ( met_t * met )`

Create meteorological data with periodic boundary conditions.

Definition at line 3767 of file libtrac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("READ_MET_PERIODIC", "METPROC", NVTX_READ);
  LOG(2, "Apply periodic boundary conditions...");

  /* Check longitudes... */
  if (!(fabs(met->lon[met->nx - 1] - met->lon[0]
             + met->lon[1] - met->lon[0] - 360) < 0.01))
    return;

  /* Increase longitude counter... */
  if ((++met->nx) > EX)
    ERRMSG("Cannot create periodic boundary conditions!");

  /* Set longitude... */
  met->lon[met->nx - 1] = met->lon[met->nx - 2] + met->lon[1] - met->lon[0];

  /* Loop over latitudes and pressure levels... */
#pragma omp parallel for default(shared)
  for (int iy = 0; iy < met->ny; iy++) {
    met->ps[met->nx - 1][iy] = met->ps[0][iy];
    met->zs[met->nx - 1][iy] = met->zs[0][iy];
```

```
    met->ts[met->nx - 1][iy] = met->ts[0][iy];
    met->us[met->nx - 1][iy] = met->us[0][iy];
    met->vs[met->nx - 1][iy] = met->vs[0][iy];
    for (int ip = 0; ip < met->np; ip++) {
      met->t[met->nx - 1][iy][ip] = met->t[0][iy][ip];
      met->u[met->nx - 1][iy][ip] = met->u[0][iy][ip];
      met->v[met->nx - 1][iy][ip] = met->v[0][iy][ip];
      met->w[met->nx - 1][iy][ip] = met->w[0][iy][ip];
      met->h2o[met->nx - 1][iy][ip] = met->h2o[0][iy][ip];
      met->o3[met->nx - 1][iy][ip] = met->o3[0][iy][ip];
      met->lwc[met->nx - 1][iy][ip] = met->lwc[0][iy][ip];
      met->iwc[met->nx - 1][iy][ip] = met->iwc[0][iy][ip];
    }
  }
}
```

#### 5.21.3.36 read_met_pv() void read_met_pv ( met_t * met )

Calculate potential vorticity.

Definition at line 3809 of file libtrac.c.

```
               {

  double pows[EP];

  /* Set timer... */
  SELECT_TIMER("READ_MET_PV", "METPROC", NVTX_READ);
  LOG(2, "Calculate potential vorticity...");

  /* Set powers... */
#pragma omp parallel for default(shared)
  for (int ip = 0; ip < met->np; ip++)
    pows[ip] = pow(1000. / met->p[ip], 0.286);

  /* Loop over grid points... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++) {

    /* Set indices... */
    int ix0 = GSL_MAX(ix - 1, 0);
    int ix1 = GSL_MIN(ix + 1, met->nx - 1);

    /* Loop over grid points... */
    for (int iy = 0; iy < met->ny; iy++) {

      /* Set indices... */
      int iy0 = GSL_MAX(iy - 1, 0);
      int iy1 = GSL_MIN(iy + 1, met->ny - 1);

      /* Set auxiliary variables... */
      double latr = 0.5 * (met->lat[iy1] + met->lat[iy0]);
      double dx = 1000. * DEG2DX(met->lon[ix1] - met->lon[ix0], latr);
      double dy = 1000. * DEG2DY(met->lat[iy1] - met->lat[iy0]);
      double c0 = cos(met->lat[iy0] / 180. * M_PI);
      double c1 = cos(met->lat[iy1] / 180. * M_PI);
      double cr = cos(latr / 180. * M_PI);
      double vort = 2 * 7.2921e-5 * sin(latr * M_PI / 180.);

      /* Loop over grid points... */
      for (int ip = 0; ip < met->np; ip++) {

        /* Get gradients in longitude... */
        double dtdx
          = (met->t[ix1][iy][ip] - met->t[ix0][iy][ip]) * pows[ip] / dx;
        double dvdx = (met->v[ix1][iy][ip] - met->v[ix0][iy][ip]) / dx;

        /* Get gradients in latitude... */
        double dtdy
          = (met->t[ix][iy1][ip] - met->t[ix][iy0][ip]) * pows[ip] / dy;
        double dudy
          = (met->u[ix][iy1][ip] * c1 - met->u[ix][iy0][ip] * c0) / dy;

        /* Set indices... */
        int ip0 = GSL_MAX(ip - 1, 0);
        int ip1 = GSL_MIN(ip + 1, met->np - 1);

        /* Get gradients in pressure... */
        double dtdp, dudp, dvdp;
```

```
        double dp0 = 100. * (met->p[ip] - met->p[ip0]);
        double dp1 = 100. * (met->p[ip1] - met->p[ip]);
        if (ip != ip0 && ip != ip1) {
          double denom = dp0 * dp1 * (dp0 + dp1);
          dtdp = (dp0 * dp0 * met->t[ix][iy][ip1] * pows[ip1]
                  - dp1 * dp1 * met->t[ix][iy][ip0] * pows[ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->t[ix][iy][ip] * pows[ip])
            / denom;
          dudp = (dp0 * dp0 * met->u[ix][iy][ip1]
                  - dp1 * dp1 * met->u[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->u[ix][iy][ip])
            / denom;
          dvdp = (dp0 * dp0 * met->v[ix][iy][ip1]
                  - dp1 * dp1 * met->v[ix][iy][ip0]
                  + (dp1 * dp1 - dp0 * dp0) * met->v[ix][iy][ip])
            / denom;
        } else {
          double denom = dp0 + dp1;
          dtdp =
            (met->t[ix][iy][ip1] * pows[ip1] -
             met->t[ix][iy][ip0] * pows[ip0]) / denom;
          dudp = (met->u[ix][iy][ip1] - met->u[ix][iy][ip0]) / denom;
          dvdp = (met->v[ix][iy][ip1] - met->v[ix][iy][ip0]) / denom;
        }

        /* Calculate PV... */
        met->pv[ix][iy][ip] = (float)
          (1e6 * G0 *
           (-dtdp * (dvdx - dudy / cr + vort) + dvdp * dtdx - dudp * dtdy));
      }
    }
  }

  /* Fix for polar regions... */
#pragma omp parallel for default(shared)
  for (int ix = 0; ix < met->nx; ix++)
    for (int ip = 0; ip < met->np; ip++) {
      met->pv[ix][0][ip]
        = met->pv[ix][1][ip]
        = met->pv[ix][2][ip];
      met->pv[ix][met->ny - 1][ip]
        = met->pv[ix][met->ny - 2][ip]
        = met->pv[ix][met->ny - 3][ip];
    }
}
```

### 5.21.3.37 read_met_sample()

```
void read_met_sample (
        ctl_t * ctl,
        met_t * met )
```

Downsampling of meteorological data.

Definition at line 3915 of file libtrac.c.

```
                  {

  met_t *help;

  /* Check parameters... */
  if (ctl->met_dp <= 1 && ctl->met_dx <= 1 && ctl->met_dy <= 1
      && ctl->met_sp <= 1 && ctl->met_sx <= 1 && ctl->met_sy <= 1)
    return;

  /* Set timer... */
  SELECT_TIMER("READ_MET_SAMPLE", "METPROC", NVTX_READ);
  LOG(2, "Downsampling of meteo data...");

  /* Allocate... */
  ALLOC(help, met_t, 1);

  /* Copy data... */
  help->nx = met->nx;
  help->ny = met->ny;
  help->np = met->np;
  memcpy(help->lon, met->lon, sizeof(met->lon));
  memcpy(help->lat, met->lat, sizeof(met->lat));
  memcpy(help->p, met->p, sizeof(met->p));

  /* Smoothing... */
```

```
  for (int ix = 0; ix < met->nx; ix += ctl->met_dx) {
    for (int iy = 0; iy < met->ny; iy += ctl->met_dy) {
      for (int ip = 0; ip < met->np; ip += ctl->met_dp) {
        help->ps[ix][iy] = 0;
        help->zs[ix][iy] = 0;
        help->ts[ix][iy] = 0;
        help->us[ix][iy] = 0;
        help->vs[ix][iy] = 0;
        help->t[ix][iy][ip] = 0;
        help->u[ix][iy][ip] = 0;
        help->v[ix][iy][ip] = 0;
        help->w[ix][iy][ip] = 0;
        help->h2o[ix][iy][ip] = 0;
        help->o3[ix][iy][ip] = 0;
        help->lwc[ix][iy][ip] = 0;
        help->iwc[ix][iy][ip] = 0;
        float wsum = 0;
        for (int ix2 = ix - ctl->met_sx + 1; ix2 <= ix + ctl->met_sx - 1;
             ix2++) {
          int ix3 = ix2;
          if (ix3 < 0)
            ix3 += met->nx;
          else if (ix3 >= met->nx)
            ix3 -= met->nx;

          for (int iy2 = GSL_MAX(iy - ctl->met_sy + 1, 0);
               iy2 <= GSL_MIN(iy + ctl->met_sy - 1, met->ny - 1); iy2++)
            for (int ip2 = GSL_MAX(ip - ctl->met_sp + 1, 0);
                 ip2 <= GSL_MIN(ip + ctl->met_sp - 1, met->np - 1); ip2++) {
              float w = (1.0f - (float) abs(ix - ix2) / (float) ctl->met_sx)
                * (1.0f - (float) abs(iy - iy2) / (float) ctl->met_sy)
                * (1.0f - (float) abs(ip - ip2) / (float) ctl->met_sp);
              help->ps[ix][iy] += w * met->ps[ix3][iy2];
              help->zs[ix][iy] += w * met->zs[ix3][iy2];
              help->ts[ix][iy] += w * met->ts[ix3][iy2];
              help->us[ix][iy] += w * met->us[ix3][iy2];
              help->vs[ix][iy] += w * met->vs[ix3][iy2];
              help->t[ix][iy][ip] += w * met->t[ix3][iy2][ip2];
              help->u[ix][iy][ip] += w * met->u[ix3][iy2][ip2];
              help->v[ix][iy][ip] += w * met->v[ix3][iy2][ip2];
              help->w[ix][iy][ip] += w * met->w[ix3][iy2][ip2];
              help->h2o[ix][iy][ip] += w * met->h2o[ix3][iy2][ip2];
              help->o3[ix][iy][ip] += w * met->o3[ix3][iy2][ip2];
              help->lwc[ix][iy][ip] += w * met->lwc[ix3][iy2][ip2];
              help->iwc[ix][iy][ip] += w * met->iwc[ix3][iy2][ip2];
              wsum += w;
            }
        }
        help->ps[ix][iy] /= wsum;
        help->zs[ix][iy] /= wsum;
        help->ts[ix][iy] /= wsum;
        help->us[ix][iy] /= wsum;
        help->vs[ix][iy] /= wsum;
        help->t[ix][iy][ip] /= wsum;
        help->u[ix][iy][ip] /= wsum;
        help->v[ix][iy][ip] /= wsum;
        help->w[ix][iy][ip] /= wsum;
        help->h2o[ix][iy][ip] /= wsum;
        help->o3[ix][iy][ip] /= wsum;
        help->lwc[ix][iy][ip] /= wsum;
        help->iwc[ix][iy][ip] /= wsum;
      }
    }
  }

  /* Downsampling... */
  met->nx = 0;
  for (int ix = 0; ix < help->nx; ix += ctl->met_dx) {
    met->lon[met->nx] = help->lon[ix];
    met->ny = 0;
    for (int iy = 0; iy < help->ny; iy += ctl->met_dy) {
      met->lat[met->ny] = help->lat[iy];
      met->ps[met->nx][met->ny] = help->ps[ix][iy];
      met->zs[met->nx][met->ny] = help->zs[ix][iy];
      met->ts[met->nx][met->ny] = help->ts[ix][iy];
      met->us[met->nx][met->ny] = help->us[ix][iy];
      met->vs[met->nx][met->ny] = help->vs[ix][iy];
      met->np = 0;
      for (int ip = 0; ip < help->np; ip += ctl->met_dp) {
        met->p[met->np] = help->p[ip];
        met->t[met->nx][met->ny][met->np] = help->t[ix][iy][ip];
        met->u[met->nx][met->ny][met->np] = help->u[ix][iy][ip];
        met->v[met->nx][met->ny][met->np] = help->v[ix][iy][ip];
        met->w[met->nx][met->ny][met->np] = help->w[ix][iy][ip];
        met->h2o[met->nx][met->ny][met->np] = help->h2o[ix][iy][ip];
        met->o3[met->nx][met->ny][met->np] = help->o3[ix][iy][ip];
        met->lwc[met->nx][met->ny][met->np] = help->lwc[ix][iy][ip];
```

```
        met->iwc[met->nx][met->ny][met->np] = help->iwc[ix][iy][ip];
        met->np++;
      }
      met->ny++;
    }
    met->nx++;
  }

  /* Free... */
  free(help);
}
```

### 5.21.3.38 read_met_surface() void read_met_surface (

int *ncid,*

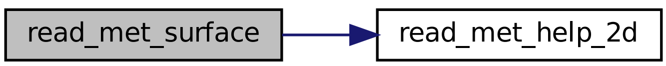
met_t * *met* )

Read surface data.

Definition at line 4043 of file libtrac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("READ_MET_SURFACE", "INPUT", NVTX_READ);
  LOG(2, "Read surface data...");

  /* Read surface pressure... */
  if (!read_met_help_2d(ncid, "lnsp", "LNSP", met, met->ps, 1.0f, 1)) {
    if (!read_met_help_2d(ncid, "ps", "PS", met, met->ps, 0.01f, 1)) {
      WARN("Cannot not read surface pressure data (use lowest level)!");
      for (int ix = 0; ix < met->nx; ix++)
        for (int iy = 0; iy < met->ny; iy++)
          met->ps[ix][iy] = (float) met->p[0];
    }
  } else
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->ps[ix][iy] = (float) (exp(met->ps[ix][iy]) / 100.);

  /* Read geopotential height at the surface... */
  if (!read_met_help_2d
      (ncid, "z", "Z", met, met->zs, (float) (1. / (1000. * G0)), 1))
    if (!read_met_help_2d
        (ncid, "zm", "ZM", met, met->zs, (float) (1. / 1000.), 1))
      WARN("Cannot read surface geopotential height!");

  /* Read temperature at the surface... */
  if (!read_met_help_2d(ncid, "t2m", "T2M", met, met->ts, 1.0, 1))
    WARN("Cannot read surface temperature!");

  /* Read zonal wind at the surface... */
  if (!read_met_help_2d(ncid, "u10m", "U10M", met, met->us, 1.0, 1))
    WARN("Cannot read surface zonal wind!");

  /* Read meridional wind at the surface... */
  if (!read_met_help_2d(ncid, "v10m", "V10M", met, met->vs, 1.0, 1))
    WARN("Cannot read surface meridional wind!");
}
```

Here is the call graph for this function:



#### 5.21.3.39 read_met_tropo()

void read_met_tropo (
  ctl_t * ctl,
  met_t * met )

Calculate tropopause data.

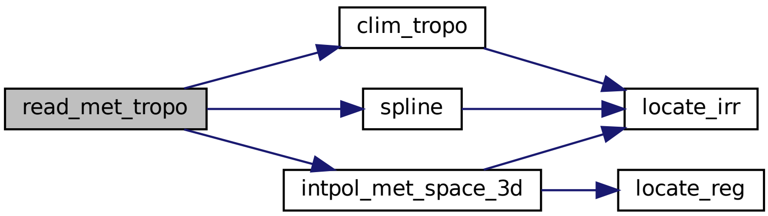
Definition at line 4086 of file libtrac.c.

```
                 {

  double p2[200], pv[EP], pv2[200], t[EP], t2[200], th[EP],
    th2[200], z[EP], z2[200];

  /* Set timer... */
  SELECT_TIMER("READ_MET_TROPO", "METPROC", NVTX_READ);
  LOG(2, "Calculate tropopause...");

  /* Get altitude and pressure profiles... */
#pragma omp parallel for default(shared)
  for (int iz = 0; iz < met->np; iz++)
    z[iz] = Z(met->p[iz]);
#pragma omp parallel for default(shared)
  for (int iz = 0; iz <= 190; iz++) {
    z2[iz] = 4.5 + 0.1 * iz;
    p2[iz] = P(z2[iz]);
  }

  /* Do not calculate tropopause... */
  if (ctl->met_tropo == 0)
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = GSL_NAN;

  /* Use tropopause climatology... */
  else if (ctl->met_tropo == 1) {
#pragma omp parallel for default(shared) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++)
        met->pt[ix][iy] = (float) clim_tropo(met->time, met->lat[iy]);
  }

  /* Use cold point... */
  else if (ctl->met_tropo == 2) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 171, ctl->met_tropo_spline);

        /* Find minimum... */
        int iz = (int) gsl_stats_min_index(t2, 1, 171);
        if (iz > 0 && iz < 170)
          met->pt[ix][iy] = (float) p2[iz];
        else
          met->pt[ix][iy] = GSL_NAN;
      }
  }

  /* Use WMO definition... */
  else if (ctl->met_tropo == 3 || ctl->met_tropo == 4) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(t,t2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate temperature profile... */
        int iz;
        for (iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        spline(z, t, met->np, z2, t2, 191, ctl->met_tropo_spline);

        /* Find 1st tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (iz = 0; iz <= 170; iz++) {
          int found = 1;
          for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
            if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                ctl->met_tropo_lapse) {
```

```
              found = 0;
              break;
            }
          if (found) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
        }

        /* Find 2nd tropopause... */
        if (ctl->met_tropo == 4) {
          met->pt[ix][iy] = GSL_NAN;
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev_sep; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) <
                  ctl->met_tropo_lapse_sep) {
                found = 0;
                break;
              }
            if (found)
              break;
          }
          for (; iz <= 170; iz++) {
            int found = 1;
            for (int iz2 = iz + 1; iz2 <= iz + ctl->met_tropo_nlev; iz2++)
              if (LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]) >
                  ctl->met_tropo_lapse) {
                found = 0;
                break;
              }
            if (found) {
              if (iz > 0 && iz < 170)
                met->pt[ix][iy] = (float) p2[iz];
              break;
            }
          }
        }
      }
  }

  /* Use dynamical tropopause... */
  else if (ctl->met_tropo == 5) {

    /* Loop over grid points... */
#pragma omp parallel for default(shared) private(pv,pv2,th,th2) collapse(2)
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Interpolate potential vorticity profile... */
        for (int iz = 0; iz < met->np; iz++)
          pv[iz] = met->pv[ix][iy][iz];
        spline(z, pv, met->np, z2, pv2, 171, ctl->met_tropo_spline);

        /* Interpolate potential temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          th[iz] = THETA(met->p[iz], met->t[ix][iy][iz]);
        spline(z, th, met->np, z2, th2, 171, ctl->met_tropo_spline);

        /* Find dynamical tropopause... */
        met->pt[ix][iy] = GSL_NAN;
        for (int iz = 0; iz <= 170; iz++)
          if (fabs(pv2[iz]) >= ctl->met_tropo_pv
              || th2[iz] >= ctl->met_tropo_theta) {
            if (iz > 0 && iz < 170)
              met->pt[ix][iy] = (float) p2[iz];
            break;
          }
      }
  }

  else
    ERRMSG("Cannot calculate tropopause!");

  /* Interpolate temperature, geopotential height, and water vapor vmr... */
#pragma omp parallel for default(shared) collapse(2)
  for (int ix = 0; ix < met->nx; ix++)
    for (int iy = 0; iy < met->ny; iy++) {
      double h2ot, tt, zt;
      INTPOL_INIT;
      intpol_met_space_3d(met, met->t, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &tt, ci, cw, 1);
      intpol_met_space_3d(met, met->z, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &zt, ci, cw, 0);
      intpol_met_space_3d(met, met->h2o, met->pt[ix][iy], met->lon[ix],
                          met->lat[iy], &h2ot, ci, cw, 0);
```

```
      met->tt[ix][iy] = (float) tt;
      met->zt[ix][iy] = (float) zt;
      met->h2ot[ix][iy] = (float) h2ot;
    }
}
```

Here is the call graph for this function:




### 5.21.3.40 scan_ctl()

```
double scan_ctl (
    const char * filename,
    int argc,
    char * argv[ ],
    const char * varname,
    int arridx,
    const char * defvalue,
    char * value )
```

Read a control parameter from file or command line.

Definition at line 4260 of file libtrac.c.

```
                   {

  FILE *in = NULL;

  char dummy[LEN], fullname1[LEN], fullname2[LEN], line[LEN],
    rvarname[LEN], rval[LEN];

  int contain = 0, i;

  /* Open file... */
  if (filename[strlen(filename) - 1] != '-')
    if (!(in = fopen(filename, "r")))
      ERRMSG("Cannot open file!");

  /* Set full variable name... */
  if (arridx >= 0) {
    sprintf(fullname1, "%s[%d]", varname, arridx);
    sprintf(fullname2, "%s[*]", varname);
  } else {
    sprintf(fullname1, "%s", varname);
    sprintf(fullname2, "%s", varname);
  }

  /* Read data... */
  if (in != NULL)
    while (fgets(line, LEN, in))
      if (sscanf(line, "%s %s %s", rvarname, dummy, rval) == 3)
        if (strcasecmp(rvarname, fullname1) == 0 ||
            strcasecmp(rvarname, fullname2) == 0) {
          contain = 1;
          break;
        }
  for (i = 1; i < argc - 1; i++)
```

```
04300     if (strcasecmp(argv[i], fullname1) == 0 ||
04301         strcasecmp(argv[i], fullname2) == 0) {
04302       sprintf(rval, "%s", argv[i + 1]);
04303       contain = 1;
04304       break;
04305     }
04306 
04307   /* Close file... */
04308   if (in != NULL)
04309     fclose(in);
04310 
04311   /* Check for missing variables... */
04312   if (!contain) {
04313     if (strlen(defvalue) > 0)
04314       sprintf(rval, "%s", defvalue);
04315     else
04316       ERRMSG("Missing variable %s!\n", fullname1);
04317   }
04318 
04319   /* Write info... */
04320   LOG(1, "%s = %s", fullname1, rval);
04321 
04322   /* Return values... */
04323   if (value != NULL)
04324     sprintf(value, "%s", rval);
04325   return atof(rval);
04326 }
```

#### 5.21.3.41 sedi()

```
double sedi (
    double p,
    double T,
    double r_p,
    double rho_p )
```

Calculate sedimentation velocity.

Definition at line 4330 of file libtrac.c.

```
04334                       {
04335 
04336   double eta, G, K, lambda, rho, v;
04337 
04338   /* Convert pressure from hPa to Pa... */
04339   p *= 100.;
04340 
04341   /* Convert particle radius from microns to m... */
04342   r_p *= 1e-6;
04343 
04344   /* Density of dry air [kg / m^3]... */
04345   rho = p / (RA * T);
04346 
04347   /* Dynamic viscosity of air [kg / (m s)]... */
04348   eta = 1.8325e-5 * (416.16 / (T + 120.)) * pow(T / 296.16, 1.5);
04349 
04350   /* Thermal velocity of an air molecule [m / s]... */
04351   v = sqrt(8. * KB * T / (M_PI * 4.8096e-26));
04352 
04353   /* Mean free path of an air molecule [m]... */
04354   lambda = 2. * eta / (rho * v);
04355 
04356   /* Knudsen number for air (dimensionless)... */
04357   K = lambda / r_p;
04358 
04359   /* Cunningham slip-flow correction (dimensionless)... */
04360   G = 1. + K * (1.249 + 0.42 * exp(-0.87 / K));
04361 
04362   /* Sedimentation velocity [m / s]... */
04363   return 2. * SQR(r_p) * (rho_p - rho) * G0 / (9. * eta) * G;
04364 }
```

#### 5.21.3.42 spline()

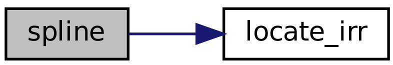
```
void spline (
    double * x,
    double * y,
    int n,
    double * x2,
    double * y2,
    int n2,
    int method )
```

Spline interpolation.

Definition at line 4368 of file libtrac.c.

```
                    {

  /* Cubic spline interpolation... */
  if (method == 1) {

    /* Allocate... */
    gsl_interp_accel *acc;
    gsl_spline *s;
    acc = gsl_interp_accel_alloc();
    s = gsl_spline_alloc(gsl_interp_cspline, (size_t) n);

    /* Interpolate profile... */
    gsl_spline_init(s, x, y, (size_t) n);
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else
        y2[i] = gsl_spline_eval(s, x2[i], acc);

    /* Free... */
    gsl_spline_free(s);
    gsl_interp_accel_free(acc);
  }

  /* Linear interpolation... */
  else {
    for (int i = 0; i < n2; i++)
      if (x2[i] <= x[0])
        y2[i] = y[0];
      else if (x2[i] >= x[n - 1])
        y2[i] = y[n - 1];
      else {
        int idx = locate_irr(x, n, x2[i]);
        y2[i] = LIN(x[idx], y[idx], x[idx + 1], y[idx + 1], x2[i]);
      }
  }
}
```

Here is the call graph for this function:




#### 5.21.3.43 stddev()

```
float stddev (
    float * data,
    int n )
```

Calculate standard deviation.

Definition at line 4417 of file libtrac.c.

```
                {

  if (n <= 0)
    return 0;

  float mean = 0, var = 0;

  for (int i = 0; i < n; ++i) {
    mean += data[i];
    var += SQR(data[i]);
  }

  return sqrtf(var / (float) n - SQR(mean / (float) n));
}
```

#### 5.21.3.44 time2jsec()

```
void time2jsec (
    int year,
    int mon,
    int day,
    int hour,
    int min,
    int sec,
    double remain,
    double * jsec )
```

Convert date to seconds.

Definition at line 4436 of file libtrac.c.

```
                       {

  struct tm t0, t1;

  t0.tm_year = 100;
  t0.tm_mon = 0;
  t0.tm_mday = 1;
  t0.tm_hour = 0;
  t0.tm_min = 0;
  t0.tm_sec = 0;

  t1.tm_year = year - 1900;
  t1.tm_mon = mon - 1;
  t1.tm_mday = day;
  t1.tm_hour = hour;
  t1.tm_min = min;
  t1.tm_sec = sec;

  *jsec = (double) timegm(&t1) - (double) timegm(&t0) + remain;
}
```

#### 5.21.3.45 timer()

```
void timer (
    const char * name,
    const char * group,
    int output )
```

Measure wall-clock time.

Definition at line 4467 of file libtrac.c.

```
                     {

  static char names[NTIMER][100], groups[NTIMER][100];

  static double rt_name[NTIMER], rt_group[NTIMER], t0, t1;
```

```
  static int iname = -1, igroup = -1, nname, ngroup;

  /* Get time... */
  t1 = omp_get_wtime();

  /* Add elapsed time to current timers... */
  if (iname >= 0)
    rt_name[iname] += t1 - t0;
  if (igroup >= 0)
    rt_group[igroup] += t1 - t0;

  /* Report timers... */
  if (output) {
    for (int i = 0; i < nname; i++)
      LOG(1, "TIMER_%s = %.3f s", names[i], rt_name[i]);
    for (int i = 0; i < ngroup; i++)
      LOG(1, "TIMER_%s = %.3f s", groups[i], rt_group[i]);
    double total = 0.0;
    for (int i = 0; i < nname; i++)
      total += rt_name[i];
    LOG(1, "TIMER_TOTAL = %.3f s", total);
  }

  /* Identify IDs of next timer... */
  for (iname = 0; iname < nname; iname++)
    if (strcasecmp(name, names[iname]) == 0)
      break;
  for (igroup = 0; igroup < ngroup; igroup++)
    if (strcasecmp(group, groups[igroup]) == 0)
      break;

  /* Check whether this is a new timer... */
  if (iname >= nname) {
    sprintf(names[iname], "%s", name);
    if ((++nname) > NTIMER)
      ERRMSG("Too many timers!");
  }

  /* Check whether this is a new group... */
  if (igroup >= ngroup) {
    sprintf(groups[igroup], "%s", group);
    if ((++ngroup) > NTIMER)
      ERRMSG("Too many groups!");
  }

  /* Save starting time... */
  t0 = t1;
}
```

#### 5.21.3.46 tropo_weight()

```
double tropo_weight (
          double t,
          double lat,
          double p )
```

Get weighting factor based on tropopause distance.

Definition at line 4527 of file libtrac.c.

```
                {

  /* Get tropopause pressure... */
  double pt = clim_tropo(t, lat);

  /* Get pressure range... */
  double p1 = pt * 0.866877899;
  double p0 = pt / 0.866877899;

  /* Get weighting factor... */
  if (p > p0)
    return 1;
  else if (p < p1)
    return 0;
  else
    return LIN(p0, 1.0, p1, 0.0, p);
}
```

Here is the call graph for this function:


#### 5.21.3.47 write_atm()

```
void write_atm (
    const char * filename,
    ctl_t * ctl,
    atm_t * atm,
    double t )
```

Write atmospheric data.

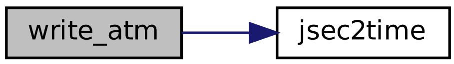
Definition at line 4550 of file libtrac.c.

```
                 {

  FILE *in, *out;

  char line[LEN];

  double r, t0, t1;

  int year, mon, day, hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_ATM", "OUTPUT", NVTX_WRITE);

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Write info... */
  LOG(1, "Write atmospheric data: %s", filename);

  /* Write ASCII data... */
  if (ctl->atm_type == 0) {

    /* Check if gnuplot output is requested... */
    if (ctl->atm_gpfile[0] != '-') {

      /* Create gnuplot pipe... */
      if (!(out = popen("gnuplot", "w")))
        ERRMSG("Cannot create pipe to gnuplot!");

      /* Set plot filename... */
      fprintf(out, "set out \"%s.png\"\n", filename);

      /* Set time string... */
      jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
      fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
              year, mon, day, hour, min);

      /* Dump gnuplot file to pipe... */
      if (!(in = fopen(ctl->atm_gpfile, "r")))
        ERRMSG("Cannot open file!");
      while (fgets(line, LEN, in))
        fprintf(out, "%s", line);
      fclose(in);
    }

    else {

      /* Create file... */
      if (!(out = fopen(filename, "w")))
```

```
        ERRMSG("Cannot create file!");
    }

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (int iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%i = %s [%s]\n", iq + 5, ctl->qnt_name[iq],
              ctl->qnt_unit[iq]);
    fprintf(out, "\n");

    /* Write data... */
    for (int ip = 0; ip < atm->np; ip += ctl->atm_stride) {

      /* Check time... */
      if (ctl->atm_filter == 2 && (atm->time[ip] < t0 || atm->time[ip] > t1))
        continue;

      /* Write output... */
      fprintf(out, "%.2f %g %g %g", atm->time[ip], Z(atm->p[ip]),
              atm->lon[ip], atm->lat[ip]);
      for (int iq = 0; iq < ctl->nq; iq++) {
        fprintf(out, " ");
        if (ctl->atm_filter == 1
            && (atm->time[ip] < t0 || atm->time[ip] > t1))
          fprintf(out, ctl->qnt_format[iq], GSL_NAN);
        else
          fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
      }
      fprintf(out, "\n");
    }

    /* Close file... */
    fclose(out);
  }

  /* Write binary data... */
  else if (ctl->atm_type == 1) {

    /* Create file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write data... */
    FWRITE(&atm->np, int,
           1,
           out);
    FWRITE(atm->time, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->p, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->lon, double,
             (size_t) atm->np,
           out);
    FWRITE(atm->lat, double,
             (size_t) atm->np,
           out);
    for (int iq = 0; iq < ctl->nq; iq++)
      FWRITE(atm->q[iq], double,
               (size_t) atm->np,
             out);

    /* Close file... */
    fclose(out);
  }

  /* Error... */
  else
    ERRMSG("Atmospheric data type not supported!");

  /* Write info... */
  double mini, maxi;
  LOG(2, "Number of particles: %d", atm->np);
  gsl_stats_minmax(&mini, &maxi, atm->time, 1, (size_t) atm->np);
  LOG(2, "Time range: %.2f ... %.2f s", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->p, 1, (size_t) atm->np);
  LOG(2, "Altitude range: %g ... %g km", Z(mini), Z(maxi));
  LOG(2, "Pressure range: %g ... %g hPa", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lon, 1, (size_t) atm->np);
  LOG(2, "Longitude range: %g ... %g deg", mini, maxi);
  gsl_stats_minmax(&mini, &maxi, atm->lat, 1, (size_t) atm->np);
  LOG(2, "Latitude range: %g ... %g deg", mini, maxi);
  for (int iq = 0; iq < ctl->nq; iq++) {
```

```
    char msg[LEN];
    sprintf(msg, "Quantity %s range: %s ... %s %s",
            ctl->qnt_name[iq], ctl->qnt_format[iq],
            ctl->qnt_format[iq], ctl->qnt_unit[iq]);
    gsl_stats_minmax(&mini, &maxi, atm->q[iq], 1, (size_t) atm->np);
    LOG(2, msg, mini, maxi);
  }
}
```

Here is the call graph for this function:




#### 5.21.3.48 write_csi() `void write_csi ( const char * filename, ctl_t * ctl, atm_t * atm, double t )`

Write CSI data.

Definition at line 4702 of file libtrac.c.

```
            {

  static FILE *in, *out;

  static char line[LEN];

  static double modmean[GX][GY][GZ], obsmean[GX][GY][GZ], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dlon, dlat, dz, lat,
    x[1000000], y[1000000], work[2000000];

  static int obscount[GX][GY][GZ], ct, cx, cy, cz, ip, ix, iy, iz, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_CSI", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Open observation data file... */
    LOG(1, "Read CSI observation data: %s", ctl->csi_obsfile);
    if (!(in = fopen(ctl->csi_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new file... */
    LOG(1, "Write CSI data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = number of hits (cx)\n"
            "# $3 = number of misses (cy)\n"
```

```
            "# $4 = number of false alarms (cz)\n"
            "# $5 = number of observations (cx + cy)\n"
            "# $6 = number of forecasts (cx + cz)\n"
            "# $7 = bias (ratio of forecasts and observations) [%%]\n"
            "# $8 = probability of detection (POD) [%%]\n"
            "# $9 = false alarm rate (FAR) [%%]\n"
            "# $10 = critical success index (CSI) [%%]\n");
    fprintf(out,
            "# $11 = hits associated with random chance\n"
            "# $12 = equitable threat score (ETS) [%%]\n"
            "# $13 = Pearson linear correlation coefficient\n"
            "# $14 = Spearman rank-order correlation coefficient\n"
            "# $15 = column density mean error (F - O) [kg/m^2]\n"
            "# $16 = column density root mean square error (RMSE) [kg/m^2]\n"
            "# $17 = column density mean absolute error [kg/m^2]\n"
            "# $18 = number of data points\n\n");

    /* Set grid box size... */
    dz = (ctl->csi_z1 - ctl->csi_z0) / ctl->csi_nz;
    dlon = (ctl->csi_lon1 - ctl->csi_lon0) / ctl->csi_nx;
    dlat = (ctl->csi_lat1 - ctl->csi_lat0) / ctl->csi_ny;

    /* Set horizontal coordinates... */
    for (iy = 0; iy < ctl->csi_ny; iy++) {
      lat = ctl->csi_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.) * cos(lat * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid cells... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++)
        modmean[ix][iy][iz] = obsmean[ix][iy][iz] = obscount[ix][iy][iz] = 0;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->csi_lon0) / dlon);
    iy = (int) ((rlat - ctl->csi_lat0) / dlat);
    iz = (int) ((rz - ctl->csi_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy][iz] += robs;
    obscount[ix][iy][iz]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->csi_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->csi_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->csi_z0) / dz);
```

```

    /* Check indices... */
    if (ix < 0 || ix >= ctl->csi_nx ||
        iy < 0 || iy >= ctl->csi_ny || iz < 0 || iz >= ctl->csi_nz)
      continue;

    /* Get total mass in grid cell... */
    modmean[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Analyze all grid cells... */
  for (ix = 0; ix < ctl->csi_nx; ix++)
    for (iy = 0; iy < ctl->csi_ny; iy++)
      for (iz = 0; iz < ctl->csi_nz; iz++) {

        /* Calculate mean observation index... */
        if (obscount[ix][iy][iz] > 0)
          obsmean[ix][iy][iz] /= obscount[ix][iy][iz];

        /* Calculate column density... */
        if (modmean[ix][iy][iz] > 0)
          modmean[ix][iy][iz] /= (1e6 * area[iy]);

        /* Calculate CSI... */
        if (obscount[ix][iy][iz] > 0) {
          ct++;
          if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
              modmean[ix][iy][iz] >= ctl->csi_modmin)
            cx++;
          else if (obsmean[ix][iy][iz] >= ctl->csi_obsmin &&
                   modmean[ix][iy][iz] < ctl->csi_modmin)
            cy++;
          else if (obsmean[ix][iy][iz] < ctl->csi_obsmin &&
                   modmean[ix][iy][iz] >= ctl->csi_modmin)
            cz++;
        }

        /* Save data for other verification statistics... */
        if (obscount[ix][iy][iz] > 0
            && (obsmean[ix][iy][iz] >= ctl->csi_obsmin
                || modmean[ix][iy][iz] >= ctl->csi_modmin)) {
          x[n] = modmean[ix][iy][iz];
          y[n] = obsmean[ix][iy][iz];
          if ((++n) > 1000000)
            ERRMSG("Too many data points to calculate statistics!");
        }
      }

  /* Write output... */
  if (fmod(t, ctl->csi_dt_out) == 0) {

    /* Calculate verification statistics
       (https://www.cawcr.gov.au/projects/verification/) ... */
    int nobs = cx + cy;
    int nfor = cx + cz;
    double bias = (nobs > 0) ? 100. * nfor / nobs : GSL_NAN;
    double pod = (nobs > 0) ? (100. * cx) / nobs : GSL_NAN;
    double far = (nfor > 0) ? (100. * cz) / nfor : GSL_NAN;
    double csi = (cx + cy + cz > 0) ? (100. * cx) / (cx + cy + cz) : GSL_NAN;
    double cx_rd = (ct > 0) ? (1. * nobs * nfor) / ct : GSL_NAN;
    double ets = (cx + cy + cz - cx_rd > 0) ?
      (100. * (cx - cx_rd)) / (cx + cy + cz - cx_rd) : GSL_NAN;
    double rho_p =
      (n > 0) ? gsl_stats_correlation(x, 1, y, 1, (size_t) n) : GSL_NAN;
    double rho_s =
      (n > 0) ? gsl_stats_spearman(x, 1, y, 1, (size_t) n, work) : GSL_NAN;
    for (int i = 0; i < n; i++)
      work[i] = x[i] - y[i];
    double mean = (n > 0) ? gsl_stats_mean(work, 1, (size_t) n) : GSL_NAN;
    double rmse = (n > 0) ? gsl_stats_sd_with_fixed_mean(work, 1, (size_t) n,
                                                         0.0) : GSL_NAN;
    double absdev =
      (n > 0) ? gsl_stats_absdev_m(work, 1, (size_t) n, 0.0) : GSL_NAN;

    /* Write... */
    fprintf(out, "%.2f %d %d %d %d %d %g %g %g %g %g %g %g %g %g %g %g %d\n",
            t, cx, cy, cz, nobs, nfor, bias, pod, far, csi, cx_rd, ets,
            rho_p, rho_s, mean, rmse, absdev, n);

    /* Set counters to zero... */
    n = ct = cx = cy = cz = 0;
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

#### 5.21.3.49 write_ens()

```
void write_ens (
    const char * filename,
    ctl_t * ctl,
    atm_t * atm,
    double t )
```

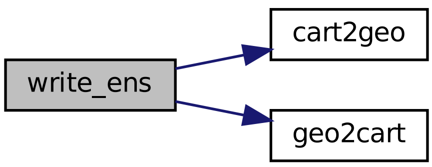
Write ensemble data.

Definition at line 4923 of file libtrac.c.

```
          {

  static FILE *out;

  static double dummy, ens, lat, lon, p[NENS], q[NQ][NENS],
    t0, t1, x[NENS][3], xm[3];

  static int ip, iq;

  static size_t i, n;

  /* Set timer... */
  SELECT_TIMER("WRITE_ENS", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantities... */
    if (ctl->qnt_ens < 0)
      ERRMSG("Missing ensemble IDs!");

    /* Create new file... */
    LOG(1, "Write ensemble data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (mean) [%s]\n", 5 + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    for (iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%d = %s (sigma) [%s]\n", 5 + ctl->nq + iq,
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "# $%d = number of members\n\n", 5 + 2 * ctl->nq);
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Init... */
  ens = GSL_NAN;
  n = 0;

  /* Loop over air parcels... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check ensemble id... */
    if (atm->q[ctl->qnt_ens][ip] != ens) {

      /* Write results... */
      if (n > 0) {

        /* Get mean position... */
        xm[0] = xm[1] = xm[2] = 0;
        for (i = 0; i < n; i++) {
          xm[0] += x[i][0] / (double) n;
          xm[1] += x[i][1] / (double) n;
          xm[2] += x[i][2] / (double) n;
        }
        cart2geo(xm, &dummy, &lon, &lat);
```

```
        fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon,
                lat);

        /* Get quantity statistics... */
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
        }
        for (iq = 0; iq < ctl->nq; iq++) {
          fprintf(out, " ");
          fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
        }
        fprintf(out, " %zu\n", n);
      }

      /* Init new ensemble... */
      ens = atm->q[ctl->qnt_ens][ip];
      n = 0;
    }

    /* Save data... */
    p[n] = atm->p[ip];
    geo2cart(0, atm->lon[ip], atm->lat[ip], x[n]);
    for (iq = 0; iq < ctl->nq; iq++)
      q[iq][n] = atm->q[iq][ip];
    if ((++n) >= NENS)
      ERRMSG("Too many data points!");
  }

  /* Write results... */
  if (n > 0) {

    /* Get mean position... */
    xm[0] = xm[1] = xm[2] = 0;
    for (i = 0; i < n; i++) {
      xm[0] += x[i][0] / (double) n;
      xm[1] += x[i][1] / (double) n;
      xm[2] += x[i][2] / (double) n;
    }
    cart2geo(xm, &dummy, &lon, &lat);
    fprintf(out, "%.2f %g %g %g", t, Z(gsl_stats_mean(p, 1, n)), lon, lat);

    /* Get quantity statistics... */
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_mean(q[iq], 1, n));
    }
    for (iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], gsl_stats_sd(q[iq], 1, n));
    }
    fprintf(out, " %zu\n", n);
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

Here is the call graph for this function:



#### 5.21.3.50 write_grid()

```
void write_grid (
    const char * filename,
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double t )
```

Write gridded data.

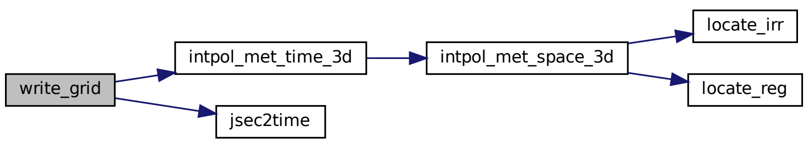
Definition at line 5057 of file libtrac.c.

```
                   {

  FILE *in, *out;

  char line[LEN];

  static double mass[GX][GY][GZ], vmr[GX][GY][GZ], vmr_expl, vmr_impl,
    z[GZ], dz, lon[GX], dlon, lat[GY], dlat, area[GY], rho_air,
    press[GZ], temp, cd, t0, t1, r;

  static int ip, ix, *ixs, iy, *iys, iz, *izs, np[GX][GY][GZ], year, mon, day,
    hour, min, sec;

  /* Set timer... */
  SELECT_TIMER("WRITE_GRID", "OUTPUT", NVTX_WRITE);

  /* Check dimensions... */
  if (ctl->grid_nx > GX || ctl->grid_ny > GY || ctl->grid_nz > GZ)
    ERRMSG("Grid dimensions too large!");

  /* Set grid box size... */
  dz = (ctl->grid_z1 - ctl->grid_z0) / ctl->grid_nz;
  dlon = (ctl->grid_lon1 - ctl->grid_lon0) / ctl->grid_nx;
  dlat = (ctl->grid_lat1 - ctl->grid_lat0) / ctl->grid_ny;

  /* Set vertical coordinates... */
#pragma omp parallel for default(shared) private(iz)
  for (iz = 0; iz < ctl->grid_nz; iz++) {
    z[iz] = ctl->grid_z0 + dz * (iz + 0.5);
    press[iz] = P(z[iz]);
  }

  /* Set horizontal coordinates... */
  for (ix = 0; ix < ctl->grid_nx; ix++)
    lon[ix] = ctl->grid_lon0 + dlon * (ix + 0.5);
#pragma omp parallel for default(shared) private(iy)
  for (iy = 0; iy < ctl->grid_ny; iy++) {
    lat[iy] = ctl->grid_lat0 + dlat * (iy + 0.5);
    area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
      * cos(lat[iy] * M_PI / 180.);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize grid... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(3)
  for (ix = 0; ix < ctl->grid_nx; ix++)
    for (iy = 0; iy < ctl->grid_ny; iy++)
      for (iz = 0; iz < ctl->grid_nz; iz++) {
        mass[ix][iy][iz] = 0;
        vmr[ix][iy][iz] = 0;
        np[ix][iy][iz] = 0;
      }

  /* Allocate... */
  ALLOC(ixs, int,
        atm->np);
  ALLOC(iys, int,
        atm->np);
  ALLOC(izs, int,
        atm->np);

  /* Get indices... */
#pragma omp parallel for default(shared) private(ip)
  for (ip = 0; ip < atm->np; ip++) {
    ixs[ip] = (int) ((atm->lon[ip] - ctl->grid_lon0) / dlon);
    iys[ip] = (int) ((atm->lat[ip] - ctl->grid_lat0) / dlat);
    izs[ip] = (int) ((Z(atm->p[ip]) - ctl->grid_z0) / dz);
    if (atm->time[ip] < t0 || atm->time[ip] > t1
```

```
        || ixs[ip] < 0 || ixs[ip] >= ctl->grid_nx
        || iys[ip] < 0 || iys[ip] >= ctl->grid_ny
        || izs[ip] < 0 || izs[ip] >= ctl->grid_nz)
      izs[ip] = -1;
  }

  /* Average data... */
  for (ip = 0; ip < atm->np; ip++)
    if (izs[ip] >= 0) {
      np[ixs[ip]][iys[ip]][izs[ip]]++;
      if (ctl->qnt_m >= 0)
        mass[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_m][ip];
      if (ctl->qnt_vmr >= 0)
        vmr[ixs[ip]][iys[ip]][izs[ip]] += atm->q[ctl->qnt_vmr][ip];
    }

  /* Free... */
  free(ixs);
  free(iys);
  free(izs);

  /* Check if gnuplot output is requested... */
  if (ctl->grid_gpfile[0] != '-') {

    /* Write info... */
    LOG(1, "Plot grid data: %s.png", filename);

    /* Create gnuplot pipe... */
    if (!(out = popen("gnuplot", "w")))
      ERRMSG("Cannot create pipe to gnuplot!");

    /* Set plot filename... */
    fprintf(out, "set out \"%s.png\"\n", filename);

    /* Set time string... */
    jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);
    fprintf(out, "timestr=\"%d-%02d-%02d, %02d:%02d UTC\"\n",
            year, mon, day, hour, min);

    /* Dump gnuplot file to pipe... */
    if (!(in = fopen(ctl->grid_gpfile, "r")))
      ERRMSG("Cannot open file!");
    while (fgets(line, LEN, in))
      fprintf(out, "%s", line);
    fclose(in);
  }

  else {

    /* Write info... */
    LOG(1, "Write grid data: %s", filename);

    /* Create file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");
  }

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = surface area [km^2]\n"
          "# $6 = layer width [km]\n"
          "# $7 = number of particles [1]\n"
          "# $8 = column density (implicit) [kg/m^2]\n"
          "# $9 = volume mixing ratio (implicit) [ppv]\n"
          "# $10 = volume mixing ratio (explicit) [ppv]\n\n");

  /* Write data... */
  for (ix = 0; ix < ctl->grid_nx; ix++) {
    if (ix > 0 && ctl->grid_ny > 1 && !ctl->grid_sparse)
      fprintf(out, "\n");
    for (iy = 0; iy < ctl->grid_ny; iy++) {
      if (iy > 0 && ctl->grid_nz > 1 && !ctl->grid_sparse)
        fprintf(out, "\n");
      for (iz = 0; iz < ctl->grid_nz; iz++)
        if (!ctl->grid_sparse || mass[ix][iy][iz] > 0 || vmr[ix][iy][iz] > 0) {

          /* Calculate column density... */
          if (ctl->qnt_m >= 0)
            cd = mass[ix][iy][iz] / (1e6 * area[iy]);
          else
            cd = GSL_NAN;

          /* Calculate volume mixing ratio (implicit)... */
```

```
          if (ctl->qnt_m >= 0 && ctl->molmass > 0) {
            vmr_impl = 0;
            if (mass[ix][iy][iz] > 0) {

              /* Get temperature... */
              INTPOL_INIT;
              intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                                 lon[ix], lat[iy], &temp, ci, cw, 1);

              /* Calculate density of air... */
              rho_air = 100. * press[iz] / (RA * temp);

              /* Calculate volume mixing ratio... */
              vmr_impl = MA / ctl->molmass * mass[ix][iy][iz]
                / (rho_air * 1e6 * area[iy] * 1e3 * dz);
            }
          } else
            vmr_impl = GSL_NAN;

          /* Calculate volume mixing ratio (explicit)... */
          if (ctl->qnt_vmr >= 0 && np[ix][iy][iz] > 0)
            vmr_expl = vmr[ix][iy][iz] / np[ix][iy][iz];
          else
            vmr_expl = GSL_NAN;

          /* Write output... */
          fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", t, z[iz],
                  lon[ix], lat[iy], area[iy], dz, np[ix][iy][iz], cd,
                  vmr_impl, vmr_expl);
        }
    }
  }

  /* Close file... */
  fclose(out);
}
```

Here is the call graph for this function:




#### 5.21.3.51 write_prof() void write_prof (

const char * *filename*,
ctl_t * *ctl*,
met_t * *met0*,
met_t * *met1*,
atm_t * *atm*,
double *t* )

Write profile data.

Definition at line 5260 of file libtrac.c.

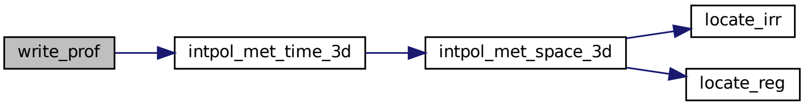
```
                {

  static FILE *in, *out;

  static char line[LEN];

  static double mass[GX][GY][GZ], obsmean[GX][GY], rt, rt_old,
    rz, rlon, rlat, robs, t0, t1, area[GY], dz, dlon, dlat,
    lon[GX], lat[GY], z[GZ], press[GZ], temp, rho_air, vmr, h2o, o3;
```

```
  static int obscount[GX][GY], ip, ix, iy, iz, okay;

  /* Set timer... */
  SELECT_TIMER("WRITE_PROF", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Check quantity index for mass... */
    if (ctl->qnt_m < 0)
      ERRMSG("Need quantity mass!");

    /* Check dimensions... */
    if (ctl->prof_nx > GX || ctl->prof_ny > GY || ctl->prof_nz > GZ)
      ERRMSG("Grid dimensions too large!");

    /* Check molar mass... */
    if (ctl->molmass <= 0)
      ERRMSG("Specify molar mass!");

    /* Open observation data file... */
    LOG(1, "Read profile observation data: %s", ctl->prof_obsfile);
    if (!(in = fopen(ctl->prof_obsfile, "r")))
      ERRMSG("Cannot open file!");

    /* Initialize time for file input... */
    rt_old = -1e99;

    /* Create new output file... */
    LOG(1, "Write profile data: %s", filename);
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
            "# $4 = latitude [deg]\n"
            "# $5 = pressure [hPa]\n"
            "# $6 = temperature [K]\n"
            "# $7 = volume mixing ratio [ppv]\n"
            "# $8 = H2O volume mixing ratio [ppv]\n"
            "# $9 = O3 volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n"
            "# $11 = number of observations\n");

    /* Set grid box size... */
    dz = (ctl->prof_z1 - ctl->prof_z0) / ctl->prof_nz;
    dlon = (ctl->prof_lon1 - ctl->prof_lon0) / ctl->prof_nx;
    dlat = (ctl->prof_lat1 - ctl->prof_lat0) / ctl->prof_ny;

    /* Set vertical coordinates... */
    for (iz = 0; iz < ctl->prof_nz; iz++) {
      z[iz] = ctl->prof_z0 + dz * (iz + 0.5);
      press[iz] = P(z[iz]);
    }

    /* Set horizontal coordinates... */
    for (ix = 0; ix < ctl->prof_nx; ix++)
      lon[ix] = ctl->prof_lon0 + dlon * (ix + 0.5);
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      lat[iy] = ctl->prof_lat0 + dlat * (iy + 0.5);
      area[iy] = dlat * dlon * SQR(RE * M_PI / 180.)
        * cos(lat[iy] * M_PI / 180.);
    }
  }

  /* Set time interval... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Initialize... */
#pragma omp parallel for default(shared) private(ix,iy,iz) collapse(2)
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++) {
      obsmean[ix][iy] = 0;
      obscount[ix][iy] = 0;
      for (iz = 0; iz < ctl->prof_nz; iz++)
        mass[ix][iy][iz] = 0;
    }

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
```

```
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt > t1)
      break;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Check observation data... */
    if (!isfinite(robs))
      continue;

    /* Calculate indices... */
    ix = (int) ((rlon - ctl->prof_lon0) / dlon);
    iy = (int) ((rlat - ctl->prof_lat0) / dlat);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx || iy < 0 || iy >= ctl->prof_ny)
      continue;

    /* Get mean observation index... */
    obsmean[ix][iy] += robs;

    /* Count observations... */
    obscount[ix][iy]++;
  }

  /* Analyze model data... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Get indices... */
    ix = (int) ((atm->lon[ip] - ctl->prof_lon0) / dlon);
    iy = (int) ((atm->lat[ip] - ctl->prof_lat0) / dlat);
    iz = (int) ((Z(atm->p[ip]) - ctl->prof_z0) / dz);

    /* Check indices... */
    if (ix < 0 || ix >= ctl->prof_nx ||
        iy < 0 || iy >= ctl->prof_ny || iz < 0 || iz >= ctl->prof_nz)
      continue;

    /* Get total mass in grid cell... */
    mass[ix][iy][iz] += atm->q[ctl->qnt_m][ip];
  }

  /* Extract profiles... */
  for (ix = 0; ix < ctl->prof_nx; ix++)
    for (iy = 0; iy < ctl->prof_ny; iy++)
      if (obscount[ix][iy] >= 1) {

        /* Check profile... */
        okay = 0;
        for (iz = 0; iz < ctl->prof_nz; iz++)
          if (mass[ix][iy][iz] > 0) {
            okay = 1;
            break;
          }
        if (!okay)
          continue;

        /* Write output... */
        fprintf(out, "\n");

        /* Loop over altitudes... */
        for (iz = 0; iz < ctl->prof_nz; iz++) {

          /* Get pressure and temperature... */
          INTPOL_INIT;
          intpol_met_time_3d(met0, met0->t, met1, met1->t, t, press[iz],
                             lon[ix], lat[iy], &temp, ci, cw, 1);
          intpol_met_time_3d(met0, met0->h2o, met1, met1->h2o, t, press[iz],
                             lon[ix], lat[iy], &h2o, ci, cw, 0);
          intpol_met_time_3d(met0, met0->o3, met1, met1->o3, t, press[iz],
                             lon[ix], lat[iy], &o3, ci, cw, 0);

          /* Calculate volume mixing ratio... */
          rho_air = 100. * press[iz] / (RA * temp);
          vmr = MA / ctl->molmass * mass[ix][iy][iz]
            / (rho_air * area[iy] * dz * 1e9);
```

```
            /* Write output... */
            fprintf(out, "%.2f %g %g %g %g %g %g %g %g %g %d\n",
                    t, z[iz], lon[ix], lat[iy], press[iz], temp, vmr, h2o, o3,
                    obsmean[ix][iy] / obscount[ix][iy], obscount[ix][iy]);
          }
        }

    /* Close files... */
    if (t == ctl->t_stop) {
      fclose(in);
      fclose(out);
    }
  }
```

Here is the call graph for this function:




### 5.21.3.52 write_sample()

```
void write_sample (
    const char * filename,
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double t )
```

Write sample data.

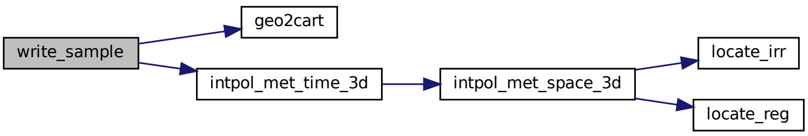
Definition at line 5466 of file libtrac.c.

```
                 {

    static FILE *in, *out;

    static char line[LEN];

    static double area, dlat, rmax2, t0, t1, rt, rt_old, rz, rlon, rlat, robs;

    /* Set timer... */
    SELECT_TIMER("WRITE_SAMPLE", "OUTPUT", NVTX_WRITE);

    /* Init... */
    if (t == ctl->t_start) {

      /* Open observation data file... */
      LOG(1, "Read sample observation data: %s", ctl->sample_obsfile);
      if (!(in = fopen(ctl->sample_obsfile, "r")))
        ERRMSG("Cannot open file!");

      /* Initialize time for file input... */
      rt_old = -1e99;

      /* Create new file... */
      LOG(1, "Write sample data: %s", filename);
      if (!(out = fopen(filename, "w")))
        ERRMSG("Cannot create file!");

      /* Write header... */
      fprintf(out,
              "# $1 = time [s]\n"
              "# $2 = altitude [km]\n"
              "# $3 = longitude [deg]\n"
```

```
            "# $4 = latitude [deg]\n"
            "# $5 = surface area [km^2]\n"
            "# $6 = layer width [km]\n"
            "# $7 = number of particles [1]\n"
            "# $8 = column density [kg/m^2]\n"
            "# $9 = volume mixing ratio [ppv]\n"
            "# $10 = observed BT index [K]\n\n");

    /* Set latitude range, squared radius, and area... */
    dlat = DY2DEG(ctl->sample_dx);
    rmax2 = SQR(ctl->sample_dx);
    area = M_PI * rmax2;
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Read observation data... */
  while (fgets(line, LEN, in)) {

    /* Read data... */
    if (sscanf(line, "%lg %lg %lg %lg %lg", &rt, &rz, &rlon, &rlat, &robs) !=
        5)
      continue;

    /* Check time... */
    if (rt < t0)
      continue;
    if (rt < rt_old)
      ERRMSG("Time must be ascending!");
    rt_old = rt;

    /* Calculate Cartesian coordinates... */
    double x0[3];
    geo2cart(0, rlon, rlat, x0);

    /* Set pressure range... */
    double rp = P(rz);
    double ptop = P(rz + ctl->sample_dz);
    double pbot = P(rz - ctl->sample_dz);

    /* Init... */
    double mass = 0;
    int np = 0;

    /* Loop over air parcels... */
#pragma omp parallel for default(shared) reduction(+:mass,np)
    for (int ip = 0; ip < atm->np; ip++) {

      /* Check time... */
      if (atm->time[ip] < t0 || atm->time[ip] > t1)
        continue;

      /* Check latitude... */
      if (fabs(rlat - atm->lat[ip]) > dlat)
        continue;

      /* Check horizontal distance... */
      double x1[3];
      geo2cart(0, atm->lon[ip], atm->lat[ip], x1);
      if (DIST2(x0, x1) > rmax2)
        continue;

      /* Check pressure... */
      if (ctl->sample_dz > 0)
        if (atm->p[ip] > pbot || atm->p[ip] < ptop)
          continue;

      /* Add mass... */
      if (ctl->qnt_m >= 0)
        mass += atm->q[ctl->qnt_m][ip];
      np++;
    }

    /* Calculate column density... */
    double cd = mass / (1e6 * area);

    /* Calculate volume mixing ratio... */
    double vmr = 0;
    if (ctl->molmass > 0 && ctl->sample_dz > 0) {
      if (mass > 0) {

        /* Get temperature... */
        double temp;
        INTPOL_INIT;
        intpol_met_time_3d(met0, met0->t, met1, met1->t, rt, rp,
```

```
                               rlon, rlat, &temp, ci, cw, 1);

        /* Calculate density of air... */
        double rho_air = 100. * rp / (RA * temp);

        /* Calculate volume mixing ratio... */
        vmr = MA / ctl->molmass * mass
          / (rho_air * 1e6 * area * 1e3 * ctl->sample_dz);
      }
    } else
      vmr = GSL_NAN;

    /* Write output... */
    fprintf(out, "%.2f %g %g %g %g %g %d %g %g %g\n", rt, rz, rlon, rlat,
            area, ctl->sample_dz, np, cd, vmr, robs);

    /* Check time... */
    if (rt >= t1)
      break;
  }

  /* Close files... */
  if (t == ctl->t_stop) {
    fclose(in);
    fclose(out);
  }
}
```

Here is the call graph for this function:




### 5.21.3.53 write_station()

```
void write_station (
        const char * filename,
        ctl_t * ctl,
        atm_t * atm,
        double t )
```

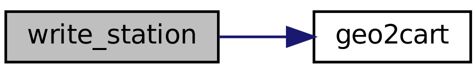
Write station data.

Definition at line 5621 of file libtrac.c.

```
                    {

  static FILE *out;

  static double rmax2, t0, t1, x0[3], x1[3];

  /* Set timer... */
  SELECT_TIMER("WRITE_STATION", "OUTPUT", NVTX_WRITE);

  /* Init... */
  if (t == ctl->t_start) {

    /* Write info... */
    LOG(1, "Write station data: %s", filename);

    /* Create new file... */
    if (!(out = fopen(filename, "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
```

```
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
    for (int iq = 0; iq < ctl->nq; iq++)
      fprintf(out, "# $%i = %s [%s]\n", (iq + 5),
              ctl->qnt_name[iq], ctl->qnt_unit[iq]);
    fprintf(out, "\n");

    /* Set geolocation and search radius... */
    geo2cart(0, ctl->stat_lon, ctl->stat_lat, x0);
    rmax2 = SQR(ctl->stat_r);
  }

  /* Set time interval for output... */
  t0 = t - 0.5 * ctl->dt_mod;
  t1 = t + 0.5 * ctl->dt_mod;

  /* Loop over air parcels... */
  for (int ip = 0; ip < atm->np; ip++) {

    /* Check time... */
    if (atm->time[ip] < t0 || atm->time[ip] > t1)
      continue;

    /* Check time range for station output... */
    if (atm->time[ip] < ctl->stat_t0 || atm->time[ip] > ctl->stat_t1)
      continue;

    /* Check station flag... */
    if (ctl->qnt_stat >= 0)
      if (atm->q[ctl->qnt_stat][ip])
        continue;

    /* Get Cartesian coordinates... */
    geo2cart(0, atm->lon[ip], atm->lat[ip], x1);

    /* Check horizontal distance... */
    if (DIST2(x0, x1) > rmax2)
      continue;

    /* Set station flag... */
    if (ctl->qnt_stat >= 0)
      atm->q[ctl->qnt_stat][ip] = 1;

    /* Write data... */
    fprintf(out, "%.2f %g %g %g",
            atm->time[ip], Z(atm->p[ip]), atm->lon[ip], atm->lat[ip]);
    for (int iq = 0; iq < ctl->nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl->qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, "\n");
  }

  /* Close file... */
  if (t == ctl->t_stop)
    fclose(out);
}
```

Here is the call graph for this function:




## 5.22 libtrac.h

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
```

```
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#ifndef LIBTRAC_H
#define LIBTRAC_H

/* ------------------------------------------------------------
   Includes...
   ------------------------------------------------------------ */

#include <ctype.h>
#include <gsl/gsl_fft_complex.h>
#include <gsl/gsl_math.h>
#include <gsl/gsl_randist.h>
#include <gsl/gsl_rng.h>
#include <gsl/gsl_sort.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_statistics.h>
#include <math.h>
#include <netcdf.h>
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>
#include <sys/time.h>

#ifdef MPI
#include "mpi.h"
#endif

#ifdef _OPENACC
#include "openacc.h"
#include "curand.h"
#endif

/* ------------------------------------------------------------
   Constants...
   ------------------------------------------------------------ */

#define CPD 1003.5

#define EPS (MH2O / MA)

#define G0 9.80665

#define H0 7.0

#define LV 2501000.

#define KB 1.3806504e-23

#define MA 28.9644

#define MH2O 18.01528

#define MO3 48.00

#define P0 1013.25

#define RA (1e3 * RI / MA)

#define RE 6367.421

#define RI 8.3144598

#define T0 273.15

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#ifndef LEN
#define LEN 5000
#endif

```

```
#ifndef NP
#define NP 10000000
#endif

#ifndef NQ
#define NQ 15
#endif

#ifndef EP
#define EP 140
#endif

#ifndef EX
#define EX 1201
#endif

#ifndef EY
#define EY 601
#endif

#ifndef GX
#define GX 720
#endif

#ifndef GY
#define GY 360
#endif

#ifndef GZ
#define GZ 100
#endif

#ifndef NENS
#define NENS 2000
#endif

#ifndef NTHREADS
#define NTHREADS 512
#endif

/* ------------------------------------------------------------
   Macros...
   ------------------------------------------------------------ */

#ifdef _OPENACC
#define ALLOC(ptr, type, n)                                  \
  if(acc_get_num_devices(acc_device_nvidia) <= 0)           \
    ERRMSG("Not running on a GPU device!");                  \
  if((ptr=calloc((size_t)(n), sizeof(type)))==NULL)         \
    ERRMSG("Out of memory!");
#else
#define ALLOC(ptr, type, n)                                   \
  if((ptr=calloc((size_t)(n), sizeof(type)))==NULL)          \
    ERRMSG("Out of memory!");
#endif

#define DEG2DX(dlon, lat)                                            \
  ((dlon) * M_PI * RE / 180. * cos((lat) / 180. * M_PI))

#define DEG2DY(dlat)                                 \
  ((dlat) * M_PI * RE / 180.)

#define DP2DZ(dp, p)                                 \
  (- (dp) * H0 / (p))

#define DX2DEG(dx, lat)                                              \
  (((lat) < -89.999 || (lat) > 89.999) ? 0                           \
   : (dx) * 180. / (M_PI * RE * cos((lat) / 180. * M_PI)))

#define DY2DEG(dy)                                   \
  ((dy) * 180. / (M_PI * RE))

#define DZ2DP(dz, p)                                 \
  (-(dz) * (p) / H0)

#define DIST(a, b) \
  sqrt(DIST2(a, b))

#define DIST2(a, b)                                                        \
  ((a[0]-b[0])*(a[0]-b[0])+(a[1]-b[1])*(a[1]-b[1])+(a[2]-b[2])*(a[2]-b[2]))

#define DOTP(a, b) \
  (a[0]*b[0]+a[1]*b[1]+a[2]*b[2])

#define FMOD(x, y)                                   \
  ((x) - (int) ((x) / (y)) * (y))
```

```
#define FREAD(ptr, type, size, out) {                                   \
    if(fread(ptr, sizeof(type), size, out)!=size)                       \
      ERRMSG("Error while reading!");                                   \
  }

#define FWRITE(ptr, type, size, out) {                                  \
    if(fwrite(ptr, sizeof(type), size, out)!=size)                      \
      ERRMSG("Error while writing!");                                   \
  }

#define INTPOL_INIT                                             \
  double cw[3] = {0.0, 0.0, 0.0}; int ci[3] = {0, 0, 0};

#define INTPOL_2D(var, init)                                            \
  intpol_met_time_2d(met0, met0->var, met1, met1->var,                  \
                     atm->time[ip], atm->lon[ip], atm->lat[ip],         \
                     &var, ci, cw, init);

#define INTPOL_3D(var, init)                                            \
  intpol_met_time_3d(met0, met0->var, met1, met1->var,                  \
                     atm->time[ip], atm->p[ip],                         \
                     atm->lon[ip], atm->lat[ip],                        \
                     &var, ci, cw, init);

#define INTPOL_SPACE_ALL(p, lon, lat) {                                 \
  intpol_met_space_3d(met, met->z, p, lon, lat, &z, ci, cw, 1);         \
  intpol_met_space_3d(met, met->t, p, lon, lat, &t, ci, cw, 0);         \
  intpol_met_space_3d(met, met->u, p, lon, lat, &u, ci, cw, 0);         \
  intpol_met_space_3d(met, met->v, p, lon, lat, &v, ci, cw, 0);         \
  intpol_met_space_3d(met, met->w, p, lon, lat, &w, ci, cw, 0);         \
  intpol_met_space_3d(met, met->pv, p, lon, lat, &pv, ci, cw, 0);       \
  intpol_met_space_3d(met, met->h2o, p, lon, lat, &h2o, ci, cw, 0);     \
  intpol_met_space_3d(met, met->o3, p, lon, lat, &o3, ci, cw, 0);       \
  intpol_met_space_3d(met, met->lwc, p, lon, lat, &lwc, ci, cw, 0);     \
  intpol_met_space_3d(met, met->iwc, p, lon, lat, &iwc, ci, cw, 0);     \
  intpol_met_space_2d(met, met->ps, lon, lat, &ps, ci, cw, 0);          \
  intpol_met_space_2d(met, met->ts, lon, lat, &ts, ci, cw, 0);          \
  intpol_met_space_2d(met, met->zs, lon, lat, &zs, ci, cw, 0);          \
  intpol_met_space_2d(met, met->us, lon, lat, &us, ci, cw, 0);          \
  intpol_met_space_2d(met, met->vs, lon, lat, &vs, ci, cw, 0);          \
  intpol_met_space_2d(met, met->pbl, lon, lat, &pbl, ci, cw, 0);        \
  intpol_met_space_2d(met, met->pt, lon, lat, &pt, ci, cw, 0);          \
  intpol_met_space_2d(met, met->tt, lon, lat, &tt, ci, cw, 0);          \
  intpol_met_space_2d(met, met->zt, lon, lat, &zt, ci, cw, 0);          \
  intpol_met_space_2d(met, met->h2ot, lon, lat, &h2ot, ci, cw, 0);      \
  intpol_met_space_2d(met, met->pct, lon, lat, &pct, ci, cw, 0);        \
  intpol_met_space_2d(met, met->pcb, lon, lat, &pcb, ci, cw, 0);        \
  intpol_met_space_2d(met, met->cl, lon, lat, &cl, ci, cw, 0);          \
  intpol_met_space_2d(met, met->plcl, lon, lat, &plcl, ci, cw, 0);      \
  intpol_met_space_2d(met, met->plfc, lon, lat, &plfc, ci, cw, 0);      \
  intpol_met_space_2d(met, met->pel, lon, lat, &pel, ci, cw, 0);        \
  intpol_met_space_2d(met, met->cape, lon, lat, &cape, ci, cw, 0);      \
  intpol_met_space_2d(met, met->cin, lon, lat, &cin, ci, cw, 0);        \
  }

#define INTPOL_TIME_ALL(time, p, lon, lat) {                            \
  intpol_met_time_3d(met0, met0->z, met1, met1->z, time, p, lon, lat, &z, ci, cw, 1); \
  intpol_met_time_3d(met0, met0->t, met1, met1->t, time, p, lon, lat, &t, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->u, met1, met1->u, time, p, lon, lat, &u, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->v, met1, met1->v, time, p, lon, lat, &v, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->w, met1, met1->w, time, p, lon, lat, &w, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->pv, met1, met1->pv, time, p, lon, lat, &pv, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->h2o, met1, met1->h2o, time, p, lon, lat, &h2o, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->o3, met1, met1->o3, time, p, lon, lat, &o3, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->lwc, met1, met1->lwc, time, p, lon, lat, &lwc, ci, cw, 0); \
  intpol_met_time_3d(met0, met0->iwc, met1, met1->iwc, time, p, lon, lat, &iwc, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->ps, met1, met1->ps, time, lon, lat, &ps, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->ts, met1, met1->ts, time, lon, lat, &ts, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->zs, met1, met1->zs, time, lon, lat, &zs, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->us, met1, met1->us, time, lon, lat, &us, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->vs, met1, met1->vs, time, lon, lat, &vs, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->pbl, met1, met1->pbl, time, lon, lat, &pbl, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->pt, met1, met1->pt, time, lon, lat, &pt, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->tt, met1, met1->tt, time, lon, lat, &tt, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->zt, met1, met1->zt, time, lon, lat, &zt, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->h2ot, met1, met1->h2ot, time, lon, lat, &h2ot, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->pct, met1, met1->pct, time, lon, lat, &pct, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->pcb, met1, met1->pcb, time, lon, lat, &pcb, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->cl, met1, met1->cl, time, lon, lat, &cl, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->plcl, met1, met1->plcl, time, lon, lat, &plcl, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->plfc, met1, met1->plfc, time, lon, lat, &plfc, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->pel, met1, met1->pel, time, lon, lat, &pel, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->cape, met1, met1->cape, time, lon, lat, &cape, ci, cw, 0); \
  intpol_met_time_2d(met0, met0->cin, met1, met1->cin, time, lon, lat, &cin, ci, cw, 0); \
  }

#define LAPSE(p1, t1, p2, t2)                                           \
```

```
  (1e3 * G0 / RA * ((t2) - (t1)) / ((t2) + (t1))                         \
   * ((p2) + (p1)) / ((p2) - (p1)))

#define LIN(x0, y0, x1, y1, x)                        \
  ((y0)+((y1)-(y0))/((x1)-(x0))*((x)-(x0)))

#define NC(cmd) {                                          \
  int nc_result=(cmd);                                     \
  if(nc_result!=NC_NOERR)                                  \
    ERRMSG("%s", nc_strerror(nc_result));                  \
}

#define NN(x0, y0, x1, y1, x)                                 \
  (fabs((x) - (x0)) <= fabs((x) - (x1)) ? (y0) : (y1))

#define NORM(a) \
  sqrt(DOTP(a, a))

#define P(z)                                          \
  (P0 * exp(-(z) / H0))

#define PSAT(t)                                                       \
  (6.112 * exp(17.62 * ((t) - T0) / (243.12 + (t) - T0)))

#define PSICE(t)                                      \
  (0.01 * pow(10., -2663.5 / (t) + 12.537))

#define PW(p, h2o)                                            \
  ((p) * GSL_MAX((h2o), 0.1e-6)                               \
   / (1. + (1. - EPS) * GSL_MAX((h2o), 0.1e-6)))

#define RH(p, t, h2o)                                 \
  (PW(p, h2o) / PSAT(t) * 100.)

#define RHICE(p, t, h2o)                              \
  (PW(p, h2o) / PSICE(t) * 100.)

#define SET_ATM(qnt, val)                             \
  if (ctl->qnt >= 0)                                  \
    atm->q[ctl->qnt][ip] = val;

#define SET_QNT(qnt, name, unit)                              \
  if (strcasecmp(ctl->qnt_name[iq], name) == 0) {             \
    ctl->qnt = iq;                                            \
    sprintf(ctl->qnt_unit[iq], unit);                         \
  } else

#define SH(h2o)                                       \
  (EPS * GSL_MAX((h2o), 0.1e-6))

#define SQR(x)                                        \
  ((x)*(x))

#define TDEW(p, h2o)                                  \
  (T0 + 243.12 * log(PW((p), (h2o)) / 6.112)          \
   / (17.62 - log(PW((p), (h2o)) / 6.112)))

#define TICE(p, h2o)                                          \
  (-2663.5 / (log10(100. * PW((p), (h2o))) - 12.537))

#define THETA(p, t)                                   \
  ((t) * pow(1000. / (p), 0.286))

#define THETAVIRT(p, t, h2o)                                  \
  (TVIRT(THETA((p), (t)), GSL_MAX((h2o), 0.1e-6)))

#define TOK(line, tok, format, var) {                                     \
    if(((tok)=strtok((line), " \t"))) {                                   \
      if(sscanf(tok, format, &(var))!=1) continue;                        \
    } else ERRMSG("Error while reading!");                                \
  }

#define TVIRT(t, h2o)                                         \
  ((t) * (1. + (1. - EPS) * GSL_MAX((h2o), 0.1e-6)))

#define Z(p)                                          \
  (H0 * log(P0 / (p)))

#define ZDIFF(lnp0, t0, h2o0, lnp1, t1, h2o1)                             \
  (RI / MA / G0 * 0.5 * (TVIRT((t0), (h2o0)) + TVIRT((t1), (h2o1)))       \
   * ((lnp0) - (lnp1)))

#define ZETA(ps, p, t)                                                    \
  (((p) / (ps) <= 0.3 ? 1. :                                              \
    sin(M_PI / 2. * (1. - (p) / (ps)) / (1. - 0.3)))                      \
   * THETA((p), (t)))
```

```
/* -------------------------------------------------------------
   Log messages...
   ------------------------------------------------------------- */

#ifndef LOGLEV
#define LOGLEV 2
#endif

#define LOG(level, ...) {                                          \
    if(level >= 2)                                                 \
      printf("  ");                                                \
    if(level <= LOGLEV) {                                          \
      printf(__VA_ARGS__);                                         \
      printf("\n");                                                \
    }                                                              \
  }

#define WARN(...) {                                                \
    printf("\nWarning (%s, %s, l%d): ", __FILE__, __func__, __LINE__); \
    LOG(0, __VA_ARGS__);                                           \
  }

#define ERRMSG(...) {                                              \
    printf("\nError (%s, %s, l%d): ", __FILE__, __func__, __LINE__);   \
    LOG(0, __VA_ARGS__);                                           \
    exit(EXIT_FAILURE);                                            \
  }

#define PRINT(format, var)                                         \
  printf("Print (%s, %s, l%d): %s= "format"\n",                    \
         __FILE__, __func__, __LINE__, #var, var);

/* -------------------------------------------------------------
   Timers...
   ------------------------------------------------------------- */

#define NTIMER 100

#define PRINT_TIMERS                         \
  timer("END", "END", 1);

#define SELECT_TIMER(id, group, color) {                           \
    NVTX_POP;                                                      \
    NVTX_PUSH(id, color);                                          \
    timer(id, group, 0);                                           \
  }

#define START_TIMERS                         \
  NVTX_PUSH("START", NVTX_CPU);

#define STOP_TIMERS                          \
  NVTX_POP;

/* -------------------------------------------------------------
   NVIDIA Tools Extension (NVTX)...
   ------------------------------------------------------------- */

#ifdef NVTX
#include "nvToolsExt.h"

#define NVTX_CPU 0xFFADD8E6

#define NVTX_GPU 0xFF00008B

#define NVTX_H2D 0xFFFFFF00

#define NVTX_D2H 0xFFFF8800

#define NVTX_READ 0xFFFFCCCB

#define NVTX_WRITE 0xFF8B0000

#define NVTX_PUSH(range_title, range_color) {             \
    nvtxEventAttributes_t eventAttrib = {0};              \
    eventAttrib.version = NVTX_VERSION;                   \
    eventAttrib.size = NVTX_EVENT_ATTRIB_STRUCT_SIZE;     \
    eventAttrib.messageType = NVTX_MESSAGE_TYPE_ASCII;    \
    eventAttrib.colorType = NVTX_COLOR_ARGB;              \
    eventAttrib.color = range_color;                      \
    eventAttrib.message.ascii = range_title;              \
    nvtxRangePushEx(&eventAttrib);                        \
  }

#define NVTX_POP {                           \
    nvtxRangePop();                          \
  }
#else
```

```
/* Empty definitions of NVTX_PUSH and NVTX_POP... */
#define NVTX_PUSH(range_title, range_color) {}
#define NVTX_POP {}
#endif
/* ------------------------------------------------------------
   Structs...
   ------------------------------------------------------------ */
typedef struct {
  size_t chunkszhint;
  int read_mode;
  int nq;
  char qnt_name[NQ][LEN];
  char qnt_unit[NQ][LEN];
  char qnt_format[NQ][LEN];
  int qnt_ens;
  int qnt_stat;
  int qnt_m;
  int qnt_vmr;
  int qnt_rho;
  int qnt_r;
  int qnt_ps;
  int qnt_ts;
  int qnt_zs;
  int qnt_us;
  int qnt_vs;
  int qnt_pbl;
  int qnt_pt;
  int qnt_tt;
  int qnt_zt;
  int qnt_h2ot;
  int qnt_z;
  int qnt_p;
  int qnt_t;
  int qnt_u;
  int qnt_v;
  int qnt_w;
  int qnt_h2o;
  int qnt_o3;
  int qnt_lwc;
  int qnt_iwc;
  int qnt_pct;
  int qnt_pcb;
  int qnt_cl;
  int qnt_plcl;
  int qnt_plfc;
  int qnt_pel;
```

```
  int qnt_cape;

  int qnt_cin;

  int qnt_hno3;

  int qnt_oh;

  int qnt_psat;

  int qnt_psice;

  int qnt_pw;

  int qnt_sh;

  int qnt_rh;

  int qnt_rhice;

  int qnt_theta;

  int qnt_zeta;

  int qnt_tvirt;

  int qnt_lapse;

  int qnt_vh;

  int qnt_vz;

  int qnt_pv;

  int qnt_tdew;

  int qnt_tice;

  int qnt_tsts;

  int qnt_tnat;

  int direction;

  double t_start;

  double t_stop;

  double dt_mod;

  char metbase[LEN];

  double dt_met;

  int met_dx;

  int met_dy;

  int met_dp;

  int met_sx;

  int met_sy;

  int met_sp;

  double met_detrend;

  int met_np;

  double met_p[EP];

  int met_geopot_sx;

  int met_geopot_sy;

  int met_tropo;

  double met_tropo_lapse;

  int met_tropo_nlev;

  double met_tropo_lapse_sep;

  int met_tropo_nlev_sep;

```

```
double met_tropo_pv;
double met_tropo_theta;
int met_tropo_spline;
double met_cloud;
double met_dt_out;
int met_cache;
int isosurf;
char balloon[LEN];
int advect;
int reflect;
double turb_dx_trop;
double turb_dx_strat;
double turb_dz_trop;
double turb_dz_strat;
double turb_mesox;
double turb_mesoz;
double conv_cape;
double conv_cin;
double conv_wmax;
double conv_wcape;
double conv_dt;
int conv_mix_bot;
int conv_mix_top;
double bound_mass;
double bound_vmr;
double bound_lat0;
double bound_lat1;
double bound_p0;
double bound_p1;
double bound_dps;
char species[LEN];
double molmass;
double tdec_trop;
double tdec_strat;
int oh_chem_reaction;
double oh_chem[4];
double dry_depo[1];
double wet_depo[8];
double psc_h2o;
double psc_hno3;
char atm_basename[LEN];
char atm_gpfile[LEN];
double atm_dt_out;
int atm_filter;
```

```
int atm_stride;
int atm_type;
char csi_basename[LEN];
double csi_dt_out;
char csi_obsfile[LEN];
double csi_obsmin;
double csi_modmin;
int csi_nz;
double csi_z0;
double csi_z1;
int csi_nx;
double csi_lon0;
double csi_lon1;
int csi_ny;
double csi_lat0;
double csi_lat1;
char grid_basename[LEN];
char grid_gpfile[LEN];
double grid_dt_out;
int grid_sparse;
int grid_nz;
double grid_z0;
double grid_z1;
int grid_nx;
double grid_lon0;
double grid_lon1;
int grid_ny;
double grid_lat0;
double grid_lat1;
char prof_basename[LEN];
char prof_obsfile[LEN];
int prof_nz;
double prof_z0;
double prof_z1;
int prof_nx;
double prof_lon0;
double prof_lon1;
int prof_ny;
double prof_lat0;
double prof_lat1;
char ens_basename[LEN];
char sample_basename[LEN];
char sample_obsfile[LEN];
```

```
  double sample_dx;
  double sample_dz;
  char stat_basename[LEN];
  double stat_lon;
  double stat_lat;
  double stat_r;
  double stat_t0;
  double stat_t1;
} ctl_t;
typedef struct {
  int np;
  double time[NP];
  double p[NP];
  double lon[NP];
  double lat[NP];
  double q[NQ][NP];
} atm_t;
typedef struct {
  double tsig[EX][EY][EP];
  float uvwsig[EX][EY][EP][3];
  float uvwp[NP][3];
  double iso_var[NP];
  double iso_ps[NP];
  double iso_ts[NP];
  int iso_n;
} cache_t;
typedef struct {
  double time;
  int nx;
  int ny;
  int np;
  double lon[EX];
  double lat[EY];
  double p[EP];
  float ps[EX][EY];
  float ts[EX][EY];
  float zs[EX][EY];
  float us[EX][EY];
  float vs[EX][EY];
  float pbl[EX][EY];
  float pt[EX][EY];
  float tt[EX][EY];
  float zt[EX][EY];
  float h2ot[EX][EY];
```

```
  float pct[EX][EY];
  float pcb[EX][EY];
  float cl[EX][EY];
  float plcl[EX][EY];
  float plfc[EX][EY];
  float pel[EX][EY];
  float cape[EX][EY];
  float cin[EX][EY];
  float z[EX][EY][EP];
  float t[EX][EY][EP];
  float u[EX][EY][EP];
  float v[EX][EY][EP];
  float w[EX][EY][EP];
  float pv[EX][EY][EP];
  float h2o[EX][EY][EP];
  float o3[EX][EY][EP];
  float lwc[EX][EY][EP];
  float iwc[EX][EY][EP];
  float pl[EX][EY][EP];
} met_t;
/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */
void cart2geo(
  double *x,
  double *z,
  double *lon,
  double *lat);
#ifdef _OPENACC
#pragma acc routine (check_finite)
#endif
int check_finite(
  const double x);
#ifdef _OPENACC
#pragma acc routine (clim_hno3)
#endif
double clim_hno3(
  double t,
  double lat,
  double p);
#ifdef _OPENACC
#pragma acc routine (clim_oh)
#endif
double clim_oh(
  double t,
  double lat,
  double p);
#ifdef _OPENACC
#pragma acc routine (clim_tropo)
#endif
double clim_tropo(
  double t,
  double lat);
void day2doy(
  int year,
  int mon,
  int day,
  int *doy);
void doy2day(
```

```
  int year,
  int doy,
  int *mon,
  int *day);

void geo2cart(
  double z,
  double lon,
  double lat,
  double *x);

void get_met(
  ctl_t * ctl,
  double t,
  met_t ** met0,
  met_t ** met1);

void get_met_help(
  double t,
  int direct,
  char *metbase,
  double dt_met,
  char *filename);

void get_met_replace(
  char *orig,
  char *search,
  char *repl);

#ifdef _OPENACC
#pragma acc routine (intpol_met_space_3d)
#endif
void intpol_met_space_3d(
  met_t * met,
  float array[EX][EY][EP],
  double p,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init);

#ifdef _OPENACC
#pragma acc routine (intpol_met_space_2d)
#endif
void intpol_met_space_2d(
  met_t * met,
  float array[EX][EY],
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init);

#ifdef _OPENACC
#pragma acc routine (intpol_met_time_3d)
#endif
void intpol_met_time_3d(
  met_t * met0,
  float array0[EX][EY][EP],
  met_t * met1,
  float array1[EX][EY][EP],
  double ts,
  double p,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
  int init);

#ifdef _OPENACC
#pragma acc routine (intpol_met_time_2d)
#endif
void intpol_met_time_2d(
  met_t * met0,
  float array0[EX][EY],
  met_t * met1,
  float array1[EX][EY],
  double ts,
  double lon,
  double lat,
  double *var,
  int *ci,
  double *cw,
```

```
  int init);

void jsec2time(
  double jsec,
  int *year,
  int *mon,
  int *day,
  int *hour,
  int *min,
  int *sec,
  double *remain);

#ifdef _OPENACC
#pragma acc routine (lapse_rate)
#endif
double lapse_rate(
  double t,
  double h2o);

#ifdef _OPENACC
#pragma acc routine (locate_irr)
#endif
int locate_irr(
  double *xx,
  int n,
  double x);

#ifdef _OPENACC
#pragma acc routine (locate_reg)
#endif
int locate_reg(
  double *xx,
  int n,
  double x);

#ifdef _OPENACC
#pragma acc routine (nat_temperature)
#endif
double nat_temperature(
  double p,
  double h2o,
  double hno3);

int read_atm(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm);

void read_ctl(
  const char *filename,
  int argc,
  char *argv[],
  ctl_t * ctl);

int read_met(
  ctl_t * ctl,
  char *filename,
  met_t * met);

void read_met_cape(
  met_t * met);

void read_met_cloud(
  met_t * met);

void read_met_detrend(
  ctl_t * ctl,
  met_t * met);

void read_met_extrapolate(
  met_t * met);

void read_met_geopot(
  ctl_t * ctl,
  met_t * met);

void read_met_grid(
  char *filename,
  int ncid,
  ctl_t * ctl,
  met_t * met);

int read_met_help_3d(
  int ncid,
  char *varname,
  char *varname2,
  met_t * met,
```

```
  float dest[EX][EY][EP],
  float scl,
  int init);

int read_met_help_2d(
  int ncid,
  char *varname,
  char *varname2,
  met_t * met,
  float dest[EX][EY],
  float scl,
  int init);

void read_met_levels(
  int ncid,
  ctl_t * ctl,
  met_t * met);

void read_met_ml2pl(
  ctl_t * ctl,
  met_t * met,
  float var[EX][EY][EP]);

void read_met_pbl(
  met_t * met);

void read_met_periodic(
  met_t * met);

void read_met_pv(
  met_t * met);

void read_met_sample(
  ctl_t * ctl,
  met_t * met);

void read_met_surface(
  int ncid,
  met_t * met);

void read_met_tropo(
  ctl_t * ctl,
  met_t * met);

double scan_ctl(
  const char *filename,
  int argc,
  char *argv[],
  const char *varname,
  int arridx,
  const char *defvalue,
  char *value);

#ifdef _OPENACC
#pragma acc routine (sedi)
#endif
double sedi(
  double p,
  double T,
  double r_p,
  double rho_p);

void spline(
  double *x,
  double *y,
  int n,
  double *x2,
  double *y2,
  int n2,
  int method);

#ifdef _OPENACC
#pragma acc routine (stddev)
#endif
float stddev(
  float *data,
  int n);

void time2jsec(
  int year,
  int mon,
  int day,
  int hour,
  int min,
  int sec,
  double remain,
  double *jsec);
```

```
void timer(
  const char *name,
  const char *group,
  int output);

#ifdef _OPENACC
#pragma acc routine (tropo_weight)
#endif
double tropo_weight(
  double t,
  double lat,
  double p);

void write_atm(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t);

void write_csi(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t);

void write_ens(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t);

void write_grid(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t);

void write_prof(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t);

void write_sample(
  const char *filename,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t);

void write_station(
  const char *filename,
  ctl_t * ctl,
  atm_t * atm,
  double t);

#endif /* LIBTRAC_H */
```

## 5.23 met_lapse.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define LAPSEMIN -20.0

  *Lapse rate minimum [K/km.*
- #define DLAPSE 0.1

  *Lapse rate bin size [K/km].*
- #define IDXMAX 400

  *Maximum number of histogram bins.*

## Functions

- int main (int argc, char *argv[ ])

### 5.23.1 Detailed Description

Calculate lapse rate statistics.

Definition in file met_lapse.c.

### 5.23.2 Macro Definition Documentation

#### 5.23.2.1 LAPSEMIN `#define LAPSEMIN -20.0`

Lapse rate minimum [K/km.

Definition at line 32 of file met_lapse.c.

#### 5.23.2.2 DLAPSE `#define DLAPSE 0.1`

Lapse rate bin size [K/km].

Definition at line 35 of file met_lapse.c.

#### 5.23.2.3 IDXMAX `#define IDXMAX 400`

Maximum number of histogram bins.

Definition at line 38 of file met_lapse.c.

### 5.23.3 Function Documentation

#### 5.23.3.1 main()

```
int main (
    int argc,
    char * argv[] )
```

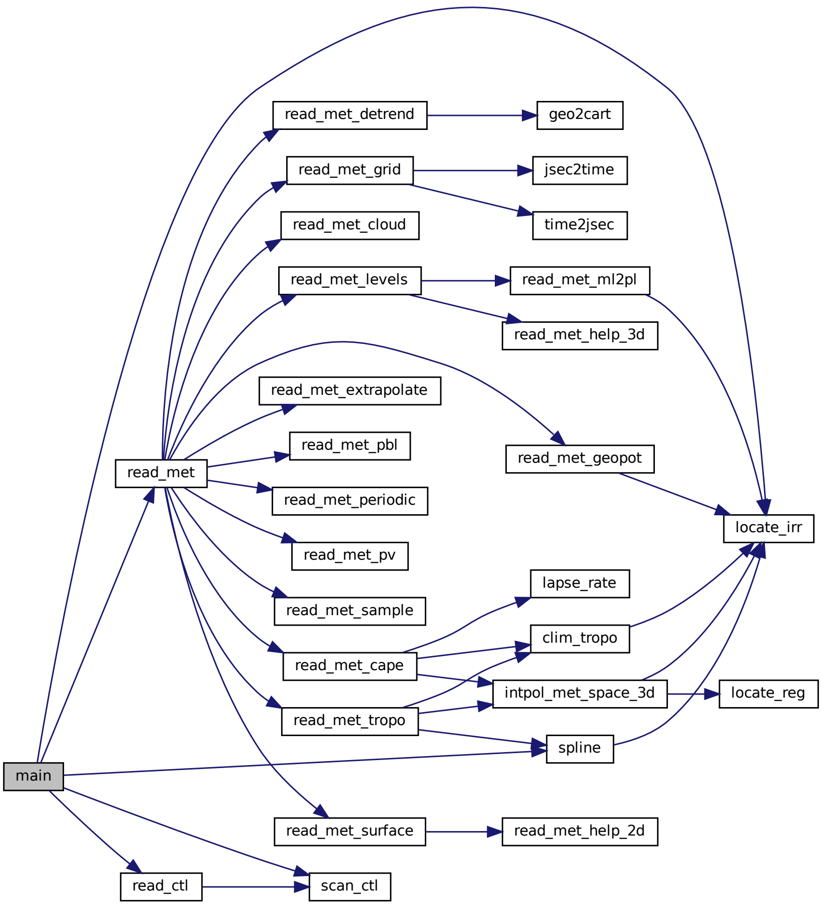
Definition at line 44 of file met_lapse.c.

```
                     {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double p2[1000], t[1000], t2[1000], z[1000], z2[1000], lat_mean,
    z_mean;

  static int hist_max[1000], hist_min[1000], hist_mean[1000], hist_sig[1000],
    nhist_max, nhist_min, nhist_mean, nhist_sig, np;

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <hist.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  int dz = (int) scan_ctl(argv[1], argc, argv, "LAPSE_DZ", -1, "20", NULL);
  double lat0 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_LAT0", -1, "-90", NULL);
  double lat1 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_LAT1", -1, "90", NULL);
  double z0 = (int) scan_ctl(argv[1], argc, argv, "LAPSE_Z0", -1, "0", NULL);
  double z1 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_Z1", -1, "100", NULL);
  int intpol =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_INTPOL", -1, "1", NULL);

  /* Loop over files... */
  for (int i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Get altitude and pressure profiles... */
    for (int iz = 0; iz < met->np; iz++)
      z[iz] = Z(met->p[iz]);
    for (int iz = 0; iz <= 250; iz++) {
      z2[iz] = 0.0 + 0.1 * iz;
      p2[iz] = P(z2[iz]);
    }

    /* Loop over grid points... */
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Check latitude range... */
        if (met->lat[iy] < lat0 || met->lat[iy] > lat1)
          continue;

        /* Interpolate temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        if (intpol == 1)
          spline(z, t, met->np, z2, t2, 251, ctl.met_tropo_spline);
        else
          for (int iz = 0; iz <= 250; iz++) {
            int idx = locate_irr(z, met->np, z2[iz]);
            t2[iz] = LIN(z[idx], t[idx], z[idx + 1], t[idx + 1], z2[iz]);
          }

        /* Loop over vertical levels... */
        for (int iz = 0; iz <= 250; iz++) {

          /* Check height range... */
          if (z2[iz] < z0 || z2[iz] > z1)
            continue;

          /* Check surface pressure... */
          if (p2[iz] > met->ps[ix][iy])
            continue;

          /* Get mean latitude and height... */
```

```
          lat_mean += met->lat[iy];
          z_mean += z2[iz];
          np++;

          /* Get lapse rates within a vertical layer... */
          int nlapse = 0;
          double lapse_max = -1e99, lapse_min = 1e99, lapse_mean =
            0, lapse_sig = 0;
          for (int iz2 = iz + 1; iz2 <= iz + dz; iz2++) {
            lapse_max =
              GSL_MAX(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]), lapse_max);
            lapse_min =
              GSL_MIN(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]), lapse_min);
            lapse_mean += LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]);
            lapse_sig += SQR(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]));
            nlapse++;
          }
          lapse_mean /= nlapse;
          lapse_sig = sqrt(GSL_MAX(lapse_sig / nlapse - SQR(lapse_mean), 0));

          /* Get histograms... */
          int idx = (int) ((lapse_max - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_max[idx]++;
            nhist_max++;
          }

          idx = (int) ((lapse_min - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_min[idx]++;
            nhist_min++;
          }

          idx = (int) ((lapse_mean - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_mean[idx]++;
            nhist_mean++;
          }

          idx = (int) ((lapse_sig - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_sig[idx]++;
            nhist_sig++;
          }
        }
      }
  }

  /* Create output file... */
  LOG(1, "Write lapse rate data: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = mean altitude [km]\n"
          "# $2 = mean latitude [deg]\n"
          "# $3 = lapse rate [K/km]\n"
          "# $4 = counts of maxima per bin\n"
          "# $5 = total number of maxima\n"
          "# $6 = normalized frequency of maxima\n"
          "# $7 = counts of minima per bin\n"
          "# $8 = total number of minima\n"
          "# $9 = normalized frequency of minima\n"
          "# $10 = counts of means per bin\n"
          "# $11 = total number of means\n"
          "# $12 = normalized frequency of means\n"
          "# $13 = counts of sigmas per bin\n"
          "# $14 = total number of sigmas\n"
          "# $15 = normalized frequency of sigmas\n\n");

  /* Write data... */
  double nmax_max = 0, nmax_min = 0, nmax_mean = 0, nmax_sig = 0;
  for (int idx = 0; idx < IDXMAX; idx++) {
    nmax_max = GSL_MAX(hist_max[idx], nmax_max);
    nmax_min = GSL_MAX(hist_min[idx], nmax_min);
    nmax_mean = GSL_MAX(hist_mean[idx], nmax_mean);
    nmax_sig = GSL_MAX(hist_sig[idx], nmax_sig);
  }
  for (int idx = 0; idx < IDXMAX; idx++)
    fprintf(out,
            "%g %g %g %d %d %g %d %d %g %d %d %g %d %d %g\n",
            z_mean / np, lat_mean / np, (idx + .5) * DLAPSE + LAPSEMIN,
            hist_max[idx], nhist_max,
            (double) hist_max[idx] / (double) nmax_max, hist_min[idx],
            nhist_min, (double) hist_min[idx] / (double) nmax_min,
            hist_mean[idx], nhist_mean,
```

```
            (double) hist_mean[idx] / (double) nmax_mean, hist_sig[idx],
            nhist_sig, (double) hist_sig[idx] / (double) nmax_sig);

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.24 met_lapse.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
```

```
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define LAPSEMIN -20.0

#define DLAPSE 0.1

#define IDXMAX 400

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double p2[1000], t[1000], t2[1000], z[1000], z2[1000], lat_mean,
    z_mean;

  static int hist_max[1000], hist_min[1000], hist_mean[1000], hist_sig[1000],
    nhist_max, nhist_min, nhist_mean, nhist_sig, np;

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <hist.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  int dz = (int) scan_ctl(argv[1], argc, argv, "LAPSE_DZ", -1, "20", NULL);
  double lat0 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_LAT0", -1, "-90", NULL);
  double lat1 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_LAT1", -1, "90", NULL);
  double z0 = (int) scan_ctl(argv[1], argc, argv, "LAPSE_Z0", -1, "0", NULL);
  double z1 =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_Z1", -1, "100", NULL);
  int intpol =
    (int) scan_ctl(argv[1], argc, argv, "LAPSE_INTPOL", -1, "1", NULL);

  /* Loop over files... */
  for (int i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Get altitude and pressure profiles... */
    for (int iz = 0; iz < met->np; iz++)
      z[iz] = Z(met->p[iz]);
    for (int iz = 0; iz <= 250; iz++) {
      z2[iz] = 0.0 + 0.1 * iz;
      p2[iz] = P(z2[iz]);
    }

    /* Loop over grid points... */
    for (int ix = 0; ix < met->nx; ix++)
      for (int iy = 0; iy < met->ny; iy++) {

        /* Check latitude range... */
        if (met->lat[iy] < lat0 || met->lat[iy] > lat1)
          continue;

        /* Interpolate temperature profile... */
        for (int iz = 0; iz < met->np; iz++)
          t[iz] = met->t[ix][iy][iz];
        if (intpol == 1)
          spline(z, t, met->np, z2, t2, 251, ctl.met_tropo_spline);
        else
          for (int iz = 0; iz <= 250; iz++) {
            int idx = locate_irr(z, met->np, z2[iz]);
            t2[iz] = LIN(z[idx], t[idx], z[idx + 1], t[idx + 1], z2[iz]);
          }
```

```

        /* Loop over vertical levels... */
        for (int iz = 0; iz <= 250; iz++) {

          /* Check height range... */
          if (z2[iz] < z0 || z2[iz] > z1)
            continue;

          /* Check surface pressure... */
          if (p2[iz] > met->ps[ix][iy])
            continue;

          /* Get mean latitude and height... */
          lat_mean += met->lat[iy];
          z_mean += z2[iz];
          np++;

          /* Get lapse rates within a vertical layer... */
          int nlapse = 0;
          double lapse_max = -1e99, lapse_min = 1e99, lapse_mean =
            0, lapse_sig = 0;
          for (int iz2 = iz + 1; iz2 <= iz + dz; iz2++) {
            lapse_max =
              GSL_MAX(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]), lapse_max);
            lapse_min =
              GSL_MIN(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]), lapse_min);
            lapse_mean += LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]);
            lapse_sig += SQR(LAPSE(p2[iz], t2[iz], p2[iz2], t2[iz2]));
            nlapse++;
          }
          lapse_mean /= nlapse;
          lapse_sig = sqrt(GSL_MAX(lapse_sig / nlapse - SQR(lapse_mean), 0));

          /* Get histograms... */
          int idx = (int) ((lapse_max - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_max[idx]++;
            nhist_max++;
          }

          idx = (int) ((lapse_min - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_min[idx]++;
            nhist_min++;
          }

          idx = (int) ((lapse_mean - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_mean[idx]++;
            nhist_mean++;
          }

          idx = (int) ((lapse_sig - LAPSEMIN) / DLAPSE);
          if (idx >= 0 && idx < IDXMAX) {
            hist_sig[idx]++;
            nhist_sig++;
          }
        }
      }
  }

  /* Create output file... */
  LOG(1, "Write lapse rate data: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = mean altitude [km]\n"
          "# $2 = mean latitude [deg]\n"
          "# $3 = lapse rate [K/km]\n"
          "# $4 = counts of maxima per bin\n"
          "# $5 = total number of maxima\n"
          "# $6 = normalized frequency of maxima\n"
          "# $7 = counts of minima per bin\n"
          "# $8 = total number of minima\n"
          "# $9 = normalized frequency of minima\n"
          "# $10 = counts of means per bin\n"
          "# $11 = total number of means\n"
          "# $12 = normalized frequency of means\n"
          "# $13 = counts of sigmas per bin\n"
          "# $14 = total number of sigmas\n"
          "# $15 = normalized frequency of sigmas\n\n");

  /* Write data... */
  double nmax_max = 0, nmax_min = 0, nmax_mean = 0, nmax_sig = 0;
  for (int idx = 0; idx < IDXMAX; idx++) {
```

```
    nmax_max = GSL_MAX(hist_max[idx], nmax_max);
    nmax_min = GSL_MAX(hist_min[idx], nmax_min);
    nmax_mean = GSL_MAX(hist_mean[idx], nmax_mean);
    nmax_sig = GSL_MAX(hist_sig[idx], nmax_sig);
  }
  for (int idx = 0; idx < IDXMAX; idx++)
    fprintf(out,
            "%g %g %g %d %d %g %d %d %g %d %d %g %d %d %g\n",
            z_mean / np, lat_mean / np, (idx + .5) * DLAPSE + LAPSEMIN,
            hist_max[idx], nhist_max,
            (double) hist_max[idx] / (double) nmax_max, hist_min[idx],
            nhist_min, (double) hist_min[idx] / (double) nmax_min,
            hist_mean[idx], nhist_mean,
            (double) hist_mean[idx] / (double) nmax_mean, hist_sig[idx],
            nhist_sig, (double) hist_sig[idx] / (double) nmax_sig);

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

## 5.25 met_map.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define NX 1441

  *Maximum number of longitudes.*
- #define NY 721

  *Maximum number of latitudes.*

### Functions

- int main (int argc, char *argv[ ])

### 5.25.1 Detailed Description

Extract map from meteorological data.

Definition in file met_map.c.

### 5.25.2 Macro Definition Documentation

#### 5.25.2.1 NX `#define NX 1441`

Maximum number of longitudes.

Definition at line 32 of file met_map.c.

#### 5.25.2.2 NY `#define NY 721`

Maximum number of latitudes.

Definition at line 35 of file met_map.c.

### 5.25.3 Function Documentation

#### 5.25.3.1 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 41 of file met_map.c.

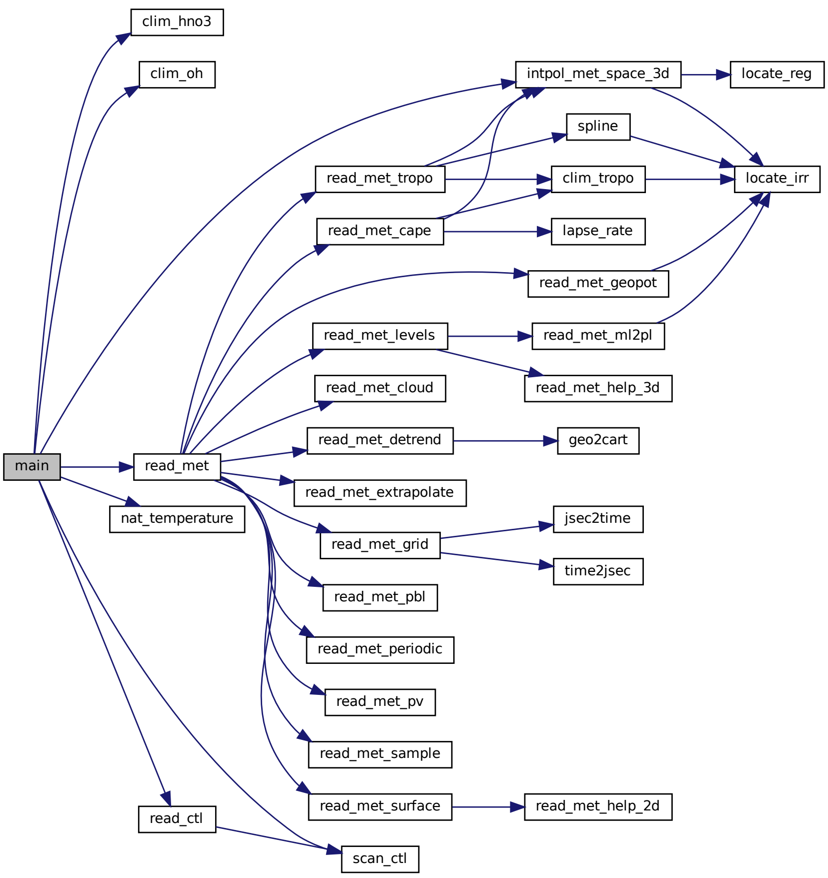
```
                    {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NX][NY], p0, ps, psm[NX][NY], ts, tsm[NX][NY], zs,
    zsm[NX][NY], us, usm[NX][NY], vs, vsm[NX][NY], pbl, pblm[NX][NY], pt,
    ptm[NX][NY], t, pm[NX][NY], tm[NX][NY], u, um[NX][NY], v, vm[NX][NY],
    w, wm[NX][NY], h2o, h2om[NX][NY], h2ot, h2otm[NX][NY], o3, o3m[NX][NY],
    hno3m[NX][NY], ohm[NX][NY], tdewm[NX][NY], ticem[NX][NY], tnatm[NX][NY],
    lwc, lwcm[NX][NY], iwc, iwcm[NX][NY], z, zm[NX][NY], pv, pvm[NX][NY],
    zt, ztm[NX][NY], tt, ttm[NX][NY], pct, pctm[NX][NY], pcb, pcbm[NX][NY],
    cl, clm[NX][NY], plcl, plclm[NX][NY], plfc, plfcm[NX][NY],
    pel, pelm[NX][NY], cape, capem[NX][NY], cin, cinm[NX][NY],
    rhm[NX][NY], rhicem[NX][NY], theta, ptop, pbot, t0,
    lon, lon0, lon1, lons[NX], dlon, lat, lat0, lat1, lats[NY], dlat, cw[3];

  static int i, ix, iy, np[NX][NY], npc[NX][NY], npt[NX][NY], nx, ny, ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <map.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  p0 = P(scan_ctl(argv[1], argc, argv, "MAP_Z0", -1, "10", NULL));
  lon0 = scan_ctl(argv[1], argc, argv, "MAP_LON0", -1, "-180", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "MAP_LON1", -1, "180", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "MAP_DLON", -1, "-999", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "MAP_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "MAP_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "MAP_DLAT", -1, "-999", NULL);
  theta = scan_ctl(argv[1], argc, argv, "MAP_THETA", -1, "-999", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set horizontal grid... */
    if (dlon <= 0)
      dlon = fabs(met->lon[1] - met->lon[0]);
    if (dlat <= 0)
      dlat = fabs(met->lat[1] - met->lat[0]);
    if (lon0 < -360 && lon1 > 360) {
      lon0 = gsl_stats_min(met->lon, 1, (size_t) met->nx);
      lon1 = gsl_stats_max(met->lon, 1, (size_t) met->nx);
    }
    nx = ny = 0;
    for (lon = lon0; lon <= lon1; lon += dlon) {
      lons[nx] = lon;
      if ((++nx) > NX)
        ERRMSG("Too many longitudes!");
```

```
    }
    if (lat0 < -90 && lat1 > 90) {
      lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
      lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
    }
    for (lat = lat0; lat <= lat1; lat += dlat) {
      lats[ny] = lat;
      if ((++ny) > NY)
        ERRMSG("Too many latitudes!");
    }

    /* Average... */
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {

        /* Find pressure level for given theta level... */
        if (theta > 0) {
          ptop = met->p[met->np - 1];
          pbot = met->p[0];
          do {
            p0 = 0.5 * (ptop + pbot);
            intpol_met_space_3d(met, met->t, p0, lons[ix], lats[iy],
                                &t0, ci, cw, 1);
            if (THETA(p0, t0) > theta)
              ptop = p0;
            else
              pbot = p0;
          } while (fabs(ptop - pbot) > 1e-5);
        }

        /* Interpolate meteo data... */
        INTPOL_SPACE_ALL(p0, lons[ix], lats[iy]);

        /* Averaging... */
        timem[ix][iy] += met->time;
        zm[ix][iy] += z;
        pm[ix][iy] += p0;
        tm[ix][iy] += t;
        um[ix][iy] += u;
        vm[ix][iy] += v;
        wm[ix][iy] += w;
        pvm[ix][iy] += pv;
        h2om[ix][iy] += h2o;
        o3m[ix][iy] += o3;
        lwcm[ix][iy] += lwc;
        iwcm[ix][iy] += iwc;
        psm[ix][iy] += ps;
        tsm[ix][iy] += ts;
        zsm[ix][iy] += zs;
        usm[ix][iy] += us;
        vsm[ix][iy] += vs;
        pblm[ix][iy] += pbl;
        pctm[ix][iy] += pct;
        pcbm[ix][iy] += pcb;
        clm[ix][iy] += cl;
        if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
            && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
          plclm[ix][iy] += plcl;
          plfcm[ix][iy] += plfc;
          pelm[ix][iy] += pel;
          capem[ix][iy] += cape;
          cinm[ix][iy] += cin;
          npc[ix][iy]++;
        }
        if (gsl_finite(pt)) {
          ptm[ix][iy] += pt;
          ztm[ix][iy] += zt;
          ttm[ix][iy] += tt;
          h2otm[ix][iy] += h2ot;
          npt[ix][iy]++;
        }
        hno3m[ix][iy] += clim_hno3(met->time, lats[iy], p0);
        tnatm[ix][iy] +=
          nat_temperature(p0, h2o, clim_hno3(met->time, lats[iy], p0));
        ohm[ix][iy] += clim_oh(met->time, lats[iy], p0);
        rhm[ix][iy] += RH(p0, t, h2o);
        rhicem[ix][iy] += RHICE(p0, t, h2o);
        tdewm[ix][iy] += TDEW(p0, h2o);
        ticem[ix][iy] += TICE(p0, h2o);
        np[ix][iy]++;
      }
  }

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");
```

```
/* Write header... */
fprintf(out,
        "# $1 = time [s]\n"
        "# $2 = altitude [km]\n"
        "# $3 = longitude [deg]\n"
        "# $4 = latitude [deg]\n"
        "# $5 = pressure [hPa]\n"
        "# $6 = temperature [K]\n"
        "# $7 = zonal wind [m/s]\n"
        "# $8 = meridional wind [m/s]\n"
        "# $9 = vertical velocity [hPa/s]\n"
        "# $10 = H2O volume mixing ratio [ppv]\n");
fprintf(out,
        "# $11 = O3 volume mixing ratio [ppv]\n"
        "# $12 = geopotential height [km]\n"
        "# $13 = potential vorticity [PVU]\n"
        "# $14 = surface pressure [hPa]\n"
        "# $15 = surface temperature [K]\n"
        "# $16 = surface geopotential height [km]\n"
        "# $17 = surface zonal wind [m/s]\n"
        "# $18 = surface meridional wind [m/s]\n"
        "# $19 = tropopause pressure [hPa]\n"
        "# $20 = tropopause geopotential height [km]\n");
fprintf(out,
        "# $21 = tropopause temperature [K]\n"
        "# $22 = tropopause water vapor [ppv]\n"
        "# $23 = cloud liquid water content [kg/kg]\n"
        "# $24 = cloud ice water content [kg/kg]\n"
        "# $25 = total column cloud water [kg/m^2]\n"
        "# $26 = cloud top pressure [hPa]\n"
        "# $27 = cloud bottom pressure [hPa]\n"
        "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
        "# $29 = pressure at level of free convection (LFC) [hPa]\n"
        "# $30 = pressure at equilibrium level (EL) [hPa]\n");
fprintf(out,
        "# $31 = convective available potential energy (CAPE) [J/kg]\n"
        "# $32 = convective inhibition (CIN) [J/kg]\n"
        "# $33 = relative humidity over water [%%]\n"
        "# $34 = relative humidity over ice [%%]\n"
        "# $35 = dew point temperature [K]\n"
        "# $36 = frost point temperature [K]\n"
        "# $37 = NAT temperature [K]\n"
        "# $38 = HNO3 volume mixing ratio [ppv]\n"
        "# $39 = OH concentration [molec/cm^3]\n"
        "# $40 = boundary layer pressure [hPa]\n");
fprintf(out,
        "# $41 = number of data points\n"
        "# $42 = number of tropopause data points\n"
        "# $43 = number of CAPE data points\n");

/* Write data... */
for (iy = 0; iy < ny; iy++) {
  fprintf(out, "\n");
  for (ix = 0; ix < nx; ix++)
    fprintf(out,
            "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g"
            " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
            " %g %g %g %g %g %g %g %g %g %g %g %d %d %d\n",
            timem[ix][iy] / np[ix][iy], Z(pm[ix][iy] / np[ix][iy]),
            lons[ix], lats[iy], pm[ix][iy] / np[ix][iy],
            tm[ix][iy] / np[ix][iy], um[ix][iy] / np[ix][iy],
            vm[ix][iy] / np[ix][iy], wm[ix][iy] / np[ix][iy],
            h2om[ix][iy] / np[ix][iy], o3m[ix][iy] / np[ix][iy],
            zm[ix][iy] / np[ix][iy], pvm[ix][iy] / np[ix][iy],
            psm[ix][iy] / np[ix][iy], tsm[ix][iy] / np[ix][iy],
            zsm[ix][iy] / np[ix][iy], usm[ix][iy] / np[ix][iy],
            vsm[ix][iy] / np[ix][iy], ptm[ix][iy] / npt[ix][iy],
            ztm[ix][iy] / npt[ix][iy], ttm[ix][iy] / npt[ix][iy],
            h2otm[ix][iy] / npt[ix][iy], lwcm[ix][iy] / np[ix][iy],
            iwcm[ix][iy] / np[ix][iy], clm[ix][iy] / np[ix][iy],
            pctm[ix][iy] / np[ix][iy], pcbm[ix][iy] / np[ix][iy],
            plclm[ix][iy] / npc[ix][iy], plfcm[ix][iy] / npc[ix][iy],
            pelm[ix][iy] / npc[ix][iy], capem[ix][iy] / npc[ix][iy],
            cinm[ix][iy] / npc[ix][iy], rhm[ix][iy] / np[ix][iy],
            rhicem[ix][iy] / np[ix][iy], tdewm[ix][iy] / np[ix][iy],
            ticem[ix][iy] / np[ix][iy], tnatm[ix][iy] / np[ix][iy],
            hno3m[ix][iy] / np[ix][iy], ohm[ix][iy] / np[ix][iy],
            pblm[ix][iy] / np[ix][iy], np[ix][iy],
            npt[ix][iy], npc[ix][iy]);
}

/* Close file... */
fclose(out);

/* Free... */
free(met);
```

```

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.26 met_map.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define NX 1441
```

```
#define NY 721

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NX][NY], p0, ps, psm[NX][NY], ts, tsm[NX][NY], zs,
    zsm[NX][NY], us, usm[NX][NY], vs, vsm[NX][NY], pbl, pblm[NX][NY], pt,
    ptm[NX][NY], t, pm[NX][NY], tm[NX][NY], u, um[NX][NY], v, vm[NX][NY],
    w, wm[NX][NY], h2o, h2om[NX][NY], h2ot, h2otm[NX][NY], o3, o3m[NX][NY],
    hno3m[NX][NY], ohm[NX][NY], tdewm[NX][NY], ticem[NX][NY], tnatm[NX][NY],
    lwc, lwcm[NX][NY], iwc, iwcm[NX][NY], z, zm[NX][NY], pv, pvm[NX][NY],
    zt, ztm[NX][NY], tt, ttm[NX][NY], pct, pctm[NX][NY], pcb, pcbm[NX][NY],
    cl, clm[NX][NY], plcl, plclm[NX][NY], plfc, plfcm[NX][NY],
    pel, pelm[NX][NY], cape, capem[NX][NY], cin, cinm[NX][NY],
    rhm[NX][NY], rhicem[NX][NY], theta, ptop, pbot, t0,
    lon, lon0, lon1, lons[NX], dlon, lat, lat0, lat1, lats[NY], dlat, cw[3];

  static int i, ix, iy, np[NX][NY], npc[NX][NY], npt[NX][NY], nx, ny, ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <map.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  p0 = P(scan_ctl(argv[1], argc, argv, "MAP_Z0", -1, "10", NULL));
  lon0 = scan_ctl(argv[1], argc, argv, "MAP_LON0", -1, "-180", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "MAP_LON1", -1, "180", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "MAP_DLON", -1, "-999", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "MAP_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "MAP_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "MAP_DLAT", -1, "-999", NULL);
  theta = scan_ctl(argv[1], argc, argv, "MAP_THETA", -1, "-999", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set horizontal grid... */
    if (dlon <= 0)
      dlon = fabs(met->lon[1] - met->lon[0]);
    if (dlat <= 0)
      dlat = fabs(met->lat[1] - met->lat[0]);
    if (lon0 < -360 && lon1 > 360) {
      lon0 = gsl_stats_min(met->lon, 1, (size_t) met->nx);
      lon1 = gsl_stats_max(met->lon, 1, (size_t) met->nx);
    }
    nx = ny = 0;
    for (lon = lon0; lon <= lon1; lon += dlon) {
      lons[nx] = lon;
      if ((++nx) > NX)
        ERRMSG("Too many longitudes!");
    }
    if (lat0 < -90 && lat1 > 90) {
      lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
      lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
    }
    for (lat = lat0; lat <= lat1; lat += dlat) {
      lats[ny] = lat;
      if ((++ny) > NY)
        ERRMSG("Too many latitudes!");
    }

    /* Average... */
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {

        /* Find pressure level for given theta level... */
        if (theta > 0) {
```

```
          ptop = met->p[met->np - 1];
          pbot = met->p[0];
          do {
            p0 = 0.5 * (ptop + pbot);
            intpol_met_space_3d(met, met->t, p0, lons[ix], lats[iy],
                                &t0, ci, cw, 1);
            if (THETA(p0, t0) > theta)
              ptop = p0;
            else
              pbot = p0;
          } while (fabs(ptop - pbot) > 1e-5);
        }

        /* Interpolate meteo data... */
        INTPOL_SPACE_ALL(p0, lons[ix], lats[iy]);

        /* Averaging... */
        timem[ix][iy] += met->time;
        zm[ix][iy] += z;
        pm[ix][iy] += p0;
        tm[ix][iy] += t;
        um[ix][iy] += u;
        vm[ix][iy] += v;
        wm[ix][iy] += w;
        pvm[ix][iy] += pv;
        h2om[ix][iy] += h2o;
        o3m[ix][iy] += o3;
        lwcm[ix][iy] += lwc;
        iwcm[ix][iy] += iwc;
        psm[ix][iy] += ps;
        tsm[ix][iy] += ts;
        zsm[ix][iy] += zs;
        usm[ix][iy] += us;
        vsm[ix][iy] += vs;
        pblm[ix][iy] += pbl;
        pctm[ix][iy] += pct;
        pcbm[ix][iy] += pcb;
        clm[ix][iy] += cl;
        if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
            && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
          plclm[ix][iy] += plcl;
          plfcm[ix][iy] += plfc;
          pelm[ix][iy] += pel;
          capem[ix][iy] += cape;
          cinm[ix][iy] += cin;
          npc[ix][iy]++;
        }
        if (gsl_finite(pt)) {
          ptm[ix][iy] += pt;
          ztm[ix][iy] += zt;
          ttm[ix][iy] += tt;
          h2otm[ix][iy] += h2ot;
          npt[ix][iy]++;
        }
        hno3m[ix][iy] += clim_hno3(met->time, lats[iy], p0);
        tnatm[ix][iy] +=
          nat_temperature(p0, h2o, clim_hno3(met->time, lats[iy], p0));
        ohm[ix][iy] += clim_oh(met->time, lats[iy], p0);
        rhm[ix][iy] += RH(p0, t, h2o);
        rhicem[ix][iy] += RHICE(p0, t, h2o);
        tdewm[ix][iy] += TDEW(p0, h2o);
        ticem[ix][iy] += TICE(p0, h2o);
        np[ix][iy]++;
      }
  }

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
          "# $7 = zonal wind [m/s]\n"
          "# $8 = meridional wind [m/s]\n"
          "# $9 = vertical velocity [hPa/s]\n"
          "# $10 = H2O volume mixing ratio [ppv]\n");
  fprintf(out,
          "# $11 = O3 volume mixing ratio [ppv]\n"
          "# $12 = geopotential height [km]\n"
          "# $13 = potential vorticity [PVU]\n"
```

```
          "# $14 = surface pressure [hPa]\n"
          "# $15 = surface temperature [K]\n"
          "# $16 = surface geopotential height [km]\n"
          "# $17 = surface zonal wind [m/s]\n"
          "# $18 = surface meridional wind [m/s]\n"
          "# $19 = tropopause pressure [hPa]\n"
          "# $20 = tropopause geopotential height [km]\n");
  fprintf(out,
          "# $21 = tropopause temperature [K]\n"
          "# $22 = tropopause water vapor [ppv]\n"
          "# $23 = cloud liquid water content [kg/kg]\n"
          "# $24 = cloud ice water content [kg/kg]\n"
          "# $25 = total column cloud water [kg/m^2]\n"
          "# $26 = cloud top pressure [hPa]\n"
          "# $27 = cloud bottom pressure [hPa]\n"
          "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
          "# $29 = pressure at level of free convection (LFC) [hPa]\n"
          "# $30 = pressure at equilibrium level (EL) [hPa]\n");
  fprintf(out,
          "# $31 = convective available potential energy (CAPE) [J/kg]\n"
          "# $32 = convective inhibition (CIN) [J/kg]\n"
          "# $33 = relative humidity over water [%%]\n"
          "# $34 = relative humidity over ice [%%]\n"
          "# $35 = dew point temperature [K]\n"
          "# $36 = frost point temperature [K]\n"
          "# $37 = NAT temperature [K]\n"
          "# $38 = HNO3 volume mixing ratio [ppv]\n"
          "# $39 = OH concentration [molec/cm^3]\n"
          "# $40 = boundary layer pressure [hPa]\n");
  fprintf(out,
          "# $41 = number of data points\n"
          "# $42 = number of tropopause data points\n"
          "# $43 = number of CAPE data points\n");

  /* Write data... */
  for (iy = 0; iy < ny; iy++) {
    fprintf(out, "\n");
    for (ix = 0; ix < nx; ix++)
      fprintf(out,
              "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %g %g %g %g %g %g %d %d %d\n",
              timem[ix][iy] / np[ix][iy], Z(pm[ix][iy] / np[ix][iy]),
              lons[ix], lats[iy], pm[ix][iy] / np[ix][iy],
              tm[ix][iy] / np[ix][iy], um[ix][iy] / np[ix][iy],
              vm[ix][iy] / np[ix][iy], wm[ix][iy] / np[ix][iy],
              h2om[ix][iy] / np[ix][iy], o3m[ix][iy] / np[ix][iy],
              zm[ix][iy] / np[ix][iy], pvm[ix][iy] / np[ix][iy],
              psm[ix][iy] / np[ix][iy], tsm[ix][iy] / np[ix][iy],
              zsm[ix][iy] / np[ix][iy], usm[ix][iy] / np[ix][iy],
              vsm[ix][iy] / np[ix][iy], ptm[ix][iy] / npt[ix][iy],
              ztm[ix][iy] / npt[ix][iy], ttm[ix][iy] / npt[ix][iy],
              h2otm[ix][iy] / npt[ix][iy], lwcm[ix][iy] / np[ix][iy],
              iwcm[ix][iy] / np[ix][iy], clm[ix][iy] / np[ix][iy],
              pctm[ix][iy] / np[ix][iy], pcbm[ix][iy] / np[ix][iy],
              plclm[ix][iy] / npc[ix][iy], plfcm[ix][iy] / npc[ix][iy],
              pelm[ix][iy] / npc[ix][iy], capem[ix][iy] / npc[ix][iy],
              cinm[ix][iy] / npc[ix][iy], rhm[ix][iy] / np[ix][iy],
              rhicem[ix][iy] / np[ix][iy], tdewm[ix][iy] / np[ix][iy],
              ticem[ix][iy] / np[ix][iy], tnatm[ix][iy] / np[ix][iy],
              hno3m[ix][iy] / np[ix][iy], ohm[ix][iy] / np[ix][iy],
              pblm[ix][iy] / np[ix][iy], np[ix][iy],
              npt[ix][iy], npc[ix][iy]);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

## 5.27 met_prof.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define NZ 1000

  *Maximum number of altitudes.*

### Functions

- int main (int argc, char ∗argv[ ])

## 5.27.1 Detailed Description

Extract vertical profile from meteorological data.

Definition in file met_prof.c.

## 5.27.2 Macro Definition Documentation

### 5.27.2.1 NZ `#define NZ 1000`

Maximum number of altitudes.

Definition at line 32 of file met_prof.c.

## 5.27.3 Function Documentation

### 5.27.3.1 main()

```
int main (
        int argc,
        char * argv[ ] )
```

Definition at line 38 of file met_prof.c.

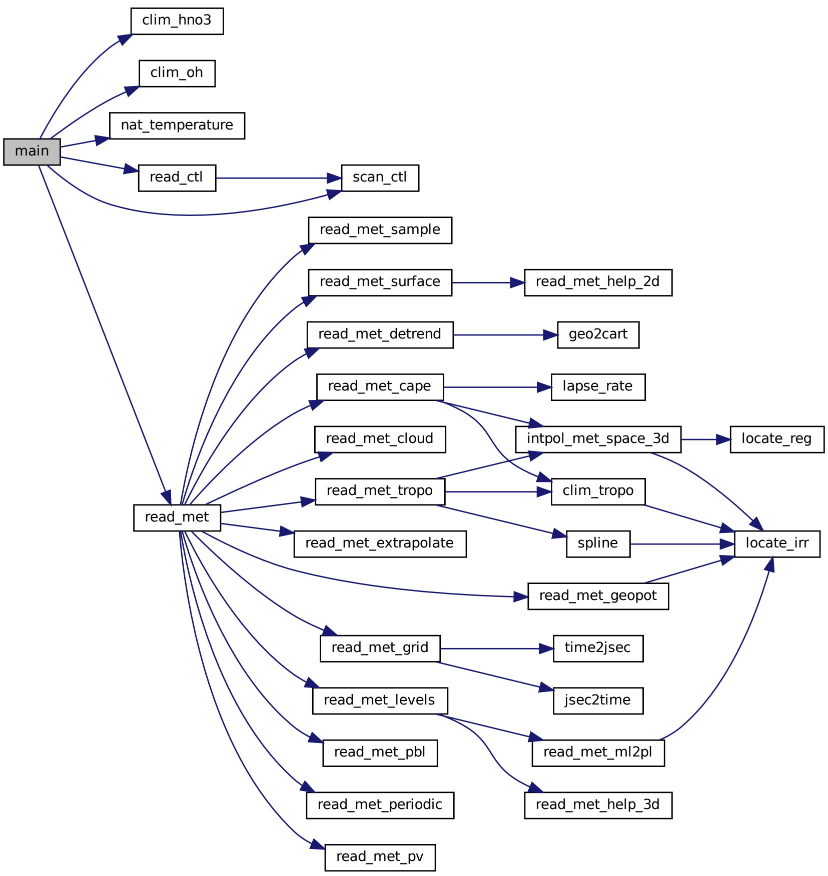
```
                  {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NZ], z, z0, z1, dz, lon, lon0, lon1, dlon, lonm[NZ],
    lat, lat0, lat1, dlat, latm[NZ], t, tm[NZ], u, um[NZ], v, vm[NZ], w,
    wm[NZ], h2o, h2om[NZ], h2ot, h2otm[NZ], o3, o3m[NZ], lwc, lwcm[NZ],
    iwc, iwcm[NZ], ps, psm[NZ], ts, tsm[NZ], zs, zsm[NZ], us, usm[NZ],
    vs, vsm[NZ], pbl, pblm[NZ], pt, ptm[NZ], pct, pctm[NZ], pcb, pcbm[NZ],
    cl, clm[NZ], plcl, plclm[NZ], plfc, plfcm[NZ], pel, pelm[NZ],
    cape, capem[NZ], cin, cinm[NZ], tt, ttm[NZ], zm[NZ], zt, ztm[NZ],
    pv, pvm[NZ], plev[NZ], rhm[NZ], rhicem[NZ], tdewm[NZ], ticem[NZ],
    tnatm[NZ], hno3m[NZ], ohm[NZ], cw[3];

  static int i, iz, np[NZ], npc[NZ], npt[NZ], nz, ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

```

```
/* Check arguments... */
if (argc < 4)
  ERRMSG("Give parameters: <ctl> <prof.tab> <met0> [ <met1> ... ]");

/* Read control parameters... */
read_ctl(argv[1], argc, argv, &ctl);
z0 = scan_ctl(argv[1], argc, argv, "PROF_Z0", -1, "-999", NULL);
z1 = scan_ctl(argv[1], argc, argv, "PROF_Z1", -1, "-999", NULL);
dz = scan_ctl(argv[1], argc, argv, "PROF_DZ", -1, "-999", NULL);
lon0 = scan_ctl(argv[1], argc, argv, "PROF_LON0", -1, "0", NULL);
lon1 = scan_ctl(argv[1], argc, argv, "PROF_LON1", -1, "0", NULL);
dlon = scan_ctl(argv[1], argc, argv, "PROF_DLON", -1, "-999", NULL);
lat0 = scan_ctl(argv[1], argc, argv, "PROF_LAT0", -1, "0", NULL);
lat1 = scan_ctl(argv[1], argc, argv, "PROF_LAT1", -1, "0", NULL);
dlat = scan_ctl(argv[1], argc, argv, "PROF_DLAT", -1, "-999", NULL);

/* Loop over input files... */
for (i = 3; i < argc; i++) {

  /* Read meteorological data... */
  if (!read_met(&ctl, argv[i], met))
    continue;

  /* Set vertical grid... */
  if (z0 < 0)
    z0 = Z(met->p[0]);
  if (z1 < 0)
    z1 = Z(met->p[met->np - 1]);
  nz = 0;
  if (dz < 0) {
    for (iz = 0; iz < met->np; iz++)
      if (Z(met->p[iz]) >= z0 && Z(met->p[iz]) <= z1) {
        plev[nz] = met->p[iz];
        if ((++nz) > NZ)
          ERRMSG("Too many pressure levels!");
      }
  } else
    for (z = z0; z <= z1; z += dz) {
      plev[nz] = P(z);
      if ((++nz) > NZ)
        ERRMSG("Too many pressure levels!");
    }

  /* Set horizontal grid... */
  if (dlon <= 0)
    dlon = fabs(met->lon[1] - met->lon[0]);
  if (dlat <= 0)
    dlat = fabs(met->lat[1] - met->lat[0]);

  /* Average... */
  for (iz = 0; iz < nz; iz++)
    for (lon = lon0; lon <= lon1; lon += dlon)
      for (lat = lat0; lat <= lat1; lat += dlat) {

        /* Interpolate meteo data... */
        INTPOL_SPACE_ALL(plev[iz], lon, lat);

        /* Averaging... */
        if (gsl_finite(t) && gsl_finite(u)
            && gsl_finite(v) && gsl_finite(w)) {
          timem[iz] += met->time;
          lonm[iz] += lon;
          latm[iz] += lat;
          zm[iz] += z;
          tm[iz] += t;
          um[iz] += u;
          vm[iz] += v;
          wm[iz] += w;
          pvm[iz] += pv;
          h2om[iz] += h2o;
          o3m[iz] += o3;
          lwcm[iz] += lwc;
          iwcm[iz] += iwc;
          psm[iz] += ps;
          tsm[iz] += ts;
          zsm[iz] += zs;
          usm[iz] += us;
          vsm[iz] += vs;
          pblm[iz] += pbl;
          pctm[iz] += pct;
          pcbm[iz] += pcb;
          clm[iz] += cl;
          if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
              && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
            plclm[iz] += plcl;
            plfcm[iz] += plfc;
            pelm[iz] += pel;
```

```
              capem[iz] += cape;
              cinm[iz] += cin;
              npc[iz]++;
            }
            if (gsl_finite(pt)) {
              ptm[iz] += pt;
              ztm[iz] += zt;
              ttm[iz] += tt;
              h2otm[iz] += h2ot;
              npt[iz]++;
            }
            rhm[iz] += RH(plev[iz], t, h2o);
            rhicem[iz] += RHICE(plev[iz], t, h2o);
            tdewm[iz] += TDEW(plev[iz], h2o);
            ticem[iz] += TICE(plev[iz], h2o);
            hno3m[iz] += clim_hno3(met->time, lat, plev[iz]);
            tnatm[iz] +=
              nat_temperature(plev[iz], h2o,
                              clim_hno3(met->time, lat, plev[iz]));
            ohm[iz] += clim_oh(met->time, lat, plev[iz]);
            np[iz]++;
          }
        }
    }

    /* Create output file... */
    LOG(1, "Write meteorological data file: %s", argv[2]);
    if (!(out = fopen(argv[2], "w")))
      ERRMSG("Cannot create file!");

    /* Write header... */
    fprintf(out,
            "# $1 = time [s]\n"
            "# $2 = altitude [km]\n"
            "# $3 = longitude [deg]\n"
            "# $4 = latitude [deg]\n"
            "# $5 = pressure [hPa]\n"
            "# $6 = temperature [K]\n"
            "# $7 = zonal wind [m/s]\n"
            "# $8 = meridional wind [m/s]\n"
            "# $9 = vertical velocity [hPa/s]\n"
            "# $10 = H2O volume mixing ratio [ppv]\n");
    fprintf(out,
            "# $11 = O3 volume mixing ratio [ppv]\n"
            "# $12 = geopotential height [km]\n"
            "# $13 = potential vorticity [PVU]\n"
            "# $14 = surface pressure [hPa]\n"
            "# $15 = surface temperature [K]\n"
            "# $16 = surface geopotential height [km]\n"
            "# $17 = surface zonal wind [m/s]\n"
            "# $18 = surface meridional wind [m/s]\n"
            "# $19 = tropopause pressure [hPa]\n"
            "# $20 = tropopause geopotential height [km]\n");
    fprintf(out,
            "# $21 = tropopause temperature [K]\n"
            "# $22 = tropopause water vapor [ppv]\n"
            "# $23 = cloud liquid water content [kg/kg]\n"
            "# $24 = cloud ice water content [kg/kg]\n"
            "# $25 = total column cloud water [kg/m^2]\n"
            "# $26 = cloud top pressure [hPa]\n"
            "# $27 = cloud bottom pressure [hPa]\n"
            "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
            "# $29 = pressure at level of free convection (LFC) [hPa]\n"
            "# $30 = pressure at equilibrium level (EL) [hPa]\n");
    fprintf(out,
            "# $31 = convective available potential energy (CAPE) [J/kg]\n"
            "# $32 = convective inhibition (CIN) [J/kg]\n"
            "# $33 = relative humidity over water [%%]\n"
            "# $34 = relative humidity over ice [%%]\n"
            "# $35 = dew point temperature [K]\n"
            "# $36 = frost point temperature [K]\n"
            "# $37 = NAT temperature [K]\n"
            "# $38 = HNO3 volume mixing ratio [ppv]\n"
            "# $39 = OH concentration [molec/cm^3]\n"
            "# $40 = boundary layer pressure [hPa]\n");
    fprintf(out,
            "# $41 = number of data points\n"
            "# $42 = number of tropopause data points\n"
            "# $43 = number of CAPE data points\n\n");

    /* Write data... */
    for (iz = 0; iz < nz; iz++)
      fprintf(out,
              "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %g %g %g %g %d %d %d\n",
              timem[iz] / np[iz], Z(plev[iz]), lonm[iz] / np[iz],
```

```
              latm[iz] / np[iz], plev[iz], tm[iz] / np[iz], um[iz] / np[iz],
              vm[iz] / np[iz], wm[iz] / np[iz], h2om[iz] / np[iz],
              o3m[iz] / np[iz], zm[iz] / np[iz], pvm[iz] / np[iz],
              psm[iz] / np[iz], tsm[iz] / np[iz], zsm[iz] / np[iz],
              usm[iz] / np[iz], vsm[iz] / np[iz], ptm[iz] / npt[iz],
              ztm[iz] / npt[iz], ttm[iz] / npt[iz], h2otm[iz] / npt[iz],
              lwcm[iz] / np[iz], iwcm[iz] / np[iz], clm[iz] / np[iz],
              pctm[iz] / np[iz], pcbm[iz] / np[iz], plclm[iz] / npc[iz],
              plfcm[iz] / npc[iz], pelm[iz] / npc[iz], capem[iz] / npc[iz],
              cinm[iz] / npc[iz], rhm[iz] / np[iz], rhicem[iz] / np[iz],
              tdewm[iz] / np[iz], ticem[iz] / np[iz], tnatm[iz] / np[iz],
              hno3m[iz] / np[iz], ohm[iz] / np[iz], pblm[iz] / np[iz],
              np[iz], npt[iz], npc[iz]);

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.28 met_prof.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.
```

```

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define NZ 1000

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NZ], z, z0, z1, dz, lon, lon0, lon1, dlon, lonm[NZ],
    lat, lat0, lat1, dlat, latm[NZ], t, tm[NZ], u, um[NZ], v, vm[NZ], w,
    wm[NZ], h2o, h2om[NZ], h2ot, h2otm[NZ], o3, o3m[NZ], lwc, lwcm[NZ],
    iwc, iwcm[NZ], ps, psm[NZ], ts, tsm[NZ], zs, zsm[NZ], us, usm[NZ],
    vs, vsm[NZ], pbl, pblm[NZ], pt, ptm[NZ], pct, pctm[NZ], pcb, pcbm[NZ],
    cl, clm[NZ], plcl, plclm[NZ], plfc, plfcm[NZ], pel, pelm[NZ],
    cape, capem[NZ], cin, cinm[NZ], tt, ttm[NZ], zm[NZ], zt, ztm[NZ],
    pv, pvm[NZ], plev[NZ], rhm[NZ], rhicem[NZ], tdewm[NZ], ticem[NZ],
    tnatm[NZ], hno3m[NZ], ohm[NZ], cw[3];

  static int i, iz, np[NZ], npc[NZ], npt[NZ], nz, ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <prof.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  z0 = scan_ctl(argv[1], argc, argv, "PROF_Z0", -1, "-999", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "PROF_Z1", -1, "-999", NULL);
  dz = scan_ctl(argv[1], argc, argv, "PROF_DZ", -1, "-999", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "PROF_LON0", -1, "0", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "PROF_LON1", -1, "0", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "PROF_DLON", -1, "-999", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "PROF_LAT0", -1, "0", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "PROF_LAT1", -1, "0", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "PROF_DLAT", -1, "-999", NULL);

  /* Loop over input files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set vertical grid... */
    if (z0 < 0)
      z0 = Z(met->p[0]);
    if (z1 < 0)
      z1 = Z(met->p[met->np - 1]);
    nz = 0;
    if (dz < 0) {
      for (iz = 0; iz < met->np; iz++)
        if (Z(met->p[iz]) >= z0 && Z(met->p[iz]) <= z1) {
          plev[nz] = met->p[iz];
          if ((++nz) > NZ)
            ERRMSG("Too many pressure levels!");
        }
    } else
      for (z = z0; z <= z1; z += dz) {
```

```
        plev[nz] = P(z);
        if ((++nz) > NZ)
          ERRMSG("Too many pressure levels!");
      }

    /* Set horizontal grid... */
    if (dlon <= 0)
      dlon = fabs(met->lon[1] - met->lon[0]);
    if (dlat <= 0)
      dlat = fabs(met->lat[1] - met->lat[0]);

    /* Average... */
    for (iz = 0; iz < nz; iz++)
      for (lon = lon0; lon <= lon1; lon += dlon)
        for (lat = lat0; lat <= lat1; lat += dlat) {

          /* Interpolate meteo data... */
          INTPOL_SPACE_ALL(plev[iz], lon, lat);

          /* Averaging... */
          if (gsl_finite(t) && gsl_finite(u)
              && gsl_finite(v) && gsl_finite(w)) {
            timem[iz] += met->time;
            lonm[iz] += lon;
            latm[iz] += lat;
            zm[iz] += z;
            tm[iz] += t;
            um[iz] += u;
            vm[iz] += v;
            wm[iz] += w;
            pvm[iz] += pv;
            h2om[iz] += h2o;
            o3m[iz] += o3;
            lwcm[iz] += lwc;
            iwcm[iz] += iwc;
            psm[iz] += ps;
            tsm[iz] += ts;
            zsm[iz] += zs;
            usm[iz] += us;
            vsm[iz] += vs;
            pblm[iz] += pbl;
            pctm[iz] += pct;
            pcbm[iz] += pcb;
            clm[iz] += cl;
            if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
                && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
              plclm[iz] += plcl;
              plfcm[iz] += plfc;
              pelm[iz] += pel;
              capem[iz] += cape;
              cinm[iz] += cin;
              npc[iz]++;
            }
            if (gsl_finite(pt)) {
              ptm[iz] += pt;
              ztm[iz] += zt;
              ttm[iz] += tt;
              h2otm[iz] += h2ot;
              npt[iz]++;
            }
            rhm[iz] += RH(plev[iz], t, h2o);
            rhicem[iz] += RHICE(plev[iz], t, h2o);
            tdewm[iz] += TDEW(plev[iz], h2o);
            ticem[iz] += TICE(plev[iz], h2o);
            hno3m[iz] += clim_hno3(met->time, lat, plev[iz]);
            tnatm[iz] +=
              nat_temperature(plev[iz], h2o,
                              clim_hno3(met->time, lat, plev[iz]));
            ohm[iz] += clim_oh(met->time, lat, plev[iz]);
            np[iz]++;
          }
        }
  }

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
```

```
        "# $7 = zonal wind [m/s]\n"
        "# $8 = meridional wind [m/s]\n"
        "# $9 = vertical velocity [hPa/s]\n"
        "# $10 = H2O volume mixing ratio [ppv]\n");
fprintf(out,
        "# $11 = O3 volume mixing ratio [ppv]\n"
        "# $12 = geopotential height [km]\n"
        "# $13 = potential vorticity [PVU]\n"
        "# $14 = surface pressure [hPa]\n"
        "# $15 = surface temperature [K]\n"
        "# $16 = surface geopotential height [km]\n"
        "# $17 = surface zonal wind [m/s]\n"
        "# $18 = surface meridional wind [m/s]\n"
        "# $19 = tropopause pressure [hPa]\n"
        "# $20 = tropopause geopotential height [km]\n");
fprintf(out,
        "# $21 = tropopause temperature [K]\n"
        "# $22 = tropopause water vapor [ppv]\n"
        "# $23 = cloud liquid water content [kg/kg]\n"
        "# $24 = cloud ice water content [kg/kg]\n"
        "# $25 = total column cloud water [kg/m^2]\n"
        "# $26 = cloud top pressure [hPa]\n"
        "# $27 = cloud bottom pressure [hPa]\n"
        "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
        "# $29 = pressure at level of free convection (LFC) [hPa]\n"
        "# $30 = pressure at equilibrium level (EL) [hPa]\n");
fprintf(out,
        "# $31 = convective available potential energy (CAPE) [J/kg]\n"
        "# $32 = convective inhibition (CIN) [J/kg]\n"
        "# $33 = relative humidity over water [%%]\n"
        "# $34 = relative humidity over ice [%%]\n"
        "# $35 = dew point temperature [K]\n"
        "# $36 = frost point temperature [K]\n"
        "# $37 = NAT temperature [K]\n"
        "# $38 = HNO3 volume mixing ratio [ppv]\n"
        "# $39 = OH concentration [molec/cm^3]\n"
        "# $40 = boundary layer pressure [hPa]\n");
fprintf(out,
        "# $41 = number of data points\n"
        "# $42 = number of tropopause data points\n"
        "# $43 = number of CAPE data points\n\n");

/* Write data... */
for (iz = 0; iz < nz; iz++)
  fprintf(out,
          "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
          " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
          " %g %g %g %g %g %g %g %g %g %d %d %d\n",
          timem[iz] / np[iz], Z(plev[iz]), lonm[iz] / np[iz],
          latm[iz] / np[iz], plev[iz], tm[iz] / np[iz], um[iz] / np[iz],
          vm[iz] / np[iz], wm[iz] / np[iz], h2om[iz] / np[iz],
          o3m[iz] / np[iz], zm[iz] / np[iz], pvm[iz] / np[iz],
          psm[iz] / np[iz], tsm[iz] / np[iz], zsm[iz] / np[iz],
          usm[iz] / np[iz], vsm[iz] / np[iz], ptm[iz] / npt[iz],
          ztm[iz] / npt[iz], ttm[iz] / npt[iz], h2otm[iz] / npt[iz],
          lwcm[iz] / np[iz], iwcm[iz] / np[iz], clm[iz] / np[iz],
          pctm[iz] / np[iz], pcbm[iz] / np[iz], plclm[iz] / npc[iz],
          plfcm[iz] / npc[iz], pelm[iz] / npc[iz], capem[iz] / npc[iz],
          cinm[iz] / npc[iz], rhm[iz] / np[iz], rhicem[iz] / np[iz],
          tdewm[iz] / np[iz], ticem[iz] / np[iz], tnatm[iz] / np[iz],
          hno3m[iz] / np[iz], ohm[iz] / np[iz], pblm[iz] / np[iz],
          np[iz], npt[iz], npc[iz]);

/* Close file... */
fclose(out);

/* Free... */
free(met);

return EXIT_SUCCESS;
}
```

## 5.29 met_sample.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.29.1 Detailed Description

Sample meteorological data at given geolocations.

Definition in file met_sample.c.

### 5.29.2 Function Documentation

#### 5.29.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

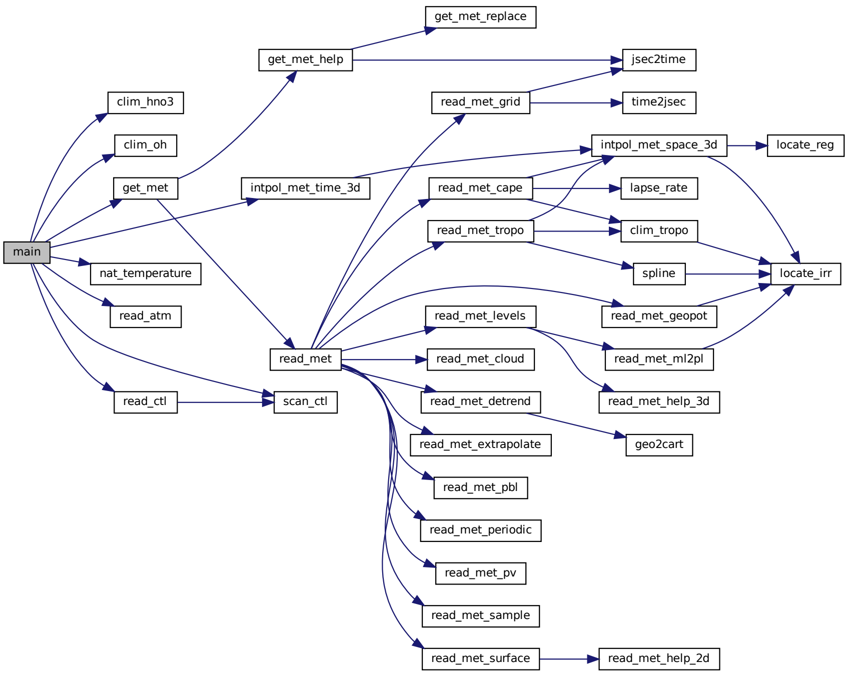
Definition at line 31 of file met_sample.c.

```
                      {

  ctl_t ctl;

  atm_t *atm;

  met_t *met0, *met1;

  FILE *out;

  double h2o, h2ot, o3, lwc, iwc, p0, p1, ps, ts, zs, us, vs, pbl, pt,
    pct, pcb, cl, plcl, plfc, pel, cape, cin, pv, t, tt, u, v, w, z, zm, zref,
    zt, cw[3], time_old = -999, p_old = -999, lon_old = -999, lat_old = -999;

  int geopot, grid_time, grid_z, grid_lon, grid_lat, ip, it, ci[3];

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <sample.tab> <atm_in>");

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(met0, met_t, 1);
  ALLOC(met1, met_t, 1);

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  geopot =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GEOPOT", -1, "0", NULL);
  grid_time =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_TIME", -1, "0", NULL);
  grid_z =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_Z", -1, "0", NULL);
  grid_lon =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_LON", -1, "0", NULL);
  grid_lat =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_LAT", -1, "0", NULL);

  /* Read atmospheric data... */
  if (!read_atm(argv[3], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
          "# $7 = zonal wind [m/s]\n"
          "# $8 = meridional wind [m/s]\n"
          "# $9 = vertical velocity [hPa/s]\n"
          "# $10 = H2O volume mixing ratio [ppv]\n");
  fprintf(out,
```

```
          "# $11 = O3 volume mixing ratio [ppv]\n"
          "# $12 = geopotential height [km]\n"
          "# $13 = potential vorticity [PVU]\n"
          "# $14 = surface pressure [hPa]\n"
          "# $15 = surface temperature [K]\n"
          "# $16 = surface geopotential height [km]\n"
          "# $17 = surface zonal wind [m/s]\n"
          "# $18 = surface meridional wind [m/s]\n"
          "# $19 = tropopause pressure [hPa]\n"
          "# $20 = tropopause geopotential height [km]\n");
  fprintf(out,
          "# $21 = tropopause temperature [K]\n"
          "# $22 = tropopause water vapor [ppv]\n"
          "# $23 = cloud liquid water content [kg/kg]\n"
          "# $24 = cloud ice water content [kg/kg]\n"
          "# $25 = total column cloud water [kg/m^2]\n"
          "# $26 = cloud top pressure [hPa]\n"
          "# $27 = cloud bottom pressure [hPa]\n"
          "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
          "# $29 = pressure at level of free convection (LFC) [hPa]\n"
          "# $30 = pressure at equilibrium level (EL) [hPa]\n");
  fprintf(out,
          "# $31 = convective available potential energy (CAPE) [J/kg]\n"
          "# $32 = convective inhibition (CIN) [J/kg]\n"
          "# $33 = relative humidity over water [%%]\n"
          "# $34 = relative humidity over ice [%%]\n"
          "# $35 = dew point temperature [K]\n"
          "# $36 = frost point temperature [K]\n"
          "# $37 = NAT temperature [K]\n"
          "# $38 = HNO3 volume mixing ratio [ppv]\n"
          "# $39 = OH concentration [molec/cm^3]\n"
          "# $40 = boundary layer pressure [hPa]\n");

  /* Loop over air parcels... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Get meteorological data... */
    get_met(&ctl, atm->time[ip], &met0, &met1);

    /* Set reference pressure for interpolation... */
    double pref = atm->p[ip];
    if (geopot) {
      zref = Z(pref);
      p0 = met0->p[0];
      p1 = met0->p[met0->np - 1];
      for (it = 0; it < 24; it++) {
        pref = 0.5 * (p0 + p1);
        intpol_met_time_3d(met0, met0->z, met1, met1->z, atm->time[ip], pref,
                           atm->lon[ip], atm->lat[ip], &zm, ci, cw, 1);
        if (zref > zm || !gsl_finite(zm))
          p0 = pref;
        else
          p1 = pref;
      }
      pref = 0.5 * (p0 + p1);
    }

    /* Interpolate meteo data... */
    INTPOL_TIME_ALL(atm->time[ip], pref, atm->lon[ip], atm->lat[ip]);

    /* Make blank lines... */
    if (ip == 0 || (grid_time && atm->time[ip] != time_old)
        || (grid_z && atm->p[ip] != p_old)
        || (grid_lon && atm->lon[ip] != lon_old)
        || (grid_lat && atm->lat[ip] != lat_old))
      fprintf(out, "\n");
    time_old = atm->time[ip];
    p_old = atm->p[ip];
    lon_old = atm->lon[ip];
    lat_old = atm->lat[ip];

    /* Write data... */
    fprintf(out,
            "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
            " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g\n",
            atm->time[ip], Z(atm->p[ip]), atm->lon[ip], atm->lat[ip],
            atm->p[ip], t, u, v, w, h2o, o3, z, pv, ps, ts, zs, us, vs,
            pt, zt, tt, h2ot, lwc, iwc, cl, pct, pcb, plcl, plfc, pel, cape,
            cin, RH(atm->p[ip], t, h2o), RHICE(atm->p[ip], t, h2o),
            TDEW(atm->p[ip], h2o), TICE(atm->p[ip], h2o),
            nat_temperature(atm->p[ip], h2o,
                            clim_hno3(atm->time[ip], atm->lat[ip],
                                      atm->p[ip])), clim_hno3(atm->time[ip],
                                                              atm->lat[ip],
                                                              atm->p[ip]),
            clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]), pbl);
  }
```

```
  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm);
  free(met0);
  free(met1);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.30 met_sample.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

```

```
  ctl_t ctl;

  atm_t *atm;

  met_t *met0, *met1;

  FILE *out;

  double h2o, h2ot, o3, lwc, iwc, p0, p1, ps, ts, zs, us, vs, pbl, pt,
    pct, pcb, cl, plcl, plfc, pel, cape, cin, pv, t, tt, u, v, w, z, zm, zref,
    zt, cw[3], time_old = -999, p_old = -999, lon_old = -999, lat_old = -999;

  int geopot, grid_time, grid_z, grid_lon, grid_lat, ip, it, ci[3];

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <sample.tab> <atm_in>");

  /* Allocate... */
  ALLOC(atm, atm_t, 1);
  ALLOC(met0, met_t, 1);
  ALLOC(met1, met_t, 1);

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  geopot =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GEOPOT", -1, "0", NULL);
  grid_time =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_TIME", -1, "0", NULL);
  grid_z =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_Z", -1, "0", NULL);
  grid_lon =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_LON", -1, "0", NULL);
  grid_lat =
    (int) scan_ctl(argv[1], argc, argv, "SAMPLE_GRID_LAT", -1, "0", NULL);

  /* Read atmospheric data... */
  if (!read_atm(argv[3], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
          "# $7 = zonal wind [m/s]\n"
          "# $8 = meridional wind [m/s]\n"
          "# $9 = vertical velocity [hPa/s]\n"
          "# $10 = H2O volume mixing ratio [ppv]\n");
  fprintf(out,
          "# $11 = O3 volume mixing ratio [ppv]\n"
          "# $12 = geopotential height [km]\n"
          "# $13 = potential vorticity [PVU]\n"
          "# $14 = surface pressure [hPa]\n"
          "# $15 = surface temperature [K]\n"
          "# $16 = surface geopotential height [km]\n"
          "# $17 = surface zonal wind [m/s]\n"
          "# $18 = surface meridional wind [m/s]\n"
          "# $19 = tropopause pressure [hPa]\n"
          "# $20 = tropopause geopotential height [km]\n");
  fprintf(out,
          "# $21 = tropopause temperature [K]\n"
          "# $22 = tropopause water vapor [ppv]\n"
          "# $23 = cloud liquid water content [kg/kg]\n"
          "# $24 = cloud ice water content [kg/kg]\n"
          "# $25 = total column cloud water [kg/m^2]\n"
          "# $26 = cloud top pressure [hPa]\n"
          "# $27 = cloud bottom pressure [hPa]\n"
          "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
          "# $29 = pressure at level of free convection (LFC) [hPa]\n"
          "# $30 = pressure at equilibrium level (EL) [hPa]\n");
  fprintf(out,
          "# $31 = convective available potential energy (CAPE) [J/kg]\n"
          "# $32 = convective inhibition (CIN) [J/kg]\n"
          "# $33 = relative humidity over water [%%]\n"
          "# $34 = relative humidity over ice [%%]\n"
          "# $35 = dew point temperature [K]\n"
          "# $36 = frost point temperature [K]\n"
          "# $37 = NAT temperature [K]\n"
```

```
          "# $38 = HNO3 volume mixing ratio [ppv]\n"
          "# $39 = OH concentration [molec/cm^3]\n"
          "# $40 = boundary layer pressure [hPa]\n");

  /* Loop over air parcels... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Get meteorological data... */
    get_met(&ctl, atm->time[ip], &met0, &met1);

    /* Set reference pressure for interpolation... */
    double pref = atm->p[ip];
    if (geopot) {
      zref = Z(pref);
      p0 = met0->p[0];
      p1 = met0->p[met0->np - 1];
      for (it = 0; it < 24; it++) {
        pref = 0.5 * (p0 + p1);
        intpol_met_time_3d(met0, met0->z, met1, met1->z, atm->time[ip], pref,
                           atm->lon[ip], atm->lat[ip], &zm, ci, cw, 1);
        if (zref > zm || !gsl_finite(zm))
          p0 = pref;
        else
          p1 = pref;
      }
      pref = 0.5 * (p0 + p1);
    }

    /* Interpolate meteo data... */
    INTPOL_TIME_ALL(atm->time[ip], pref, atm->lon[ip], atm->lat[ip]);

    /* Make blank lines... */
    if (ip == 0 || (grid_time && atm->time[ip] != time_old)
        || (grid_z && atm->p[ip] != p_old)
        || (grid_lon && atm->lon[ip] != lon_old)
        || (grid_lat && atm->lat[ip] != lat_old))
      fprintf(out, "\n");
    time_old = atm->time[ip];
    p_old = atm->p[ip];
    lon_old = atm->lon[ip];
    lat_old = atm->lat[ip];

    /* Write data... */
    fprintf(out,
            "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
            " %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g\n",
            atm->time[ip], Z(atm->p[ip]), atm->lon[ip], atm->lat[ip],
            atm->p[ip], t, u, v, w, h2o, o3, z, pv, ps, ts, zs, us, vs,
            pt, zt, tt, h2ot, lwc, iwc, cl, pct, pcb, plcl, plfc, pel, cape,
            cin, RH(atm->p[ip], t, h2o), RHICE(atm->p[ip], t, h2o),
            TDEW(atm->p[ip], h2o), TICE(atm->p[ip], h2o),
            nat_temperature(atm->p[ip], h2o,
                            clim_hno3(atm->time[ip], atm->lat[ip],
                                      atm->p[ip])), clim_hno3(atm->time[ip],
                                                              atm->lat[ip],
                                                              atm->p[ip]),
            clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]), pbl);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(atm);
  free(met0);
  free(met1);

  return EXIT_SUCCESS;
}
```

## 5.31 met_spec.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define PMAX EX

  *Maximum number of data points for spectral analysis.*

## Functions

- void fft_help (double *fcReal, double *fcImag, int n)
- int main (int argc, char *argv[ ])

### 5.31.1 Detailed Description

Spectral analysis of meteorological data.

Definition in file met_spec.c.

### 5.31.2 Macro Definition Documentation

#### 5.31.2.1 PMAX `#define PMAX EX`

Maximum number of data points for spectral analysis.

Definition at line 32 of file met_spec.c.

### 5.31.3 Function Documentation

#### 5.31.3.1 fft_help()

```
void fft_help (
        double * fcReal,
        double * fcImag,
        int n )
```

Definition at line 143 of file met_spec.c.

```
                   {

  gsl_fft_complex_wavetable *wavetable;
  gsl_fft_complex_workspace *workspace;

  double data[2 * PMAX];

  int i;

  /* Check size... */
  if (n > PMAX)
    ERRMSG("Too many data points!");

  /* Allocate... */
  wavetable = gsl_fft_complex_wavetable_alloc((size_t) n);
  workspace = gsl_fft_complex_workspace_alloc((size_t) n);

  /* Set data (real, complex)... */
  for (i = 0; i < n; i++) {
    data[2 * i] = fcReal[i];
    data[2 * i + 1] = fcImag[i];
  }

  /* Calculate FFT... */
  gsl_fft_complex_forward(data, 1, (size_t) n, wavetable, workspace);

  /* Copy data... */
  for (i = 0; i < n; i++) {
    fcReal[i] = data[2 * i];
    fcImag[i] = data[2 * i + 1];
  }

  /* Free... */
  gsl_fft_complex_wavetable_free(wavetable);
  gsl_fft_complex_workspace_free(workspace);
}
```

#### 5.31.3.2 main()

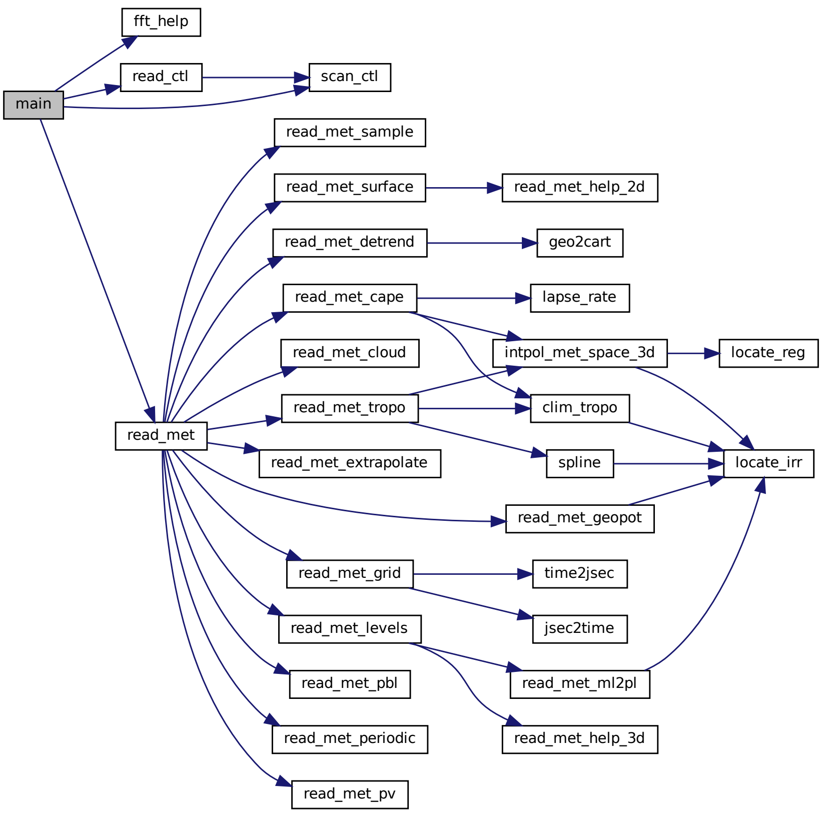
```
int main (
    int argc,
    char * argv[] )
```

Definition at line 47 of file met_spec.c.

```
                 {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double cutImag[PMAX], cutReal[PMAX], lx[PMAX], A[PMAX], phi[PMAX],
    wavemax;

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <spec.tab> <met0>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  wavemax =
    (int) scan_ctl(argv[1], argc, argv, "SPEC_WAVEMAX", -1, "7", NULL);

  /* Read meteorological data... */
  if (!read_met(&ctl, argv[3], met))
    ERRMSG("Cannot read meteo data!");

  /* Create output file... */
  printf("Write spectral data file: %s\n", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
  for (int ix = 0; ix <= wavemax; ix++) {
    fprintf(out, "# $%d = wavelength (PW%d) [km]\n", 5 + 3 * ix, ix);
    fprintf(out, "# $%d = amplitude (PW%d) [K]\n", 6 + 3 * ix, ix);
    fprintf(out, "# $%d = phase (PW%d) [deg]\n", 7 + 3 * ix, ix);
  }

  /* Loop over pressure levels... */
  for (int ip = 0; ip < met->np; ip++) {

    /* Write output... */
    fprintf(out, "\n");

    /* Loop over latitudes... */
    for (int iy = 0; iy < met->ny; iy++) {

      /* Copy data... */
      for (int ix = 0; ix < met->nx; ix++) {
        cutReal[ix] = met->t[ix][iy][ip];
        cutImag[ix] = 0.0;
      }

      /* FFT... */
      fft_help(cutReal, cutImag, met->nx);

      /*
         Get wavelength, amplitude, and phase:
         A(x) = A[0] + A[1] * cos(2 pi x / lx[1] + phi[1]) + A[2] * cos...
       */
      for (int ix = 0; ix < met->nx; ix++) {
        lx[ix] = DEG2DX(met->lon[met->nx - 1] - met->lon[0], met->lat[iy])
          / ((ix < met->nx / 2) ? (double) ix : -(double) (met->nx - ix));
        A[ix] = (ix == 0 ? 1.0 : 2.0) / (met->nx)
          * sqrt(gsl_pow_2(cutReal[ix]) + gsl_pow_2(cutImag[ix]));
        phi[ix]
          = 180. / M_PI * atan2(cutImag[ix], cutReal[ix]);
      }

      /* Write data... */
      fprintf(out, "%.2f %g %g %g", met->time, Z(met->p[ip]), 0.0,
              met->lat[iy]);
      for (int ix = 0; ix <= wavemax; ix++)
        fprintf(out, " %g %g %g", lx[ix], A[ix], phi[ix]);
      fprintf(out, "\n");
```

```
    }
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.32 met_spec.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

```

```
/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define PMAX EX

/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */

void fft_help(
  double *fcReal,
  double *fcImag,
  int n);

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double cutImag[PMAX], cutReal[PMAX], lx[PMAX], A[PMAX], phi[PMAX],
    wavemax;

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <spec.tab> <met0>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  wavemax =
    (int) scan_ctl(argv[1], argc, argv, "SPEC_WAVEMAX", -1, "7", NULL);

  /* Read meteorological data... */
  if (!read_met(&ctl, argv[3], met))
    ERRMSG("Cannot read meteo data!");

  /* Create output file... */
  printf("Write spectral data file: %s\n", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
  for (int ix = 0; ix <= wavemax; ix++) {
    fprintf(out, "# $%d = wavelength (PW%d) [km]\n", 5 + 3 * ix, ix);
    fprintf(out, "# $%d = amplitude (PW%d) [K]\n", 6 + 3 * ix, ix);
    fprintf(out, "# $%d = phase (PW%d) [deg]\n", 7 + 3 * ix, ix);
  }

  /* Loop over pressure levels... */
  for (int ip = 0; ip < met->np; ip++) {

    /* Write output... */
    fprintf(out, "\n");

    /* Loop over latitudes... */
    for (int iy = 0; iy < met->ny; iy++) {

      /* Copy data... */
      for (int ix = 0; ix < met->nx; ix++) {
        cutReal[ix] = met->t[ix][iy][ip];
        cutImag[ix] = 0.0;
      }

      /* FFT... */
      fft_help(cutReal, cutImag, met->nx);

      /*
         Get wavelength, amplitude, and phase:
         A(x) = A[0] + A[1] * cos(2 pi x / lx[1] + phi[1]) + A[2] * cos...
       */
      for (int ix = 0; ix < met->nx; ix++) {
```

```
        lx[ix] = DEG2DX(met->lon[met->nx - 1] - met->lon[0], met->lat[iy])
          / ((ix < met->nx / 2) ? (double) ix : -(double) (met->nx - ix));
        A[ix] = (ix == 0 ? 1.0 : 2.0) / (met->nx)
          * sqrt(gsl_pow_2(cutReal[ix]) + gsl_pow_2(cutImag[ix]));
        phi[ix]
          = 180. / M_PI * atan2(cutImag[ix], cutReal[ix]);
      }

      /* Write data... */
      fprintf(out, "%.2f %g %g %g", met->time, Z(met->p[ip]), 0.0,
              met->lat[iy]);
      for (int ix = 0; ix <= wavemax; ix++)
        fprintf(out, " %g %g %g", lx[ix], A[ix], phi[ix]);
      fprintf(out, "\n");
    }
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}

/*****************************************************************************/

void fft_help(
  double *fcReal,
  double *fcImag,
  int n) {

  gsl_fft_complex_wavetable *wavetable;
  gsl_fft_complex_workspace *workspace;

  double data[2 * PMAX];

  int i;

  /* Check size... */
  if (n > PMAX)
    ERRMSG("Too many data points!");

  /* Allocate... */
  wavetable = gsl_fft_complex_wavetable_alloc((size_t) n);
  workspace = gsl_fft_complex_workspace_alloc((size_t) n);

  /* Set data (real, complex)... */
  for (i = 0; i < n; i++) {
    data[2 * i] = fcReal[i];
    data[2 * i + 1] = fcImag[i];
  }

  /* Calculate FFT... */
  gsl_fft_complex_forward(data, 1, (size_t) n, wavetable, workspace);

  /* Copy data... */
  for (i = 0; i < n; i++) {
    fcReal[i] = data[2 * i];
    fcImag[i] = data[2 * i + 1];
  }

  /* Free... */
  gsl_fft_complex_wavetable_free(wavetable);
  gsl_fft_complex_workspace_free(workspace);
}
```

## 5.33 met_subgrid.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.33.1 Detailed Description

Calculate standard deviations of horizontal wind and vertical velocity.

Definition in file met_subgrid.c.

### 5.33.2 Function Documentation

#### 5.33.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

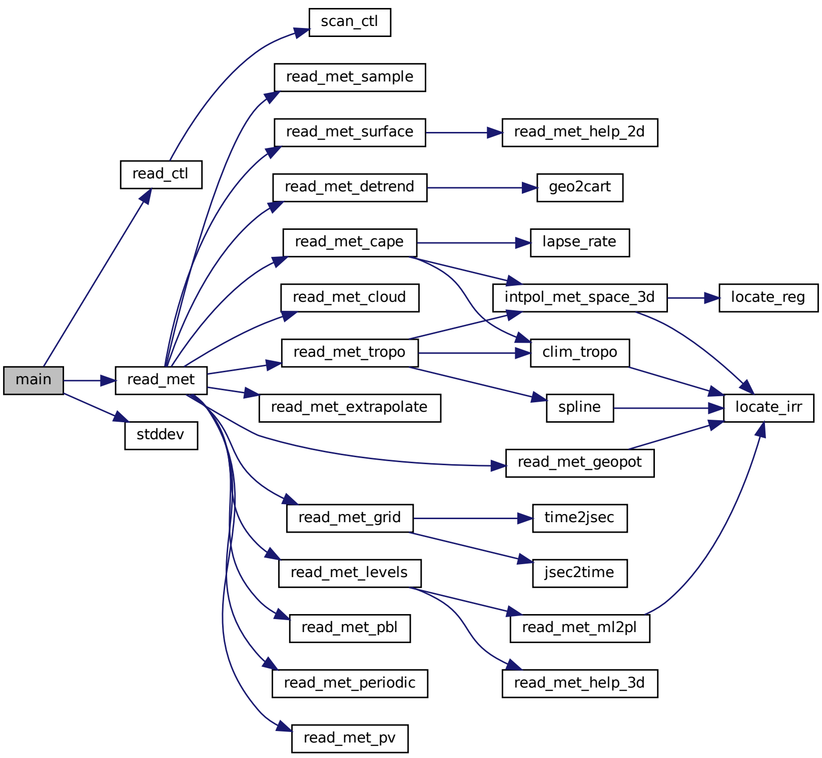
Definition at line 31 of file met_subgrid.c.

```
                   {

  ctl_t ctl;

  met_t *met0, *met1;

  FILE *out;

  static double usig[EP][EY], vsig[EP][EY], wsig[EP][EY];

  static float u[16], v[16], w[16];

  static int i, ix, iy, iz, n[EP][EY];

  /* Allocate... */
  ALLOC(met0, met_t, 1);
  ALLOC(met1, met_t, 1);

  /* Check arguments... */
  if (argc < 4 && argc % 2 != 0)
    ERRMSG
      ("Give parameters: <ctl> <zm.tab> <met0> <met1> [ <met0> <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);

  /* Loop over data files... */
  for (i = 3; i < argc - 1; i += 2) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met0))
      ERRMSG("Cannot open file!");
    if (!read_met(&ctl, argv[i + 1], met1))
      ERRMSG("Cannot open file!");

    /* Loop over grid boxes... */
    for (ix = 0; ix < met0->nx - 1; ix++)
      for (iy = 0; iy < met0->ny - 1; iy++)
        for (iz = 0; iz < met0->np - 1; iz++) {

          /* Collect local wind data... */
          u[0] = met0->u[ix][iy][iz];
          u[1] = met0->u[ix + 1][iy][iz];
          u[2] = met0->u[ix][iy + 1][iz];
          u[3] = met0->u[ix + 1][iy + 1][iz];
          u[4] = met0->u[ix][iy][iz + 1];
          u[5] = met0->u[ix + 1][iy][iz + 1];
          u[6] = met0->u[ix][iy + 1][iz + 1];
          u[7] = met0->u[ix + 1][iy + 1][iz + 1];

          v[0] = met0->v[ix][iy][iz];
          v[1] = met0->v[ix + 1][iy][iz];
          v[2] = met0->v[ix][iy + 1][iz];
          v[3] = met0->v[ix + 1][iy + 1][iz];
          v[4] = met0->v[ix][iy][iz + 1];
          v[5] = met0->v[ix + 1][iy][iz + 1];
          v[6] = met0->v[ix][iy + 1][iz + 1];
          v[7] = met0->v[ix + 1][iy + 1][iz + 1];

          w[0] = (float) (1e3 * DP2DZ(met0->w[ix][iy][iz], met0->p[iz]));
```

```
        w[1] = (float) (1e3 * DP2DZ(met0->w[ix + 1][iy][iz], met0->p[iz]));
        w[2] = (float) (1e3 * DP2DZ(met0->w[ix][iy + 1][iz], met0->p[iz]));
        w[3] =
          (float) (1e3 * DP2DZ(met0->w[ix + 1][iy + 1][iz], met0->p[iz]));
        w[4] =
          (float) (1e3 * DP2DZ(met0->w[ix][iy][iz + 1], met0->p[iz + 1]));
        w[5] =
          (float) (1e3 *
                   DP2DZ(met0->w[ix + 1][iy][iz + 1], met0->p[iz + 1]));
        w[6] =
          (float) (1e3 *
                   DP2DZ(met0->w[ix][iy + 1][iz + 1], met0->p[iz + 1]));
        w[7] =
          (float) (1e3 *
                   DP2DZ(met0->w[ix + 1][iy + 1][iz + 1], met0->p[iz + 1]));

        /* Collect local wind data... */
        u[8] = met1->u[ix][iy][iz];
        u[9] = met1->u[ix + 1][iy][iz];
        u[10] = met1->u[ix][iy + 1][iz];
        u[11] = met1->u[ix + 1][iy + 1][iz];
        u[12] = met1->u[ix][iy][iz + 1];
        u[13] = met1->u[ix + 1][iy][iz + 1];
        u[14] = met1->u[ix][iy + 1][iz + 1];
        u[15] = met1->u[ix + 1][iy + 1][iz + 1];

        v[8] = met1->v[ix][iy][iz];
        v[9] = met1->v[ix + 1][iy][iz];
        v[10] = met1->v[ix][iy + 1][iz];
        v[11] = met1->v[ix + 1][iy + 1][iz];
        v[12] = met1->v[ix][iy][iz + 1];
        v[13] = met1->v[ix + 1][iy][iz + 1];
        v[14] = met1->v[ix][iy + 1][iz + 1];
        v[15] = met1->v[ix + 1][iy + 1][iz + 1];

        w[8] = (float) (1e3 * DP2DZ(met1->w[ix][iy][iz], met1->p[iz]));
        w[9] = (float) (1e3 * DP2DZ(met1->w[ix + 1][iy][iz], met1->p[iz]));
        w[10] = (float) (1e3 * DP2DZ(met1->w[ix][iy + 1][iz], met1->p[iz]));
        w[11] =
          (float) (1e3 * DP2DZ(met1->w[ix + 1][iy + 1][iz], met1->p[iz]));
        w[12] =
          (float) (1e3 * DP2DZ(met1->w[ix][iy][iz + 1], met1->p[iz + 1]));
        w[13] =
          (float) (1e3 *
                   DP2DZ(met1->w[ix + 1][iy][iz + 1], met1->p[iz + 1]));
        w[14] =
          (float) (1e3 *
                   DP2DZ(met1->w[ix][iy + 1][iz + 1], met1->p[iz + 1]));
        w[15] =
          (float) (1e3 *
                   DP2DZ(met1->w[ix + 1][iy + 1][iz + 1], met1->p[iz + 1]));

        /* Get standard deviations of local wind data... */
        usig[iz][iy] += stddev(u, 16);
        vsig[iz][iy] += stddev(v, 16);
        wsig[iz][iy] += stddev(w, 16);
        n[iz][iy]++;

        /* Check surface pressure... */
        if (met0->p[iz] > met0->ps[ix][iy]
            || met1->p[iz] > met1->ps[ix][iy]) {
          usig[iz][iy] = GSL_NAN;
          vsig[iz][iy] = GSL_NAN;
          wsig[iz][iy] = GSL_NAN;
          n[iz][iy] = 0;
        }
      }
}

/* Create output file... */
LOG(1, "Write subgrid data file: %s", argv[2]);
if (!(out = fopen(argv[2], "w")))
  ERRMSG("Cannot create file!");

/* Write header... */
fprintf(out,
        "# $1 = time [s]\n"
        "# $2 = altitude [km]\n"
        "# $3 = longitude [deg]\n"
        "# $4 = latitude [deg]\n"
        "# $5 = zonal wind standard deviation [m/s]\n"
        "# $6 = meridional wind standard deviation [m/s]\n"
        "# $7 = vertical velocity standard deviation [m/s]\n"
        "# $8 = number of data points\n");

/* Write output... */
for (iy = 0; iy < met0->ny - 1; iy++) {
```

```
    fprintf(out, "\n");
    for (iz = 0; iz < met0->np - 1; iz++)
      fprintf(out, "%.2f %g %g %g %g %g %g %d\n",
              0.5 * (met0->time + met1->time),
              0.5 * (Z(met0->p[iz]) + Z(met1->p[iz + 1])),
              0.0, 0.5 * (met0->lat[iy] + met1->lat[iy + 1]),
              usig[iz][iy] / n[iz][iy], vsig[iz][iy] / n[iz][iy],
              wsig[iz][iy] / n[iz][iy], n[iz][iy]);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met0);
  free(met1);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.34 met_subgrid.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

```

```
  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met0, *met1;

  FILE *out;

  static double usig[EP][EY], vsig[EP][EY], wsig[EP][EY];

  static float u[16], v[16], w[16];

  static int i, ix, iy, iz, n[EP][EY];

  /* Allocate... */
  ALLOC(met0, met_t, 1);
  ALLOC(met1, met_t, 1);

  /* Check arguments... */
  if (argc < 4 && argc % 2 != 0)
    ERRMSG
      ("Give parameters: <ctl> <zm.tab> <met0> <met1> [ <met0> <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);

  /* Loop over data files... */
  for (i = 3; i < argc - 1; i += 2) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met0))
      ERRMSG("Cannot open file!");
    if (!read_met(&ctl, argv[i + 1], met1))
      ERRMSG("Cannot open file!");

    /* Loop over grid boxes... */
    for (ix = 0; ix < met0->nx - 1; ix++)
      for (iy = 0; iy < met0->ny - 1; iy++)
        for (iz = 0; iz < met0->np - 1; iz++) {

          /* Collect local wind data... */
          u[0] = met0->u[ix][iy][iz];
          u[1] = met0->u[ix + 1][iy][iz];
          u[2] = met0->u[ix][iy + 1][iz];
          u[3] = met0->u[ix + 1][iy + 1][iz];
          u[4] = met0->u[ix][iy][iz + 1];
          u[5] = met0->u[ix + 1][iy][iz + 1];
          u[6] = met0->u[ix][iy + 1][iz + 1];
          u[7] = met0->u[ix + 1][iy + 1][iz + 1];

          v[0] = met0->v[ix][iy][iz];
          v[1] = met0->v[ix + 1][iy][iz];
          v[2] = met0->v[ix][iy + 1][iz];
          v[3] = met0->v[ix + 1][iy + 1][iz];
          v[4] = met0->v[ix][iy][iz + 1];
          v[5] = met0->v[ix + 1][iy][iz + 1];
          v[6] = met0->v[ix][iy + 1][iz + 1];
          v[7] = met0->v[ix + 1][iy + 1][iz + 1];

          w[0] = (float) (1e3 * DP2DZ(met0->w[ix][iy][iz], met0->p[iz]));
          w[1] = (float) (1e3 * DP2DZ(met0->w[ix + 1][iy][iz], met0->p[iz]));
          w[2] = (float) (1e3 * DP2DZ(met0->w[ix][iy + 1][iz], met0->p[iz]));
          w[3] =
            (float) (1e3 * DP2DZ(met0->w[ix + 1][iy + 1][iz], met0->p[iz]));
          w[4] =
            (float) (1e3 * DP2DZ(met0->w[ix][iy][iz + 1], met0->p[iz + 1]));
          w[5] =
            (float) (1e3 *
                     DP2DZ(met0->w[ix + 1][iy][iz + 1], met0->p[iz + 1]));
          w[6] =
            (float) (1e3 *
                     DP2DZ(met0->w[ix][iy + 1][iz + 1], met0->p[iz + 1]));
          w[7] =
            (float) (1e3 *
                     DP2DZ(met0->w[ix + 1][iy + 1][iz + 1], met0->p[iz + 1]));

```

```
          /* Collect local wind data... */
          u[8] = met1->u[ix][iy][iz];
          u[9] = met1->u[ix + 1][iy][iz];
          u[10] = met1->u[ix][iy + 1][iz];
          u[11] = met1->u[ix + 1][iy + 1][iz];
          u[12] = met1->u[ix][iy][iz + 1];
          u[13] = met1->u[ix + 1][iy][iz + 1];
          u[14] = met1->u[ix][iy + 1][iz + 1];
          u[15] = met1->u[ix + 1][iy + 1][iz + 1];

          v[8] = met1->v[ix][iy][iz];
          v[9] = met1->v[ix + 1][iy][iz];
          v[10] = met1->v[ix][iy + 1][iz];
          v[11] = met1->v[ix + 1][iy + 1][iz];
          v[12] = met1->v[ix][iy][iz + 1];
          v[13] = met1->v[ix + 1][iy][iz + 1];
          v[14] = met1->v[ix][iy + 1][iz + 1];
          v[15] = met1->v[ix + 1][iy + 1][iz + 1];

          w[8] = (float) (1e3 * DP2DZ(met1->w[ix][iy][iz], met1->p[iz]));
          w[9] = (float) (1e3 * DP2DZ(met1->w[ix + 1][iy][iz], met1->p[iz]));
          w[10] = (float) (1e3 * DP2DZ(met1->w[ix][iy + 1][iz], met1->p[iz]));
          w[11] =
            (float) (1e3 * DP2DZ(met1->w[ix + 1][iy + 1][iz], met1->p[iz]));
          w[12] =
            (float) (1e3 * DP2DZ(met1->w[ix][iy][iz + 1], met1->p[iz + 1]));
          w[13] =
            (float) (1e3 *
                     DP2DZ(met1->w[ix + 1][iy][iz + 1], met1->p[iz + 1]));
          w[14] =
            (float) (1e3 *
                     DP2DZ(met1->w[ix][iy + 1][iz + 1], met1->p[iz + 1]));
          w[15] =
            (float) (1e3 *
                     DP2DZ(met1->w[ix + 1][iy + 1][iz + 1], met1->p[iz + 1]));

          /* Get standard deviations of local wind data... */
          usig[iz][iy] += stddev(u, 16);
          vsig[iz][iy] += stddev(v, 16);
          wsig[iz][iy] += stddev(w, 16);
          n[iz][iy]++;

          /* Check surface pressure... */
          if (met0->p[iz] > met0->ps[ix][iy]
              || met1->p[iz] > met1->ps[ix][iy]) {
            usig[iz][iy] = GSL_NAN;
            vsig[iz][iy] = GSL_NAN;
            wsig[iz][iy] = GSL_NAN;
            n[iz][iy] = 0;
          }
        }
  }

  /* Create output file... */
  LOG(1, "Write subgrid data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = zonal wind standard deviation [m/s]\n"
          "# $6 = meridional wind standard deviation [m/s]\n"
          "# $7 = vertical velocity standard deviation [m/s]\n"
          "# $8 = number of data points\n");

  /* Write output... */
  for (iy = 0; iy < met0->ny - 1; iy++) {
    fprintf(out, "\n");
    for (iz = 0; iz < met0->np - 1; iz++)
      fprintf(out, "%.2f %g %g %g %g %g %g %d\n",
              0.5 * (met0->time + met1->time),
              0.5 * (Z(met0->p[iz]) + Z(met1->p[iz + 1])),
              0.0, 0.5 * (met0->lat[iy] + met1->lat[iy + 1]),
              usig[iz][iy] / n[iz][iy], vsig[iz][iy] / n[iz][iy],
              wsig[iz][iy] / n[iz][iy], n[iz][iy]);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met0);
  free(met1);
```

```
00196
00197   return EXIT_SUCCESS;
00198 }
```

## 5.35 met_zm.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define NZ 1000
  *Maximum number of altitudes.*
- #define NY 721
  *Maximum number of latitudes.*

### Functions

- int main (int argc, char *argv[ ])

### 5.35.1 Detailed Description

Extract zonal mean from meteorological data.

Definition in file met_zm.c.

### 5.35.2 Macro Definition Documentation

#### 5.35.2.1 NZ `#define NZ 1000`

Maximum number of altitudes.

Definition at line 32 of file met_zm.c.

#### 5.35.2.2 NY `#define NY 721`

Maximum number of latitudes.

Definition at line 35 of file met_zm.c.

### 5.35.3 Function Documentation

#### 5.35.3.1 main()

```
int main (
    int argc,
    char * argv[] )
```

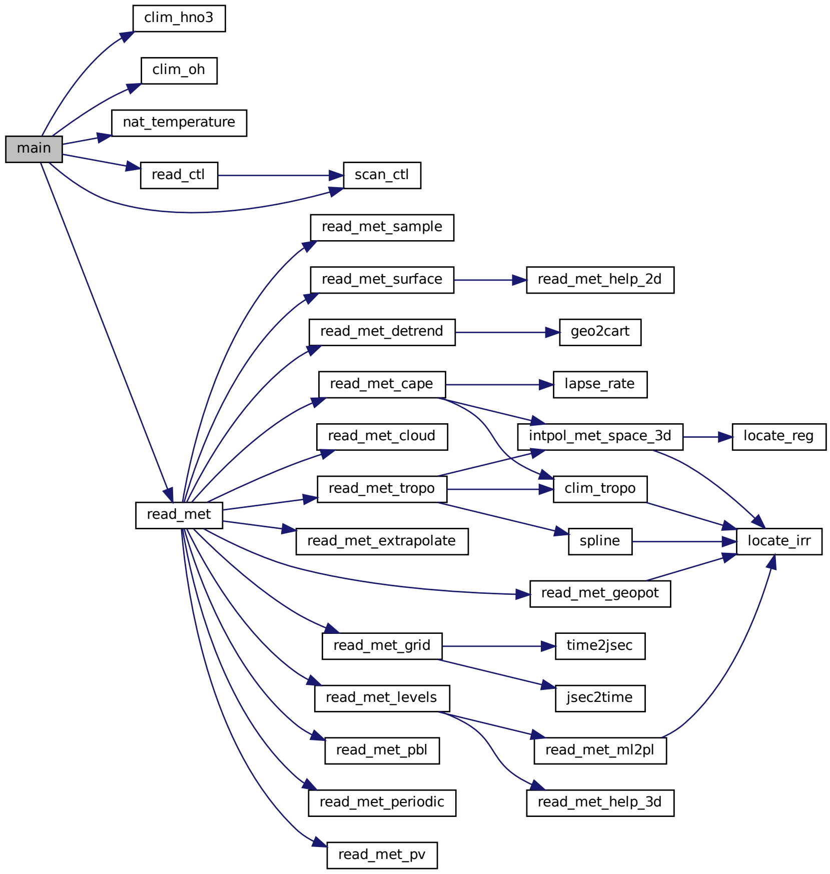
Definition at line 41 of file met_zm.c.

```
                  {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NZ][NY], psm[NZ][NY], tsm[NZ][NY], zsm[NZ][NY],
    usm[NZ][NY], vsm[NZ][NY], pblm[NZ][NY], ptm[NZ][NY], pctm[NZ][NY],
    pcbm[NZ][NY], clm[NZ][NY], plclm[NZ][NY], plfcm[NZ][NY], pelm[NZ][NY],
    capem[NZ][NY], cinm[NZ][NY], ttm[NZ][NY], ztm[NZ][NY], tm[NZ][NY],
    um[NZ][NY], vm[NZ][NY], wm[NZ][NY], h2om[NZ][NY], h2otm[NZ][NY],
    pvm[NZ][NY], o3m[NZ][NY], lwcm[NZ][NY], iwcm[NZ][NY], zm[NZ][NY],
    rhm[NZ][NY], rhicem[NZ][NY], tdewm[NZ][NY], ticem[NZ][NY], tnatm[NZ][NY],
    hno3m[NZ][NY], ohm[NZ][NY], z, z0, z1, dz, zt, tt, plev[NZ],
    ps, ts, zs, us, vs, pbl, pt, pct, pcb, plcl, plfc, pel,
    cape, cin, cl, t, u, v, w, pv, h2o, h2ot, o3, lwc, iwc,
    lat, lat0, lat1, dlat, lats[NY], lon0, lon1, lonm[NZ][NY], cw[3];

  static int i, ix, iy, iz, np[NZ][NY], npc[NZ][NY], npt[NZ][NY], ny, nz,
    ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <zm.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  z0 = scan_ctl(argv[1], argc, argv, "ZM_Z0", -1, "-999", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "ZM_Z1", -1, "-999", NULL);
  dz = scan_ctl(argv[1], argc, argv, "ZM_DZ", -1, "-999", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "ZM_LON0", -1, "-360", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "ZM_LON1", -1, "360", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "ZM_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "ZM_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "ZM_DLAT", -1, "-999", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set vertical grid... */
    if (z0 < 0)
      z0 = Z(met->p[0]);
    if (z1 < 0)
      z1 = Z(met->p[met->np - 1]);
    nz = 0;
    if (dz < 0) {
      for (iz = 0; iz < met->np; iz++)
        if (Z(met->p[iz]) >= z0 && Z(met->p[iz]) <= z1) {
          plev[nz] = met->p[iz];
          if ((++nz) > NZ)
            ERRMSG("Too many pressure levels!");
        }
    } else
      for (z = z0; z <= z1; z += dz) {
        plev[nz] = P(z);
        if ((++nz) > NZ)
          ERRMSG("Too many pressure levels!");
      }

    /* Set horizontal grid... */
    if (dlat <= 0)
      dlat = fabs(met->lat[1] - met->lat[0]);
    ny = 0;
    if (lat0 < -90 && lat1 > 90) {
      lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
      lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
    }
    for (lat = lat0; lat <= lat1; lat += dlat) {
      lats[ny] = lat;
      if ((++ny) > NY)
        ERRMSG("Too many latitudes!");
```

```
    }

    /* Average... */
    for (ix = 0; ix < met->nx; ix++)
      if (met->lon[ix] >= lon0 && met->lon[ix] <= lon1)
        for (iy = 0; iy < ny; iy++)
          for (iz = 0; iz < nz; iz++) {

            /* Interpolate meteo data... */
            INTPOL_SPACE_ALL(plev[iz], met->lon[ix], lats[iy]);

            /* Averaging... */
            timem[iz][iy] += met->time;
            lonm[iz][iy] += met->lon[ix];
            zm[iz][iy] += z;
            tm[iz][iy] += t;
            um[iz][iy] += u;
            vm[iz][iy] += v;
            wm[iz][iy] += w;
            pvm[iz][iy] += pv;
            h2om[iz][iy] += h2o;
            o3m[iz][iy] += o3;
            lwcm[iz][iy] += lwc;
            iwcm[iz][iy] += iwc;
            psm[iz][iy] += ps;
            tsm[iz][iy] += ts;
            zsm[iz][iy] += zs;
            usm[iz][iy] += us;
            vsm[iz][iy] += vs;
            pblm[iz][iy] += pbl;
            pctm[iz][iy] += pct;
            pcbm[iz][iy] += pcb;
            clm[iz][iy] += cl;
            if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
                && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
              plclm[iz][iy] += plcl;
              plfcm[iz][iy] += plfc;
              pelm[iz][iy] += pel;
              capem[iz][iy] += cape;
              cinm[iz][iy] += cin;
              npc[iz][iy]++;
            }
            if (gsl_finite(pt)) {
              ptm[iz][iy] += pt;
              ztm[iz][iy] += zt;
              ttm[iz][iy] += tt;
              h2otm[iz][iy] += h2ot;
              npt[iz][iy]++;
            }
            rhm[iz][iy] += RH(plev[iz], t, h2o);
            rhicem[iz][iy] += RHICE(plev[iz], t, h2o);
            tdewm[iz][iy] += TDEW(plev[iz], h2o);
            ticem[iz][iy] += TICE(plev[iz], h2o);
            hno3m[iz][iy] += clim_hno3(met->time, lats[iy], plev[iz]);
            tnatm[iz][iy] +=
              nat_temperature(plev[iz], h2o,
                              clim_hno3(met->time, lats[iy], plev[iz]));
            ohm[iz][iy] += clim_oh(met->time, lats[iy], plev[iz]);
            np[iz][iy]++;
          }
  }

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
          "# $7 = zonal wind [m/s]\n"
          "# $8 = meridional wind [m/s]\n"
          "# $9 = vertical velocity [hPa/s]\n"
          "# $10 = H2O volume mixing ratio [ppv]\n");
  fprintf(out,
          "# $11 = O3 volume mixing ratio [ppv]\n"
          "# $12 = geopotential height [km]\n"
          "# $13 = potential vorticity [PVU]\n"
          "# $14 = surface pressure [hPa]\n"
          "# $15 = surface temperature [K]\n"
          "# $16 = surface geopotential height [km]\n"
          "# $17 = surface zonal wind [m/s]\n"
```

```
          "# $18 = surface meridional wind [m/s]\n"
          "# $19 = tropopause pressure [hPa]\n"
          "# $20 = tropopause geopotential height [km]\n");
  fprintf(out,
          "# $21 = tropopause temperature [K]\n"
          "# $22 = tropopause water vapor [ppv]\n"
          "# $23 = cloud liquid water content [kg/kg]\n"
          "# $24 = cloud ice water content [kg/kg]\n"
          "# $25 = total column cloud water [kg/m^2]\n"
          "# $26 = cloud top pressure [hPa]\n"
          "# $27 = cloud bottom pressure [hPa]\n"
          "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
          "# $29 = pressure at level of free convection (LFC) [hPa]\n"
          "# $30 = pressure at equilibrium level (EL) [hPa]\n");
  fprintf(out,
          "# $31 = convective available potential energy (CAPE) [J/kg]\n"
          "# $32 = convective inhibition (CIN) [J/kg]\n"
          "# $33 = relative humidity over water [%%]\n"
          "# $34 = relative humidity over ice [%%]\n"
          "# $35 = dew point temperature [K]\n"
          "# $36 = frost point temperature [K]\n"
          "# $37 = NAT temperature [K]\n"
          "# $38 = HNO3 volume mixing ratio [ppv]\n"
          "# $39 = OH concentration [molec/cm^3]\n"
          "# $40 = boundary layer pressure [hPa]\n");
  fprintf(out,
          "# $41 = number of data points\n"
          "# $42 = number of tropopause data points\n"
          "# $43 = number of CAPE data points\n");

  /* Write data... */
  for (iz = 0; iz < nz; iz++) {
    fprintf(out, "\n");
    for (iy = 0; iy < ny; iy++)
      fprintf(out,
              "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              "%g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %d %d %d\n",
              timem[iz][iy] / np[iz][iy], Z(plev[iz]),
              lonm[iz][iy] / np[iz][iy], lats[iy],
              plev[iz], tm[iz][iy] / np[iz][iy], um[iz][iy] / np[iz][iy],
              vm[iz][iy] / np[iz][iy], wm[iz][iy] / np[iz][iy],
              h2om[iz][iy] / np[iz][iy], o3m[iz][iy] / np[iz][iy],
              zm[iz][iy] / np[iz][iy], pvm[iz][iy] / np[iz][iy],
              psm[iz][iy] / np[iz][iy], tsm[iz][iy] / np[iz][iy],
              zsm[iz][iy] / np[iz][iy], usm[iz][iy] / np[iz][iy],
              vsm[iz][iy] / np[iz][iy], ptm[iz][iy] / npt[iz][iy],
              ztm[iz][iy] / npt[iz][iy], ttm[iz][iy] / npt[iz][iy],
              h2otm[iz][iy] / npt[iz][iy], lwcm[iz][iy] / np[iz][iy],
              iwcm[iz][iy] / np[iz][iy], clm[iz][iy] / np[iz][iy],
              pctm[iz][iy] / np[iz][iy], pcbm[iz][iy] / np[iz][iy],
              plclm[iz][iy] / npc[iz][iy], plfcm[iz][iy] / npc[iz][iy],
              pelm[iz][iy] / npc[iz][iy], capem[iz][iy] / npc[iz][iy],
              cinm[iz][iy] / npc[iz][iy], rhm[iz][iy] / np[iz][iy],
              rhicem[iz][iy] / np[iz][iy], tdewm[iz][iy] / np[iz][iy],
              ticem[iz][iy] / np[iz][iy], tnatm[iz][iy] / np[iz][iy],
              hno3m[iz][iy] / np[iz][iy], ohm[iz][iy] / np[iz][iy],
              pblm[iz][iy] / np[iz][iy], np[iz][iy],
              npt[iz][iy], npc[iz][iy]);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.36 met_zm.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
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  GNU General Public License for more details.

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  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define NZ 1000

#define NY 721

/* ------------------------------------------------------------
   Main...
```

```
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  FILE *out;

  static double timem[NZ][NY], psm[NZ][NY], tsm[NZ][NY], zsm[NZ][NY],
    usm[NZ][NY], vsm[NZ][NY], pblm[NZ][NY], ptm[NZ][NY], pctm[NZ][NY],
    pcbm[NZ][NY], clm[NZ][NY], plclm[NZ][NY], plfcm[NZ][NY], pelm[NZ][NY],
    capem[NZ][NY], cinm[NZ][NY], ttm[NZ][NY], ztm[NZ][NY], tm[NZ][NY],
    um[NZ][NY], vm[NZ][NY], wm[NZ][NY], h2om[NZ][NY], h2otm[NZ][NY],
    pvm[NZ][NY], o3m[NZ][NY], lwcm[NZ][NY], iwcm[NZ][NY], zm[NZ][NY],
    rhm[NZ][NY], rhicem[NZ][NY], tdewm[NZ][NY], ticem[NZ][NY], tnatm[NZ][NY],
    hno3m[NZ][NY], ohm[NZ][NY], z, z0, z1, dz, zt, tt, plev[NZ],
    ps, ts, zs, us, vs, pbl, pt, pct, pcb, plcl, plfc, pel,
    cape, cin, cl, t, u, v, w, pv, h2o, h2ot, o3, lwc, iwc,
    lat, lat0, lat1, dlat, lats[NY], lon0, lon1, lonm[NZ][NY], cw[3];

  static int i, ix, iy, iz, np[NZ][NY], npc[NZ][NY], npt[NZ][NY], ny, nz,
    ci[3];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <zm.tab> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  z0 = scan_ctl(argv[1], argc, argv, "ZM_Z0", -1, "-999", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "ZM_Z1", -1, "-999", NULL);
  dz = scan_ctl(argv[1], argc, argv, "ZM_DZ", -1, "-999", NULL);
  lon0 = scan_ctl(argv[1], argc, argv, "ZM_LON0", -1, "-360", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "ZM_LON1", -1, "360", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "ZM_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "ZM_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "ZM_DLAT", -1, "-999", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set vertical grid... */
    if (z0 < 0)
      z0 = Z(met->p[0]);
    if (z1 < 0)
      z1 = Z(met->p[met->np - 1]);
    nz = 0;
    if (dz < 0) {
      for (iz = 0; iz < met->np; iz++)
        if (Z(met->p[iz]) >= z0 && Z(met->p[iz]) <= z1) {
          plev[nz] = met->p[iz];
          if ((++nz) > NZ)
            ERRMSG("Too many pressure levels!");
        }
    } else
      for (z = z0; z <= z1; z += dz) {
        plev[nz] = P(z);
        if ((++nz) > NZ)
          ERRMSG("Too many pressure levels!");
      }

    /* Set horizontal grid... */
    if (dlat <= 0)
      dlat = fabs(met->lat[1] - met->lat[0]);
    ny = 0;
    if (lat0 < -90 && lat1 > 90) {
      lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
      lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
    }
    for (lat = lat0; lat <= lat1; lat += dlat) {
      lats[ny] = lat;
      if ((++ny) > NY)
        ERRMSG("Too many latitudes!");
    }

    /* Average... */
```

```
    for (ix = 0; ix < met->nx; ix++)
      if (met->lon[ix] >= lon0 && met->lon[ix] <= lon1)
        for (iy = 0; iy < ny; iy++)
          for (iz = 0; iz < nz; iz++) {

            /* Interpolate meteo data... */
            INTPOL_SPACE_ALL(plev[iz], met->lon[ix], lats[iy]);

            /* Averaging... */
            timem[iz][iy] += met->time;
            lonm[iz][iy] += met->lon[ix];
            zm[iz][iy] += z;
            tm[iz][iy] += t;
            um[iz][iy] += u;
            vm[iz][iy] += v;
            wm[iz][iy] += w;
            pvm[iz][iy] += pv;
            h2om[iz][iy] += h2o;
            o3m[iz][iy] += o3;
            lwcm[iz][iy] += lwc;
            iwcm[iz][iy] += iwc;
            psm[iz][iy] += ps;
            tsm[iz][iy] += ts;
            zsm[iz][iy] += zs;
            usm[iz][iy] += us;
            vsm[iz][iy] += vs;
            pblm[iz][iy] += pbl;
            pctm[iz][iy] += pct;
            pcbm[iz][iy] += pcb;
            clm[iz][iy] += cl;
            if (gsl_finite(plfc) && gsl_finite(pel) && cape >= ctl.conv_cape
                && (ctl.conv_cin <= 0 || cin < ctl.conv_cin)) {
              plclm[iz][iy] += plcl;
              plfcm[iz][iy] += plfc;
              pelm[iz][iy] += pel;
              capem[iz][iy] += cape;
              cinm[iz][iy] += cin;
              npc[iz][iy]++;
            }
            if (gsl_finite(pt)) {
              ptm[iz][iy] += pt;
              ztm[iz][iy] += zt;
              ttm[iz][iy] += tt;
              h2otm[iz][iy] += h2ot;
              npt[iz][iy]++;
            }
            rhm[iz][iy] += RH(plev[iz], t, h2o);
            rhicem[iz][iy] += RHICE(plev[iz], t, h2o);
            tdewm[iz][iy] += TDEW(plev[iz], h2o);
            ticem[iz][iy] += TICE(plev[iz], h2o);
            hno3m[iz][iy] += clim_hno3(met->time, lats[iy], plev[iz]);
            tnatm[iz][iy] +=
              nat_temperature(plev[iz], h2o,
                              clim_hno3(met->time, lats[iy], plev[iz]));
            ohm[iz][iy] += clim_oh(met->time, lats[iy], plev[iz]);
            np[iz][iy]++;
          }
  }

  /* Create output file... */
  LOG(1, "Write meteorological data file: %s", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n"
          "# $4 = latitude [deg]\n"
          "# $5 = pressure [hPa]\n"
          "# $6 = temperature [K]\n"
          "# $7 = zonal wind [m/s]\n"
          "# $8 = meridional wind [m/s]\n"
          "# $9 = vertical velocity [hPa/s]\n"
          "# $10 = H2O volume mixing ratio [ppv]\n");
  fprintf(out,
          "# $11 = O3 volume mixing ratio [ppv]\n"
          "# $12 = geopotential height [km]\n"
          "# $13 = potential vorticity [PVU]\n"
          "# $14 = surface pressure [hPa]\n"
          "# $15 = surface temperature [K]\n"
          "# $16 = surface geopotential height [km]\n"
          "# $17 = surface zonal wind [m/s]\n"
          "# $18 = surface meridional wind [m/s]\n"
          "# $19 = tropopause pressure [hPa]\n"
          "# $20 = tropopause geopotential height [km]\n");
```

```
  fprintf(out,
          "# $21 = tropopause temperature [K]\n"
          "# $22 = tropopause water vapor [ppv]\n"
          "# $23 = cloud liquid water content [kg/kg]\n"
          "# $24 = cloud ice water content [kg/kg]\n"
          "# $25 = total column cloud water [kg/m^2]\n"
          "# $26 = cloud top pressure [hPa]\n"
          "# $27 = cloud bottom pressure [hPa]\n"
          "# $28 = pressure at lifted condensation level (LCL) [hPa]\n"
          "# $29 = pressure at level of free convection (LFC) [hPa]\n"
          "# $30 = pressure at equilibrium level (EL) [hPa]\n");
  fprintf(out,
          "# $31 = convective available potential energy (CAPE) [J/kg]\n"
          "# $32 = convective inhibition (CIN) [J/kg]\n"
          "# $33 = relative humidity over water [%%]\n"
          "# $34 = relative humidity over ice [%%]\n"
          "# $35 = dew point temperature [K]\n"
          "# $36 = frost point temperature [K]\n"
          "# $37 = NAT temperature [K]\n"
          "# $38 = HNO3 volume mixing ratio [ppv]\n"
          "# $39 = OH concentration [molec/cm^3]\n"
          "# $40 = boundary layer pressure [hPa]\n");
  fprintf(out,
          "# $41 = number of data points\n"
          "# $42 = number of tropopause data points\n"
          "# $43 = number of CAPE data points\n");

  /* Write data... */
  for (iz = 0; iz < nz; iz++) {
    fprintf(out, "\n");
    for (iy = 0; iy < ny; iy++)
      fprintf(out,
              "%.2f %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              "%g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g %g"
              " %g %g %g %g %g %d %d %d\n",
              timem[iz][iy] / np[iz][iy], Z(plev[iz]),
              lonm[iz][iy] / np[iz][iy], lats[iy],
              plev[iz], tm[iz][iy] / np[iz][iy], um[iz][iy] / np[iz][iy],
              vm[iz][iy] / np[iz][iy], wm[iz][iy] / np[iz][iy],
              h2om[iz][iy] / np[iz][iy], o3m[iz][iy] / np[iz][iy],
              zm[iz][iy] / np[iz][iy], pvm[iz][iy] / np[iz][iy],
              psm[iz][iy] / np[iz][iy], tsm[iz][iy] / np[iz][iy],
              zsm[iz][iy] / np[iz][iy], usm[iz][iy] / np[iz][iy],
              vsm[iz][iy] / np[iz][iy], ptm[iz][iy] / npt[iz][iy],
              ztm[iz][iy] / npt[iz][iy], ttm[iz][iy] / npt[iz][iy],
              h2otm[iz][iy] / npt[iz][iy], lwcm[iz][iy] / np[iz][iy],
              iwcm[iz][iy] / np[iz][iy], clm[iz][iy] / np[iz][iy],
              pctm[iz][iy] / np[iz][iy], pcbm[iz][iy] / np[iz][iy],
              plclm[iz][iy] / npc[iz][iy], plfcm[iz][iy] / npc[iz][iy],
              pelm[iz][iy] / npc[iz][iy], capem[iz][iy] / npc[iz][iy],
              cinm[iz][iy] / npc[iz][iy], rhm[iz][iy] / np[iz][iy],
              rhicem[iz][iy] / np[iz][iy], tdewm[iz][iy] / np[iz][iy],
              ticem[iz][iy] / np[iz][iy], tnatm[iz][iy] / np[iz][iy],
              hno3m[iz][iy] / np[iz][iy], ohm[iz][iy] / np[iz][iy],
              pblm[iz][iy] / np[iz][iy], np[iz][iy],
              npt[iz][iy], npc[iz][iy]);
  }

  /* Close file... */
  fclose(out);

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

## 5.37 sedi.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.37.1 Detailed Description

Calculate sedimentation velocity.

Definition in file sedi.c.

### 5.37.2 Function Documentation

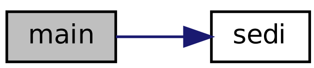
#### 5.37.2.1 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 27 of file sedi.c.

```
00029                  {
00030 
00031   double eta, p, T, r_p, rho, Re, rho_p, vs;
00032 
00033   /* Check arguments... */
00034   if (argc < 5)
00035     ERRMSG("Give parameters: <p> <T> <r_p> <rho_p>");
00036 
00037   /* Read arguments... */
00038   p = atof(argv[1]);
00039   T = atof(argv[2]);
00040   r_p = atof(argv[3]);
00041   rho_p = atof(argv[4]);
00042 
00043   /* Calculate sedimentation velocity... */
00044   vs = sedi(p, T, r_p, rho_p);
00045 
00046   /* Density of dry air [kg / m^3]... */
00047   rho = 100. * p / (RA * T);
00048 
00049   /* Dynamic viscosity of air [kg / (m s)]... */
00050   eta = 1.8325e-5 * (416.16 / (T + 120.)) * pow(T / 296.16, 1.5);
00051 
00052   /* Particle Reynolds number... */
00053   Re = 2e-6 * r_p * vs * rho / eta;
00054 
00055   /* Convert... */
00056   printf("%g %g\n", vs, Re);
00057 
00058   return EXIT_SUCCESS;
00059 }
```

Here is the call graph for this function:



## 5.38 sedi.c

```c
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

int main(
  int argc,
  char *argv[]) {

  double eta, p, T, r_p, rho, Re, rho_p, vs;

  /* Check arguments... */
  if (argc < 5)
    ERRMSG("Give parameters: <p> <T> <r_p> <rho_p>");

  /* Read arguments... */
  p = atof(argv[1]);
  T = atof(argv[2]);
  r_p = atof(argv[3]);
  rho_p = atof(argv[4]);

  /* Calculate sedimentation velocity... */
  vs = sedi(p, T, r_p, rho_p);

  /* Density of dry air [kg / m^3]... */
  rho = 100. * p / (RA * T);

  /* Dynamic viscosity of air [kg / (m s)]... */
  eta = 1.8325e-5 * (416.16 / (T + 120.)) * pow(T / 296.16, 1.5);

  /* Particle Reynolds number... */
  Re = 2e-6 * r_p * vs * rho / eta;

  /* Convert... */
  printf("%g %g\n", vs, Re);

  return EXIT_SUCCESS;
}
```

## 5.39 time2jsec.c File Reference

```c
#include "libtrac.h"
```

### Functions

- int main (int argc, char *argv[ ])

### 5.39.1 Detailed Description

Convert date to Julian seconds.

Definition in file time2jsec.c.

### 5.39.2 Function Documentation

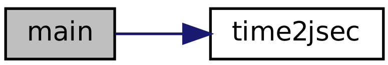
#### 5.39.2.1 main()

```
int main (
int argc,
char * argv[] )
```

Definition at line 27 of file time2jsec.c.

```
00029                {
00030
00031   double jsec, remain;
00032
00033   int day, hour, min, mon, sec, year;
00034
00035   /* Check arguments... */
00036   if (argc < 8)
00037     ERRMSG("Give parameters: <year> <mon> <day> <hour> <min> <sec> <remain>");
00038
00039   /* Read arguments... */
00040   year = atoi(argv[1]);
00041   mon = atoi(argv[2]);
00042   day = atoi(argv[3]);
00043   hour = atoi(argv[4]);
00044   min = atoi(argv[5]);
00045   sec = atoi(argv[6]);
00046   remain = atof(argv[7]);
00047
00048   /* Convert... */
00049   time2jsec(year, mon, day, hour, min, sec, remain, &jsec);
00050   printf("%.2f\n", jsec);
00051
00052   return EXIT_SUCCESS;
00053 }
```

Here is the call graph for this function:




## 5.40 time2jsec.c

```
00001 /*
00002   This file is part of MPTRAC.
00003
00004   MPTRAC is free software: you can redistribute it and/or modify
00005   it under the terms of the GNU General Public License as published by
00006   the Free Software Foundation, either version 3 of the License, or
00007   (at your option) any later version.
00008
00009   MPTRAC is distributed in the hope that it will be useful,
00010   but WITHOUT ANY WARRANTY; without even the implied warranty of
00011   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
00012   GNU General Public License for more details.
00013
00014   You should have received a copy of the GNU General Public License
00015   along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.
00016
00017   Copyright (C) 2013-2019 Forschungszentrum Juelich GmbH
00018 */
00019
00025 #include "libtrac.h"
00026
00027 int main(
```

```
  int argc,
  char *argv[]) {

  double jsec, remain;

  int day, hour, min, mon, sec, year;

  /* Check arguments... */
  if (argc < 8)
    ERRMSG("Give parameters: <year> <mon> <day> <hour> <min> <sec> <remain>");

  /* Read arguments... */
  year = atoi(argv[1]);
  mon = atoi(argv[2]);
  day = atoi(argv[3]);
  hour = atoi(argv[4]);
  min = atoi(argv[5]);
  sec = atoi(argv[6]);
  remain = atof(argv[7]);

  /* Convert... */
  time2jsec(year, mon, day, hour, min, sec, remain, &jsec);
  printf("%.2f\n", jsec);

  return EXIT_SUCCESS;
}
```

## 5.41 tnat.c File Reference

```
#include "libtrac.h"
```

### Functions

- int main (int argc, char ∗argv[ ])

### 5.41.1 Detailed Description

Calculate PSC temperatures.

Definition in file tnat.c.

### 5.41.2 Function Documentation

#### 5.41.2.1 main()

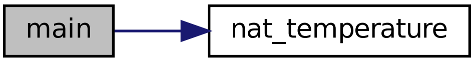
```
int main (
    int argc,
    char ∗ argv[ ] )
```

Definition at line 31 of file tnat.c.

```
                  {

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <p> <h2o> <hno3>");

  /* Get varibles... */
  double p = atof(argv[1]);
  double h2o = atof(argv[2]);
  double hno3 = atof(argv[3]);

  /* Calculate T_ice and T_NAT... */
```

```
  double tice = TICE(p, h2o);
  double tnat = nat_temperature(p, h2o, hno3);

  /* Write output... */
  printf("p= %g hPa\n", p);
  printf("q_H2O= %g ppv\n", h2o);
  printf("q_HNO3= %g ppv\n", hno3);
  printf("T_ice= %g K\n", tice);
  printf("T_NAT= %g K\n", tnat);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.42 tnat.c

```
/*
  This file is part of MPTRAC.

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  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <p> <h2o> <hno3>");

  /* Get varibles... */
  double p = atof(argv[1]);
  double h2o = atof(argv[2]);
  double hno3 = atof(argv[3]);

  /* Calculate T_ice and T_NAT... */
  double tice = TICE(p, h2o);
  double tnat = nat_temperature(p, h2o, hno3);

  /* Write output... */
  printf("p= %g hPa\n", p);
  printf("q_H2O= %g ppv\n", h2o);
  printf("q_HNO3= %g ppv\n", hno3);
  printf("T_ice= %g K\n", tice);
  printf("T_NAT= %g K\n", tnat);

  return EXIT_SUCCESS;
}
```

## 5.43 trac.c File Reference

```
#include "libtrac.h"
```

### Functions

- void module_advect_mp (met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate advection of air parcels (mipoint method).*
- void module_advect_rk (met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate advection of air parcels (Runge-Kutta).*
- void module_bound_cond (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Apply boundary conditions.*
- void module_convection (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt, double ∗rs)

    *Calculate convection of air parcels.*
- void module_decay (ctl_t ∗ctl, atm_t ∗atm, double ∗dt)

    *Calculate exponential decay of particle mass.*
- void module_diffusion_meso (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, cache_t ∗cache, double ∗dt, double ∗rs)

    *Calculate mesoscale diffusion.*
- void module_diffusion_turb (ctl_t ∗ctl, atm_t ∗atm, double ∗dt, double ∗rs)

    *Calculate turbulent diffusion.*
- void module_dry_deposition (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate dry deposition.*
- void module_isosurf_init (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, cache_t ∗cache)

    *Initialize isosurface module.*
- void module_isosurf (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, cache_t ∗cache)

    *Force air parcels to stay on isosurface.*
- void module_meteo (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm)

    *Interpolate meteorological data for air parcel positions.*
- void module_oh_chem (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate OH chemistry.*
- void module_position (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Check position of air parcels.*
- void module_rng_init (int ntask)

    *Initialize random number generator...*
- void module_rng (double ∗rs, size_t n, int method)

    *Generate random numbers.*
- void module_sedi (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate sedimentation of air parcels.*
- void module_timesteps (ctl_t ∗ctl, atm_t ∗atm, double ∗dt, double t)

    *Calculate time steps.*
- void module_timesteps_init (ctl_t ∗ctl, atm_t ∗atm)

    *Initialize timesteps.*
- void module_wet_deposition (ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double ∗dt)

    *Calculate wet deposition.*
- void write_output (const char ∗dirname, ctl_t ∗ctl, met_t ∗met0, met_t ∗met1, atm_t ∗atm, double t)

    *Write simulation output.*
- int main (int argc, char ∗argv[ ])

### 5.43.1 Detailed Description

Lagrangian particle dispersion model.

Definition in file trac.c.

### 5.43.2 Function Documentation

#### 5.43.2.1 module_advect_mp()

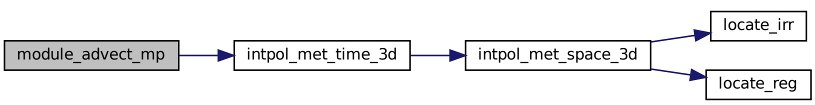
```
void module_advect_mp (
        met_t * met0,
        met_t * met1,
        atm_t * atm,
        double * dt )
```

Calculate advection of air parcels (mipoint method).

Definition at line 449 of file trac.c.

```
                              {

  /* Set timer... */
  SELECT_TIMER("MODULE_ADVECTION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double u, v, w;

      /* Interpolate meteorological data... */
      INTPOL_INIT;
      INTPOL_3D(u, 1);
      INTPOL_3D(v, 0);
      INTPOL_3D(w, 0);

      /* Get position of the mid point... */
      double dtm = atm->time[ip] + 0.5 * dt[ip];
      double xm0 =
        atm->lon[ip] + DX2DEG(0.5 * dt[ip] * u / 1000., atm->lat[ip]);
      double xm1 = atm->lat[ip] + DY2DEG(0.5 * dt[ip] * v / 1000.);
      double xm2 = atm->p[ip] + 0.5 * dt[ip] * w;

      /* Interpolate meteorological data for mid point... */
      intpol_met_time_3d(met0, met0->u, met1, met1->u,
                         dtm, xm2, xm0, xm1, &u, ci, cw, 1);
      intpol_met_time_3d(met0, met0->v, met1, met1->v,
                         dtm, xm2, xm0, xm1, &v, ci, cw, 0);
      intpol_met_time_3d(met0, met0->w, met1, met1->w,
                         dtm, xm2, xm0, xm1, &w, ci, cw, 0);

      /* Save new position... */
      atm->time[ip] += dt[ip];
      atm->lon[ip] += DX2DEG(dt[ip] * u / 1000., xm1);
      atm->lat[ip] += DY2DEG(dt[ip] * v / 1000.);
      atm->p[ip] += dt[ip] * w;
    }
}
```

Here is the call graph for this function:



#### 5.43.2.2 module_advect_rk()

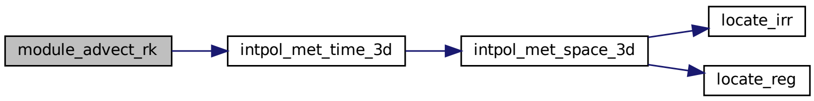
```
void module_advect_rk (
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

Calculate advection of air parcels (Runge-Kutta).

Definition at line 501 of file trac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("MODULE_ADVECTION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Init... */
      double dts, u[4], um = 0, v[4], vm = 0, w[4], wm = 0, x[3];
      INTPOL_INIT;

      /* Loop over integration nodes... */
      for (int i = 0; i < 4; i++) {

        /* Set position... */
        if (i == 0) {
          dts = 0.0;
          x[0] = atm->lon[ip];
          x[1] = atm->lat[ip];
          x[2] = atm->p[ip];
        } else {
          dts = (i == 3 ? 1.0 : 0.5) * dt[ip];
          x[0] = atm->lon[ip] + DX2DEG(dts * u[i - 1] / 1000., atm->lat[ip]);
          x[1] = atm->lat[ip] + DY2DEG(dts * v[i - 1] / 1000.);
          x[2] = atm->p[ip] + dts * w[i - 1];
        }

        /* Interpolate meteo data... */
        double tm = atm->time[ip] + dts;
        intpol_met_time_3d(met0, met0->u, met1, met1->u, tm, x[2], x[0], x[1],
                           &u[i], ci, cw, 1);
        intpol_met_time_3d(met0, met0->v, met1, met1->v, tm, x[2], x[0], x[1],
                           &v[i], ci, cw, 0);
        intpol_met_time_3d(met0, met0->w, met1, met1->w, tm, x[2], x[0], x[1],
                           &w[i], ci, cw, 0);

        /* Get mean wind... */
        double k = (i == 0 || i == 3 ? 1.0 / 6.0 : 2.0 / 6.0);
        um += k * u[i];
        vm += k * v[i];
        wm += k * w[i];
      }

      /* Set new position... */
      atm->time[ip] += dt[ip];
      atm->lon[ip] += DX2DEG(dt[ip] * um / 1000., atm->lat[ip]);
      atm->lat[ip] += DY2DEG(dt[ip] * vm / 1000.);
      atm->p[ip] += dt[ip] * wm;
    }
}
```

Here is the call graph for this function:




### 5.43.2.3 module_bound_cond()

```
void module_bound_cond (
        ctl_t * ctl,
        met_t * met0,
        met_t * met1,
        atm_t * atm,
        double * dt )
```

Apply boundary conditions.

Definition at line 566 of file trac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("MODULE_BOUNDCOND", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double ps;

      /* Check latitude and pressure range... */
      if (atm->lat[ip] < ctl->bound_lat0 || atm->lat[ip] > ctl->bound_lat1
          || atm->p[ip] > ctl->bound_p0 || atm->p[ip] < ctl->bound_p1)
        continue;

      /* Check surface layer... */
      if (ctl->bound_dps > 0) {

        /* Get surface pressure... */
        INTPOL_INIT;
        INTPOL_2D(ps, 1);

        /* Check whether particle is above the surface layer... */
        if (atm->p[ip] < ps - ctl->bound_dps)
          continue;
      }

      /* Set mass and volume mixing ratio... */
      if (ctl->qnt_m >= 0 && ctl->bound_mass >= 0)
        atm->q[ctl->qnt_m][ip] = ctl->bound_mass;
      if (ctl->qnt_vmr >= 0 && ctl->bound_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] = ctl->bound_vmr;
    }
}
```

#### 5.43.2.4 module_convection()

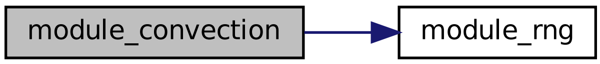
```
void module_convection (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt,
    double * rs )
```

Calculate convection of air parcels.

Definition at line 619 of file trac.c.

```
                 {

  /* Set timer... */
  SELECT_TIMER("MODULE_CONVECTION", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, (size_t) atm->np, 0);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double cape, cin, pel, ps;

      /* Interpolate CAPE... */
      INTPOL_INIT;
      INTPOL_2D(cape, 1);

      /* Check threshold... */
      if (isfinite(cape) && cape >= ctl->conv_cape) {

        /* Check CIN... */
        if (ctl->conv_cin > 0) {
          INTPOL_2D(cin, 0);
          if (isfinite(cin) && cin >= ctl->conv_cin)
            continue;
        }

        /* Interpolate equilibrium level... */
        INTPOL_2D(pel, 0);

        /* Check whether particle is above cloud top... */
        if (!isfinite(pel) || atm->p[ip] < pel)
          continue;

        /* Set pressure range for mixing... */
        double pbot = atm->p[ip];
        double ptop = atm->p[ip];
        if (ctl->conv_mix_bot == 1) {
          INTPOL_2D(ps, 0);
          pbot = ps;
        }
        if (ctl->conv_mix_top == 1)
          ptop = pel;

        /* Limit vertical velocity... */
        if (ctl->conv_wmax > 0 || ctl->conv_wcape) {
          double z = Z(atm->p[ip]);
          double wmax = (ctl->conv_wcape) ? sqrt(2. * cape) : ctl->conv_wmax;
          double pmax = P(z - wmax * dt[ip] / 1000.);
          double pmin = P(z + wmax * dt[ip] / 1000.);
          ptop = GSL_MAX(ptop, pmin);
          pbot = GSL_MIN(pbot, pmax);
        }

        /* Vertical mixing... */
        atm->p[ip] = pbot + (ptop - pbot) * rs[ip];
      }
    }
}
```

Here is the call graph for this function:




#### 5.43.2.5 module_decay()

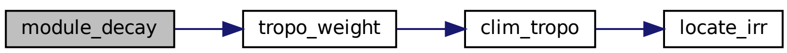
```
void module_decay (
        ctl_t * ctl,
        atm_t * atm,
        double * dt )
```

Calculate exponential decay of particle mass.

Definition at line 694 of file trac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("MODULE_DECAY", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get weighting factor... */
      double w = tropo_weight(atm->time[ip], atm->lat[ip], atm->p[ip]);

      /* Set lifetime... */
      double tdec = w * ctl->tdec_trop + (1 - w) * ctl->tdec_strat;

      /* Calculate exponential decay... */
      double aux = exp(-dt[ip] / tdec);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}
```

Here is the call graph for this function:



#### 5.43.2.6 module_diffusion_meso()

```
void module_diffusion_meso (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    cache_t * cache,
    double * dt,
    double * rs )
```

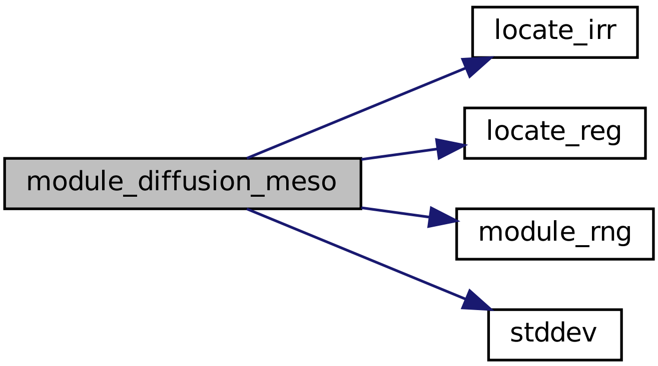
Calculate mesoscale diffusion.

Definition at line 733 of file trac.c.

```
                 {

  /* Set timer... */
  SELECT_TIMER("MODULE_TURBMESO", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, 3 * (size_t) atm->np, 1);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,cache,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get indices... */
      int ix = locate_reg(met0->lon, met0->nx, atm->lon[ip]);
      int iy = locate_reg(met0->lat, met0->ny, atm->lat[ip]);
      int iz = locate_irr(met0->p, met0->np, atm->p[ip]);

      /* Caching of wind standard deviations... */
      if (cache->tsig[ix][iy][iz] != met0->time) {

        /* Collect local wind data... */
        int n = 0;
        float u[16], v[16], w[16];
        for (int i = 0; i < 2; i++)
          for (int j = 0; j < 2; j++)
            for (int k = 0; k < 2; k++) {
              u[n] = met0->u[ix + i][iy + j][iz + k];
              v[n] = met0->v[ix + i][iy + j][iz + k];
              w[n] = met0->w[ix + i][iy + j][iz + k];
              n++;
              u[n] = met1->u[ix + i][iy + j][iz + k];
              v[n] = met1->v[ix + i][iy + j][iz + k];
              w[n] = met1->w[ix + i][iy + j][iz + k];
              n++;
            }

        /* Get standard deviations of local wind data... */
        cache->uvwsig[ix][iy][iz][0] = stddev(u, n);
        cache->uvwsig[ix][iy][iz][1] = stddev(v, n);
        cache->uvwsig[ix][iy][iz][2] = stddev(w, n);

        /* Save new time... */
        cache->tsig[ix][iy][iz] = met0->time;
      }

      /* Set temporal correlations for mesoscale fluctuations... */
      double r = 1 - 2 * fabs(dt[ip]) / ctl->dt_met;
      double r2 = sqrt(1 - r * r);

      /* Calculate horizontal mesoscale wind fluctuations... */
      if (ctl->turb_mesox > 0) {
        cache->uvwp[ip][0] = (float)
          (r * cache->uvwp[ip][0]
           +
           r2 * rs[3 * ip] * ctl->turb_mesox * cache->uvwsig[ix][iy][iz][0]);
        atm->lon[ip] +=
          DX2DEG(cache->uvwp[ip][0] * dt[ip] / 1000., atm->lat[ip]);

        cache->uvwp[ip][1] = (float)
          (r * cache->uvwp[ip][1]
           + r2 * rs[3 * ip +
                     1] * ctl->turb_mesox * cache->uvwsig[ix][iy][iz][1]);
        atm->lat[ip] += DY2DEG(cache->uvwp[ip][1] * dt[ip] / 1000.);
      }
```

```

      /* Calculate vertical mesoscale wind fluctuations... */
      if (ctl->turb_mesoz > 0) {
        cache->uvwp[ip][2] = (float)
          (r * cache->uvwp[ip][2]
           + r2 * rs[3 * ip +
                     2] * ctl->turb_mesoz * cache->uvwsig[ix][iy][iz][2]);
        atm->p[ip] += cache->uvwp[ip][2] * dt[ip];
      }
    }
}
```

Here is the call graph for this function:




#### 5.43.2.7 module_diffusion_turb() void module_diffusion_turb (

ctl_t * *ctl*,
atm_t * *atm*,
double * *dt*,
double * *rs* )

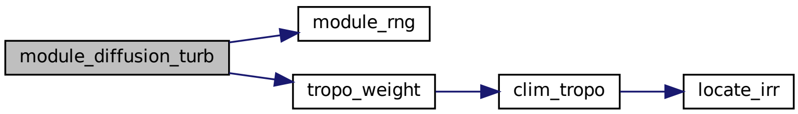
Calculate turbulent diffusion.

Definition at line 824 of file trac.c.

```
              {

  /* Set timer... */
  SELECT_TIMER("MODULE_TURBDIFF", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, 3 * (size_t) atm->np, 1);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get weighting factor... */
      double w = tropo_weight(atm->time[ip], atm->lat[ip], atm->p[ip]);

      /* Set diffusivity... */
```

```
      double dx = w * ctl->turb_dx_trop + (1 - w) * ctl->turb_dx_strat;
      double dz = w * ctl->turb_dz_trop + (1 - w) * ctl->turb_dz_strat;

      /* Horizontal turbulent diffusion... */
      if (dx > 0) {
        double sigma = sqrt(2.0 * dx * fabs(dt[ip]));
        atm->lon[ip] += DX2DEG(rs[3 * ip] * sigma / 1000., atm->lat[ip]);
        atm->lat[ip] += DY2DEG(rs[3 * ip + 1] * sigma / 1000.);
      }

      /* Vertical turbulent diffusion... */
      if (dz > 0) {
        double sigma = sqrt(2.0 * dz * fabs(dt[ip]));
        atm->p[ip]
          += DZ2DP(rs[3 * ip + 2] * sigma / 1000., atm->p[ip]);
      }
    }
}
```

Here is the call graph for this function:




### 5.43.2.8 module_dry_deposition()

```
void module_dry_deposition (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

Calculate dry deposition.

Definition at line 871 of file trac.c.

```
              {

  /* Set timer... */
  SELECT_TIMER("MODULE_DRYDEPO", "PHYSICS", NVTX_GPU);

  /* Width of the surface layer [hPa]. */
  const double dp = 30.;

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double ps, t, v_dep;

      /* Get surface pressure... */
      INTPOL_INIT;
      INTPOL_2D(ps, 1);

      /* Check whether particle is above the surface layer... */
```

```
      if (atm->p[ip] < ps - dp)
        continue;

      /* Set width of surface layer... */
      double dz = 1000. * (Z(ps - dp) - Z(ps));

      /* Calculate sedimentation velocity for particles... */
      if (ctl->qnt_r > 0 && ctl->qnt_rho > 0) {

        /* Get temperature... */
        INTPOL_3D(t, 1);

        /* Set deposition velocity... */
        v_dep = sedi(atm->p[ip], t, atm->q[ctl->qnt_r][ip],
                     atm->q[ctl->qnt_rho][ip]);
      }

      /* Use explicit sedimentation velocity for gases... */
      else
        v_dep = ctl->dry_depo[0];

      /* Calculate loss of mass based on deposition velocity... */
      double aux = exp(-dt[ip] * v_dep / dz);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}
```

Here is the call graph for this function:


#### 5.43.2.9 module_isosurf_init()

```
void module_isosurf_init (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    cache_t * cache )
```

Initialize isosurface module.

Definition at line 937 of file trac.c.

```
                          {

  FILE *in;

  char line[LEN];

  double t;

  /* Set timer... */
  SELECT_TIMER("MODULE_ISOSURF", "PHYSICS", NVTX_GPU);

  /* Init... */
  INTPOL_INIT;

  /* Save pressure... */
  if (ctl->isosurf == 1)
    for (int ip = 0; ip < atm->np; ip++)
```

```
      cache->iso_var[ip] = atm->p[ip];

  /* Save density... */
  else if (ctl->isosurf == 2)
    for (int ip = 0; ip < atm->np; ip++) {
      INTPOL_3D(t, 1);
      cache->iso_var[ip] = atm->p[ip] / t;
    }

  /* Save potential temperature... */
  else if (ctl->isosurf == 3)
    for (int ip = 0; ip < atm->np; ip++) {
      INTPOL_3D(t, 1);
      cache->iso_var[ip] = THETA(atm->p[ip], t);
    }

  /* Read balloon pressure data... */
  else if (ctl->isosurf == 4) {

    /* Write info... */
    LOG(1, "Read balloon pressure data: %s", ctl->balloon);

    /* Open file... */
    if (!(in = fopen(ctl->balloon, "r")))
      ERRMSG("Cannot open file!");

    /* Read pressure time series... */
    while (fgets(line, LEN, in))
      if (sscanf(line, "%lg %lg", &(cache->iso_ts[cache->iso_n]),
                 &(cache->iso_ps[cache->iso_n])) == 2)
        if ((++cache->iso_n) > NP)
          ERRMSG("Too many data points!");

    /* Check number of points... */
    if (cache->iso_n < 1)
      ERRMSG("Could not read any data!");

    /* Close file... */
    fclose(in);
  }
}
```

### 5.43.2.10 module_isosurf()

```
void module_isosurf (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    cache_t * cache )
```

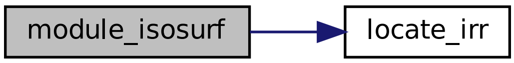
Force air parcels to stay on isosurface.

Definition at line 1003 of file trac.c.

```
                        {

  /* Set timer... */
  SELECT_TIMER("MODULE_ISOSURF", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,cache)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {

    double t;

    /* Init... */
    INTPOL_INIT;

    /* Restore pressure... */
    if (ctl->isosurf == 1)
      atm->p[ip] = cache->iso_var[ip];

    /* Restore density... */
    else if (ctl->isosurf == 2) {
```

```
      INTPOL_3D(t, 1);
      atm->p[ip] = cache->iso_var[ip] * t;
    }

    /* Restore potential temperature... */
    else if (ctl->isosurf == 3) {
      INTPOL_3D(t, 1);
      atm->p[ip] = 1000. * pow(cache->iso_var[ip] / t, -1. / 0.286);
    }

    /* Interpolate pressure... */
    else if (ctl->isosurf == 4) {
      if (atm->time[ip] <= cache->iso_ts[0])
        atm->p[ip] = cache->iso_ps[0];
      else if (atm->time[ip] >= cache->iso_ts[cache->iso_n - 1])
        atm->p[ip] = cache->iso_ps[cache->iso_n - 1];
      else {
        int idx = locate_irr(cache->iso_ts, cache->iso_n, atm->time[ip]);
        atm->p[ip] = LIN(cache->iso_ts[idx], cache->iso_ps[idx],
                         cache->iso_ts[idx + 1], cache->iso_ps[idx + 1],
                         atm->time[ip]);
      }
    }
  }
}
```

Here is the call graph for this function:




#### 5.43.2.11 module_meteo() void module_meteo (

ctl_t * *ctl*,
met_t * *met0*,
met_t * *met1*,
atm_t * *atm* )

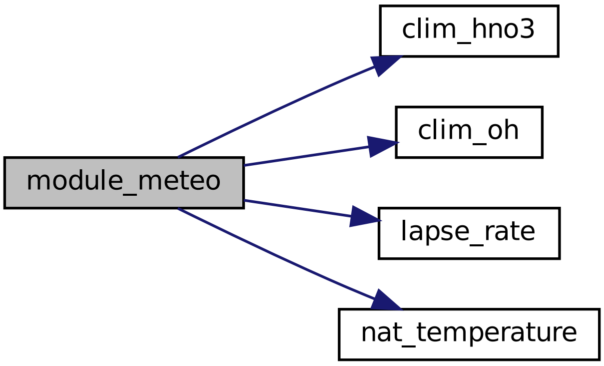
Interpolate meteorological data for air parcel positions.

Definition at line 1061 of file trac.c.

```
               {

  /* Set timer... */
  SELECT_TIMER("MODULE_METEO", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_tsts >= 0)
    if (ctl->qnt_tice < 0 || ctl->qnt_tnat < 0)
      ERRMSG("Need T_ice and T_NAT to calculate T_STS!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {

    double ps, ts, zs, us, vs, pbl, pt, pct, pcb, cl, plcl, plfc, pel, cape,
      cin, pv, t, tt, u, v, w, h2o, h2ot, o3, lwc, iwc, z, zt;

    /* Interpolate meteorological data... */
```

```
    INTPOL_INIT;
    INTPOL_TIME_ALL(atm->time[ip], atm->p[ip], atm->lon[ip], atm->lat[ip]);

    /* Set quantities... */
    SET_ATM(qnt_ps, ps);
    SET_ATM(qnt_ts, ts);
    SET_ATM(qnt_zs, zs);
    SET_ATM(qnt_us, us);
    SET_ATM(qnt_vs, vs);
    SET_ATM(qnt_pbl, pbl);
    SET_ATM(qnt_pt, pt);
    SET_ATM(qnt_tt, tt);
    SET_ATM(qnt_zt, zt);
    SET_ATM(qnt_h2ot, h2ot);
    SET_ATM(qnt_p, atm->p[ip]);
    SET_ATM(qnt_z, z);
    SET_ATM(qnt_t, t);
    SET_ATM(qnt_u, u);
    SET_ATM(qnt_v, v);
    SET_ATM(qnt_w, w);
    SET_ATM(qnt_h2o, h2o);
    SET_ATM(qnt_o3, o3);
    SET_ATM(qnt_lwc, lwc);
    SET_ATM(qnt_iwc, iwc);
    SET_ATM(qnt_pct, pct);
    SET_ATM(qnt_pcb, pcb);
    SET_ATM(qnt_cl, cl);
    SET_ATM(qnt_plcl, plcl);
    SET_ATM(qnt_plfc, plfc);
    SET_ATM(qnt_pel, pel);
    SET_ATM(qnt_cape, cape);
    SET_ATM(qnt_cin, cin);
    SET_ATM(qnt_hno3, clim_hno3(atm->time[ip], atm->lat[ip], atm->p[ip]));
    SET_ATM(qnt_oh, clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]));
    SET_ATM(qnt_vh, sqrt(u * u + v * v));
    SET_ATM(qnt_vz, -1e3 * H0 / atm->p[ip] * w);
    SET_ATM(qnt_psat, PSAT(t));
    SET_ATM(qnt_psice, PSICE(t));
    SET_ATM(qnt_pw, PW(atm->p[ip], h2o));
    SET_ATM(qnt_sh, SH(h2o));
    SET_ATM(qnt_rh, RH(atm->p[ip], t, h2o));
    SET_ATM(qnt_rhice, RHICE(atm->p[ip], t, h2o));
    SET_ATM(qnt_theta, THETA(atm->p[ip], t));
    SET_ATM(qnt_zeta, ZETA(ps, atm->p[ip], t));
    SET_ATM(qnt_tvirt, TVIRT(t, h2o));
    SET_ATM(qnt_lapse, lapse_rate(t, h2o));
    SET_ATM(qnt_pv, pv);
    SET_ATM(qnt_tdew, TDEW(atm->p[ip], h2o));
    SET_ATM(qnt_tice, TICE(atm->p[ip], h2o));
    SET_ATM(qnt_tnat,
            nat_temperature(atm->p[ip], h2o,
                            clim_hno3(atm->time[ip], atm->lat[ip],
                                      atm->p[ip])));
    SET_ATM(qnt_tsts,
            0.5 * (atm->q[ctl->qnt_tice][ip] + atm->q[ctl->qnt_tnat][ip]));
  }
}
```

Here is the call graph for this function:




#### 5.43.2.12 module_oh_chem()

```
void module_oh_chem (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

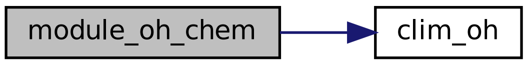
Calculate OH chemistry.

Definition at line 1148 of file trac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("MODULE_OHCHEM", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get temperature... */
      double t;
      INTPOL_INIT;
      INTPOL_3D(t, 1);

      /* Use constant reaction rate... */
      double k = GSL_NAN;
      if (ctl->oh_chem_reaction == 1)
        k = ctl->oh_chem[0];

      /* Calculate bimolecular reaction rate... */
      else if (ctl->oh_chem_reaction == 2)
        k = ctl->oh_chem[0] * exp(-ctl->oh_chem[1] / t);

      /* Calculate termolecular reaction rate... */
```

```
      if (ctl->oh_chem_reaction == 3) {

        /* Calculate molecular density (IUPAC Data Sheet I.A4.86 SOx15)... */
        double M = 7.243e21 * (atm->p[ip] / 1000.) / t;

        /* Calculate rate coefficient for X + OH + M -> XOH + M
           (JPL Publication 19-05) ... */
        double k0 = ctl->oh_chem[0] *
          (ctl->oh_chem[1] > 0 ? pow(298. / t, ctl->oh_chem[1]) : 1.);
        double ki = ctl->oh_chem[2] *
          (ctl->oh_chem[3] > 0 ? pow(298. / t, ctl->oh_chem[3]) : 1.);
        double c = log10(k0 * M / ki);
        k = k0 * M / (1. + k0 * M / ki) * pow(0.6, 1. / (1. + c * c));
      }

      /* Calculate exponential decay... */
      double aux
        = exp(-dt[ip] * k * clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]));
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}
```

Here is the call graph for this function:




### 5.43.2.13 module_position()

```
void module_position (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

Check position of air parcels.

Definition at line 1214 of file trac.c.

```
                  {

  /* Set timer... */
  SELECT_TIMER("MODULE_POSITION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Init... */
      double ps;
      INTPOL_INIT;

      /* Calculate modulo... */
      atm->lon[ip] = FMOD(atm->lon[ip], 360.);
      atm->lat[ip] = FMOD(atm->lat[ip], 360.);
```

```

      /* Check latitude... */
      while (atm->lat[ip] < -90 || atm->lat[ip] > 90) {
        if (atm->lat[ip] > 90) {
          atm->lat[ip] = 180 - atm->lat[ip];
          atm->lon[ip] += 180;
        }
        if (atm->lat[ip] < -90) {
          atm->lat[ip] = -180 - atm->lat[ip];
          atm->lon[ip] += 180;
        }
      }

      /* Check longitude... */
      while (atm->lon[ip] < -180)
        atm->lon[ip] += 360;
      while (atm->lon[ip] >= 180)
        atm->lon[ip] -= 360;

      /* Check pressure... */
      if (atm->p[ip] < met0->p[met0->np - 1]) {
        if (ctl->reflect)
          atm->p[ip] = 2. * met0->p[met0->np - 1] - atm->p[ip];
        else
          atm->p[ip] = met0->p[met0->np - 1];
      } else if (atm->p[ip] > 300.) {
        INTPOL_2D(ps, 1);
        if (atm->p[ip] > ps) {
          if (ctl->reflect)
            atm->p[ip] = 2. * ps - atm->p[ip];
          else
            atm->p[ip] = ps;
        }
      }
    }
}
```

#### 5.43.2.14 module_rng_init() void module_rng_init ( int *ntask* )

Initialize random number generator...

Definition at line 1280 of file trac.c.

```
             {

  /* Initialize random number generator... */
#ifdef _OPENACC

  if (curandCreateGenerator(&rng, CURAND_RNG_PSEUDO_DEFAULT)
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot create random number generator!");
  if (curandSetPseudoRandomGeneratorSeed(rng, ntask)
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot set seed for random number generator!");
  if (curandSetStream(rng, (cudaStream_t) acc_get_cuda_stream(acc_async_sync))
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot set stream for random number generator!");

#else

  gsl_rng_env_setup();
  if (omp_get_max_threads() > NTHREADS)
    ERRMSG("Too many threads!");
  for (int i = 0; i < NTHREADS; i++) {
    rng[i] = gsl_rng_alloc(gsl_rng_default);
    gsl_rng_set(rng[i], gsl_rng_default_seed
                + (long unsigned) (ntask * NTHREADS + i));
  }

#endif
}
```

#### 5.43.2.15 module_rng()

```
void module_rng (
    double * rs,
    size_t n,
    int method )
```

Generate random numbers.

Definition at line 1312 of file trac.c.

```
                {

#ifdef _OPENACC

#pragma acc host_data use_device(rs)
  {
    /* Uniform distribution... */
    if (method == 0) {
      if (curandGenerateUniformDouble(rng, rs, (n < 4 ? 4 : n))
          != CURAND_STATUS_SUCCESS)
        ERRMSG("Cannot create random numbers!");
    }

    /* Normal distribution... */
    else if (method == 1) {
      if (curandGenerateNormalDouble(rng, rs, (n < 4 ? 4 : n), 0.0, 1.0)
          != CURAND_STATUS_SUCCESS)
        ERRMSG("Cannot create random numbers!");
    }
  }

#else

  /* Uniform distribution... */
  if (method == 0) {
#pragma omp parallel for default(shared)
    for (size_t i = 0; i < n; ++i)
      rs[i] = gsl_rng_uniform(rng[omp_get_thread_num()]);
  }

  /* Normal distribution... */
  else if (method == 1) {
#pragma omp parallel for default(shared)
    for (size_t i = 0; i < n; ++i)
      rs[i] = gsl_ran_gaussian_ziggurat(rng[omp_get_thread_num()], 1.0);
  }
#endif

}
```

#### 5.43.2.16 module_sedi()

```
void module_sedi (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

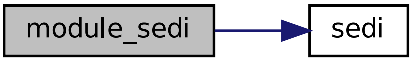
Calculate sedimentation of air parcels.

Definition at line 1357 of file trac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("MODULE_SEDI", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get temperature... */
```

```
      double t;
      INTPOL_INIT;
      INTPOL_3D(t, 1);

      /* Sedimentation velocity... */
      double v_s = sedi(atm->p[ip], t, atm->q[ctl->qnt_r][ip],
                        atm->q[ctl->qnt_rho][ip]);

      /* Calculate pressure change... */
      atm->p[ip] += DZ2DP(v_s * dt[ip] / 1000., atm->p[ip]);
    }
}
```

Here is the call graph for this function:




#### 5.43.2.17 module_timesteps()

```
void module_timesteps (
    ctl_t * ctl,
    atm_t * atm,
    double * dt,
    double t )
```

Calculate time steps.

Definition at line 1393 of file trac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("MODULE_TIMESTEPS", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {
    if ((ctl->direction * (atm->time[ip] - ctl->t_start) >= 0
         && ctl->direction * (atm->time[ip] - ctl->t_stop) <= 0
         && ctl->direction * (atm->time[ip] - t) < 0))
      dt[ip] = t - atm->time[ip];
    else
      dt[ip] = 0.0;
  }
}
```

#### 5.43.2.18 module_timesteps_init()

```
void module_timesteps_init (
    ctl_t * ctl,
    atm_t * atm )
```

Initialize timesteps.

Definition at line 1421 of file trac.c.

```
                {

  /* Set timer... */
  SELECT_TIMER("MODULE_TIMESTEPS", "PHYSICS", NVTX_GPU);

  /* Set start time... */
  if (ctl->direction == 1) {
    ctl->t_start = gsl_stats_min(atm->time, 1, (size_t) atm->np);
    if (ctl->t_stop > 1e99)
      ctl->t_stop = gsl_stats_max(atm->time, 1, (size_t) atm->np);
  } else {
    ctl->t_start = gsl_stats_max(atm->time, 1, (size_t) atm->np);
    if (ctl->t_stop > 1e99)
      ctl->t_stop = gsl_stats_min(atm->time, 1, (size_t) atm->np);
  }

  /* Check time interval... */
  if (ctl->direction * (ctl->t_stop - ctl->t_start) <= 0)
    ERRMSG("Nothing to do! Check T_STOP and DIRECTION!");

  /* Round start time... */
  if (ctl->direction == 1)
    ctl->t_start = floor(ctl->t_start / ctl->dt_mod) * ctl->dt_mod;
  else
    ctl->t_start = ceil(ctl->t_start / ctl->dt_mod) * ctl->dt_mod;
}
```

#### 5.43.2.19 module_wet_deposition()

```
void module_wet_deposition (
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double * dt )
```

Calculate wet deposition.

Definition at line 1452 of file trac.c.

```
               {

  /* Set timer... */
  SELECT_TIMER("MODULE_WETDEPO", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double cl, dz, h, lambda = 0, t, iwc, lwc, pct, pcb;

      int inside;

      /* Check whether particle is below cloud top... */
      INTPOL_INIT;
      INTPOL_2D(pct, 1);
      if (!isfinite(pct) || atm->p[ip] <= pct)
        continue;

      /* Get cloud bottom pressure... */
```

```
      INTPOL_2D(pcb, 0);

      /* Estimate precipitation rate (Pisso et al., 2019)... */
      INTPOL_2D(cl, 0);
      double Is = pow(2. * cl, 1. / 0.36);
      if (Is < 0.01)
        continue;

      /* Check whether particle is inside or below cloud... */
      INTPOL_3D(lwc, 1);
      INTPOL_3D(iwc, 0);
      inside = (iwc > 0 || lwc > 0);

      /* Calculate in-cloud scavenging coefficient... */
      if (inside) {

        /* Use exponential dependency for particles... */
        if (ctl->wet_depo[0] > 0)
          lambda = ctl->wet_depo[0] * pow(Is, ctl->wet_depo[1]);

        /* Use Henry's law for gases... */
        else if (ctl->wet_depo[2] > 0) {

          /* Get temperature... */
          INTPOL_3D(t, 0);

          /* Get Henry's constant (Sander, 2015)... */
          h = ctl->wet_depo[2]
            * exp(ctl->wet_depo[3] * (1. / t - 1. / 298.15));

          /* Estimate depth of cloud layer... */
          dz = 1e3 * (Z(pct) - Z(pcb));

          /* Calculate scavenging coefficient (Draxler and Hess, 1997)... */
          lambda = h * RI * t * Is / 3.6e6 / dz;
        }
      }

      /* Calculate below-cloud scavenging coefficient... */
      else {

        /* Use exponential dependency for particles... */
        if (ctl->wet_depo[4] > 0)
          lambda = ctl->wet_depo[4] * pow(Is, ctl->wet_depo[5]);

        /* Use Henry's law for gases... */
        else if (ctl->wet_depo[6] > 0) {

          /* Get temperature... */
          INTPOL_3D(t, 0);

          /* Get Henry's constant (Sander, 2015)... */
          h = ctl->wet_depo[6]
            * exp(ctl->wet_depo[7] * (1. / t - 1. / 298.15));

          /* Estimate depth of cloud layer... */
          dz = 1e3 * (Z(pct) - Z(pcb));

          /* Calculate scavenging coefficient (Draxler and Hess, 1997)... */
          lambda = h * RI * t * Is / 3.6e6 / dz;
        }
      }

      /* Calculate exponential decay of mass... */
      double aux = exp(-dt[ip] * lambda);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}
```

#### 5.43.2.20 write_output()

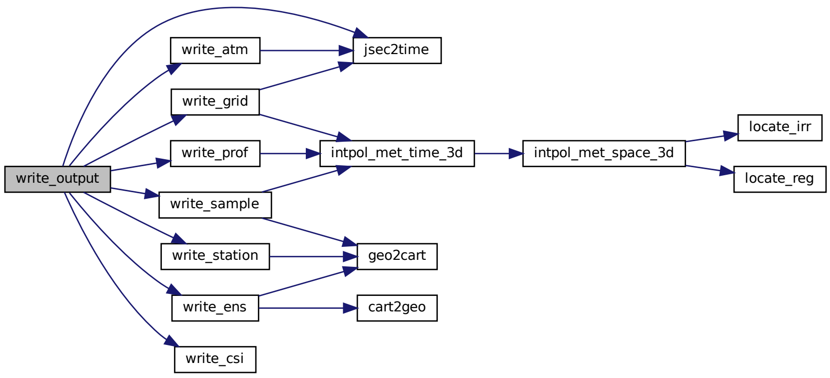
```
void write_output (
    const char * dirname,
    ctl_t * ctl,
    met_t * met0,
    met_t * met1,
    atm_t * atm,
    double t )
```

Write simulation output.

Definition at line 1561 of file trac.c.

```
            {

  char filename[2 * LEN];

  double r;

  int year, mon, day, hour, min, sec;

  /* Get time... */
  jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);

  /* Update host... */
#ifdef _OPENACC
  if ((ctl->atm_basename[0] != '-' && fmod(t, ctl->atm_dt_out) == 0)
      || (ctl->grid_basename[0] != '-' && fmod(t, ctl->grid_dt_out) == 0)
      || ctl->csi_basename[0] != '-' || ctl->ens_basename[0] != '-'
      || ctl->prof_basename[0] != '-' || ctl->sample_basename[0] != '-'
      || ctl->stat_basename[0] != '-') {
    SELECT_TIMER("UPDATE_HOST", "MEMORY", NVTX_D2H);
#pragma acc update host(atm[:1])
  }
#endif

  /* Write atmospheric data... */
  if (ctl->atm_basename[0] != '-' && fmod(t, ctl->atm_dt_out) == 0) {
    sprintf(filename, "%s/%s_%04d_%02d_%02d_%02d_%02d.tab",
            dirname, ctl->atm_basename, year, mon, day, hour, min);
    write_atm(filename, ctl, atm, t);
  }

  /* Write gridded data... */
  if (ctl->grid_basename[0] != '-' && fmod(t, ctl->grid_dt_out) == 0) {
    sprintf(filename, "%s/%s_%04d_%02d_%02d_%02d_%02d.tab",
            dirname, ctl->grid_basename, year, mon, day, hour, min);
    write_grid(filename, ctl, met0, met1, atm, t);
  }

  /* Write CSI data... */
  if (ctl->csi_basename[0] != '-') {
    sprintf(filename, "%s/%s.tab", dirname, ctl->csi_basename);
    write_csi(filename, ctl, atm, t);
  }

  /* Write ensemble data... */
  if (ctl->ens_basename[0] != '-') {
    sprintf(filename, "%s/%s.tab", dirname, ctl->ens_basename);
    write_ens(filename, ctl, atm, t);
  }

  /* Write profile data... */
  if (ctl->prof_basename[0] != '-') {
    sprintf(filename, "%s/%s.tab", dirname, ctl->prof_basename);
    write_prof(filename, ctl, met0, met1, atm, t);
  }

  /* Write sample data... */
  if (ctl->sample_basename[0] != '-') {
    sprintf(filename, "%s/%s.tab", dirname, ctl->sample_basename);
    write_sample(filename, ctl, met0, met1, atm, t);
  }

  /* Write station data... */
  if (ctl->stat_basename[0] != '-') {
    sprintf(filename, "%s/%s.tab", dirname, ctl->stat_basename);
    write_station(filename, ctl, atm, t);
  }
}
```

Here is the call graph for this function:




#### 5.43.2.21 main()

```
int main (
    int argc,
    char * argv[ ] )
```

Definition at line 193 of file trac.c.

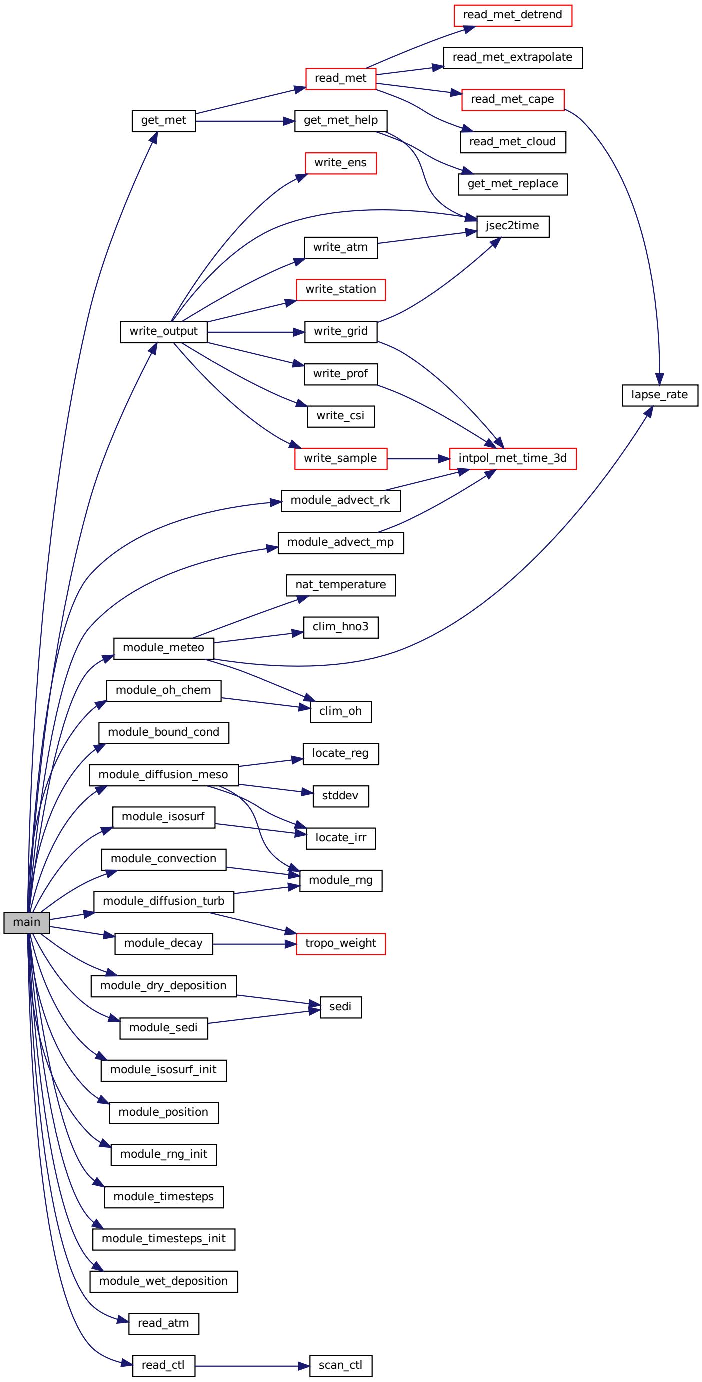
```
                   {

  ctl_t ctl;

  atm_t *atm;

  cache_t *cache;

  met_t *met0, *met1;

  FILE *dirlist;

  char dirname[LEN], filename[2 * LEN];

  double *dt, *rs, t;

  int num_devices = 0, ntask = -1, rank = 0, size = 1;

  /* Start timers... */
  START_TIMERS;

  /* Initialize MPI... */
#ifdef MPI
  SELECT_TIMER("MPI_INIT", "INIT", NVTX_CPU);
  MPI_Init(&argc, &argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
#endif

  /* Initialize GPUs... */
#ifdef _OPENACC
  SELECT_TIMER("ACC_INIT", "INIT", NVTX_GPU);
  num_devices = acc_get_num_devices(acc_device_nvidia);
  if (num_devices <= 0)
    ERRMSG("Not running on a GPU device!");
  int device_num = rank % num_devices;
  acc_set_device_num(device_num, acc_device_nvidia);
  acc_device_t device_type = acc_get_device_type();
  acc_init(device_type);
#endif

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <dirlist> <ctl> <atm_in>");

  /* Open directory list... */
```

```
  if (!(dirlist = fopen(argv[1], "r")))
    ERRMSG("Cannot open directory list!");

  /* Loop over directories... */
  while (fscanf(dirlist, "%4999s", dirname) != EOF) {

    /* MPI parallelization... */
    if ((++ntask) % size != rank)
      continue;

    /* ------------------------------------------------------------
       Initialize model run...
       ------------------------------------------------------------ */

    /* Allocate... */
    SELECT_TIMER("ALLOC", "MEMORY", NVTX_CPU);
    ALLOC(atm, atm_t, 1);
    ALLOC(cache, cache_t, 1);
    ALLOC(met0, met_t, 1);
    ALLOC(met1, met_t, 1);
    ALLOC(dt, double,
          NP);
    ALLOC(rs, double,
          3 * NP + 1);

    /* Create data region on GPUs... */
#ifdef _OPENACC
    SELECT_TIMER("CREATE_DATA_REGION", "MEMORY", NVTX_GPU);
#pragma acc enter data create(atm[:1],cache[:1],ctl,met0[:1],met1[:1],dt[:NP],rs[:3*NP])
#endif

    /* Read control parameters... */
    sprintf(filename, "%s/%s", dirname, argv[2]);
    read_ctl(filename, argc, argv, &ctl);

    /* Read atmospheric data... */
    sprintf(filename, "%s/%s", dirname, argv[3]);
    if (!read_atm(filename, &ctl, atm))
      ERRMSG("Cannot open file!");

    /* Initialize timesteps... */
    module_timesteps_init(&ctl, atm);

    /* Update GPU... */
#ifdef _OPENACC
    SELECT_TIMER("UPDATE_DEVICE", "MEMORY", NVTX_H2D);
#pragma acc update device(atm[:1],ctl)
#endif

    /* Initialize random number generator... */
    module_rng_init(ntask);

    /* Initialize meteorological data... */
    get_met(&ctl, ctl.t_start, &met0, &met1);
    if (ctl.dt_mod > fabs(met0->lon[1] - met0->lon[0]) * 111132. / 150.)
      WARN("Violation of CFL criterion! Check DT_MOD!");

    /* Initialize isosurface... */
    if (ctl.isosurf >= 1 && ctl.isosurf <= 4)
      module_isosurf_init(&ctl, met0, met1, atm, cache);

    /* Update GPU... */
#ifdef _OPENACC
    SELECT_TIMER("UPDATE_DEVICE", "MEMORY", NVTX_H2D);
#pragma acc update device(cache[:1])
#endif

    /* ------------------------------------------------------------
       Loop over timesteps...
       ------------------------------------------------------------ */

    /* Loop over timesteps... */
    for (t = ctl.t_start; ctl.direction * (t - ctl.t_stop) < ctl.dt_mod;
         t += ctl.direction * ctl.dt_mod) {

      /* Adjust length of final time step... */
      if (ctl.direction * (t - ctl.t_stop) > 0)
        t = ctl.t_stop;

      /* Set time steps of air parcels... */
      module_timesteps(&ctl, atm, dt, t);

      /* Get meteorological data... */
      if (t != ctl.t_start)
        get_met(&ctl, t, &met0, &met1);

      /* Check initial positions... */
```

```
    module_position(&ctl, met0, met1, atm, dt);

    /* Advection... */
    if (ctl.advect == 0)
      module_advect_mp(met0, met1, atm, dt);
    else
      module_advect_rk(met0, met1, atm, dt);

    /* Turbulent diffusion... */
    if (ctl.turb_dx_trop > 0 || ctl.turb_dz_trop > 0
        || ctl.turb_dx_strat > 0 || ctl.turb_dz_strat > 0)
      module_diffusion_turb(&ctl, atm, dt, rs);

    /* Mesoscale diffusion... */
    if (ctl.turb_mesox > 0 || ctl.turb_mesoz > 0)
      module_diffusion_meso(&ctl, met0, met1, atm, cache, dt, rs);

    /* Convection... */
    if (ctl.conv_cape >= 0
        && (ctl.conv_dt <= 0 || fmod(t, ctl.conv_dt) == 0))
      module_convection(&ctl, met0, met1, atm, dt, rs);

    /* Sedimentation... */
    if (ctl.qnt_r >= 0 && ctl.qnt_rho >= 0)
      module_sedi(&ctl, met0, met1, atm, dt);

    /* Isosurface... */
    if (ctl.isosurf >= 1 && ctl.isosurf <= 4)
      module_isosurf(&ctl, met0, met1, atm, cache);

    /* Check final positions... */
    module_position(&ctl, met0, met1, atm, dt);

    /* Interpolate meteorological data... */
    if (ctl.met_dt_out > 0
        && (ctl.met_dt_out < ctl.dt_mod || fmod(t, ctl.met_dt_out) == 0))
      module_meteo(&ctl, met0, met1, atm);

    /* Decay of particle mass... */
    if (ctl.tdec_trop > 0 && ctl.tdec_strat > 0)
      module_decay(&ctl, atm, dt);

    /* OH chemistry... */
    if (ctl.oh_chem_reaction != 0)
      module_oh_chem(&ctl, met0, met1, atm, dt);

    /* Dry deposition... */
    if (ctl.dry_depo[0] > 0)
      module_dry_deposition(&ctl, met0, met1, atm, dt);

    /* Wet deposition... */
    if ((ctl.wet_depo[0] > 0 || ctl.wet_depo[2] > 0)
        && (ctl.wet_depo[4] > 0 || ctl.wet_depo[6] > 0))
      module_wet_deposition(&ctl, met0, met1, atm, dt);

    /* Boundary conditions... */
    if (ctl.bound_mass >= 0 || ctl.bound_vmr >= 0)
      module_bound_cond(&ctl, met0, met1, atm, dt);

    /* Write output... */
    write_output(dirname, &ctl, met0, met1, atm, t);
  }

  /* ------------------------------------------------------------
     Finalize model run...
     ------------------------------------------------------------ */

  /* Report problem size... */
  LOG(1, "SIZE_NP = %d", atm->np);
  LOG(1, "SIZE_MPI_TASKS = %d", size);
  LOG(1, "SIZE_OMP_THREADS = %d", omp_get_max_threads());
  LOG(1, "SIZE_ACC_DEVICES = %d", num_devices);

  /* Report memory usage... */
  LOG(1, "MEMORY_ATM = %g MByte", sizeof(atm_t) / 1024. / 1024.);
  LOG(1, "MEMORY_CACHE = %g MByte", sizeof(cache_t) / 1024. / 1024.);
  LOG(1, "MEMORY_METEO = %g MByte", 2 * sizeof(met_t) / 1024. / 1024.);
  LOG(1, "MEMORY_DYNAMIC = %g MByte", (sizeof(met_t)
                                       + 4 * NP * sizeof(double)
                                       + EX * EY * EP * sizeof(float)) /
      1024. / 1024.);
  LOG(1, "MEMORY_STATIC = %g MByte", (EX * EY * sizeof(double)
                                      + EX * EY * EP * sizeof(float)
                                      + 4 * GX * GY * GZ * sizeof(double)
                                      + 2 * GX * GY * GZ * sizeof(int)
                                      + 2 * GX * GY * sizeof(double)
                                      + GX * GY * sizeof(int)) / 1024. /
```

```
        1024.);

    /* Delete data region on GPUs... */
#ifdef _OPENACC
    SELECT_TIMER("DELETE_DATA_REGION", "MEMORY", NVTX_GPU);
#pragma acc exit data delete(ctl,atm,cache,met0,met1,dt,rs)
#endif

    /* Free... */
    SELECT_TIMER("FREE", "MEMORY", NVTX_CPU);
    free(atm);
    free(cache);
    free(met0);
    free(met1);
    free(dt);
    free(rs);

    /* Report timers... */
    PRINT_TIMERS;
  }

  /* Finalize MPI... */
#ifdef MPI
  MPI_Finalize();
#endif

  /* Stop timers... */
  STOP_TIMERS;

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.44 trac.c

```
/*
  This file is part of MPTRAC.

  MPTRAC is free software: you can redistribute it and/or modify
  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

```

```
  MPTRAC is distributed in the hope that it will be useful,
  but WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
  GNU General Public License for more details.

  You should have received a copy of the GNU General Public License
  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Global variables...
   ------------------------------------------------------------ */

#ifdef _OPENACC
curandGenerator_t rng;
#else
static gsl_rng *rng[NTHREADS];
#endif

/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */

void module_advect_mp(
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_advect_rk(
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_bound_cond(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_convection(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt,
  double *rs);

void module_decay(
  ctl_t * ctl,
  atm_t * atm,
  double *dt);

void module_diffusion_meso(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache,
  double *dt,
  double *rs);

void module_diffusion_turb(
  ctl_t * ctl,
  atm_t * atm,
  double *dt,
  double *rs);

void module_dry_deposition(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_isosurf_init(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache);
```

```
void module_isosurf(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache);

void module_meteo(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm);

void module_oh_chem(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_position(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_rng_init(
  int ntask);

void module_rng(
  double *rs,
  size_t n,
  int method);

void module_sedi(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void module_timesteps(
  ctl_t * ctl,
  atm_t * atm,
  double *dt,
  double t);

void module_timesteps_init(
  ctl_t * ctl,
  atm_t * atm);

void module_wet_deposition(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt);

void write_output(
  const char *dirname,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t);

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  atm_t *atm;

  cache_t *cache;

  met_t *met0, *met1;

  FILE *dirlist;

  char dirname[LEN], filename[2 * LEN];
```

```

  double *dt, *rs, t;

  int num_devices = 0, ntask = -1, rank = 0, size = 1;

  /* Start timers... */
  START_TIMERS;

  /* Initialize MPI... */
#ifdef MPI
  SELECT_TIMER("MPI_INIT", "INIT", NVTX_CPU);
  MPI_Init(&argc, &argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  MPI_Comm_size(MPI_COMM_WORLD, &size);
#endif

  /* Initialize GPUs... */
#ifdef _OPENACC
  SELECT_TIMER("ACC_INIT", "INIT", NVTX_GPU);
  num_devices = acc_get_num_devices(acc_device_nvidia);
  if (num_devices <= 0)
    ERRMSG("Not running on a GPU device!");
  int device_num = rank % num_devices;
  acc_set_device_num(device_num, acc_device_nvidia);
  acc_device_t device_type = acc_get_device_type();
  acc_init(device_type);
#endif

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <dirlist> <ctl> <atm_in>");

  /* Open directory list... */
  if (!(dirlist = fopen(argv[1], "r")))
    ERRMSG("Cannot open directory list!");

  /* Loop over directories... */
  while (fscanf(dirlist, "%4999s", dirname) != EOF) {

    /* MPI parallelization... */
    if ((++ntask) % size != rank)
      continue;

    /* ------------------------------------------------------------
       Initialize model run...
       ------------------------------------------------------------ */

    /* Allocate... */
    SELECT_TIMER("ALLOC", "MEMORY", NVTX_CPU);
    ALLOC(atm, atm_t, 1);
    ALLOC(cache, cache_t, 1);
    ALLOC(met0, met_t, 1);
    ALLOC(met1, met_t, 1);
    ALLOC(dt, double,
          NP);
    ALLOC(rs, double,
          3 * NP + 1);

    /* Create data region on GPUs... */
#ifdef _OPENACC
    SELECT_TIMER("CREATE_DATA_REGION", "MEMORY", NVTX_GPU);
#pragma acc enter data create(atm[:1],cache[:1],ctl,met0[:1],met1[:1],dt[:NP],rs[:3*NP])
#endif

    /* Read control parameters... */
    sprintf(filename, "%s/%s", dirname, argv[2]);
    read_ctl(filename, argc, argv, &ctl);

    /* Read atmospheric data... */
    sprintf(filename, "%s/%s", dirname, argv[3]);
    if (!read_atm(filename, &ctl, atm))
      ERRMSG("Cannot open file!");

    /* Initialize timesteps... */
    module_timesteps_init(&ctl, atm);

    /* Update GPU... */
#ifdef _OPENACC
    SELECT_TIMER("UPDATE_DEVICE", "MEMORY", NVTX_H2D);
#pragma acc update device(atm[:1],ctl)
#endif

    /* Initialize random number generator... */
    module_rng_init(ntask);

    /* Initialize meteorological data... */
    get_met(&ctl, ctl.t_start, &met0, &met1);
```

```
    if (ctl.dt_mod > fabs(met0->lon[1] - met0->lon[0]) * 111132. / 150.)
      WARN("Violation of CFL criterion! Check DT_MOD!");

    /* Initialize isosurface... */
    if (ctl.isosurf >= 1 && ctl.isosurf <= 4)
      module_isosurf_init(&ctl, met0, met1, atm, cache);

    /* Update GPU... */
#ifdef _OPENACC
    SELECT_TIMER("UPDATE_DEVICE", "MEMORY", NVTX_H2D);
#pragma acc update device(cache[:1])
#endif

    /* ------------------------------------------------------------
       Loop over timesteps...
       ------------------------------------------------------------ */

    /* Loop over timesteps... */
    for (t = ctl.t_start; ctl.direction * (t - ctl.t_stop) < ctl.dt_mod;
         t += ctl.direction * ctl.dt_mod) {

      /* Adjust length of final time step... */
      if (ctl.direction * (t - ctl.t_stop) > 0)
        t = ctl.t_stop;

      /* Set time steps of air parcels... */
      module_timesteps(&ctl, atm, dt, t);

      /* Get meteorological data... */
      if (t != ctl.t_start)
        get_met(&ctl, t, &met0, &met1);

      /* Check initial positions... */
      module_position(&ctl, met0, met1, atm, dt);

      /* Advection... */
      if (ctl.advect == 0)
        module_advect_mp(met0, met1, atm, dt);
      else
        module_advect_rk(met0, met1, atm, dt);

      /* Turbulent diffusion... */
      if (ctl.turb_dx_trop > 0 || ctl.turb_dz_trop > 0
          || ctl.turb_dx_strat > 0 || ctl.turb_dz_strat > 0)
        module_diffusion_turb(&ctl, atm, dt, rs);

      /* Mesoscale diffusion... */
      if (ctl.turb_mesox > 0 || ctl.turb_mesoz > 0)
        module_diffusion_meso(&ctl, met0, met1, atm, cache, dt, rs);

      /* Convection... */
      if (ctl.conv_cape >= 0
          && (ctl.conv_dt <= 0 || fmod(t, ctl.conv_dt) == 0))
        module_convection(&ctl, met0, met1, atm, dt, rs);

      /* Sedimentation... */
      if (ctl.qnt_r >= 0 && ctl.qnt_rho >= 0)
        module_sedi(&ctl, met0, met1, atm, dt);

      /* Isosurface... */
      if (ctl.isosurf >= 1 && ctl.isosurf <= 4)
        module_isosurf(&ctl, met0, met1, atm, cache);

      /* Check final positions... */
      module_position(&ctl, met0, met1, atm, dt);

      /* Interpolate meteorological data... */
      if (ctl.met_dt_out > 0
          && (ctl.met_dt_out < ctl.dt_mod || fmod(t, ctl.met_dt_out) == 0))
        module_meteo(&ctl, met0, met1, atm);

      /* Decay of particle mass... */
      if (ctl.tdec_trop > 0 && ctl.tdec_strat > 0)
        module_decay(&ctl, atm, dt);

      /* OH chemistry... */
      if (ctl.oh_chem_reaction != 0)
        module_oh_chem(&ctl, met0, met1, atm, dt);

      /* Dry deposition... */
      if (ctl.dry_depo[0] > 0)
        module_dry_deposition(&ctl, met0, met1, atm, dt);

      /* Wet deposition... */
      if ((ctl.wet_depo[0] > 0 || ctl.wet_depo[2] > 0)
          && (ctl.wet_depo[4] > 0 || ctl.wet_depo[6] > 0))
        module_wet_deposition(&ctl, met0, met1, atm, dt);
```

```

      /* Boundary conditions... */
      if (ctl.bound_mass >= 0 || ctl.bound_vmr >= 0)
        module_bound_cond(&ctl, met0, met1, atm, dt);

      /* Write output... */
      write_output(dirname, &ctl, met0, met1, atm, t);
    }

    /* ------------------------------------------------------------
       Finalize model run...
       ------------------------------------------------------------ */

    /* Report problem size... */
    LOG(1, "SIZE_NP = %d", atm->np);
    LOG(1, "SIZE_MPI_TASKS = %d", size);
    LOG(1, "SIZE_OMP_THREADS = %d", omp_get_max_threads());
    LOG(1, "SIZE_ACC_DEVICES = %d", num_devices);

    /* Report memory usage... */
    LOG(1, "MEMORY_ATM = %g MByte", sizeof(atm_t) / 1024. / 1024.);
    LOG(1, "MEMORY_CACHE = %g MByte", sizeof(cache_t) / 1024. / 1024.);
    LOG(1, "MEMORY_METEO = %g MByte", 2 * sizeof(met_t) / 1024. / 1024.);
    LOG(1, "MEMORY_DYNAMIC = %g MByte", (sizeof(met_t)
                                         + 4 * NP * sizeof(double)
                                         + EX * EY * EP * sizeof(float)) /
        1024. / 1024.);
    LOG(1, "MEMORY_STATIC = %g MByte", (EX * EY * sizeof(double)
                                        + EX * EY * EP * sizeof(float)
                                        + 4 * GX * GY * GZ * sizeof(double)
                                        + 2 * GX * GY * GZ * sizeof(int)
                                        + 2 * GX * GY * sizeof(double)
                                        + GX * GY * sizeof(int)) / 1024. /
        1024.);

    /* Delete data region on GPUs... */
#ifdef _OPENACC
    SELECT_TIMER("DELETE_DATA_REGION", "MEMORY", NVTX_GPU);
#pragma acc exit data delete(ctl,atm,cache,met0,met1,dt,rs)
#endif

    /* Free... */
    SELECT_TIMER("FREE", "MEMORY", NVTX_CPU);
    free(atm);
    free(cache);
    free(met0);
    free(met1);
    free(dt);
    free(rs);

    /* Report timers... */
    PRINT_TIMERS;
  }

  /* Finalize MPI... */
#ifdef MPI
  MPI_Finalize();
#endif

  /* Stop timers... */
  STOP_TIMERS;

  return EXIT_SUCCESS;
}

/*****************************************************************************/

void module_advect_mp(
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_ADVECTION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double u, v, w;
```

```

      /* Interpolate meteorological data... */
      INTPOL_INIT;
      INTPOL_3D(u, 1);
      INTPOL_3D(v, 0);
      INTPOL_3D(w, 0);

      /* Get position of the mid point... */
      double dtm = atm->time[ip] + 0.5 * dt[ip];
      double xm0 =
        atm->lon[ip] + DX2DEG(0.5 * dt[ip] * u / 1000., atm->lat[ip]);
      double xm1 = atm->lat[ip] + DY2DEG(0.5 * dt[ip] * v / 1000.);
      double xm2 = atm->p[ip] + 0.5 * dt[ip] * w;

      /* Interpolate meteorological data for mid point... */
      intpol_met_time_3d(met0, met0->u, met1, met1->u,
                         dtm, xm2, xm0, xm1, &u, ci, cw, 1);
      intpol_met_time_3d(met0, met0->v, met1, met1->v,
                         dtm, xm2, xm0, xm1, &v, ci, cw, 0);
      intpol_met_time_3d(met0, met0->w, met1, met1->w,
                         dtm, xm2, xm0, xm1, &w, ci, cw, 0);

      /* Save new position... */
      atm->time[ip] += dt[ip];
      atm->lon[ip] += DX2DEG(dt[ip] * u / 1000., xm1);
      atm->lat[ip] += DY2DEG(dt[ip] * v / 1000.);
      atm->p[ip] += dt[ip] * w;
    }
}

/*****************************************************************************/

void module_advect_rk(
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_ADVECTION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Init... */
      double dts, u[4], um = 0, v[4], vm = 0, w[4], wm = 0, x[3];
      INTPOL_INIT;

      /* Loop over integration nodes... */
      for (int i = 0; i < 4; i++) {

        /* Set position... */
        if (i == 0) {
          dts = 0.0;
          x[0] = atm->lon[ip];
          x[1] = atm->lat[ip];
          x[2] = atm->p[ip];
        } else {
          dts = (i == 3 ? 1.0 : 0.5) * dt[ip];
          x[0] = atm->lon[ip] + DX2DEG(dts * u[i - 1] / 1000., atm->lat[ip]);
          x[1] = atm->lat[ip] + DY2DEG(dts * v[i - 1] / 1000.);
          x[2] = atm->p[ip] + dts * w[i - 1];
        }

        /* Interpolate meteo data... */
        double tm = atm->time[ip] + dts;
        intpol_met_time_3d(met0, met0->u, met1, met1->u, tm, x[2], x[0], x[1],
                           &u[i], ci, cw, 1);
        intpol_met_time_3d(met0, met0->v, met1, met1->v, tm, x[2], x[0], x[1],
                           &v[i], ci, cw, 0);
        intpol_met_time_3d(met0, met0->w, met1, met1->w, tm, x[2], x[0], x[1],
                           &w[i], ci, cw, 0);

        /* Get mean wind... */
        double k = (i == 0 || i == 3 ? 1.0 / 6.0 : 2.0 / 6.0);
        um += k * u[i];
        vm += k * v[i];
        wm += k * w[i];
      }

```

```
      /* Set new position... */
      atm->time[ip] += dt[ip];
      atm->lon[ip] += DX2DEG(dt[ip] * um / 1000., atm->lat[ip]);
      atm->lat[ip] += DY2DEG(dt[ip] * vm / 1000.);
      atm->p[ip] += dt[ip] * wm;
    }
}

/*****************************************************************************/

void module_bound_cond(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_BOUNDCOND", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double ps;

      /* Check latitude and pressure range... */
      if (atm->lat[ip] < ctl->bound_lat0 || atm->lat[ip] > ctl->bound_lat1
          || atm->p[ip] > ctl->bound_p0 || atm->p[ip] < ctl->bound_p1)
        continue;

      /* Check surface layer... */
      if (ctl->bound_dps > 0) {

        /* Get surface pressure... */
        INTPOL_INIT;
        INTPOL_2D(ps, 1);

        /* Check whether particle is above the surface layer... */
        if (atm->p[ip] < ps - ctl->bound_dps)
          continue;
      }

      /* Set mass and volume mixing ratio... */
      if (ctl->qnt_m >= 0 && ctl->bound_mass >= 0)
        atm->q[ctl->qnt_m][ip] = ctl->bound_mass;
      if (ctl->qnt_vmr >= 0 && ctl->bound_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] = ctl->bound_vmr;
    }
}

/*****************************************************************************/

void module_convection(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt,
  double *rs) {

  /* Set timer... */
  SELECT_TIMER("MODULE_CONVECTION", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, (size_t) atm->np, 0);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

```

```
      double cape, cin, pel, ps;

      /* Interpolate CAPE... */
      INTPOL_INIT;
      INTPOL_2D(cape, 1);

      /* Check threshold... */
      if (isfinite(cape) && cape >= ctl->conv_cape) {

        /* Check CIN... */
        if (ctl->conv_cin > 0) {
          INTPOL_2D(cin, 0);
          if (isfinite(cin) && cin >= ctl->conv_cin)
            continue;
        }

        /* Interpolate equilibrium level... */
        INTPOL_2D(pel, 0);

        /* Check whether particle is above cloud top... */
        if (!isfinite(pel) || atm->p[ip] < pel)
          continue;

        /* Set pressure range for mixing... */
        double pbot = atm->p[ip];
        double ptop = atm->p[ip];
        if (ctl->conv_mix_bot == 1) {
          INTPOL_2D(ps, 0);
          pbot = ps;
        }
        if (ctl->conv_mix_top == 1)
          ptop = pel;

        /* Limit vertical velocity... */
        if (ctl->conv_wmax > 0 || ctl->conv_wcape) {
          double z = Z(atm->p[ip]);
          double wmax = (ctl->conv_wcape) ? sqrt(2. * cape) : ctl->conv_wmax;
          double pmax = P(z - wmax * dt[ip] / 1000.);
          double pmin = P(z + wmax * dt[ip] / 1000.);
          ptop = GSL_MAX(ptop, pmin);
          pbot = GSL_MIN(pbot, pmax);
        }

        /* Vertical mixing... */
        atm->p[ip] = pbot + (ptop - pbot) * rs[ip];
      }
    }
}

/*****************************************************************************/

void module_decay(
  ctl_t * ctl,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_DECAY", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get weighting factor... */
      double w = tropo_weight(atm->time[ip], atm->lat[ip], atm->p[ip]);

      /* Set lifetime... */
      double tdec = w * ctl->tdec_trop + (1 - w) * ctl->tdec_strat;

      /* Calculate exponential decay... */
      double aux = exp(-dt[ip] / tdec);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}
```

```
/*****************************************************************************/

void module_diffusion_meso(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache,
  double *dt,
  double *rs) {

  /* Set timer... */
  SELECT_TIMER("MODULE_TURBMESO", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, 3 * (size_t) atm->np, 1);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,cache,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get indices... */
      int ix = locate_reg(met0->lon, met0->nx, atm->lon[ip]);
      int iy = locate_reg(met0->lat, met0->ny, atm->lat[ip]);
      int iz = locate_irr(met0->p, met0->np, atm->p[ip]);

      /* Caching of wind standard deviations... */
      if (cache->tsig[ix][iy][iz] != met0->time) {

        /* Collect local wind data... */
        int n = 0;
        float u[16], v[16], w[16];
        for (int i = 0; i < 2; i++)
          for (int j = 0; j < 2; j++)
            for (int k = 0; k < 2; k++) {
              u[n] = met0->u[ix + i][iy + j][iz + k];
              v[n] = met0->v[ix + i][iy + j][iz + k];
              w[n] = met0->w[ix + i][iy + j][iz + k];
              n++;
              u[n] = met1->u[ix + i][iy + j][iz + k];
              v[n] = met1->v[ix + i][iy + j][iz + k];
              w[n] = met1->w[ix + i][iy + j][iz + k];
              n++;
            }

        /* Get standard deviations of local wind data... */
        cache->uvwsig[ix][iy][iz][0] = stddev(u, n);
        cache->uvwsig[ix][iy][iz][1] = stddev(v, n);
        cache->uvwsig[ix][iy][iz][2] = stddev(w, n);

        /* Save new time... */
        cache->tsig[ix][iy][iz] = met0->time;
      }

      /* Set temporal correlations for mesoscale fluctuations... */
      double r = 1 - 2 * fabs(dt[ip]) / ctl->dt_met;
      double r2 = sqrt(1 - r * r);

      /* Calculate horizontal mesoscale wind fluctuations... */
      if (ctl->turb_mesox > 0) {
        cache->uvwp[ip][0] = (float)
          (r * cache->uvwp[ip][0]
           +
           r2 * rs[3 * ip] * ctl->turb_mesox * cache->uvwsig[ix][iy][iz][0]);
        atm->lon[ip] +=
          DX2DEG(cache->uvwp[ip][0] * dt[ip] / 1000., atm->lat[ip]);

        cache->uvwp[ip][1] = (float)
          (r * cache->uvwp[ip][1]
           + r2 * rs[3 * ip +
                     1] * ctl->turb_mesox * cache->uvwsig[ix][iy][iz][1]);
        atm->lat[ip] += DY2DEG(cache->uvwp[ip][1] * dt[ip] / 1000.);
      }

      /* Calculate vertical mesoscale wind fluctuations... */
      if (ctl->turb_mesoz > 0) {
        cache->uvwp[ip][2] = (float)
          (r * cache->uvwp[ip][2]
           + r2 * rs[3 * ip +
                     2] * ctl->turb_mesoz * cache->uvwsig[ix][iy][iz][2]);
```

```
        atm->p[ip] += cache->uvwp[ip][2] * dt[ip];
      }
    }
}

/*****************************************************************************/

void module_diffusion_turb(
  ctl_t * ctl,
  atm_t * atm,
  double *dt,
  double *rs) {

  /* Set timer... */
  SELECT_TIMER("MODULE_TURBDIFF", "PHYSICS", NVTX_GPU);

  /* Create random numbers... */
  module_rng(rs, 3 * (size_t) atm->np, 1);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt,rs)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get weighting factor... */
      double w = tropo_weight(atm->time[ip], atm->lat[ip], atm->p[ip]);

      /* Set diffusivity... */
      double dx = w * ctl->turb_dx_trop + (1 - w) * ctl->turb_dx_strat;
      double dz = w * ctl->turb_dz_trop + (1 - w) * ctl->turb_dz_strat;

      /* Horizontal turbulent diffusion... */
      if (dx > 0) {
        double sigma = sqrt(2.0 * dx * fabs(dt[ip]));
        atm->lon[ip] += DX2DEG(rs[3 * ip] * sigma / 1000., atm->lat[ip]);
        atm->lat[ip] += DY2DEG(rs[3 * ip + 1] * sigma / 1000.);
      }

      /* Vertical turbulent diffusion... */
      if (dz > 0) {
        double sigma = sqrt(2.0 * dz * fabs(dt[ip]));
        atm->p[ip]
          += DZ2DP(rs[3 * ip + 2] * sigma / 1000., atm->p[ip]);
      }
    }
}

/*****************************************************************************/

void module_dry_deposition(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_DRYDEPO", "PHYSICS", NVTX_GPU);

  /* Width of the surface layer [hPa]. */
  const double dp = 30.;

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double ps, t, v_dep;

      /* Get surface pressure... */
      INTPOL_INIT;
      INTPOL_2D(ps, 1);

```

```
      /* Check whether particle is above the surface layer... */
      if (atm->p[ip] < ps - dp)
        continue;

      /* Set width of surface layer... */
      double dz = 1000. * (Z(ps - dp) - Z(ps));

      /* Calculate sedimentation velocity for particles... */
      if (ctl->qnt_r > 0 && ctl->qnt_rho > 0) {

        /* Get temperature... */
        INTPOL_3D(t, 1);

        /* Set deposition velocity... */
        v_dep = sedi(atm->p[ip], t, atm->q[ctl->qnt_r][ip],
                     atm->q[ctl->qnt_rho][ip]);
      }

      /* Use explicit sedimentation velocity for gases... */
      else
        v_dep = ctl->dry_depo[0];

      /* Calculate loss of mass based on deposition velocity... */
      double aux = exp(-dt[ip] * v_dep / dz);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}

/*****************************************************************************/

void module_isosurf_init(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache) {

  FILE *in;

  char line[LEN];

  double t;

  /* Set timer... */
  SELECT_TIMER("MODULE_ISOSURF", "PHYSICS", NVTX_GPU);

  /* Init... */
  INTPOL_INIT;

  /* Save pressure... */
  if (ctl->isosurf == 1)
    for (int ip = 0; ip < atm->np; ip++)
      cache->iso_var[ip] = atm->p[ip];

  /* Save density... */
  else if (ctl->isosurf == 2)
    for (int ip = 0; ip < atm->np; ip++) {
      INTPOL_3D(t, 1);
      cache->iso_var[ip] = atm->p[ip] / t;
    }

  /* Save potential temperature... */
  else if (ctl->isosurf == 3)
    for (int ip = 0; ip < atm->np; ip++) {
      INTPOL_3D(t, 1);
      cache->iso_var[ip] = THETA(atm->p[ip], t);
    }

  /* Read balloon pressure data... */
  else if (ctl->isosurf == 4) {

    /* Write info... */
    LOG(1, "Read balloon pressure data: %s", ctl->balloon);

    /* Open file... */
    if (!(in = fopen(ctl->balloon, "r")))
      ERRMSG("Cannot open file!");

    /* Read pressure time series... */
    while (fgets(line, LEN, in))
      if (sscanf(line, "%lg %lg", &(cache->iso_ts[cache->iso_n]),
                 &(cache->iso_ps[cache->iso_n])) == 2)
        if ((++cache->iso_n) > NP)
          ERRMSG("Too many data points!");
```

```

    /* Check number of points... */
    if (cache->iso_n < 1)
      ERRMSG("Could not read any data!");

    /* Close file... */
    fclose(in);
  }
}

/*****************************************************************************/

void module_isosurf(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  cache_t * cache) {

  /* Set timer... */
  SELECT_TIMER("MODULE_ISOSURF", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,cache)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {

    double t;

    /* Init... */
    INTPOL_INIT;

    /* Restore pressure... */
    if (ctl->isosurf == 1)
      atm->p[ip] = cache->iso_var[ip];

    /* Restore density... */
    else if (ctl->isosurf == 2) {
      INTPOL_3D(t, 1);
      atm->p[ip] = cache->iso_var[ip] * t;
    }

    /* Restore potential temperature... */
    else if (ctl->isosurf == 3) {
      INTPOL_3D(t, 1);
      atm->p[ip] = 1000. * pow(cache->iso_var[ip] / t, -1. / 0.286);
    }

    /* Interpolate pressure... */
    else if (ctl->isosurf == 4) {
      if (atm->time[ip] <= cache->iso_ts[0])
        atm->p[ip] = cache->iso_ps[0];
      else if (atm->time[ip] >= cache->iso_ts[cache->iso_n - 1])
        atm->p[ip] = cache->iso_ps[cache->iso_n - 1];
      else {
        int idx = locate_irr(cache->iso_ts, cache->iso_n, atm->time[ip]);
        atm->p[ip] = LIN(cache->iso_ts[idx], cache->iso_ps[idx],
                         cache->iso_ts[idx + 1], cache->iso_ps[idx + 1],
                         atm->time[ip]);
      }
    }
  }
}

/*****************************************************************************/

void module_meteo(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm) {

  /* Set timer... */
  SELECT_TIMER("MODULE_METEO", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_tsts >= 0)
    if (ctl->qnt_tice < 0 || ctl->qnt_tnat < 0)
      ERRMSG("Need T_ice and T_NAT to calculate T_STS!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm)
```

```
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {

    double ps, ts, zs, us, vs, pbl, pt, pct, pcb, cl, plcl, plfc, pel, cape,
      cin, pv, t, tt, u, v, w, h2o, h2ot, o3, lwc, iwc, z, zt;

    /* Interpolate meteorological data... */
    INTPOL_INIT;
    INTPOL_TIME_ALL(atm->time[ip], atm->p[ip], atm->lon[ip], atm->lat[ip]);

    /* Set quantities... */
    SET_ATM(qnt_ps, ps);
    SET_ATM(qnt_ts, ts);
    SET_ATM(qnt_zs, zs);
    SET_ATM(qnt_us, us);
    SET_ATM(qnt_vs, vs);
    SET_ATM(qnt_pbl, pbl);
    SET_ATM(qnt_pt, pt);
    SET_ATM(qnt_tt, tt);
    SET_ATM(qnt_zt, zt);
    SET_ATM(qnt_h2ot, h2ot);
    SET_ATM(qnt_p, atm->p[ip]);
    SET_ATM(qnt_z, z);
    SET_ATM(qnt_t, t);
    SET_ATM(qnt_u, u);
    SET_ATM(qnt_v, v);
    SET_ATM(qnt_w, w);
    SET_ATM(qnt_h2o, h2o);
    SET_ATM(qnt_o3, o3);
    SET_ATM(qnt_lwc, lwc);
    SET_ATM(qnt_iwc, iwc);
    SET_ATM(qnt_pct, pct);
    SET_ATM(qnt_pcb, pcb);
    SET_ATM(qnt_cl, cl);
    SET_ATM(qnt_plcl, plcl);
    SET_ATM(qnt_plfc, plfc);
    SET_ATM(qnt_pel, pel);
    SET_ATM(qnt_cape, cape);
    SET_ATM(qnt_cin, cin);
    SET_ATM(qnt_hno3, clim_hno3(atm->time[ip], atm->lat[ip], atm->p[ip]));
    SET_ATM(qnt_oh, clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]));
    SET_ATM(qnt_vh, sqrt(u * u + v * v));
    SET_ATM(qnt_vz, -1e3 * H0 / atm->p[ip] * w);
    SET_ATM(qnt_psat, PSAT(t));
    SET_ATM(qnt_psice, PSICE(t));
    SET_ATM(qnt_pw, PW(atm->p[ip], h2o));
    SET_ATM(qnt_sh, SH(h2o));
    SET_ATM(qnt_rh, RH(atm->p[ip], t, h2o));
    SET_ATM(qnt_rhice, RHICE(atm->p[ip], t, h2o));
    SET_ATM(qnt_theta, THETA(atm->p[ip], t));
    SET_ATM(qnt_zeta, ZETA(ps, atm->p[ip], t));
    SET_ATM(qnt_tvirt, TVIRT(t, h2o));
    SET_ATM(qnt_lapse, lapse_rate(t, h2o));
    SET_ATM(qnt_pv, pv);
    SET_ATM(qnt_tdew, TDEW(atm->p[ip], h2o));
    SET_ATM(qnt_tice, TICE(atm->p[ip], h2o));
    SET_ATM(qnt_tnat,
            nat_temperature(atm->p[ip], h2o,
                            clim_hno3(atm->time[ip], atm->lat[ip],
                                      atm->p[ip])));
    SET_ATM(qnt_tsts,
            0.5 * (atm->q[ctl->qnt_tice][ip] + atm->q[ctl->qnt_tnat][ip]));
  }
}

/*****************************************************************************/

void module_oh_chem(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_OHCHEM", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
```

```
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get temperature... */
      double t;
      INTPOL_INIT;
      INTPOL_3D(t, 1);

      /* Use constant reaction rate... */
      double k = GSL_NAN;
      if (ctl->oh_chem_reaction == 1)
        k = ctl->oh_chem[0];

      /* Calculate bimolecular reaction rate... */
      else if (ctl->oh_chem_reaction == 2)
        k = ctl->oh_chem[0] * exp(-ctl->oh_chem[1] / t);

      /* Calculate termolecular reaction rate... */
      if (ctl->oh_chem_reaction == 3) {

        /* Calculate molecular density (IUPAC Data Sheet I.A4.86 SOx15)... */
        double M = 7.243e21 * (atm->p[ip] / 1000.) / t;

        /* Calculate rate coefficient for X + OH + M -> XOH + M
           (JPL Publication 19-05) ... */
        double k0 = ctl->oh_chem[0] *
          (ctl->oh_chem[1] > 0 ? pow(298. / t, ctl->oh_chem[1]) : 1.);
        double ki = ctl->oh_chem[2] *
          (ctl->oh_chem[3] > 0 ? pow(298. / t, ctl->oh_chem[3]) : 1.);
        double c = log10(k0 * M / ki);
        k = k0 * M / (1. + k0 * M / ki) * pow(0.6, 1. / (1. + c * c));
      }

      /* Calculate exponential decay... */
      double aux
        = exp(-dt[ip] * k * clim_oh(atm->time[ip], atm->lat[ip], atm->p[ip]));
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}

/*****************************************************************************/

void module_position(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_POSITION", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Init... */
      double ps;
      INTPOL_INIT;

      /* Calculate modulo... */
      atm->lon[ip] = FMOD(atm->lon[ip], 360.);
      atm->lat[ip] = FMOD(atm->lat[ip], 360.);

      /* Check latitude... */
      while (atm->lat[ip] < -90 || atm->lat[ip] > 90) {
        if (atm->lat[ip] > 90) {
          atm->lat[ip] = 180 - atm->lat[ip];
          atm->lon[ip] += 180;
        }
        if (atm->lat[ip] < -90) {
          atm->lat[ip] = -180 - atm->lat[ip];
          atm->lon[ip] += 180;
        }
```

```
      }

      /* Check longitude... */
      while (atm->lon[ip] < -180)
        atm->lon[ip] += 360;
      while (atm->lon[ip] >= 180)
        atm->lon[ip] -= 360;

      /* Check pressure... */
      if (atm->p[ip] < met0->p[met0->np - 1]) {
        if (ctl->reflect)
          atm->p[ip] = 2. * met0->p[met0->np - 1] - atm->p[ip];
        else
          atm->p[ip] = met0->p[met0->np - 1];
      } else if (atm->p[ip] > 300.) {
        INTPOL_2D(ps, 1);
        if (atm->p[ip] > ps) {
          if (ctl->reflect)
            atm->p[ip] = 2. * ps - atm->p[ip];
          else
            atm->p[ip] = ps;
        }
      }
    }
}

/*****************************************************************************/

void module_rng_init(
  int ntask) {

  /* Initialize random number generator... */
#ifdef _OPENACC

  if (curandCreateGenerator(&rng, CURAND_RNG_PSEUDO_DEFAULT)
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot create random number generator!");
  if (curandSetPseudoRandomGeneratorSeed(rng, ntask)
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot set seed for random number generator!");
  if (curandSetStream(rng, (cudaStream_t) acc_get_cuda_stream(acc_async_sync))
      != CURAND_STATUS_SUCCESS)
    ERRMSG("Cannot set stream for random number generator!");

#else

  gsl_rng_env_setup();
  if (omp_get_max_threads() > NTHREADS)
    ERRMSG("Too many threads!");
  for (int i = 0; i < NTHREADS; i++) {
    rng[i] = gsl_rng_alloc(gsl_rng_default);
    gsl_rng_set(rng[i], gsl_rng_default_seed
                + (long unsigned) (ntask * NTHREADS + i));
  }

#endif
}

/*****************************************************************************/

void module_rng(
  double *rs,
  size_t n,
  int method) {

#ifdef _OPENACC

#pragma acc host_data use_device(rs)
  {
    /* Uniform distribution... */
    if (method == 0) {
      if (curandGenerateUniformDouble(rng, rs, (n < 4 ? 4 : n))
          != CURAND_STATUS_SUCCESS)
        ERRMSG("Cannot create random numbers!");
    }

    /* Normal distribution... */
    else if (method == 1) {
      if (curandGenerateNormalDouble(rng, rs, (n < 4 ? 4 : n), 0.0, 1.0)
          != CURAND_STATUS_SUCCESS)
        ERRMSG("Cannot create random numbers!");
    }
  }

#else

  /* Uniform distribution... */
```

```
  if (method == 0) {
#pragma omp parallel for default(shared)
    for (size_t i = 0; i < n; ++i)
      rs[i] = gsl_rng_uniform(rng[omp_get_thread_num()]);
  }

  /* Normal distribution... */
  else if (method == 1) {
#pragma omp parallel for default(shared)
    for (size_t i = 0; i < n; ++i)
      rs[i] = gsl_ran_gaussian_ziggurat(rng[omp_get_thread_num()], 1.0);
  }
#endif

}

/*****************************************************************************/

void module_sedi(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_SEDI", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      /* Get temperature... */
      double t;
      INTPOL_INIT;
      INTPOL_3D(t, 1);

      /* Sedimentation velocity... */
      double v_s = sedi(atm->p[ip], t, atm->q[ctl->qnt_r][ip],
                        atm->q[ctl->qnt_rho][ip]);

      /* Calculate pressure change... */
      atm->p[ip] += DZ2DP(v_s * dt[ip] / 1000., atm->p[ip]);
    }
}

/*****************************************************************************/

void module_timesteps(
  ctl_t * ctl,
  atm_t * atm,
  double *dt,
  double t) {

  /* Set timer... */
  SELECT_TIMER("MODULE_TIMESTEPS", "PHYSICS", NVTX_GPU);

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++) {
    if ((ctl->direction * (atm->time[ip] - ctl->t_start) >= 0
         && ctl->direction * (atm->time[ip] - ctl->t_stop) <= 0
         && ctl->direction * (atm->time[ip] - t) < 0))
      dt[ip] = t - atm->time[ip];
    else
      dt[ip] = 0.0;
  }
}

/*****************************************************************************/

void module_timesteps_init(
  ctl_t * ctl,
  atm_t * atm) {

  /* Set timer... */
```

```
  SELECT_TIMER("MODULE_TIMESTEPS", "PHYSICS", NVTX_GPU);

  /* Set start time... */
  if (ctl->direction == 1) {
    ctl->t_start = gsl_stats_min(atm->time, 1, (size_t) atm->np);
    if (ctl->t_stop > 1e99)
      ctl->t_stop = gsl_stats_max(atm->time, 1, (size_t) atm->np);
  } else {
    ctl->t_start = gsl_stats_max(atm->time, 1, (size_t) atm->np);
    if (ctl->t_stop > 1e99)
      ctl->t_stop = gsl_stats_min(atm->time, 1, (size_t) atm->np);
  }

  /* Check time interval... */
  if (ctl->direction * (ctl->t_stop - ctl->t_start) <= 0)
    ERRMSG("Nothing to do! Check T_STOP and DIRECTION!");

  /* Round start time... */
  if (ctl->direction == 1)
    ctl->t_start = floor(ctl->t_start / ctl->dt_mod) * ctl->dt_mod;
  else
    ctl->t_start = ceil(ctl->t_start / ctl->dt_mod) * ctl->dt_mod;
}

/*****************************************************************************/

void module_wet_deposition(
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double *dt) {

  /* Set timer... */
  SELECT_TIMER("MODULE_WETDEPO", "PHYSICS", NVTX_GPU);

  /* Check quantity flags... */
  if (ctl->qnt_m < 0 && ctl->qnt_vmr < 0)
    ERRMSG("Module needs quantity mass or volume mixing ratio!");

  const int np = atm->np;
#ifdef _OPENACC
#pragma acc data present(ctl,met0,met1,atm,dt)
#pragma acc parallel loop independent gang vector
#else
#pragma omp parallel for default(shared)
#endif
  for (int ip = 0; ip < np; ip++)
    if (dt[ip] != 0) {

      double cl, dz, h, lambda = 0, t, iwc, lwc, pct, pcb;

      int inside;

      /* Check whether particle is below cloud top... */
      INTPOL_INIT;
      INTPOL_2D(pct, 1);
      if (!isfinite(pct) || atm->p[ip] <= pct)
        continue;

      /* Get cloud bottom pressure... */
      INTPOL_2D(pcb, 0);

      /* Estimate precipitation rate (Pisso et al., 2019)... */
      INTPOL_2D(cl, 0);
      double Is = pow(2. * cl, 1. / 0.36);
      if (Is < 0.01)
        continue;

      /* Check whether particle is inside or below cloud... */
      INTPOL_3D(lwc, 1);
      INTPOL_3D(iwc, 0);
      inside = (iwc > 0 || lwc > 0);

      /* Calculate in-cloud scavenging coefficient... */
      if (inside) {

        /* Use exponential dependency for particles... */
        if (ctl->wet_depo[0] > 0)
          lambda = ctl->wet_depo[0] * pow(Is, ctl->wet_depo[1]);

        /* Use Henry's law for gases... */
        else if (ctl->wet_depo[2] > 0) {

          /* Get temperature... */
          INTPOL_3D(t, 0);

```

```
          /* Get Henry's constant (Sander, 2015)... */
          h = ctl->wet_depo[2]
            * exp(ctl->wet_depo[3] * (1. / t - 1. / 298.15));

          /* Estimate depth of cloud layer... */
          dz = 1e3 * (Z(pct) - Z(pcb));

          /* Calculate scavenging coefficient (Draxler and Hess, 1997)... */
          lambda = h * RI * t * Is / 3.6e6 / dz;
        }
      }

      /* Calculate below-cloud scavenging coefficient... */
      else {

        /* Use exponential dependency for particles... */
        if (ctl->wet_depo[4] > 0)
          lambda = ctl->wet_depo[4] * pow(Is, ctl->wet_depo[5]);

        /* Use Henry's law for gases... */
        else if (ctl->wet_depo[6] > 0) {

          /* Get temperature... */
          INTPOL_3D(t, 0);

          /* Get Henry's constant (Sander, 2015)... */
          h = ctl->wet_depo[6]
            * exp(ctl->wet_depo[7] * (1. / t - 1. / 298.15));

          /* Estimate depth of cloud layer... */
          dz = 1e3 * (Z(pct) - Z(pcb));

          /* Calculate scavenging coefficient (Draxler and Hess, 1997)... */
          lambda = h * RI * t * Is / 3.6e6 / dz;
        }
      }

      /* Calculate exponential decay of mass... */
      double aux = exp(-dt[ip] * lambda);
      if (ctl->qnt_m >= 0)
        atm->q[ctl->qnt_m][ip] *= aux;
      if (ctl->qnt_vmr >= 0)
        atm->q[ctl->qnt_vmr][ip] *= aux;
    }
}

/*****************************************************************************/

void write_output(
  const char *dirname,
  ctl_t * ctl,
  met_t * met0,
  met_t * met1,
  atm_t * atm,
  double t) {

  char filename[2 * LEN];

  double r;

  int year, mon, day, hour, min, sec;

  /* Get time... */
  jsec2time(t, &year, &mon, &day, &hour, &min, &sec, &r);

  /* Update host... */
#ifdef _OPENACC
  if ((ctl->atm_basename[0] != '-' && fmod(t, ctl->atm_dt_out) == 0)
      || (ctl->grid_basename[0] != '-' && fmod(t, ctl->grid_dt_out) == 0)
      || ctl->csi_basename[0] != '-' || ctl->ens_basename[0] != '-'
      || ctl->prof_basename[0] != '-' || ctl->sample_basename[0] != '-'
      || ctl->stat_basename[0] != '-') {
    SELECT_TIMER("UPDATE_HOST", "MEMORY", NVTX_D2H);
#pragma acc update host(atm[:1])
  }
#endif

  /* Write atmospheric data... */
  if (ctl->atm_basename[0] != '-' && fmod(t, ctl->atm_dt_out) == 0) {
    sprintf(filename, "%s/%s_%04d_%02d_%02d_%02d_%02d.tab",
            dirname, ctl->atm_basename, year, mon, day, hour, min);
    write_atm(filename, ctl, atm, t);
  }

  /* Write gridded data... */
  if (ctl->grid_basename[0] != '-' && fmod(t, ctl->grid_dt_out) == 0) {
    sprintf(filename, "%s/%s_%04d_%02d_%02d_%02d_%02d.tab",
```

```
                dirname, ctl->grid_basename, year, mon, day, hour, min);
        write_grid(filename, ctl, met0, met1, atm, t);
    }

    /* Write CSI data... */
    if (ctl->csi_basename[0] != '-') {
        sprintf(filename, "%s/%s.tab", dirname, ctl->csi_basename);
        write_csi(filename, ctl, atm, t);
    }

    /* Write ensemble data... */
    if (ctl->ens_basename[0] != '-') {
        sprintf(filename, "%s/%s.tab", dirname, ctl->ens_basename);
        write_ens(filename, ctl, atm, t);
    }

    /* Write profile data... */
    if (ctl->prof_basename[0] != '-') {
        sprintf(filename, "%s/%s.tab", dirname, ctl->prof_basename);
        write_prof(filename, ctl, met0, met1, atm, t);
    }

    /* Write sample data... */
    if (ctl->sample_basename[0] != '-') {
        sprintf(filename, "%s/%s.tab", dirname, ctl->sample_basename);
        write_sample(filename, ctl, met0, met1, atm, t);
    }

    /* Write station data... */
    if (ctl->stat_basename[0] != '-') {
        sprintf(filename, "%s/%s.tab", dirname, ctl->stat_basename);
        write_station(filename, ctl, atm, t);
    }
}
```

## 5.45 tropo.c File Reference

```
#include "libtrac.h"
```

### Functions

- void add_text_attribute (int ncid, char ∗varname, char ∗attrname, char ∗text)
- int main (int argc, char ∗argv[ ])

### 5.45.1 Detailed Description

Create tropopause data set from meteorological data.

Definition in file tropo.c.

### 5.45.2 Function Documentation

#### 5.45.2.1 add_text_attribute()

```
void add_text_attribute (
        int ncid,
        char * varname,
        char * attrname,
        char * text )
```

Definition at line 337 of file tropo.c.

```
                      {

    int varid;

    NC(nc_inq_varid(ncid, varname, &varid));
    NC(nc_put_att_text(ncid, varid, attrname, strlen(text), text));
}
```

#### 5.45.2.2 main()

```
int main (
    int argc,
    char * argv[] )
```

Definition at line 41 of file tropo.c.

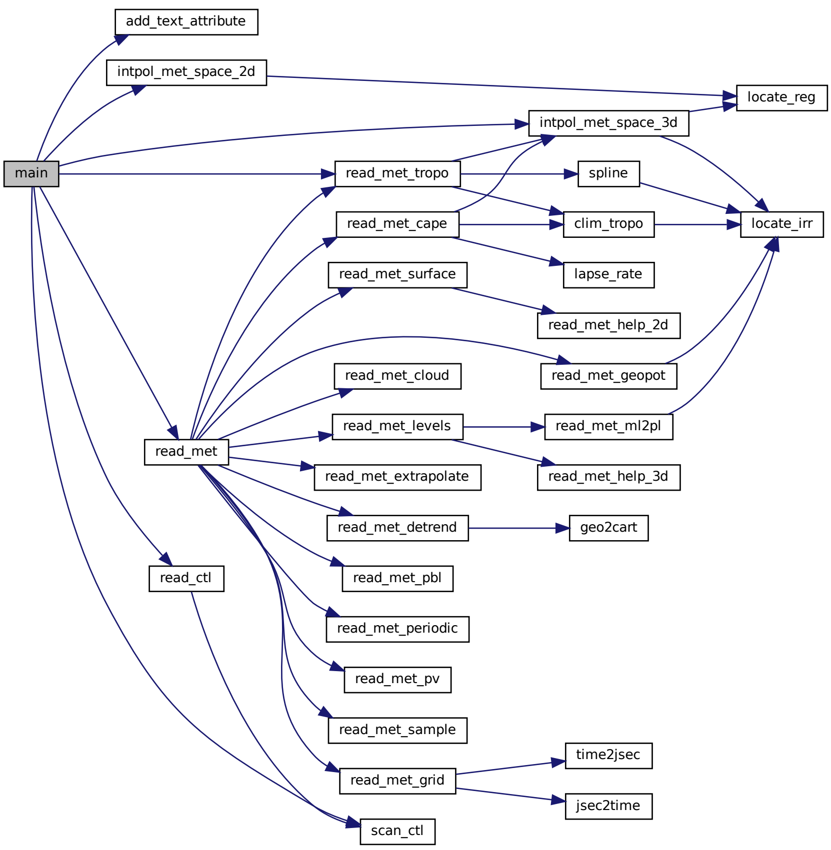
```
                      {

  ctl_t ctl;

  met_t *met;

  static double pt[EX * EY], qt[EX * EY], zt[EX * EY], tt[EX * EY], lon, lon0,
    lon1, lons[EX], dlon, lat, lat0, lat1, lats[EY], dlat, cw[3];

  static int init, i, ix, iy, nx, ny, nt, ncid, dims[3], timid, lonid, latid,
    clppid, clpqid, clptid, clpzid, dynpid, dynqid, dyntid, dynzid, wmo1pid,
    wmo1qid, wmo1tid, wmo1zid, wmo2pid, wmo2qid, wmo2tid, wmo2zid, h2o, ci[3];

  static size_t count[10], start[10];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <tropo.nc> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  lon0 = scan_ctl(argv[1], argc, argv, "TROPO_LON0", -1, "-180", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "TROPO_LON1", -1, "180", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "TROPO_DLON", -1, "-999", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "TROPO_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "TROPO_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "TROPO_DLAT", -1, "-999", NULL);
  h2o = (int) scan_ctl(argv[1], argc, argv, "TROPO_H2O", -1, "1", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    ctl.met_tropo = 0;
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set horizontal grid... */
    if (!init) {
      init = 1;

      /* Get grid... */
      if (dlon <= 0)
        dlon = fabs(met->lon[1] - met->lon[0]);
      if (dlat <= 0)
        dlat = fabs(met->lat[1] - met->lat[0]);
      if (lon0 < -360 && lon1 > 360) {
        lon0 = gsl_stats_min(met->lon, 1, (size_t) met->nx);
        lon1 = gsl_stats_max(met->lon, 1, (size_t) met->nx);
      }
      nx = ny = 0;
      for (lon = lon0; lon <= lon1; lon += dlon) {
        lons[nx] = lon;
        if ((++nx) > EX)
          ERRMSG("Too many longitudes!");
      }
      if (lat0 < -90 && lat1 > 90) {
        lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
        lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
      }
      for (lat = lat0; lat <= lat1; lat += dlat) {
        lats[ny] = lat;
        if ((++ny) > EY)
          ERRMSG("Too many latitudes!");
      }

      /* Create netCDF file... */
      printf("Write tropopause data file: %s\n", argv[2]);
      NC(nc_create(argv[2], NC_CLOBBER, &ncid));

      /* Create dimensions... */
      NC(nc_def_dim(ncid, "time", (size_t) NC_UNLIMITED, &dims[0]));
      NC(nc_def_dim(ncid, "lat", (size_t) ny, &dims[1]));
      NC(nc_def_dim(ncid, "lon", (size_t) nx, &dims[2]));

      /* Create variables... */
      NC(nc_def_var(ncid, "time", NC_DOUBLE, 1, &dims[0], &timid));
```

```
  NC(nc_def_var(ncid, "lat", NC_DOUBLE, 1, &dims[1], &latid));
  NC(nc_def_var(ncid, "lon", NC_DOUBLE, 1, &dims[2], &lonid));
  NC(nc_def_var(ncid, "clp_z", NC_FLOAT, 3, &dims[0], &clpzid));
  NC(nc_def_var(ncid, "clp_p", NC_FLOAT, 3, &dims[0], &clppid));
  NC(nc_def_var(ncid, "clp_t", NC_FLOAT, 3, &dims[0], &clptid));
  if (h2o)
    NC(nc_def_var(ncid, "clp_q", NC_FLOAT, 3, &dims[0], &clpqid));
  NC(nc_def_var(ncid, "dyn_z", NC_FLOAT, 3, &dims[0], &dynzid));
  NC(nc_def_var(ncid, "dyn_p", NC_FLOAT, 3, &dims[0], &dynpid));
  NC(nc_def_var(ncid, "dyn_t", NC_FLOAT, 3, &dims[0], &dyntid));
  if (h2o)
    NC(nc_def_var(ncid, "dyn_q", NC_FLOAT, 3, &dims[0], &dynqid));
  NC(nc_def_var(ncid, "wmo_1st_z", NC_FLOAT, 3, &dims[0], &wmo1zid));
  NC(nc_def_var(ncid, "wmo_1st_p", NC_FLOAT, 3, &dims[0], &wmo1pid));
  NC(nc_def_var(ncid, "wmo_1st_t", NC_FLOAT, 3, &dims[0], &wmo1tid));
  if (h2o)
    NC(nc_def_var(ncid, "wmo_1st_q", NC_FLOAT, 3, &dims[0], &wmo1qid));
  NC(nc_def_var(ncid, "wmo_2nd_z", NC_FLOAT, 3, &dims[0], &wmo2zid));
  NC(nc_def_var(ncid, "wmo_2nd_p", NC_FLOAT, 3, &dims[0], &wmo2pid));
  NC(nc_def_var(ncid, "wmo_2nd_t", NC_FLOAT, 3, &dims[0], &wmo2tid));
  if (h2o)
    NC(nc_def_var(ncid, "wmo_2nd_q", NC_FLOAT, 3, &dims[0], &wmo2qid));

  /* Set attributes... */
  add_text_attribute(ncid, "time", "units",
                     "seconds since 2000-01-01 00:00:00 UTC");
  add_text_attribute(ncid, "time", "long_name", "time");
  add_text_attribute(ncid, "lon", "units", "degrees_east");
  add_text_attribute(ncid, "lon", "long_name", "longitude");
  add_text_attribute(ncid, "lat", "units", "degrees_north");
  add_text_attribute(ncid, "lat", "long_name", "latitude");

  add_text_attribute(ncid, "clp_z", "units", "km");
  add_text_attribute(ncid, "clp_z", "long_name", "cold point height");
  add_text_attribute(ncid, "clp_p", "units", "hPa");
  add_text_attribute(ncid, "clp_p", "long_name", "cold point pressure");
  add_text_attribute(ncid, "clp_t", "units", "K");
  add_text_attribute(ncid, "clp_t", "long_name",
                     "cold point temperature");
  if (h2o) {
    add_text_attribute(ncid, "clp_q", "units", "ppv");
    add_text_attribute(ncid, "clp_q", "long_name",
                       "cold point water vapor");
  }

  add_text_attribute(ncid, "dyn_z", "units", "km");
  add_text_attribute(ncid, "dyn_z", "long_name",
                     "dynamical tropopause height");
  add_text_attribute(ncid, "dyn_p", "units", "hPa");
  add_text_attribute(ncid, "dyn_p", "long_name",
                     "dynamical tropopause pressure");
  add_text_attribute(ncid, "dyn_t", "units", "K");
  add_text_attribute(ncid, "dyn_t", "long_name",
                     "dynamical tropopause temperature");
  if (h2o) {
    add_text_attribute(ncid, "dyn_q", "units", "ppv");
    add_text_attribute(ncid, "dyn_q", "long_name",
                       "dynamical tropopause water vapor");
  }

  add_text_attribute(ncid, "wmo_1st_z", "units", "km");
  add_text_attribute(ncid, "wmo_1st_z", "long_name",
                     "WMO 1st tropopause height");
  add_text_attribute(ncid, "wmo_1st_p", "units", "hPa");
  add_text_attribute(ncid, "wmo_1st_p", "long_name",
                     "WMO 1st tropopause pressure");
  add_text_attribute(ncid, "wmo_1st_t", "units", "K");
  add_text_attribute(ncid, "wmo_1st_t", "long_name",
                     "WMO 1st tropopause temperature");
  if (h2o) {
    add_text_attribute(ncid, "wmo_1st_q", "units", "ppv");
    add_text_attribute(ncid, "wmo_1st_q", "long_name",
                       "WMO 1st tropopause water vapor");
  }

  add_text_attribute(ncid, "wmo_2nd_z", "units", "km");
  add_text_attribute(ncid, "wmo_2nd_z", "long_name",
                     "WMO 2nd tropopause height");
  add_text_attribute(ncid, "wmo_2nd_p", "units", "hPa");
  add_text_attribute(ncid, "wmo_2nd_p", "long_name",
                     "WMO 2nd tropopause pressure");
  add_text_attribute(ncid, "wmo_2nd_t", "units", "K");
  add_text_attribute(ncid, "wmo_2nd_t", "long_name",
                     "WMO 2nd tropopause temperature");
  if (h2o) {
    add_text_attribute(ncid, "wmo_2nd_q", "units", "ppv");
    add_text_attribute(ncid, "wmo_2nd_q", "long_name",
```

```
                           "WMO 2nd tropopause water vapor");
      }

      /* End definition... */
      NC(nc_enddef(ncid));

      /* Write longitude and latitude... */
      NC(nc_put_var_double(ncid, latid, lats));
      NC(nc_put_var_double(ncid, lonid, lons));
    }

    /* Write time... */
    start[0] = (size_t) nt;
    count[0] = 1;
    start[1] = 0;
    count[1] = (size_t) ny;
    start[2] = 0;
    count[2] = (size_t) nx;
    NC(nc_put_vara_double(ncid, timid, start, count, &met->time));

    /* Get cold point... */
    ctl.met_tropo = 2;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, clpzid, start, count, zt));
    NC(nc_put_vara_double(ncid, clppid, start, count, pt));
    NC(nc_put_vara_double(ncid, clptid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, clpqid, start, count, qt));

    /* Get dynamical tropopause... */
    ctl.met_tropo = 5;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, dynzid, start, count, zt));
    NC(nc_put_vara_double(ncid, dynpid, start, count, pt));
    NC(nc_put_vara_double(ncid, dyntid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, dynqid, start, count, qt));

    /* Get WMO 1st tropopause... */
    ctl.met_tropo = 3;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, wmo1zid, start, count, zt));
    NC(nc_put_vara_double(ncid, wmo1pid, start, count, pt));
    NC(nc_put_vara_double(ncid, wmo1tid, start, count, tt));
    if (h2o)
```

```
      NC(nc_put_vara_double(ncid, wmo1qid, start, count, qt));

    /* Get WMO 2nd tropopause... */
    ctl.met_tropo = 4;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, wmo2zid, start, count, zt));
    NC(nc_put_vara_double(ncid, wmo2pid, start, count, pt));
    NC(nc_put_vara_double(ncid, wmo2tid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, wmo2qid, start, count, qt));

    /* Increment time step counter... */
    nt++;
  }

  /* Close file... */
  NC(nc_close(ncid));

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:



## 5.46 tropo.c

```
/*
  This file is part of MPTRAC.

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  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

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  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

  Copyright (C) 2013-2021 Forschungszentrum Juelich GmbH
*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */

void add_text_attribute(
  int ncid,
  char *varname,
  char *attrname,
  char *text);

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  met_t *met;

  static double pt[EX * EY], qt[EX * EY], zt[EX * EY], tt[EX * EY], lon, lon0,
    lon1, lons[EX], dlon, lat, lat0, lat1, lats[EY], dlat, cw[3];

  static int init, i, ix, iy, nx, ny, nt, ncid, dims[3], timid, lonid, latid,
    clppid, clpqid, clptid, clpzid, dynpid, dynqid, dyntid, dynzid, wmo1pid,
    wmo1qid, wmo1tid, wmo1zid, wmo2pid, wmo2qid, wmo2tid, wmo2zid, h2o, ci[3];

  static size_t count[10], start[10];

  /* Allocate... */
  ALLOC(met, met_t, 1);

  /* Check arguments... */
  if (argc < 4)
    ERRMSG("Give parameters: <ctl> <tropo.nc> <met0> [ <met1> ... ]");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  lon0 = scan_ctl(argv[1], argc, argv, "TROPO_LON0", -1, "-180", NULL);
  lon1 = scan_ctl(argv[1], argc, argv, "TROPO_LON1", -1, "180", NULL);
  dlon = scan_ctl(argv[1], argc, argv, "TROPO_DLON", -1, "-999", NULL);
  lat0 = scan_ctl(argv[1], argc, argv, "TROPO_LAT0", -1, "-90", NULL);
  lat1 = scan_ctl(argv[1], argc, argv, "TROPO_LAT1", -1, "90", NULL);
  dlat = scan_ctl(argv[1], argc, argv, "TROPO_DLAT", -1, "-999", NULL);
  h2o = (int) scan_ctl(argv[1], argc, argv, "TROPO_H2O", -1, "1", NULL);

  /* Loop over files... */
  for (i = 3; i < argc; i++) {

    /* Read meteorological data... */
    ctl.met_tropo = 0;
    if (!read_met(&ctl, argv[i], met))
      continue;

    /* Set horizontal grid... */
    if (!init) {
      init = 1;

      /* Get grid... */
      if (dlon <= 0)
        dlon = fabs(met->lon[1] - met->lon[0]);
      if (dlat <= 0)
```

```
      dlat = fabs(met->lat[1] - met->lat[0]);
    if (lon0 < -360 && lon1 > 360) {
      lon0 = gsl_stats_min(met->lon, 1, (size_t) met->nx);
      lon1 = gsl_stats_max(met->lon, 1, (size_t) met->nx);
    }
    nx = ny = 0;
    for (lon = lon0; lon <= lon1; lon += dlon) {
      lons[nx] = lon;
      if ((++nx) > EX)
        ERRMSG("Too many longitudes!");
    }
    if (lat0 < -90 && lat1 > 90) {
      lat0 = gsl_stats_min(met->lat, 1, (size_t) met->ny);
      lat1 = gsl_stats_max(met->lat, 1, (size_t) met->ny);
    }
    for (lat = lat0; lat <= lat1; lat += dlat) {
      lats[ny] = lat;
      if ((++ny) > EY)
        ERRMSG("Too many latitudes!");
    }

    /* Create netCDF file... */
    printf("Write tropopause data file: %s\n", argv[2]);
    NC(nc_create(argv[2], NC_CLOBBER, &ncid));

    /* Create dimensions... */
    NC(nc_def_dim(ncid, "time", (size_t) NC_UNLIMITED, &dims[0]));
    NC(nc_def_dim(ncid, "lat", (size_t) ny, &dims[1]));
    NC(nc_def_dim(ncid, "lon", (size_t) nx, &dims[2]));

    /* Create variables... */
    NC(nc_def_var(ncid, "time", NC_DOUBLE, 1, &dims[0], &timid));
    NC(nc_def_var(ncid, "lat", NC_DOUBLE, 1, &dims[1], &latid));
    NC(nc_def_var(ncid, "lon", NC_DOUBLE, 1, &dims[2], &lonid));
    NC(nc_def_var(ncid, "clp_z", NC_FLOAT, 3, &dims[0], &clpzid));
    NC(nc_def_var(ncid, "clp_p", NC_FLOAT, 3, &dims[0], &clppid));
    NC(nc_def_var(ncid, "clp_t", NC_FLOAT, 3, &dims[0], &clptid));
    if (h2o)
      NC(nc_def_var(ncid, "clp_q", NC_FLOAT, 3, &dims[0], &clpqid));
    NC(nc_def_var(ncid, "dyn_z", NC_FLOAT, 3, &dims[0], &dynzid));
    NC(nc_def_var(ncid, "dyn_p", NC_FLOAT, 3, &dims[0], &dynpid));
    NC(nc_def_var(ncid, "dyn_t", NC_FLOAT, 3, &dims[0], &dyntid));
    if (h2o)
      NC(nc_def_var(ncid, "dyn_q", NC_FLOAT, 3, &dims[0], &dynqid));
    NC(nc_def_var(ncid, "wmo_1st_z", NC_FLOAT, 3, &dims[0], &wmo1zid));
    NC(nc_def_var(ncid, "wmo_1st_p", NC_FLOAT, 3, &dims[0], &wmo1pid));
    NC(nc_def_var(ncid, "wmo_1st_t", NC_FLOAT, 3, &dims[0], &wmo1tid));
    if (h2o)
      NC(nc_def_var(ncid, "wmo_1st_q", NC_FLOAT, 3, &dims[0], &wmo1qid));
    NC(nc_def_var(ncid, "wmo_2nd_z", NC_FLOAT, 3, &dims[0], &wmo2zid));
    NC(nc_def_var(ncid, "wmo_2nd_p", NC_FLOAT, 3, &dims[0], &wmo2pid));
    NC(nc_def_var(ncid, "wmo_2nd_t", NC_FLOAT, 3, &dims[0], &wmo2tid));
    if (h2o)
      NC(nc_def_var(ncid, "wmo_2nd_q", NC_FLOAT, 3, &dims[0], &wmo2qid));

    /* Set attributes... */
    add_text_attribute(ncid, "time", "units",
                       "seconds since 2000-01-01 00:00:00 UTC");
    add_text_attribute(ncid, "time", "long_name", "time");
    add_text_attribute(ncid, "lon", "units", "degrees_east");
    add_text_attribute(ncid, "lon", "long_name", "longitude");
    add_text_attribute(ncid, "lat", "units", "degrees_north");
    add_text_attribute(ncid, "lat", "long_name", "latitude");

    add_text_attribute(ncid, "clp_z", "units", "km");
    add_text_attribute(ncid, "clp_z", "long_name", "cold point height");
    add_text_attribute(ncid, "clp_p", "units", "hPa");
    add_text_attribute(ncid, "clp_p", "long_name", "cold point pressure");
    add_text_attribute(ncid, "clp_t", "units", "K");
    add_text_attribute(ncid, "clp_t", "long_name",
                       "cold point temperature");
    if (h2o) {
      add_text_attribute(ncid, "clp_q", "units", "ppv");
      add_text_attribute(ncid, "clp_q", "long_name",
                         "cold point water vapor");
    }

    add_text_attribute(ncid, "dyn_z", "units", "km");
    add_text_attribute(ncid, "dyn_z", "long_name",
                       "dynamical tropopause height");
    add_text_attribute(ncid, "dyn_p", "units", "hPa");
    add_text_attribute(ncid, "dyn_p", "long_name",
                       "dynamical tropopause pressure");
    add_text_attribute(ncid, "dyn_t", "units", "K");
    add_text_attribute(ncid, "dyn_t", "long_name",
                       "dynamical tropopause temperature");
    if (h2o) {
```

```
        add_text_attribute(ncid, "dyn_q", "units", "ppv");
        add_text_attribute(ncid, "dyn_q", "long_name",
                           "dynamical tropopause water vapor");
      }

      add_text_attribute(ncid, "wmo_1st_z", "units", "km");
      add_text_attribute(ncid, "wmo_1st_z", "long_name",
                         "WMO 1st tropopause height");
      add_text_attribute(ncid, "wmo_1st_p", "units", "hPa");
      add_text_attribute(ncid, "wmo_1st_p", "long_name",
                         "WMO 1st tropopause pressure");
      add_text_attribute(ncid, "wmo_1st_t", "units", "K");
      add_text_attribute(ncid, "wmo_1st_t", "long_name",
                         "WMO 1st tropopause temperature");
      if (h2o) {
        add_text_attribute(ncid, "wmo_1st_q", "units", "ppv");
        add_text_attribute(ncid, "wmo_1st_q", "long_name",
                           "WMO 1st tropopause water vapor");
      }

      add_text_attribute(ncid, "wmo_2nd_z", "units", "km");
      add_text_attribute(ncid, "wmo_2nd_z", "long_name",
                         "WMO 2nd tropopause height");
      add_text_attribute(ncid, "wmo_2nd_p", "units", "hPa");
      add_text_attribute(ncid, "wmo_2nd_p", "long_name",
                         "WMO 2nd tropopause pressure");
      add_text_attribute(ncid, "wmo_2nd_t", "units", "K");
      add_text_attribute(ncid, "wmo_2nd_t", "long_name",
                         "WMO 2nd tropopause temperature");
      if (h2o) {
        add_text_attribute(ncid, "wmo_2nd_q", "units", "ppv");
        add_text_attribute(ncid, "wmo_2nd_q", "long_name",
                           "WMO 2nd tropopause water vapor");
      }

      /* End definition... */
      NC(nc_enddef(ncid));

      /* Write longitude and latitude... */
      NC(nc_put_var_double(ncid, latid, lats));
      NC(nc_put_var_double(ncid, lonid, lons));
    }

    /* Write time... */
    start[0] = (size_t) nt;
    count[0] = 1;
    start[1] = 0;
    count[1] = (size_t) ny;
    start[2] = 0;
    count[2] = (size_t) nx;
    NC(nc_put_vara_double(ncid, timid, start, count, &met->time));

    /* Get cold point... */
    ctl.met_tropo = 2;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, clpzid, start, count, zt));
    NC(nc_put_vara_double(ncid, clppid, start, count, pt));
    NC(nc_put_vara_double(ncid, clptid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, clpqid, start, count, qt));

    /* Get dynamical tropopause... */
    ctl.met_tropo = 5;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
```

```
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, dynzid, start, count, zt));
    NC(nc_put_vara_double(ncid, dynpid, start, count, pt));
    NC(nc_put_vara_double(ncid, dyntid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, dynqid, start, count, qt));

    /* Get WMO 1st tropopause... */
    ctl.met_tropo = 3;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, wmo1zid, start, count, zt));
    NC(nc_put_vara_double(ncid, wmo1pid, start, count, pt));
    NC(nc_put_vara_double(ncid, wmo1tid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, wmo1qid, start, count, qt));

    /* Get WMO 2nd tropopause... */
    ctl.met_tropo = 4;
    read_met_tropo(&ctl, met);
#pragma omp parallel for default(shared) private(ix,iy,ci,cw)
    for (ix = 0; ix < nx; ix++)
      for (iy = 0; iy < ny; iy++) {
        intpol_met_space_2d(met, met->pt, lons[ix], lats[iy],
                            &pt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->z, pt[iy * nx + ix], lons[ix],
                            lats[iy], &zt[iy * nx + ix], ci, cw, 1);
        intpol_met_space_3d(met, met->t, pt[iy * nx + ix], lons[ix],
                            lats[iy], &tt[iy * nx + ix], ci, cw, 0);
        intpol_met_space_3d(met, met->h2o, pt[iy * nx + ix], lons[ix],
                            lats[iy], &qt[iy * nx + ix], ci, cw, 0);
      }

    /* Write data... */
    NC(nc_put_vara_double(ncid, wmo2zid, start, count, zt));
    NC(nc_put_vara_double(ncid, wmo2pid, start, count, pt));
    NC(nc_put_vara_double(ncid, wmo2tid, start, count, tt));
    if (h2o)
      NC(nc_put_vara_double(ncid, wmo2qid, start, count, qt));

    /* Increment time step counter... */
    nt++;
  }

  /* Close file... */
  NC(nc_close(ncid));

  /* Free... */
  free(met);

  return EXIT_SUCCESS;
}

/*****************************************************************************/

void add_text_attribute(
  int ncid,
  char *varname,
  char *attrname,
  char *text) {

  int varid;

  NC(nc_inq_varid(ncid, varname, &varid));
  NC(nc_put_att_text(ncid, varid, attrname, strlen(text), text));
}
```

## 5.47 tropo_sample.c File Reference

```
#include "libtrac.h"
```

### Macros

- #define NT 744

  *Maximum number of time steps.*

### Functions

- void intpol_tropo_3d (double time0, float array0[EX][EY], double time1, float array1[EX][EY], double lons[EX], double lats[EY], size_t nlon, size_t nlat, double time, double lon, double lat, int method, double ∗var, double ∗sigma)

  *3-D linear interpolation of tropopause data.*
- int main (int argc, char ∗argv[ ])

### 5.47.1 Detailed Description

Sample tropopause data set.

Definition in file tropo_sample.c.

### 5.47.2 Macro Definition Documentation

#### 5.47.2.1 NT `#define NT 744`

Maximum number of time steps.

Definition at line 32 of file tropo_sample.c.

### 5.47.3 Function Documentation

#### 5.47.3.1 intpol_tropo_3d()

```
void intpol_tropo_3d (
        double time0,
        float array0[EX][EY],
        double time1,
        float array1[EX][EY],
        double lons[EX],
        double lats[EY],
        size_t nlon,
        size_t nlat,
        double time,
        double lon,
        double lat,
        int method,
        double * var,
        double * sigma )
```

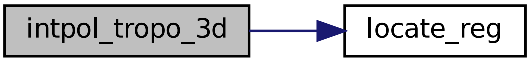
3-D linear interpolation of tropopause data.

Definition at line 266 of file tropo_sample.c.

```
                  {

  double aux0, aux1, aux00, aux01, aux10, aux11, mean = 0;

  int n = 0;

  /* Adjust longitude... */
  if (lon < lons[0])
    lon += 360;
  else if (lon > lons[nlon - 1])
    lon -= 360;

  /* Get indices... */
  int ix = locate_reg(lons, (int) nlon, lon);
  int iy = locate_reg(lats, (int) nlat, lat);

  /* Calculate standard deviation... */
  *sigma = 0;
  for (int dx = 0; dx < 2; dx++)
    for (int dy = 0; dy < 2; dy++) {
      if (isfinite(array0[ix + dx][iy + dy])) {
        mean += array0[ix + dx][iy + dy];
        *sigma += SQR(array0[ix + dx][iy + dy]);
        n++;
      }
      if (isfinite(array1[ix + dx][iy + dy])) {
        mean += array1[ix + dx][iy + dy];
        *sigma += SQR(array1[ix + dx][iy + dy]);
        n++;
      }
    }
  if (n > 0)
    *sigma = sqrt(GSL_MAX(*sigma / n - SQR(mean / n), 0.0));

  /* Linear interpolation... */
  if (method == 1 && isfinite(array0[ix][iy])
      && isfinite(array0[ix][iy + 1])
      && isfinite(array0[ix + 1][iy])
      && isfinite(array0[ix + 1][iy + 1])
      && isfinite(array1[ix][iy])
      && isfinite(array1[ix][iy + 1])
      && isfinite(array1[ix + 1][iy])
      && isfinite(array1[ix + 1][iy + 1])) {

    aux00 = LIN(lons[ix], array0[ix][iy],
                lons[ix + 1], array0[ix + 1][iy], lon);
    aux01 = LIN(lons[ix], array0[ix][iy + 1],
                lons[ix + 1], array0[ix + 1][iy + 1], lon);
    aux0 = LIN(lats[iy], aux00, lats[iy + 1], aux01, lat);

    aux10 = LIN(lons[ix], array1[ix][iy],
                lons[ix + 1], array1[ix + 1][iy], lon);
    aux11 = LIN(lons[ix], array1[ix][iy + 1],
                lons[ix + 1], array1[ix + 1][iy + 1], lon);
    aux1 = LIN(lats[iy], aux10, lats[iy + 1], aux11, lat);

    *var = LIN(time0, aux0, time1, aux1, time);
  }

```

```
  /* Nearest neighbor interpolation... */
  else {
    aux00 = NN(lons[ix], array0[ix][iy],
               lons[ix + 1], array0[ix + 1][iy], lon);
    aux01 = NN(lons[ix], array0[ix][iy + 1],
               lons[ix + 1], array0[ix + 1][iy + 1], lon);
    aux0 = NN(lats[iy], aux00, lats[iy + 1], aux01, lat);

    aux10 = NN(lons[ix], array1[ix][iy],
               lons[ix + 1], array1[ix + 1][iy], lon);
    aux11 = NN(lons[ix], array1[ix][iy + 1],
               lons[ix + 1], array1[ix + 1][iy + 1], lon);
    aux1 = NN(lats[iy], aux10, lats[iy + 1], aux11, lat);

    *var = NN(time0, aux0, time1, aux1, time);
  }
}
```

Here is the call graph for this function:




#### 5.47.3.2 main()

```
int main (
    int argc,
    char * argv[] )
```

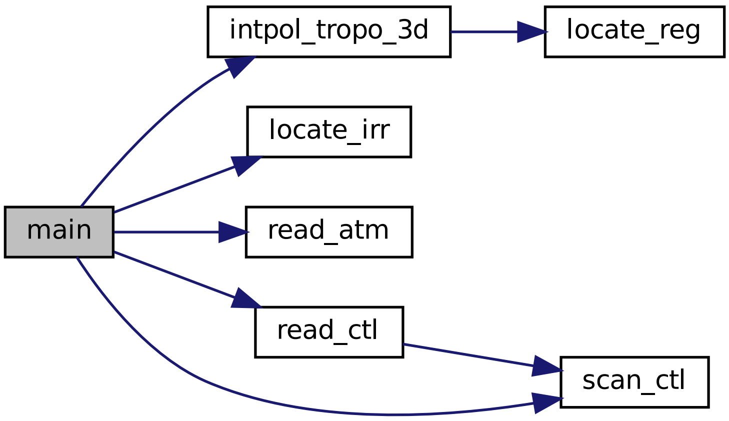
Definition at line 59 of file tropo_sample.c.

```
                      {

  ctl_t ctl;

  atm_t *atm;

  static FILE *out;

  static char varname[LEN];

  static double times[NT], lons[EX], lats[EY], time0, time1, z0, z0sig,
    p0, p0sig, t0, t0sig, q0, q0sig;

  static float help[EX * EY], tropo_z0[EX][EY], tropo_z1[EX][EY],
    tropo_p0[EX][EY], tropo_p1[EX][EY], tropo_t0[EX][EY],
    tropo_t1[EX][EY], tropo_q0[EX][EY], tropo_q1[EX][EY];

  static int ip, iq, it, it_old = -999, method, dimid[10], ncid,
    varid, varid_z, varid_p, varid_t, varid_q, h2o;

  static size_t count[10], start[10], ntime, nlon, nlat, ilon, ilat;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Check arguments... */
  if (argc < 5)
    ERRMSG("Give parameters: <ctl> <sample.tab> <tropo.nc> <var> <atm_in>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  method =
    (int) scan_ctl(argv[1], argc, argv, "TROPO_SAMPLE_METHOD", -1, "1", NULL);

  /* Read atmospheric data... */
  if (!read_atm(argv[5], &ctl, atm))
```

```
    ERRMSG("Cannot open file!");

  /* Open tropopause file... */
  printf("Read tropopause data: %s\n", argv[3]);
  if (nc_open(argv[3], NC_NOWRITE, &ncid) != NC_NOERR)
    ERRMSG("Cannot open file!");

  /* Get dimensions... */
  NC(nc_inq_dimid(ncid, "time", &dimid[0]));
  NC(nc_inq_dimlen(ncid, dimid[0], &ntime));
  if (ntime > NT)
    ERRMSG("Too many times!");
  NC(nc_inq_dimid(ncid, "lat", &dimid[1]));
  NC(nc_inq_dimlen(ncid, dimid[1], &nlat));
  if (nlat > EY)
    ERRMSG("Too many latitudes!");
  NC(nc_inq_dimid(ncid, "lon", &dimid[2]));
  NC(nc_inq_dimlen(ncid, dimid[2], &nlon));
  if (nlon > EX)
    ERRMSG("Too many longitudes!");

  /* Read coordinates... */
  NC(nc_inq_varid(ncid, "time", &varid));
  NC(nc_get_var_double(ncid, varid, times));
  NC(nc_inq_varid(ncid, "lat", &varid));
  NC(nc_get_var_double(ncid, varid, lats));
  NC(nc_inq_varid(ncid, "lon", &varid));
  NC(nc_get_var_double(ncid, varid, lons));

  /* Get variable indices... */
  sprintf(varname, "%s_z", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_z));
  sprintf(varname, "%s_p", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_p));
  sprintf(varname, "%s_t", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_t));
  sprintf(varname, "%s_q", argv[4]);
  h2o = (nc_inq_varid(ncid, varname, &varid_q) == NC_NOERR);

  /* Set dimensions... */
  count[0] = 1;
  count[1] = nlat;
  count[2] = nlon;

  /* Create file... */
  printf("Write tropopause sample data: %s\n", argv[2]);
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out, "# $%i = %s [%s]\n", iq + 5, ctl.qnt_name[iq],
            ctl.qnt_unit[iq]);
  fprintf(out, "# $%d = tropopause height [km]\n", 5 + ctl.nq);
  fprintf(out, "# $%d = tropopause pressure [hPa]\n", 6 + ctl.nq);
  fprintf(out, "# $%d = tropopause temperature [K]\n", 7 + ctl.nq);
  fprintf(out, "# $%d = tropopause water vapor [ppv]\n", 8 + ctl.nq);
  fprintf(out, "# $%d = tropopause height (sigma) [km]\n", 9 + ctl.nq);
  fprintf(out, "# $%d = tropopause pressure (sigma) [hPa]\n", 10 + ctl.nq);
  fprintf(out, "# $%d = tropopause temperature (sigma) [K]\n", 11 + ctl.nq);
  fprintf(out, "# $%d = tropopause water vapor (sigma) [ppv]\n\n",
          12 + ctl.nq);

  /* Loop over particles... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check temporal ordering... */
    if (ip > 0 && atm->time[ip] < atm->time[ip - 1])
      ERRMSG("Time must be ascending!");

    /* Check range... */
    if (atm->time[ip] < times[0] || atm->time[ip] > times[ntime - 1])
      continue;

    /* Read data... */
    it = locate_irr(times, (int) ntime, atm->time[ip]);
    if (it != it_old) {

      time0 = times[it];
      start[0] = (size_t) it;
      NC(nc_get_vara_float(ncid, varid_z, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
```

```
          tropo_z0[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_p, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_p0[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_t, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_t0[ilon][ilat] = help[ilat * nlon + ilon];
      if (h2o) {
        NC(nc_get_vara_float(ncid, varid_q, start, count, help));
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q0[ilon][ilat] = help[ilat * nlon + ilon];
      } else
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q0[ilon][ilat] = GSL_NAN;

      time1 = times[it + 1];
      start[0] = (size_t) it + 1;
      NC(nc_get_vara_float(ncid, varid_z, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_z1[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_p, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_p1[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_t, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_t1[ilon][ilat] = help[ilat * nlon + ilon];
      if (h2o) {
        NC(nc_get_vara_float(ncid, varid_q, start, count, help));
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q1[ilon][ilat] = help[ilat * nlon + ilon];
      } else
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q1[ilon][ilat] = GSL_NAN;;
    }
    it_old = it;

    /* Interpolate... */
    intpol_tropo_3d(time0, tropo_z0, time1, tropo_z1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &z0, &z0sig);
    intpol_tropo_3d(time0, tropo_p0, time1, tropo_p1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &p0, &p0sig);
    intpol_tropo_3d(time0, tropo_t0, time1, tropo_t1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &t0, &t0sig);
    intpol_tropo_3d(time0, tropo_q0, time1, tropo_q1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &q0, &q0sig);

    /* Write output... */
    fprintf(out, "%.2f %g %g %g", atm->time[ip], Z(atm->p[ip]),
            atm->lon[ip], atm->lat[ip]);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, " %g %g %g %g %g %g %g %g\n",
            z0, p0, t0, q0, z0sig, p0sig, t0sig, q0sig);
  }

  /* Close files... */
  fclose(out);
  NC(nc_close(ncid));

  /* Free... */
  free(atm);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.48 tropo_sample.c

```
/*
  This file is part of MPTRAC.

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  it under the terms of the GNU General Public License as published by
  the Free Software Foundation, either version 3 of the License, or
  (at your option) any later version.

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  along with MPTRAC. If not, see <http://www.gnu.org/licenses/>.

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*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Dimensions...
   ------------------------------------------------------------ */

#define NT 744

/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */

void intpol_tropo_3d(
  double time0,
  float array0[EX][EY],
  double time1,
  float array1[EX][EY],
  double lons[EX],
  double lats[EY],
  size_t nlon,
  size_t nlat,
  double time,
  double lon,
  double lat,
  int method,
  double *var,
  double *sigma);

/* ------------------------------------------------------------
```

```
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  atm_t *atm;

  static FILE *out;

  static char varname[LEN];

  static double times[NT], lons[EX], lats[EY], time0, time1, z0, z0sig,
    p0, p0sig, t0, t0sig, q0, q0sig;

  static float help[EX * EY], tropo_z0[EX][EY], tropo_z1[EX][EY],
    tropo_p0[EX][EY], tropo_p1[EX][EY], tropo_t0[EX][EY],
    tropo_t1[EX][EY], tropo_q0[EX][EY], tropo_q1[EX][EY];

  static int ip, iq, it, it_old = -999, method, dimid[10], ncid,
    varid, varid_z, varid_p, varid_t, varid_q, h2o;

  static size_t count[10], start[10], ntime, nlon, nlat, ilon, ilat;

  /* Allocate... */
  ALLOC(atm, atm_t, 1);

  /* Check arguments... */
  if (argc < 5)
    ERRMSG("Give parameters: <ctl> <sample.tab> <tropo.nc> <var> <atm_in>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  method =
    (int) scan_ctl(argv[1], argc, argv, "TROPO_SAMPLE_METHOD", -1, "1", NULL);

  /* Read atmospheric data... */
  if (!read_atm(argv[5], &ctl, atm))
    ERRMSG("Cannot open file!");

  /* Open tropopause file... */
  printf("Read tropopause data: %s\n", argv[3]);
  if (nc_open(argv[3], NC_NOWRITE, &ncid) != NC_NOERR)
    ERRMSG("Cannot open file!");

  /* Get dimensions... */
  NC(nc_inq_dimid(ncid, "time", &dimid[0]));
  NC(nc_inq_dimlen(ncid, dimid[0], &ntime));
  if (ntime > NT)
    ERRMSG("Too many times!");
  NC(nc_inq_dimid(ncid, "lat", &dimid[1]));
  NC(nc_inq_dimlen(ncid, dimid[1], &nlat));
  if (nlat > EY)
    ERRMSG("Too many latitudes!");
  NC(nc_inq_dimid(ncid, "lon", &dimid[2]));
  NC(nc_inq_dimlen(ncid, dimid[2], &nlon));
  if (nlon > EX)
    ERRMSG("Too many longitudes!");

  /* Read coordinates... */
  NC(nc_inq_varid(ncid, "time", &varid));
  NC(nc_get_var_double(ncid, varid, times));
  NC(nc_inq_varid(ncid, "lat", &varid));
  NC(nc_get_var_double(ncid, varid, lats));
  NC(nc_inq_varid(ncid, "lon", &varid));
  NC(nc_get_var_double(ncid, varid, lons));

  /* Get variable indices... */
  sprintf(varname, "%s_z", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_z));
  sprintf(varname, "%s_p", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_p));
  sprintf(varname, "%s_t", argv[4]);
  NC(nc_inq_varid(ncid, varname, &varid_t));
  sprintf(varname, "%s_q", argv[4]);
  h2o = (nc_inq_varid(ncid, varname, &varid_q) == NC_NOERR);

  /* Set dimensions... */
  count[0] = 1;
  count[1] = nlat;
  count[2] = nlon;

  /* Create file... */
  printf("Write tropopause sample data: %s\n", argv[2]);
```

```
  if (!(out = fopen(argv[2], "w")))
    ERRMSG("Cannot create file!");

  /* Write header... */
  fprintf(out,
          "# $1 = time [s]\n"
          "# $2 = altitude [km]\n"
          "# $3 = longitude [deg]\n" "# $4 = latitude [deg]\n");
  for (iq = 0; iq < ctl.nq; iq++)
    fprintf(out, "# $%i = %s [%s]\n", iq + 5, ctl.qnt_name[iq],
            ctl.qnt_unit[iq]);
  fprintf(out, "# $%d = tropopause height [km]\n", 5 + ctl.nq);
  fprintf(out, "# $%d = tropopause pressure [hPa]\n", 6 + ctl.nq);
  fprintf(out, "# $%d = tropopause temperature [K]\n", 7 + ctl.nq);
  fprintf(out, "# $%d = tropopause water vapor [ppv]\n", 8 + ctl.nq);
  fprintf(out, "# $%d = tropopause height (sigma) [km]\n", 9 + ctl.nq);
  fprintf(out, "# $%d = tropopause pressure (sigma) [hPa]\n", 10 + ctl.nq);
  fprintf(out, "# $%d = tropopause temperature (sigma) [K]\n", 11 + ctl.nq);
  fprintf(out, "# $%d = tropopause water vapor (sigma) [ppv]\n\n",
          12 + ctl.nq);

  /* Loop over particles... */
  for (ip = 0; ip < atm->np; ip++) {

    /* Check temporal ordering... */
    if (ip > 0 && atm->time[ip] < atm->time[ip - 1])
      ERRMSG("Time must be ascending!");

    /* Check range... */
    if (atm->time[ip] < times[0] || atm->time[ip] > times[ntime - 1])
      continue;

    /* Read data... */
    it = locate_irr(times, (int) ntime, atm->time[ip]);
    if (it != it_old) {

      time0 = times[it];
      start[0] = (size_t) it;
      NC(nc_get_vara_float(ncid, varid_z, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_z0[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_p, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_p0[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_t, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_t0[ilon][ilat] = help[ilat * nlon + ilon];
      if (h2o) {
        NC(nc_get_vara_float(ncid, varid_q, start, count, help));
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q0[ilon][ilat] = help[ilat * nlon + ilon];
      } else
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q0[ilon][ilat] = GSL_NAN;

      time1 = times[it + 1];
      start[0] = (size_t) it + 1;
      NC(nc_get_vara_float(ncid, varid_z, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_z1[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_p, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_p1[ilon][ilat] = help[ilat * nlon + ilon];
      NC(nc_get_vara_float(ncid, varid_t, start, count, help));
      for (ilon = 0; ilon < nlon; ilon++)
        for (ilat = 0; ilat < nlat; ilat++)
          tropo_t1[ilon][ilat] = help[ilat * nlon + ilon];
      if (h2o) {
        NC(nc_get_vara_float(ncid, varid_q, start, count, help));
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q1[ilon][ilat] = help[ilat * nlon + ilon];
      } else
        for (ilon = 0; ilon < nlon; ilon++)
          for (ilat = 0; ilat < nlat; ilat++)
            tropo_q1[ilon][ilat] = GSL_NAN;;
    }
    it_old = it;

    /* Interpolate... */
```

```
    intpol_tropo_3d(time0, tropo_z0, time1, tropo_z1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &z0, &z0sig);
    intpol_tropo_3d(time0, tropo_p0, time1, tropo_p1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &p0, &p0sig);
    intpol_tropo_3d(time0, tropo_t0, time1, tropo_t1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &t0, &t0sig);
    intpol_tropo_3d(time0, tropo_q0, time1, tropo_q1,
                    lons, lats, nlon, nlat, atm->time[ip], atm->lon[ip],
                    atm->lat[ip], method, &q0, &q0sig);

    /* Write output... */
    fprintf(out, "%.2f %g %g %g", atm->time[ip], Z(atm->p[ip]),
            atm->lon[ip], atm->lat[ip]);
    for (iq = 0; iq < ctl.nq; iq++) {
      fprintf(out, " ");
      fprintf(out, ctl.qnt_format[iq], atm->q[iq][ip]);
    }
    fprintf(out, " %g %g %g %g %g %g %g %g\n",
            z0, p0, t0, q0, z0sig, p0sig, t0sig, q0sig);
  }

  /* Close files... */
  fclose(out);
  NC(nc_close(ncid));

  /* Free... */
  free(atm);

  return EXIT_SUCCESS;
}

/*****************************************************************************/

void intpol_tropo_3d(
  double time0,
  float array0[EX][EY],
  double time1,
  float array1[EX][EY],
  double lons[EX],
  double lats[EY],
  size_t nlon,
  size_t nlat,
  double time,
  double lon,
  double lat,
  int method,
  double *var,
  double *sigma) {

  double aux0, aux1, aux00, aux01, aux10, aux11, mean = 0;

  int n = 0;

  /* Adjust longitude... */
  if (lon < lons[0])
    lon += 360;
  else if (lon > lons[nlon - 1])
    lon -= 360;

  /* Get indices... */
  int ix = locate_reg(lons, (int) nlon, lon);
  int iy = locate_reg(lats, (int) nlat, lat);

  /* Calculate standard deviation... */
  *sigma = 0;
  for (int dx = 0; dx < 2; dx++)
    for (int dy = 0; dy < 2; dy++) {
      if (isfinite(array0[ix + dx][iy + dy])) {
        mean += array0[ix + dx][iy + dy];
        *sigma += SQR(array0[ix + dx][iy + dy]);
        n++;
      }
      if (isfinite(array1[ix + dx][iy + dy])) {
        mean += array1[ix + dx][iy + dy];
        *sigma += SQR(array1[ix + dx][iy + dy]);
        n++;
      }
    }
  if (n > 0)
    *sigma = sqrt(GSL_MAX(*sigma / n - SQR(mean / n), 0.0));

  /* Linear interpolation... */
  if (method == 1 && isfinite(array0[ix][iy])
      && isfinite(array0[ix][iy + 1])
```

```
      && isfinite(array0[ix + 1][iy])
      && isfinite(array0[ix + 1][iy + 1])
      && isfinite(array1[ix][iy])
      && isfinite(array1[ix][iy + 1])
      && isfinite(array1[ix + 1][iy])
      && isfinite(array1[ix + 1][iy + 1])) {

    aux00 = LIN(lons[ix], array0[ix][iy],
                lons[ix + 1], array0[ix + 1][iy], lon);
    aux01 = LIN(lons[ix], array0[ix][iy + 1],
                lons[ix + 1], array0[ix + 1][iy + 1], lon);
    aux0 = LIN(lats[iy], aux00, lats[iy + 1], aux01, lat);

    aux10 = LIN(lons[ix], array1[ix][iy],
                lons[ix + 1], array1[ix + 1][iy], lon);
    aux11 = LIN(lons[ix], array1[ix][iy + 1],
                lons[ix + 1], array1[ix + 1][iy + 1], lon);
    aux1 = LIN(lats[iy], aux10, lats[iy + 1], aux11, lat);

    *var = LIN(time0, aux0, time1, aux1, time);
  }

  /* Nearest neighbor interpolation... */
  else {
    aux00 = NN(lons[ix], array0[ix][iy],
               lons[ix + 1], array0[ix + 1][iy], lon);
    aux01 = NN(lons[ix], array0[ix][iy + 1],
               lons[ix + 1], array0[ix + 1][iy + 1], lon);
    aux0 = NN(lats[iy], aux00, lats[iy + 1], aux01, lat);

    aux10 = NN(lons[ix], array1[ix][iy],
               lons[ix + 1], array1[ix + 1][iy], lon);
    aux11 = NN(lons[ix], array1[ix][iy + 1],
               lons[ix + 1], array1[ix + 1][iy + 1], lon);
    aux1 = NN(lats[iy], aux10, lats[iy + 1], aux11, lat);

    *var = NN(time0, aux0, time1, aux1, time);
  }
}
```

## 5.49 wind.c File Reference

```
#include "libtrac.h"
```

### Functions

- void add_text_attribute (int ncid, char *varname, char *attrname, char *text)
- int main (int argc, char *argv[ ])

### 5.49.1 Detailed Description

Create meteorological data files with synthetic wind fields.

Definition in file wind.c.

### 5.49.2 Function Documentation

#### 5.49.2.1 add_text_attribute()

```
void add_text_attribute (
    int ncid,
    char * varname,
    char * attrname,
    char * text )
```

Definition at line 188 of file wind.c.

```
                {

  int varid;

  NC(nc_inq_varid(ncid, varname, &varid));
  NC(nc_put_att_text(ncid, varid, attrname, strlen(text), text));
}
```

#### 5.49.2.2 main()

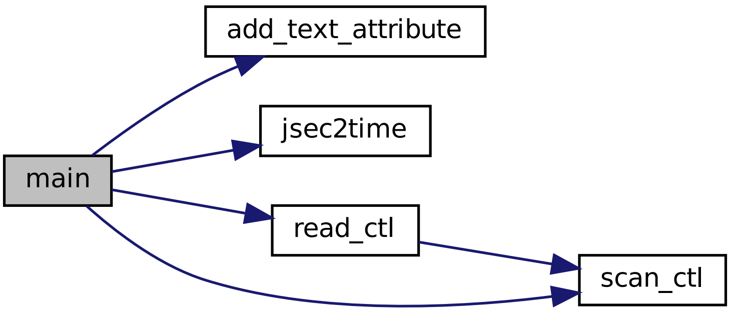
```
int main (
    int argc,
    char * argv[] )
```

Definition at line 41 of file wind.c.

```
                  {

  ctl_t ctl;

  static char filename[LEN];

  static double r, t0, z0, z1, dataLon[EX], dataLat[EY], dataZ[EP],
    u0, u1, alpha;

  static float *dataT, *dataU, *dataV, *dataW;

  static int ncid, dims[4], timid, levid, latid, lonid, tid, uid, vid, wid,
    idx, ix, iy, iz, nx, ny, nz, year, mon, day, hour, min, sec;

  /* Allocate... */
  ALLOC(dataT, float,
        EP * EY * EX);
  ALLOC(dataU, float,
        EP * EY * EX);
  ALLOC(dataV, float,
        EP * EY * EX);
  ALLOC(dataW, float,
        EP * EY * EX);

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <metbase>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  t0 = scan_ctl(argv[1], argc, argv, "WIND_T0", -1, "0", NULL);
  nx = (int) scan_ctl(argv[1], argc, argv, "WIND_NX", -1, "360", NULL);
  ny = (int) scan_ctl(argv[1], argc, argv, "WIND_NY", -1, "181", NULL);
  nz = (int) scan_ctl(argv[1], argc, argv, "WIND_NZ", -1, "61", NULL);
  z0 = scan_ctl(argv[1], argc, argv, "WIND_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "WIND_Z1", -1, "60", NULL);
  u0 = scan_ctl(argv[1], argc, argv, "WIND_U0", -1, "38.587660177302", NULL);
  u1 = scan_ctl(argv[1], argc, argv, "WIND_U1", -1, "38.587660177302", NULL);
  alpha = scan_ctl(argv[1], argc, argv, "WIND_ALPHA", -1, "0.0", NULL);

  /* Check dimensions... */
  if (nx < 1 || nx > EX)
    ERRMSG("Set 1 <= NX <= MAX!");
  if (ny < 1 || ny > EY)
    ERRMSG("Set 1 <= NY <= MAX!");
  if (nz < 1 || nz > EP)
    ERRMSG("Set 1 <= NZ <= MAX!");

  /* Get time... */
  jsec2time(t0, &year, &mon, &day, &hour, &min, &sec, &r);
  t0 = year * 10000. + mon * 100. + day + hour / 24.;

  /* Set filename... */
  sprintf(filename, "%s_%d_%02d_%02d_%02d.nc", argv[2], year, mon, day, hour);

  /* Create netCDF file... */
```

```
  NC(nc_create(filename, NC_CLOBBER, &ncid));

  /* Create dimensions... */
  NC(nc_def_dim(ncid, "time", 1, &dims[0]));
  NC(nc_def_dim(ncid, "lev", (size_t) nz, &dims[1]));
  NC(nc_def_dim(ncid, "lat", (size_t) ny, &dims[2]));
  NC(nc_def_dim(ncid, "lon", (size_t) nx, &dims[3]));

  /* Create variables... */
  NC(nc_def_var(ncid, "time", NC_DOUBLE, 1, &dims[0], &timid));
  NC(nc_def_var(ncid, "lev", NC_DOUBLE, 1, &dims[1], &levid));
  NC(nc_def_var(ncid, "lat", NC_DOUBLE, 1, &dims[2], &latid));
  NC(nc_def_var(ncid, "lon", NC_DOUBLE, 1, &dims[3], &lonid));
  NC(nc_def_var(ncid, "T", NC_FLOAT, 4, &dims[0], &tid));
  NC(nc_def_var(ncid, "U", NC_FLOAT, 4, &dims[0], &uid));
  NC(nc_def_var(ncid, "V", NC_FLOAT, 4, &dims[0], &vid));
  NC(nc_def_var(ncid, "W", NC_FLOAT, 4, &dims[0], &wid));

  /* Set attributes... */
  add_text_attribute(ncid, "time", "long_name", "time");
  add_text_attribute(ncid, "time", "units", "day as %Y%m%d.%f");
  add_text_attribute(ncid, "lon", "long_name", "longitude");
  add_text_attribute(ncid, "lon", "units", "degrees_east");
  add_text_attribute(ncid, "lat", "long_name", "latitude");
  add_text_attribute(ncid, "lat", "units", "degrees_north");
  add_text_attribute(ncid, "lev", "long_name", "air_pressure");
  add_text_attribute(ncid, "lev", "units", "Pa");
  add_text_attribute(ncid, "T", "long_name", "Temperature");
  add_text_attribute(ncid, "T", "units", "K");
  add_text_attribute(ncid, "U", "long_name", "U velocity");
  add_text_attribute(ncid, "U", "units", "m s**-1");
  add_text_attribute(ncid, "V", "long_name", "V velocity");
  add_text_attribute(ncid, "V", "units", "m s**-1");
  add_text_attribute(ncid, "W", "long_name", "Vertical velocity");
  add_text_attribute(ncid, "W", "units", "Pa s**-1");

  /* End definition... */
  NC(nc_enddef(ncid));

  /* Set coordinates... */
  for (ix = 0; ix < nx; ix++)
    dataLon[ix] = 360.0 / nx * (double) ix;
  for (iy = 0; iy < ny; iy++)
    dataLat[iy] = 180.0 / (ny - 1) * (double) iy - 90;
  for (iz = 0; iz < nz; iz++)
    dataZ[iz] = 100. * P(LIN(0.0, z0, nz - 1.0, z1, iz));

  /* Write coordinates... */
  NC(nc_put_var_double(ncid, timid, &t0));
  NC(nc_put_var_double(ncid, levid, dataZ));
  NC(nc_put_var_double(ncid, lonid, dataLon));
  NC(nc_put_var_double(ncid, latid, dataLat));

  /* Create wind fields (Williamson et al., 1992)... */
  for (ix = 0; ix < nx; ix++)
    for (iy = 0; iy < ny; iy++)
      for (iz = 0; iz < nz; iz++) {
        idx = (iz * ny + iy) * nx + ix;
        dataU[idx] = (float) (LIN(0.0, u0, nz - 1.0, u1, iz)
                              * (cos(dataLat[iy] * M_PI / 180.0)
                                 * cos(alpha * M_PI / 180.0)
                                 + sin(dataLat[iy] * M_PI / 180.0)
                                 * cos(dataLon[ix] * M_PI / 180.0)
                                 * sin(alpha * M_PI / 180.0)));
        dataV[idx] = (float) (-LIN(0.0, u0, nz - 1.0, u1, iz)
                              * sin(dataLon[ix] * M_PI / 180.0)
                              * sin(alpha * M_PI / 180.0));
      }

  /* Write wind data... */
  NC(nc_put_var_float(ncid, tid, dataT));
  NC(nc_put_var_float(ncid, uid, dataU));
  NC(nc_put_var_float(ncid, vid, dataV));
  NC(nc_put_var_float(ncid, wid, dataW));

  /* Close file... */
  NC(nc_close(ncid));

  /* Free... */
  free(dataT);
  free(dataU);
  free(dataV);
  free(dataW);

  return EXIT_SUCCESS;
}
```

Here is the call graph for this function:




## 5.50 wind.c

```c
/*
  This file is part of MPTRAC.

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  the Free Software Foundation, either version 3 of the License, or
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*/

#include "libtrac.h"

/* ------------------------------------------------------------
   Functions...
   ------------------------------------------------------------ */

void add_text_attribute(
  int ncid,
  char *varname,
  char *attrname,
  char *text);

/* ------------------------------------------------------------
   Main...
   ------------------------------------------------------------ */

int main(
  int argc,
  char *argv[]) {

  ctl_t ctl;

  static char filename[LEN];

  static double r, t0, z0, z1, dataLon[EX], dataLat[EY], dataZ[EP],
    u0, u1, alpha;

  static float *dataT, *dataU, *dataV, *dataW;

  static int ncid, dims[4], timid, levid, latid, lonid, tid, uid, vid, wid,
    idx, ix, iy, iz, nx, ny, nz, year, mon, day, hour, min, sec;

  /* Allocate... */
  ALLOC(dataT, float,
```

```
        EP * EY * EX);
  ALLOC(dataU, float,
        EP * EY * EX);
  ALLOC(dataV, float,
        EP * EY * EX);
  ALLOC(dataW, float,
        EP * EY * EX);

  /* Check arguments... */
  if (argc < 3)
    ERRMSG("Give parameters: <ctl> <metbase>");

  /* Read control parameters... */
  read_ctl(argv[1], argc, argv, &ctl);
  t0 = scan_ctl(argv[1], argc, argv, "WIND_T0", -1, "0", NULL);
  nx = (int) scan_ctl(argv[1], argc, argv, "WIND_NX", -1, "360", NULL);
  ny = (int) scan_ctl(argv[1], argc, argv, "WIND_NY", -1, "181", NULL);
  nz = (int) scan_ctl(argv[1], argc, argv, "WIND_NZ", -1, "61", NULL);
  z0 = scan_ctl(argv[1], argc, argv, "WIND_Z0", -1, "0", NULL);
  z1 = scan_ctl(argv[1], argc, argv, "WIND_Z1", -1, "60", NULL);
  u0 = scan_ctl(argv[1], argc, argv, "WIND_U0", -1, "38.587660177302", NULL);
  u1 = scan_ctl(argv[1], argc, argv, "WIND_U1", -1, "38.587660177302", NULL);
  alpha = scan_ctl(argv[1], argc, argv, "WIND_ALPHA", -1, "0.0", NULL);

  /* Check dimensions... */
  if (nx < 1 || nx > EX)
    ERRMSG("Set 1 <= NX <= MAX!");
  if (ny < 1 || ny > EY)
    ERRMSG("Set 1 <= NY <= MAX!");
  if (nz < 1 || nz > EP)
    ERRMSG("Set 1 <= NZ <= MAX!");

  /* Get time... */
  jsec2time(t0, &year, &mon, &day, &hour, &min, &sec, &r);
  t0 = year * 10000. + mon * 100. + day + hour / 24.;

  /* Set filename... */
  sprintf(filename, "%s_%d_%02d_%02d_%02d.nc", argv[2], year, mon, day, hour);

  /* Create netCDF file... */
  NC(nc_create(filename, NC_CLOBBER, &ncid));

  /* Create dimensions... */
  NC(nc_def_dim(ncid, "time", 1, &dims[0]));
  NC(nc_def_dim(ncid, "lev", (size_t) nz, &dims[1]));
  NC(nc_def_dim(ncid, "lat", (size_t) ny, &dims[2]));
  NC(nc_def_dim(ncid, "lon", (size_t) nx, &dims[3]));

  /* Create variables... */
  NC(nc_def_var(ncid, "time", NC_DOUBLE, 1, &dims[0], &timid));
  NC(nc_def_var(ncid, "lev", NC_DOUBLE, 1, &dims[1], &levid));
  NC(nc_def_var(ncid, "lat", NC_DOUBLE, 1, &dims[2], &latid));
  NC(nc_def_var(ncid, "lon", NC_DOUBLE, 1, &dims[3], &lonid));
  NC(nc_def_var(ncid, "T", NC_FLOAT, 4, &dims[0], &tid));
  NC(nc_def_var(ncid, "U", NC_FLOAT, 4, &dims[0], &uid));
  NC(nc_def_var(ncid, "V", NC_FLOAT, 4, &dims[0], &vid));
  NC(nc_def_var(ncid, "W", NC_FLOAT, 4, &dims[0], &wid));

  /* Set attributes... */
  add_text_attribute(ncid, "time", "long_name", "time");
  add_text_attribute(ncid, "time", "units", "day as %Y%m%d.%f");
  add_text_attribute(ncid, "lon", "long_name", "longitude");
  add_text_attribute(ncid, "lon", "units", "degrees_east");
  add_text_attribute(ncid, "lat", "long_name", "latitude");
  add_text_attribute(ncid, "lat", "units", "degrees_north");
  add_text_attribute(ncid, "lev", "long_name", "air_pressure");
  add_text_attribute(ncid, "lev", "units", "Pa");
  add_text_attribute(ncid, "T", "long_name", "Temperature");
  add_text_attribute(ncid, "T", "units", "K");
  add_text_attribute(ncid, "U", "long_name", "U velocity");
  add_text_attribute(ncid, "U", "units", "m s**-1");
  add_text_attribute(ncid, "V", "long_name", "V velocity");
  add_text_attribute(ncid, "V", "units", "m s**-1");
  add_text_attribute(ncid, "W", "long_name", "Vertical velocity");
  add_text_attribute(ncid, "W", "units", "Pa s**-1");

  /* End definition... */
  NC(nc_enddef(ncid));

  /* Set coordinates... */
  for (ix = 0; ix < nx; ix++)
    dataLon[ix] = 360.0 / nx * (double) ix;
  for (iy = 0; iy < ny; iy++)
    dataLat[iy] = 180.0 / (ny - 1) * (double) iy - 90;
  for (iz = 0; iz < nz; iz++)
    dataZ[iz] = 100. * P(LIN(0.0, z0, nz - 1.0, z1, iz));

```

```
  /* Write coordinates... */
  NC(nc_put_var_double(ncid, timid, &t0));
  NC(nc_put_var_double(ncid, levid, dataZ));
  NC(nc_put_var_double(ncid, lonid, dataLon));
  NC(nc_put_var_double(ncid, latid, dataLat));

  /* Create wind fields (Williamson et al., 1992)... */
  for (ix = 0; ix < nx; ix++)
    for (iy = 0; iy < ny; iy++)
      for (iz = 0; iz < nz; iz++) {
        idx = (iz * ny + iy) * nx + ix;
        dataU[idx] = (float) (LIN(0.0, u0, nz - 1.0, u1, iz)
                              * (cos(dataLat[iy] * M_PI / 180.0)
                                 * cos(alpha * M_PI / 180.0)
                                 + sin(dataLat[iy] * M_PI / 180.0)
                                 * cos(dataLon[ix] * M_PI / 180.0)
                                 * sin(alpha * M_PI / 180.0)));
        dataV[idx] = (float) (-LIN(0.0, u0, nz - 1.0, u1, iz)
                              * sin(dataLon[ix] * M_PI / 180.0)
                              * sin(alpha * M_PI / 180.0));
      }

  /* Write wind data... */
  NC(nc_put_var_float(ncid, tid, dataT));
  NC(nc_put_var_float(ncid, uid, dataU));
  NC(nc_put_var_float(ncid, vid, dataV));
  NC(nc_put_var_float(ncid, wid, dataW));

  /* Close file... */
  NC(nc_close(ncid));

  /* Free... */
  free(dataT);
  free(dataU);
  free(dataV);
  free(dataW);

  return EXIT_SUCCESS;
}

/*****************************************************************************/

void add_text_attribute(
  int ncid,
  char *varname,
  char *attrname,
  char *text) {

  int varid;

  NC(nc_inq_varid(ncid, varname, &varid));
  NC(nc_put_att_text(ncid, varid, attrname, strlen(text), text));
}
```

# Index