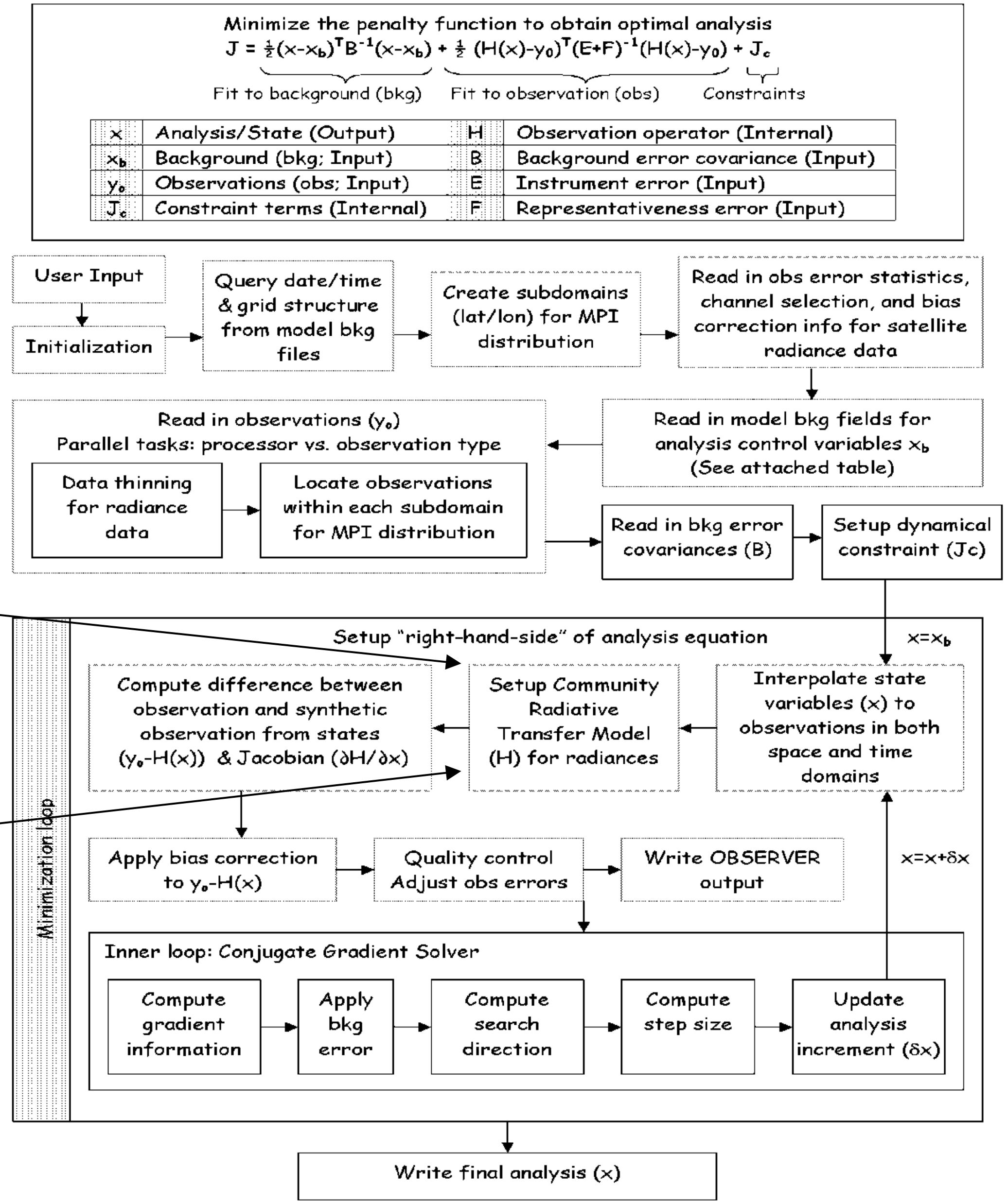
Data Assimilation of MLS/Aura radiance data

Summary for the new modules and modifications in the GSI-GMAO software

1. *MLS_CFM and MLS_CFM_RET –stand-alone source directories and libraries for simulation of MLS/Aura radiances and computation radiance innovations for 3DVar GEOS5-GMAO-GSI system*
2. *List of new and modified modules in "…./Gridcomp_GSI" for assimilation of MLS radiances*
3. *Notes for MLS data quality control and potential correction of biases*
4. *Remarks for specification of instrument and CFM errors.*
5. *Comparative look at CRTM and CFM implementations in GSI-GMAO*
6. *External software, libraries etc… for MLS_CFM*

General GSI-GMAO flow-chart for variational data analysis



CRTM => Community Radiance Transfer Model

Y=H(x), simulations of radiances measured by nadir sensors

CFM-MLS => Callable Forward model provide lim radiances measured by MLS

New directories and library: ../src/LIMB_SHARED/:
MLS_CFM , MLS_CFM_RET, libmls_cfm.a

- Similar to the CRTM library located at ../src/NCEP_SHARED/CRTM

- New **directory** MLS_CFM (Callable Forward Model, source code, lib, documentation) can be placed under ../src/LIMB_SHARED

- Additional **directory** MLS_CFM_RET =>under ../src/LIMB_SHARED will represent

  the standalone MLS retrievals of T, H2O and O3
  archiving radiance innovation for GEOS-5 background

New and modified modules in Gridcomp_Gsi:

(I) IOD, (II) Outer Loop, (III) Inner Loop

(I) IOD – Input (init), Output, Diagnostics:

- read_mls.f90 => read MLS-L1B radiance data and errors for "selected" channels used in MLS retrievals of T, H_2O, O_3.
- read_mlsret.f90 => read MLS-L2 retrievals of T, H_2O, O_3 (V3.1 data with finest vertical spacing 55-ozone levels vs 37 levels of V2.2)
- satinfo.f90 adding MLS_RAD (sis data-types)
- statsrad_mls.f90 (analog of statsrad.f90)

(II) Init CFM_MLS and Outer loop

- **setuprad_mls.f90**

and appropriate calls in **setuprhsall.f90**

- "functions, subroutines, use cfm" ⬄

"use crtm_module"

cfm_init_mls, cfm_destroy_mls,…. see also "Aura/MLS CFM Interface Requirements Document" of MLS-JPL.

(III) Inner loop

- **intrad_mls.f90**
- new

  call intrad_mls(…) in **intall.f90**

rad_ob_type & radlimb_ob_type

- **type rad_ob_type**

```
type(rad_ob_type),pointer :: llpoint => NULL()
type(odiags), dimension(:), pointer :: diags => NULL()
real(r_kind),dimension(:),pointer :: res => NULL()


real(r_kind),dimension(:),pointer :: err2 => NULL()
                        !  error variances squared (nchan)

real(r_kind),dimension(:),pointer :: raterr2 => NULL()
                        !  ratio of error variances squared (nchan)

real(r_kind)    :: time         !  observation time in sec
real(r_kind)    :: wij(4)       !  horizontal interpolation weights

real(r_kind),dimension(:),pointer :: pred1 => NULL()
                        !  predictors (not channel dependent)(npred-2)
real(r_kind),dimension(:),pointer :: pred2 => NULL()
                        !  predictors (channel dependent) (nchan)



real(r_kind),dimension(:,:),pointer :: dtb_dvar => NULL
integer(i_kind),dimension(:),pointer :: icx  => NULL()

integer(i_kind) :: nchan        !  number of channels for this profile
integer(i_kind) :: ij(4)        !  horizontal locations



logical        :: luse         !  flag indicating if ob is used in pen.
```

- **end type rad_ob_type**

- **type radlimb_ob_type**

```
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
! new type => limb (horiz/time,  nchan, nsens, nlev)
!  MLS   => Minor frames,
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    sequence
    type(rad_ob_type),pointer :: llpoint => NULL()
    type(odiags), dimension(:), pointer :: diags => NULL()
    real(r_kind),dimension(:),pointer :: res => NULL()

    real(r_kind),dimension(:),pointer :: err2 => NULL()
                            !  error variances squared (nchan)

    real(r_kind),dimension(:),pointer :: raterr2 => NULL()
                            !  ratio of error variances squared (nchan)

    real(r_kind)    :: time         !  observation time in sec
    real(r_kind)    :: wij(8)       !  Horizontal and layer  interpolation weights
```

Uncertain bias-corrections for MLS

```
    real(r_kind),dimension(:),pointer :: pred1 => NULL()
                            !  predictors (not channel dependent)(npred-2)
    real(r_kind),dimension(:),pointer :: pred2 => NULL()
                            !  predictors (channel dependent) (nchan)


    real(r_kind),dimension(:,:),pointer :: dtb_dvar => NULL()
    integer(i_kind),dimension(:),pointer :: icx  => NULL()

    integer(i_kind) :: nchan        !  number of channels for this profile
    integer(i_kind) :: ij(4)        !  horizontal locations
    logical        :: luse         !  flag indicating if ob is used in pen.
```

- **end type radlimb_ob_type**

Summary of GSI -modifications

./LIMB_SHARED/CFM_MLS

libcfm_mls.a

read_mls.f90

read_mlsret.f90

Minimization modules

Outer-loop:

setuprhsall.f90

setuprad_mls.f90

Inner loop:

intall.f90

intrad_mls.f90

Obs_diags / stats / info ………

MLS radiance data quality control, potential correction of systematic errors

- DQC:

  use QC for MLS-L1B radiances similar to MLS L2-retrieval, check for cloudy scenes

- Tuning radiance errors (measurements from L1B and FM errors from L2-MLS software)

- Biases: (a) check MLS-product validation papers; (b) analyze innovation profiles.

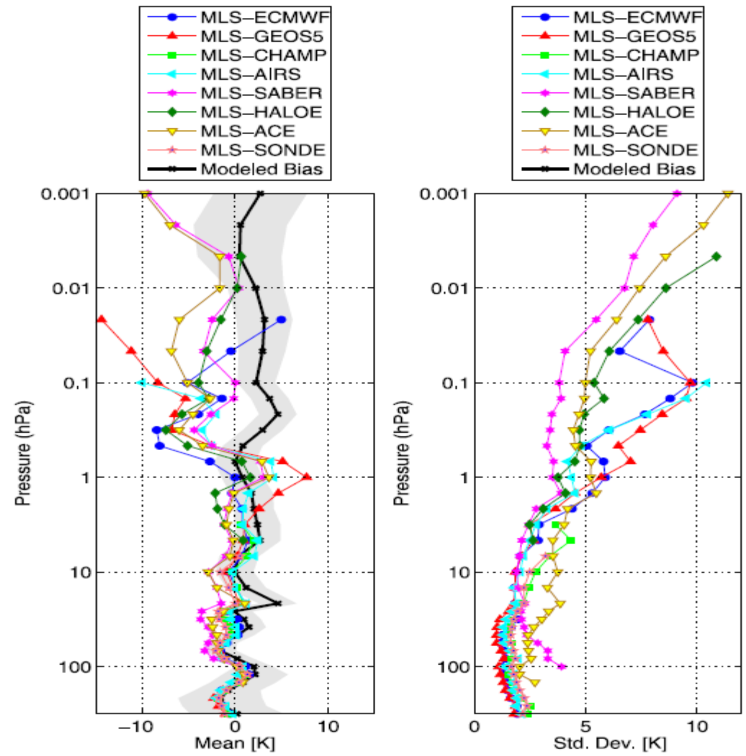


Figure 26. Summary of temperature biases and scatter between MLS and eight correlative data sets. (left) Mean differences and (right) scatter about these differences. Modeled systematic uncertainties (discussed in section 2.6) are also shown, with gain compression in black and the 2-σ contribution of the other terms, which are biases of unknown sign, summarized by the gray envelope. Mean differences from 3.16 hPa to 0.1 hPa are correlated among the comparisons and likely indicate a bias in MLS measurements.

Comparative look at CRTM and CFM implementations in GSI-GMAO

- **use crtm_module**, only:
  crtm_atmosphere_type
  crtm_surface_type
  crtm_geometryinfo_type
  crtm_options_type

  crtm_init
  crtm_destroy
  crtm_k_matrix
  crtm_allocate_atmosphere
  crtm_allocate_options

- **use CFM_MLS_module** (in progress)
- Primary types (e.g. templates, quantities, matrices) => in context of CRTM in GSI with nadir radiances.
- Types: HGrid_T, VGrid_T, QuantityTemplate_T
- Vectors: Template and Value
- Matrices: Element, Rc_info, Matrix_T
- **Subs & Functions**:

  AddQtemp2Database, CFM_MLSInit, CFM_MLSCleanup, CreateQtemp, CreateVector, InitMLSFile, MLS_closefile

use crtm_rtsolution_define, only: crtm_rtsolution_type, crtm_allocate_rtsolution, &
crtm_destroy_rtsolution
use crtm_spccoeff, only: sc
use crtm_atmosphere_define, only:h2o_id,crtm_assign_atmosphere, &
crtm_destroy_atmosphere,volume_mixing_ratio_units,crtm_zero_atmosphere
use crtm_surface_define, only: crtm_assign_surface,crtm_destroy_surface, &
crtm_zero_surface
use crtm_channelinfo_define, only: crtm_channelinfo_type
use crtm_parameters, only: limit_exp,toa_pressure,max_n_layers

```
MODULE CRTM_Module
  USE CRTM_Atmosphere_Define
  USE CRTM_Surface_Define
  USE CRTM_GeometryInfo_Define
  USE CRTM_ChannelInfo_Define
  USE CRTM_RTSolution_Define
  USE CRTM_Options_Define

  USE CRTM_Forward_Module
  USE CRTM_Tangent_Linear_Module
  USE CRTM_Adjoint_Module
  USE CRTM_K_Matrix_Module
```

External software, libraries etc… for MLS_CFM

.configure for MLS-CFM

- TK=/software/toolkit/NAG
  MLSF95=NAG
  MLSPLAT=Linux
  MLSCONFG=NAG.Linux
  PGSINC=${TK}/toolkit/include
  PGSTK=${TK}/toolkit/lib/linux
  HDFEOS=${TK}/hdfeos/lib/linux
  HDFEOS5=${TK}/hdfeos5/lib/linux
  HDF=${TK}/hdf/lib
  HDF5=${TK}/hdf5/lib
  GCTP=${TK}/hdfeos/lib/linux
  PGSLIB=${TK}/toolkit/lib/linux
  HDFEOS_LIB=${TK}/hdfeos/lib/linux
  HDFLIB=${TK}/hdf/lib
  BLAS=
  LIB_BLAS=
  LAPACK=
  LIB_LAPACK=f95
  PVM_ROOT=${TK}/pvm3
  PVM_ARCH=LINUX
  FFTW_ROOT=${TK}/fftw/lib
  FOPTS=-O2 -C=none
  LDOPTS=-Bstatic

- export MLSF95
  export MLSPLAT
  export MLSCONFG
  export PGSINC
  export PGSTK
  export HDFEOS
  export HDFEOS5
  export HDF
  export HDF5
  export GCTP
  export PGSLIB
  export HDFEOS_LIB
  export HDFLIB
  export BLAS
  export LIB_BLAS
  export LAPACK
  export LIB_LAPACK
  export PVM_ROOT
  export PVM_ARCH
  export FFTW_ROOT
  export FOPTS
  export LDOPTS

Practical steps for CFM-implementation in GSI-GMAO

- read_mls.f90, stand-alone read-in of MLS L1B radiance data and appropriate introduction/modification (types, arrays, info, file-storage, etc…), MLS-schedule in CFM-development (Feb-Mar). Discussion of instrument errors, FM errors and QC-radiance data (Mar-Apr).

- use CFM_MLS, set of parameters, types, functions, calls for interfacing in the GSI-GMAO above listed modules (Mar-May)

- Creating library: libmls_cfm.a on NCCS/discover (May-Jun)

- Coding and computing innovation of radiances:

  Y[mls_cfm]-Y[mls_rad] (May-Sep)

Extending obs-classes for resolution-dependent (data error-subspace) analysis

- Characterized retrievals: a priori and resolution kernels (RK, vertical at least);
- RK-vector (for columns) and RK-matrix for profiles;
- 3DVar => OmTF (innovation) with kernels: setup…oz.f90 (OMI, MLS)
- Vertical sensitivity of columns: OMI-TOMS (layer-efficiency, 11 layers)
- IR-CO and IR-O3, matrices of AK (MOPITT, AIRS, IASI)
- LIMB-O3 (MLS, HIRDLS), broadening of K-jacobians, UTLS and basis functions (triangular for MLS RTM-grids, typical O3 kernels)

MLS Kernels

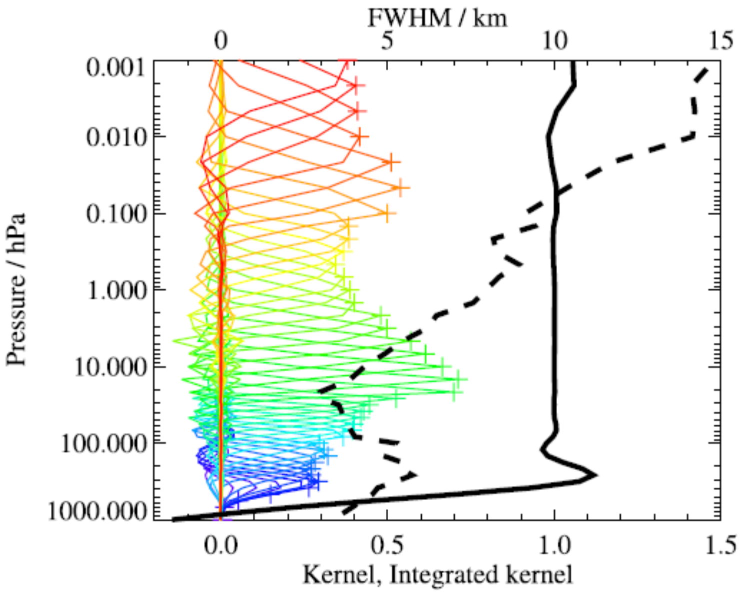
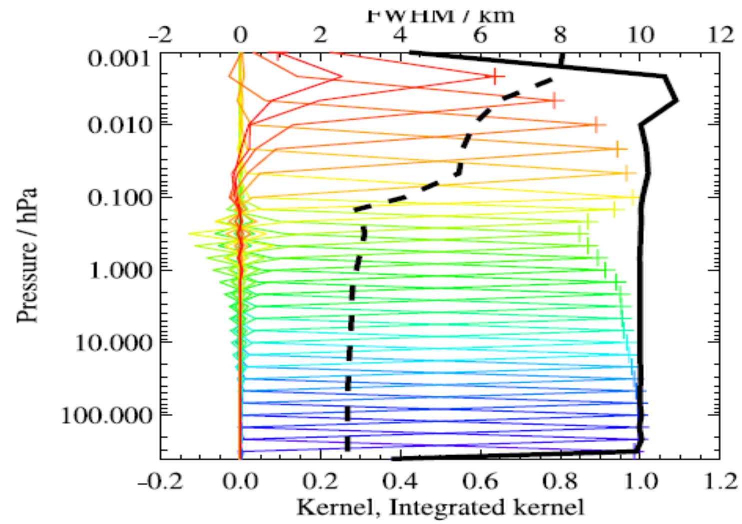


Figure 6. MLS v2.2 temperature vertical averaging kernels resulting from horizontal, along-track integration of 2-D averaging kernels for 35°N, September climatology. Individual colored lines show the contribution of atmospheric temperatures at each level to a given MLS retrieved temperature, with the retrieval level marked by a plus sign of the same color. The full width at half maximum (vertical resolution, in kilometers) is shown by the thick black dashed line. The solid black line shows the integrated area under the kernels as a function of MLS retrieval level. Where the integrated area is close to unity, the majority of the information comes from the atmosphere. Lower values are associated with increased contributions from a priori information.



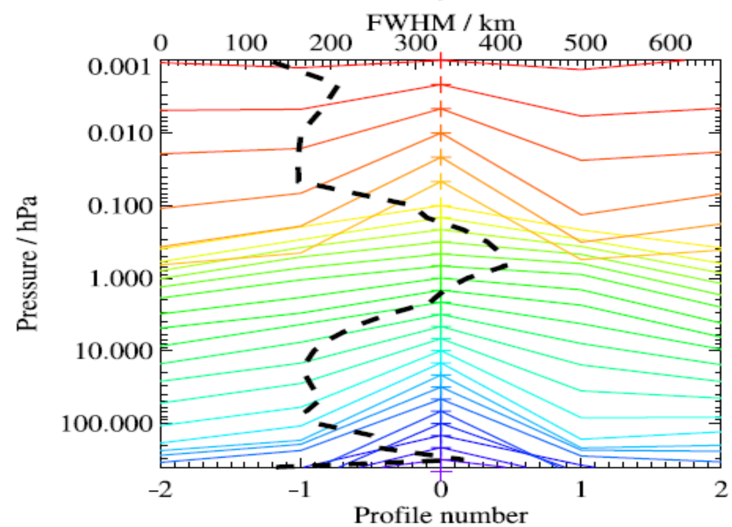
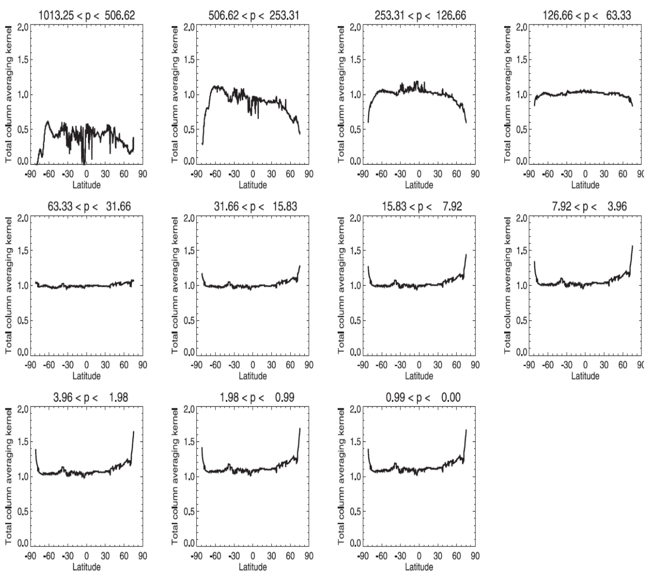


Figure 3. (top) Colored lines show typical v2.2 MLS ozone vertical averaging kernels (here for 35°N) as a function of the retrieval level, indicating the region from

Multi-sensor ozone kernels



OMI-TOMS column kernels at 11-layers, Miglirioni et al.

Type II and III: Characterization of O_3 profiles by Resolution (or Averaging) Kernels: Rows and Images (*Sharpness, Values and Properties*)