Status of LBLRTM and MonoRTM

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IRF

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  Hank Revercomb, Dave Turner, Bob Knuteson and Dave Tobin

- **JPL**

  TES Algorithm Development Team

- **ANL**

  Maria Cadeddu

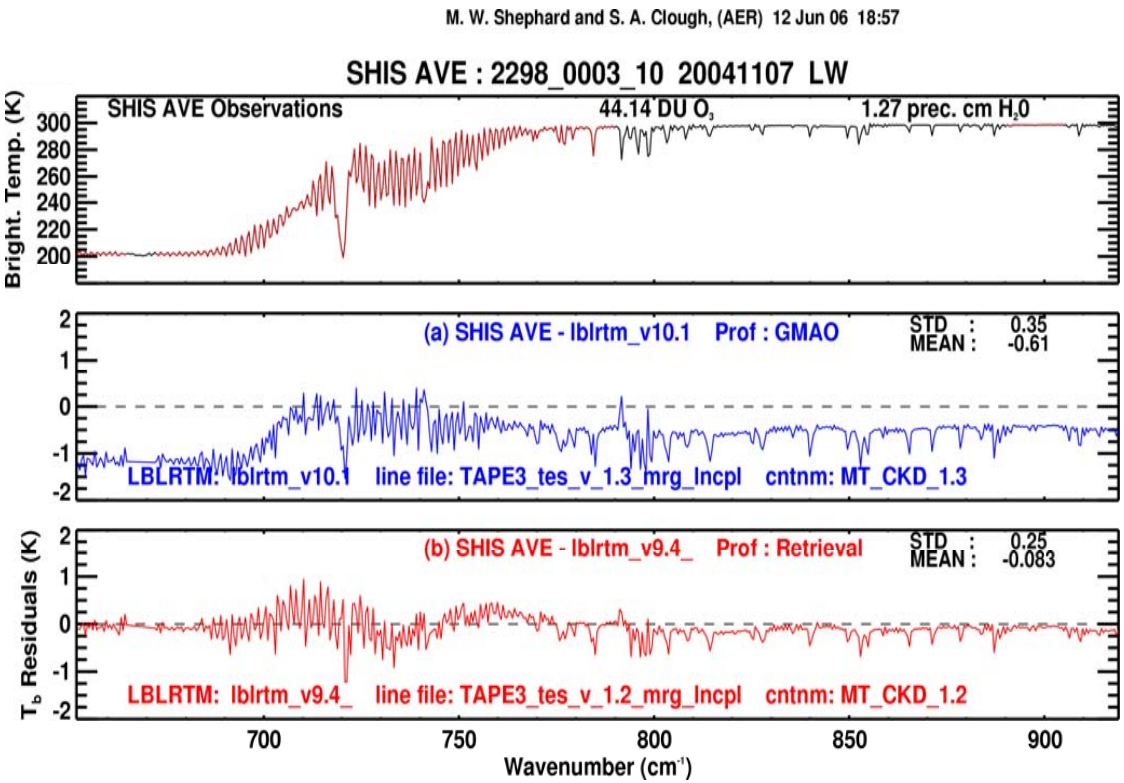
Major Improvements

- LBLRTM
  - Carbon Dioxide P-R Line Coupling (500 - 800 cm^{-1})
    - Line Parameters (Niro et al. 2005)
  - Analytic Derivatives
  - Profile Scaling
  - Instructions

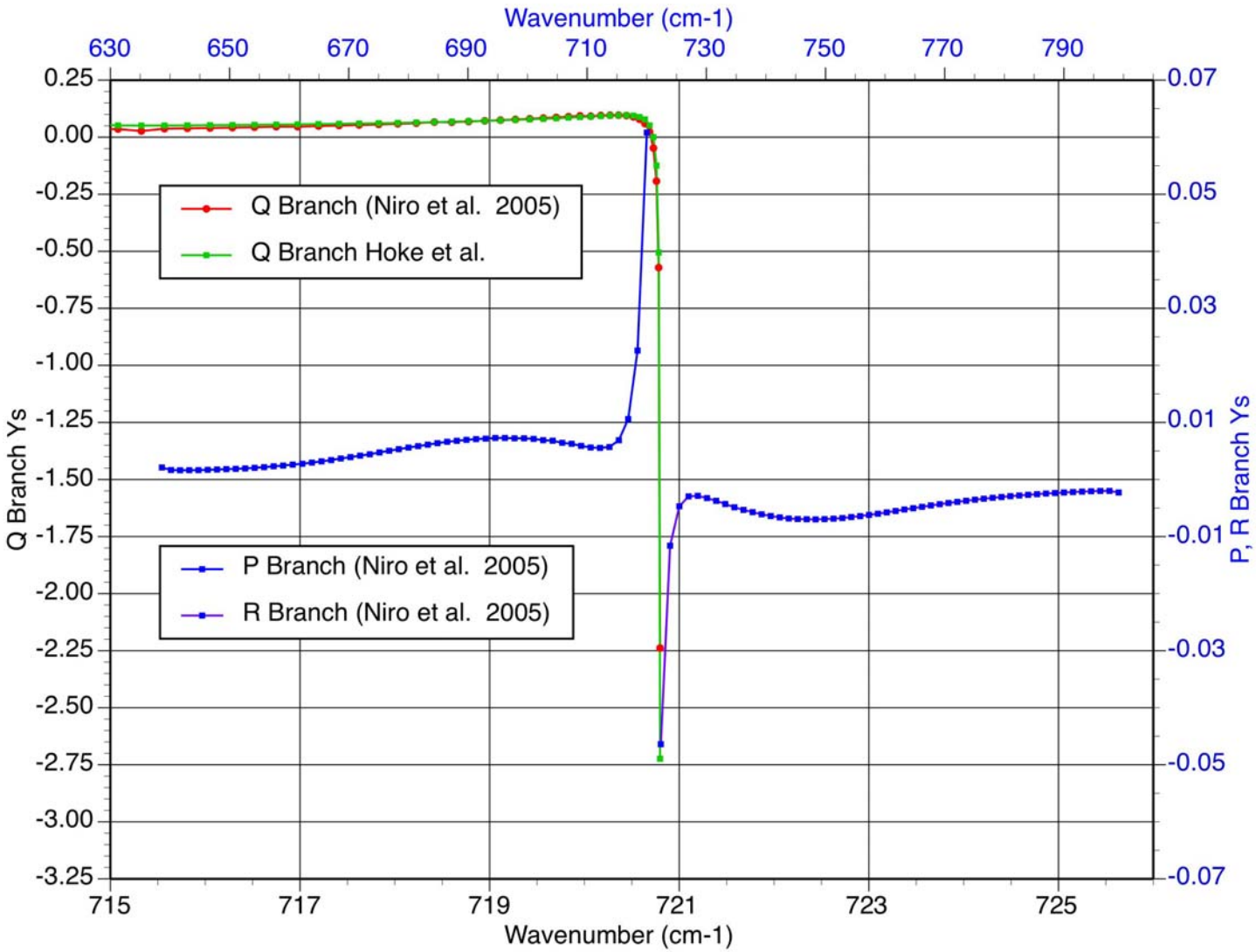
- MonoRTM
  - Spectroscopic Line Parameters
    - Oxygen: Tretyakov et al.
    - Not using HITRAN2004 (yet)
  - Fast Option: more lines included
  - 183 GHz Spectroscopy for polar atmospheres
  - Profile Scaling

- Water Vapor Continuum
  - Stable (?)
  - Issue in 10μ window (value of PWV from MWR for mt_ckd)
  - Issues with water vapor continuum have become remarkably muted

SHIS Analysis from AURA Validation Experiment
Gulf of Mexico - no sonde

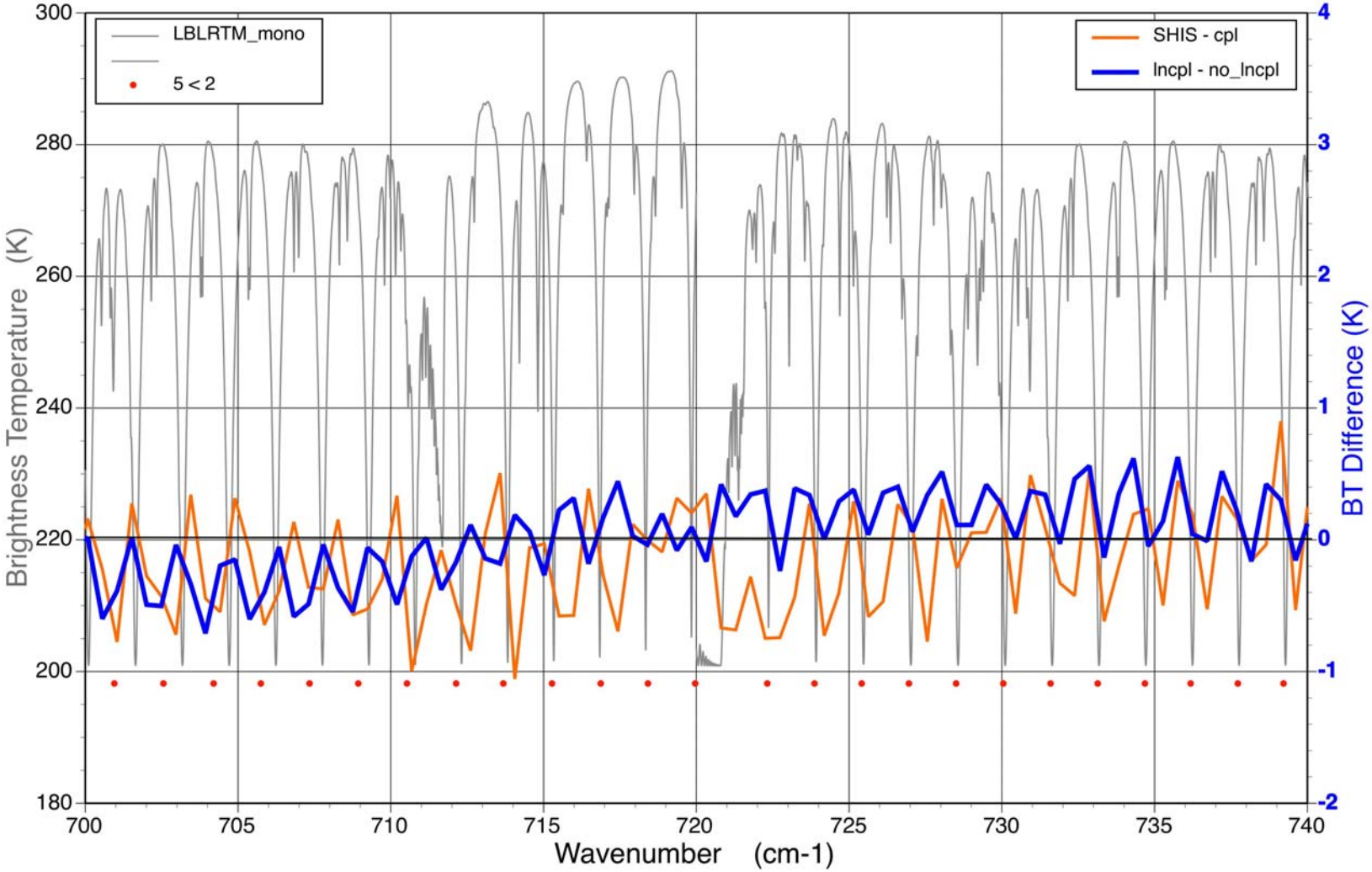


Line Coupling Parameters for the 5 < 2 Band

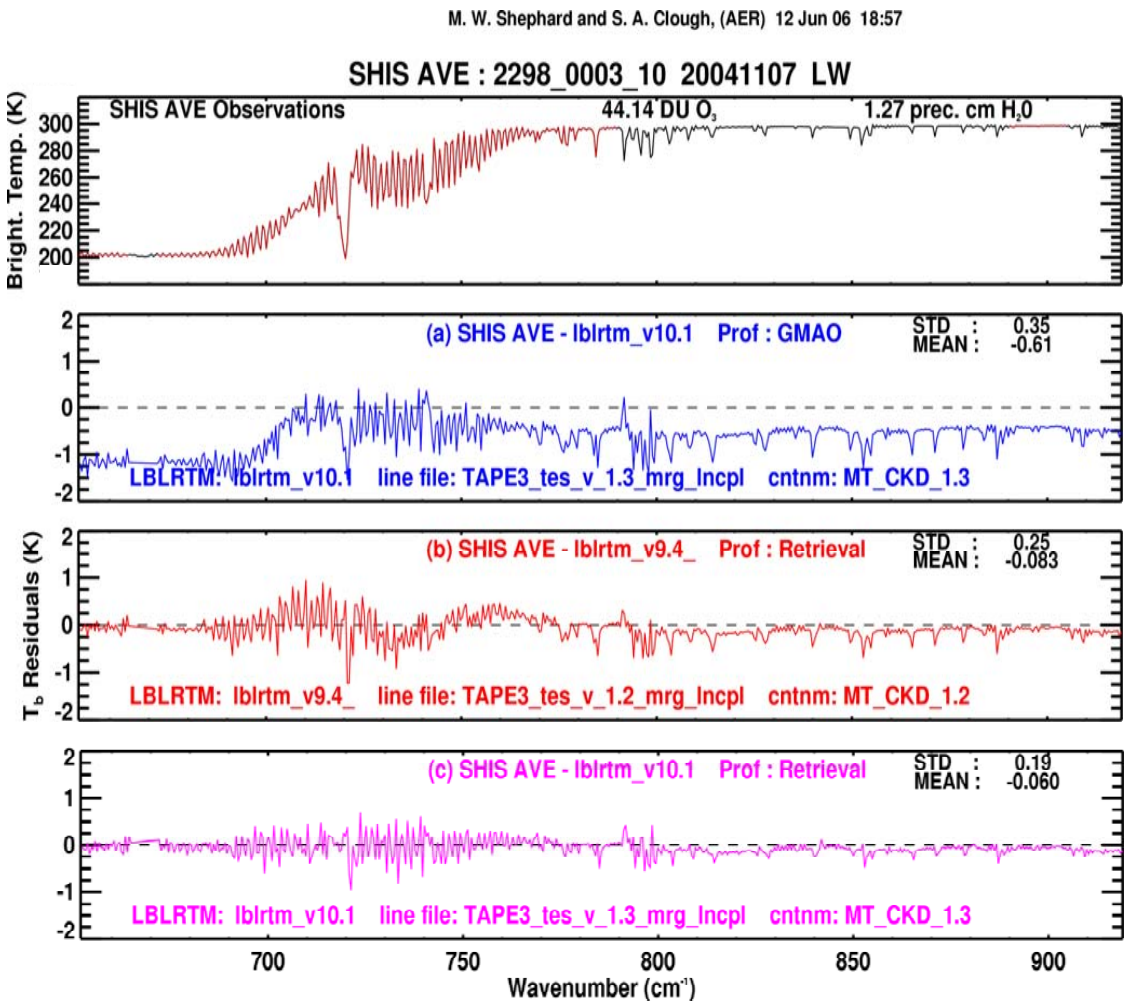


Effect of P-R Line Coupling on S-HIS Residuals

(Coupling Parameters: Niro et al. 2005; Hartmann's Group)



SHIS Analysis from AURA Validation Experiment
Gulf of Mexico - no sonde

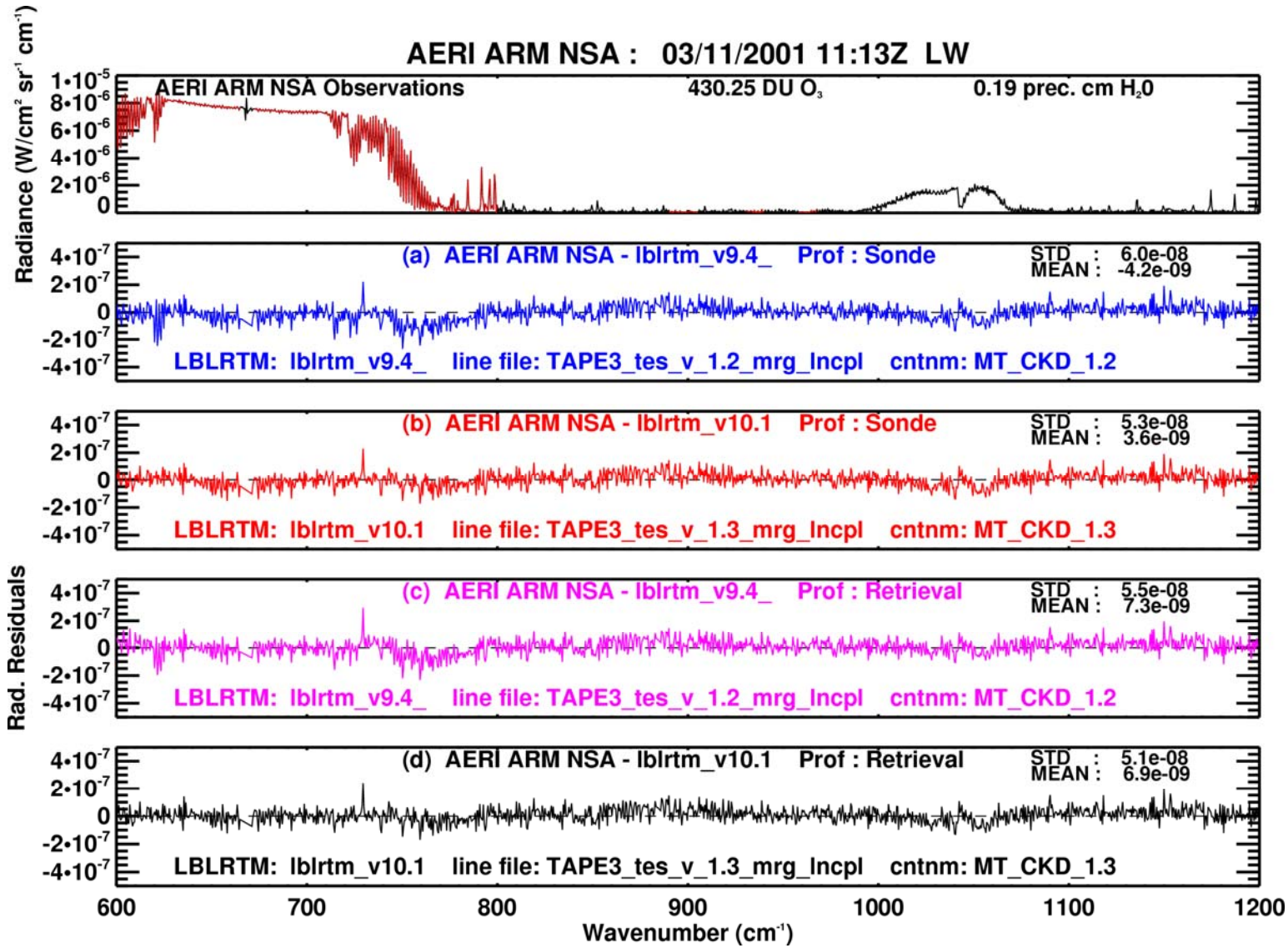


Impact on Temperature Profile
Reference: Radiosonde

Retrieved v9.4

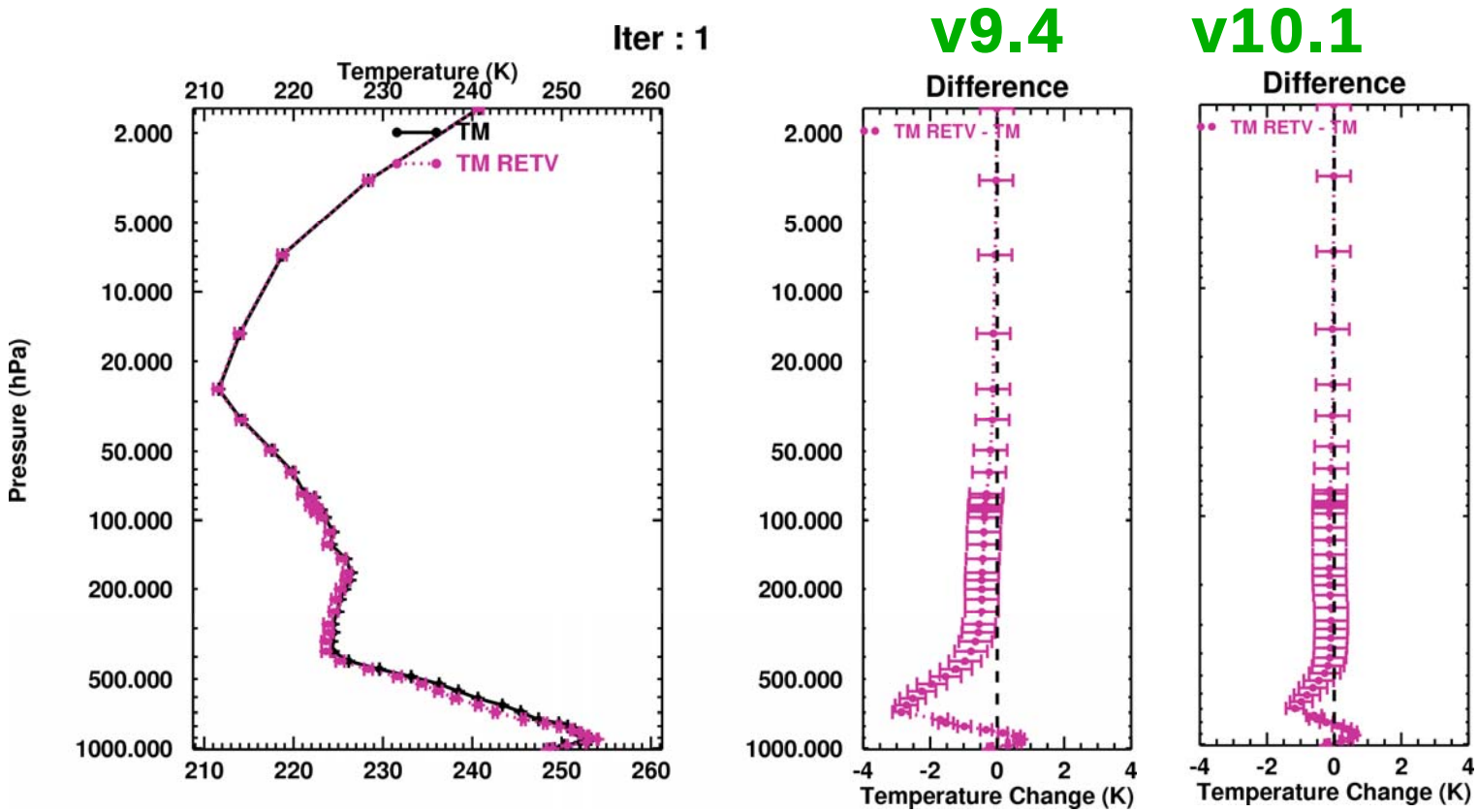
Retrieved v10.1

Pressure (hPa)


AERI ARM NSA : 03/11/2001 11:13Z LW
AERI ARM NSA Observations
430.25 DU O3
0.19 prec. cm H20
Radiance (W/cm2 sr-1 cm-1)
(a) AERI ARM NSA - lblrtm_v9.4_ Prof : Sonde
STD : 6.0e-08
MEAN : -4.2e-09
LBLRTM: lblrtm_v9.4_ line file: TAPE3_tes_v_1.2_mrg_lncpl cntnm: MT_CKD_1.2
(b) AERI ARM NSA - lblrtm_v10.1 Prof : Sonde
STD : 5.3e-08
MEAN : 3.6e-09
LBLRTM: lblrtm_v10.1 line file: TAPE3_tes_v_1.3_mrg_lncpl cntnm: MT_CKD_1.3
Rad. Residuals
(c) AERI ARM NSA - lblrtm_v9.4_ Prof : Retrieval
STD : 5.5e-08
MEAN : 7.3e-09
LBLRTM: lblrtm_v9.4_ line file: TAPE3_tes_v_1.2_mrg_lncpl cntnm: MT_CKD_1.2
(d) AERI ARM NSA - lblrtm_v10.1 Prof : Retrieval
STD : 5.1e-08
MEAN : 6.9e-09
LBLRTM: lblrtm_v10.1 line file: TAPE3_tes_v_1.3_mrg_lncpl cntnm: MT_CKD_1.3
Wavenumber (cm-1)

Result after Performing a Retrieval

Reference: sonde

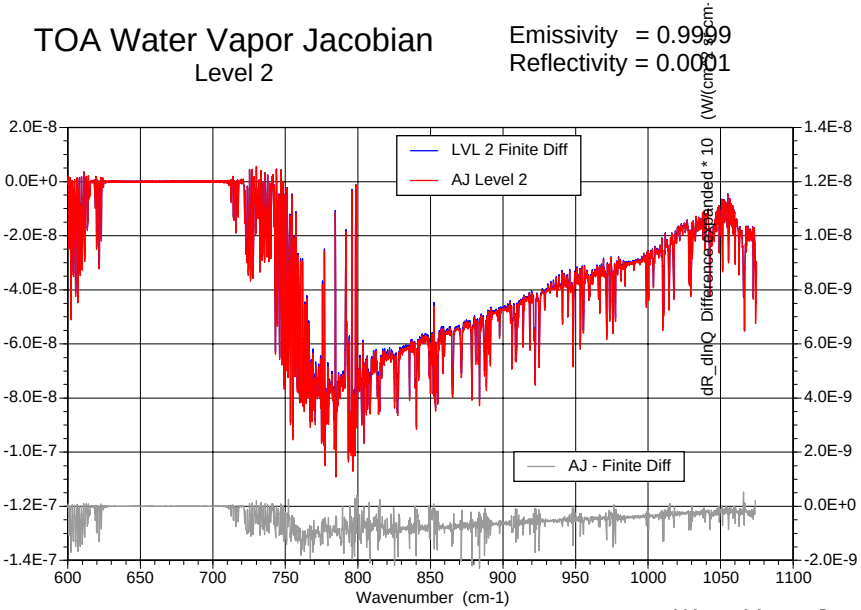


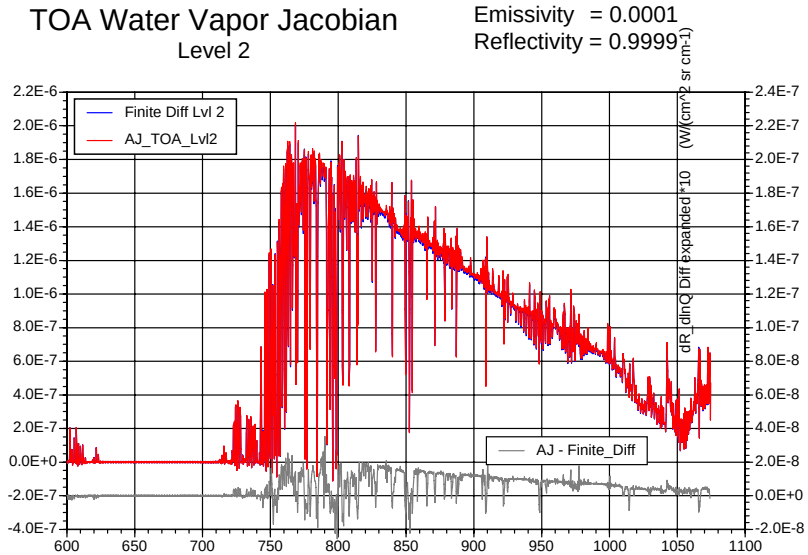
Analytic Derivative (Jacobian)

- Upwelling/Downwelling
- Layer derivative for each layer
- Level derivative at each level
  - linear combination of layer derivatives
- Temperature
  - forward finite difference for optical depth
- Species
  - single pass for each species
  - cross sections not implemented

Water Vapor Jacobians: Level 2

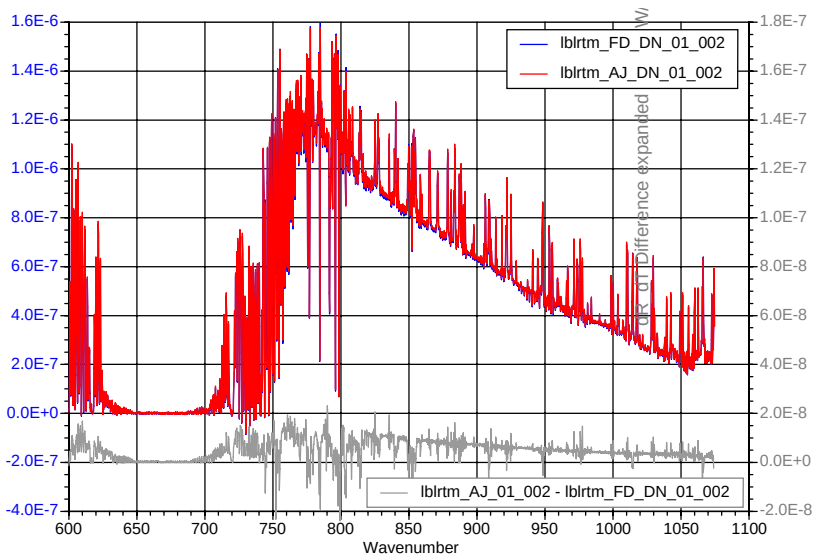
Upwelling at 20 km





Downwelling at the Surface

e.g. AERI



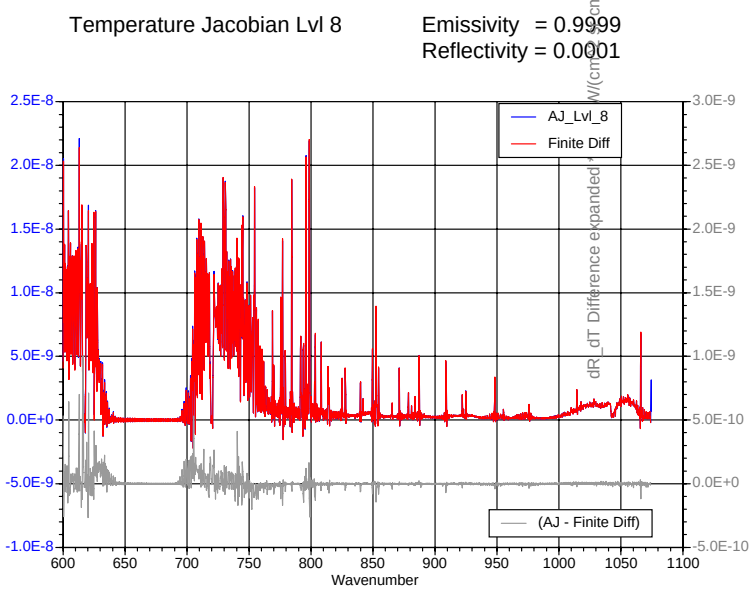
Atmosphere:
- CAMEX Case
- 27 Levels
- 0-20 km

Temperature Jacobians: Level 8

Upwelling at 20 km

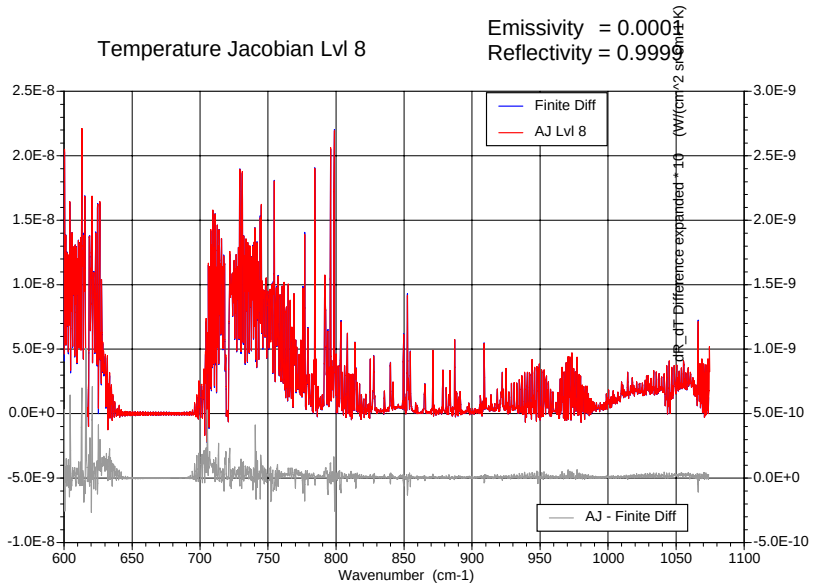
Temperature Jacobian Lvl 8

Emissivity = 0.9999
Reflectivity = 0.0001



Temperature Jacobian Lvl 8

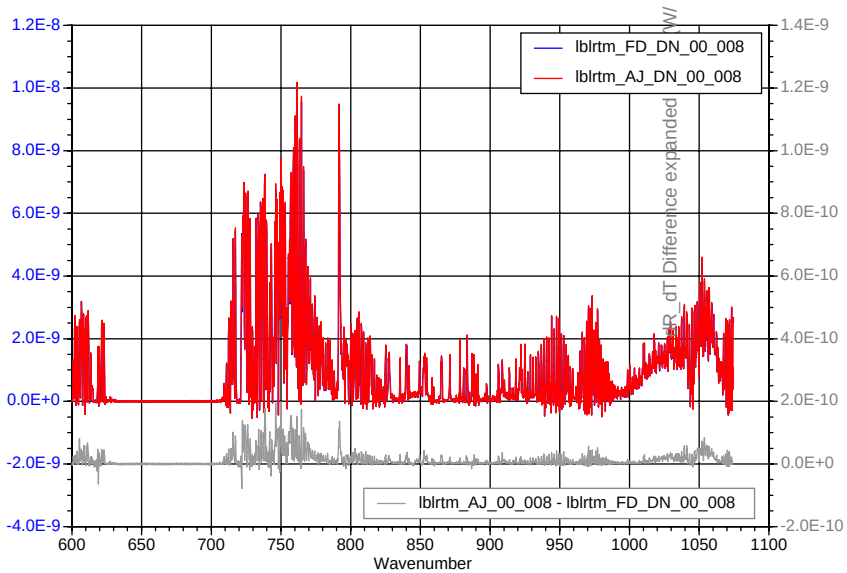
Emissivity = 0.0001
Reflectivity = 0.9999



Downwelling at the Surface

e.g. AERI

Temperature Jacobian Lvl 8



Atmosphere:
CAMEX Case
27 Levels
0-20 km

Line Parameters

issues

- **TES: tes_v_1.3 -> tes_v_1.4**
  - 600 - 3000 cm^{-1}
  - Carbon Dioxide: P-Q-R Line Coupling
    F. Niro, K. Jucks, J.-M. Hartmann, JQSRT, 2005
  - line coupling
  - hitran 2004

- **AER_v_1.0 -> AER_v_2.0**
  - 0 - 50000 cm-1
  - tes_v_2.0 will be a subset

- **LNFL**
  - LNFL_v2.1
  - 100/150 character format
  - new molecules
  - new vibrational states

Profile Scaling by Species

- Applications
  - scale sonde to PWV from MWR
  - scale h2o for column Jacobian (finite difference)
  - scale ozone to TOMS
- Scale profile
  - numerical scale factor
  - specified mixing ratio
- Scale profile to a specified column amount
  - molec/(cm^2 cm^{-1})
  - PWV
  - Dobson units

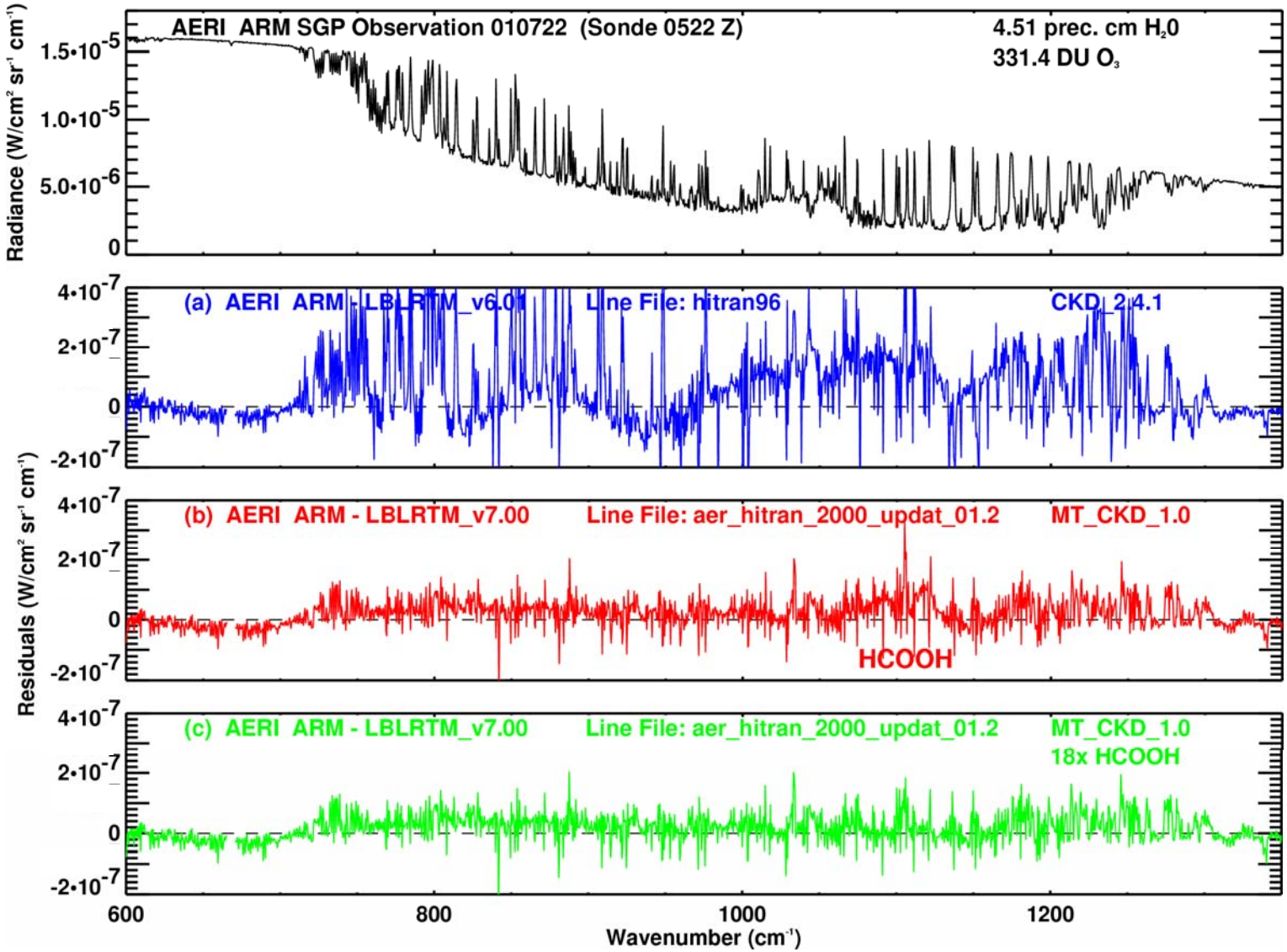
TAPE5

n_xs_scl

n_mol_scl

```
123456789_

$ t5ref 06/12/96 CAMEX NASA Flt #93-169 09/29/93 Wallops Island *ARM    ITER = 2
 HI=1 F4=1 CN=1 AE=0 EM=1 SC=3 FI=0 PL=0 TS=0 AM=1 MG=0 LA=0 OD=0 XS=1   00   00
  500.0000 1174.0000  0.00E+00 0.0000000  0.00E+00  0.00E+00  0.20E-03  0.10E-02REJ=0 DV=  0.000      3    3
 md
                   353.840e-06        287.
 1
                   2.     e+00
 293.30000-1.0000000 0.000E+00 0.000E+00-1.0000000 0.000E+00 0.000E+00    s
```

AERI Downwelling at the Surface ARM SGP Moist



Toth

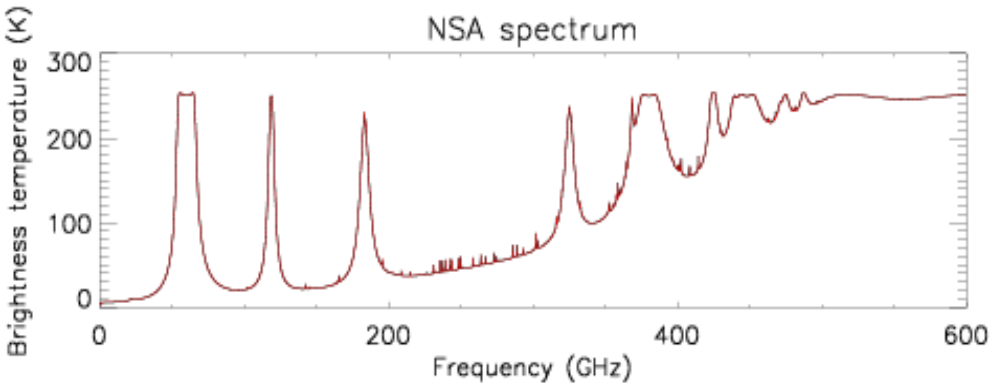
__1%

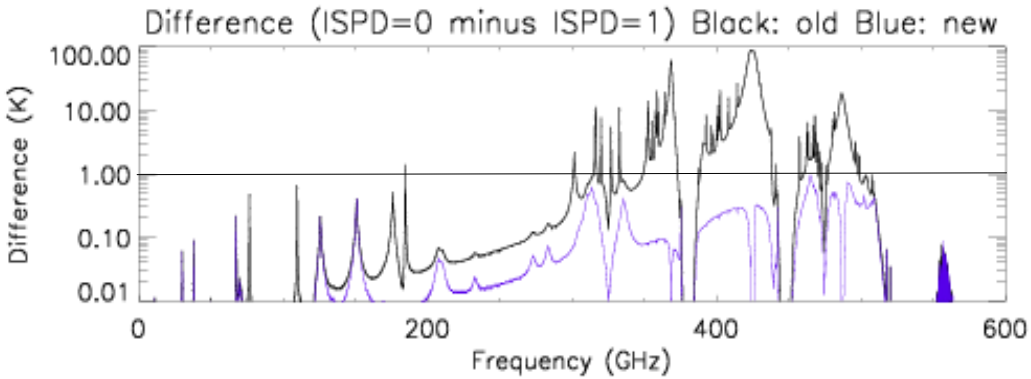
MonoRTM

- Spectroscopic Line Parameters
  - Oxygen: Tretyakov et al. 2005
  - Not using HITRAN2004 (yet)
  - 183 GHz Spectroscopy
- Fast Option: more lines included
- Profile Scaling

Speed Option Improvement

	Full Set	Reduced set (new)	Reduced set (old)	MPM98
H2O	517	53	40	15
O2	79	44	41	41
O3	421	86	32	0
N2O	28	11	4	0

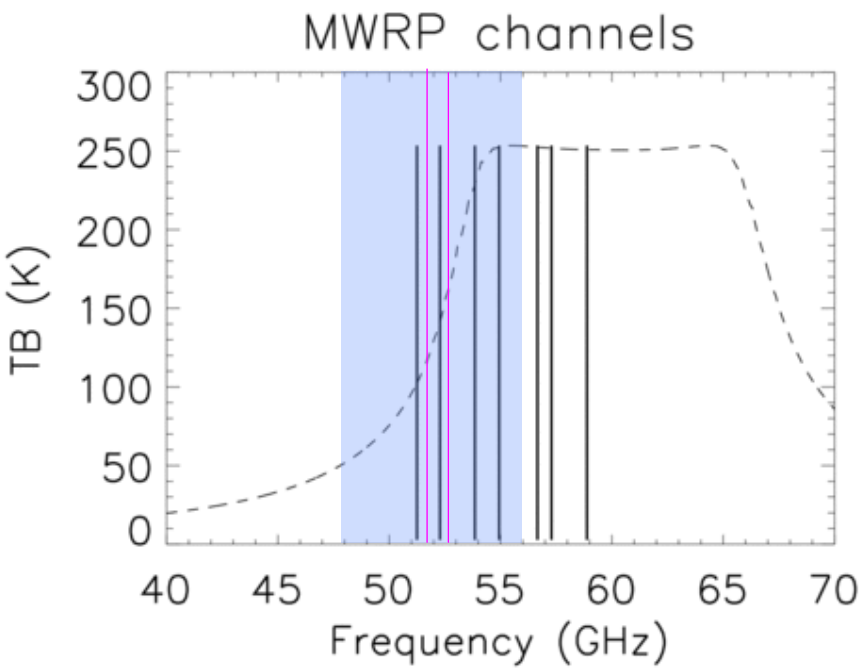




"Old" MonoRTM reduced line set was adequate for mid-latitude summer conditions up to 300 GHz.

Greater number of lines needed to maintain accuracy for low water vapor conditions and higher frequencies.

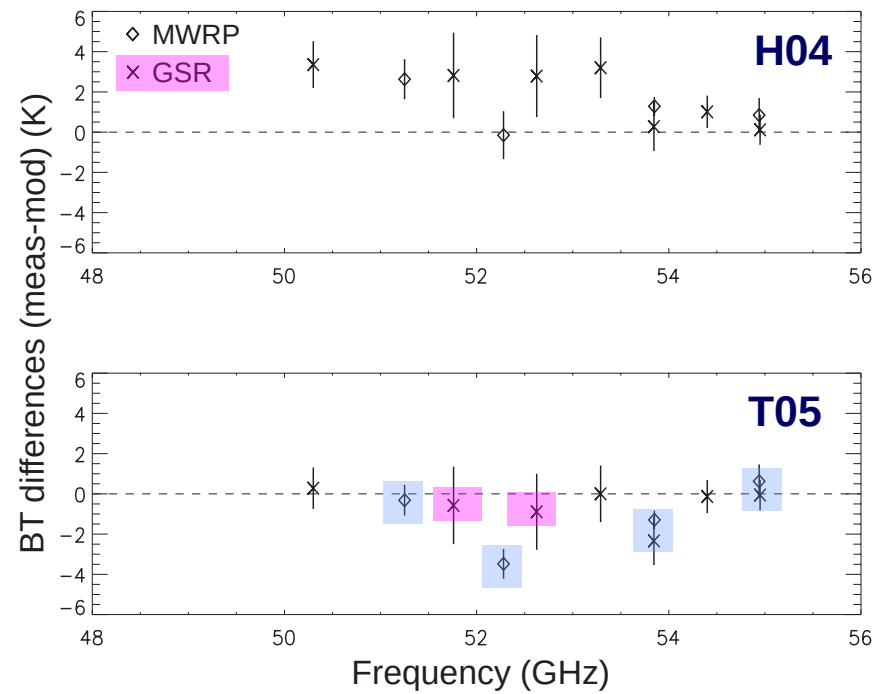
MonoRTM with H04 and T05 Oxygen Parameters
North Slope of Alaska Site



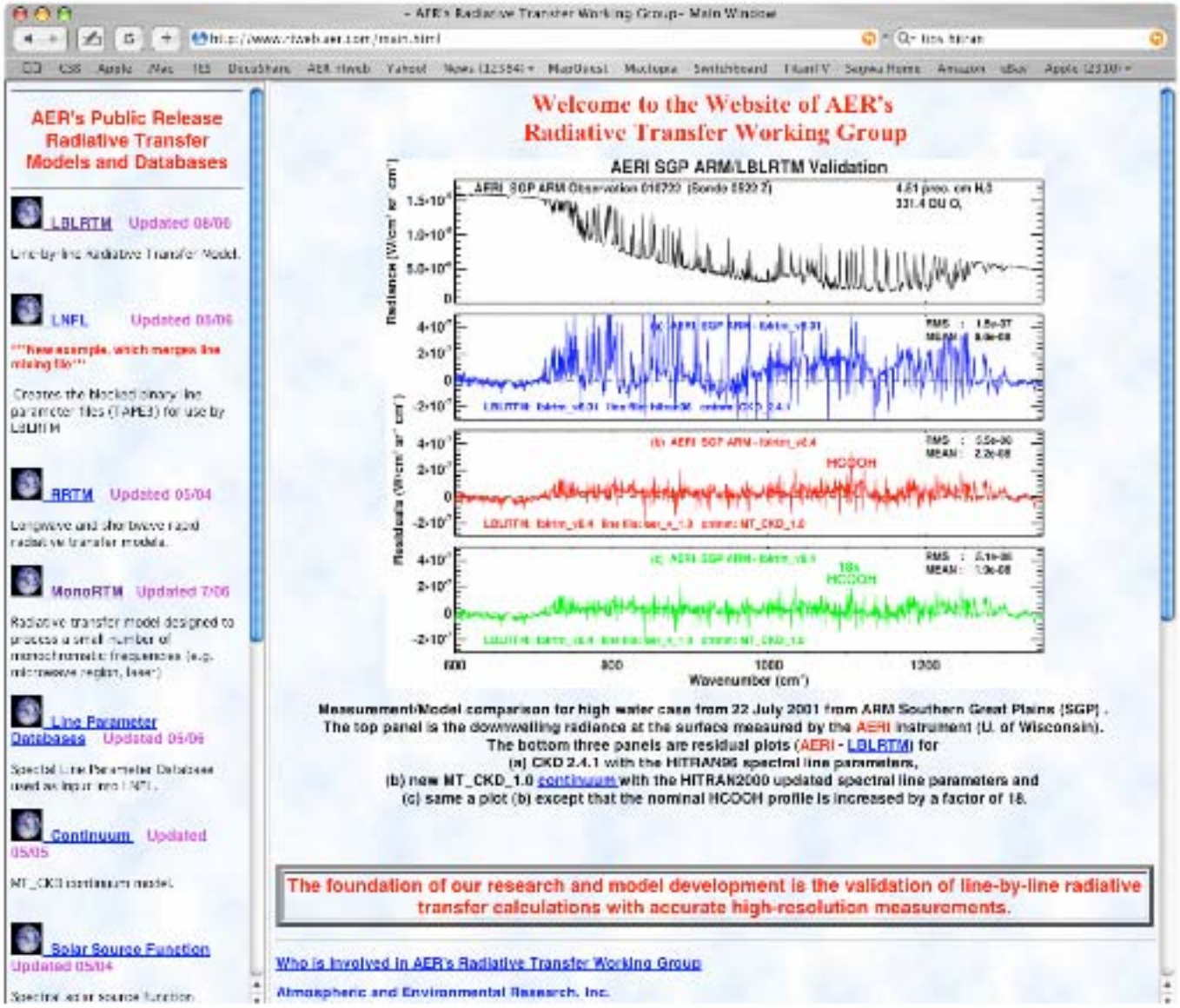
MWR - MonoRTM

H04: hitran2004 (Hoke et al.)

T05: Tretyakov et al.



rtweb.aer.com



Status Summary

- LBLRTM
  - P-R line coupling implemented 600 - 800 cm^{-1}
  - Stable at a high level of accuracy (esp. for most ARM objectives)
  - Issues with water vapor continuum have become remarkably muted
  - Water Vapor Self Continuum
    - MWR issue

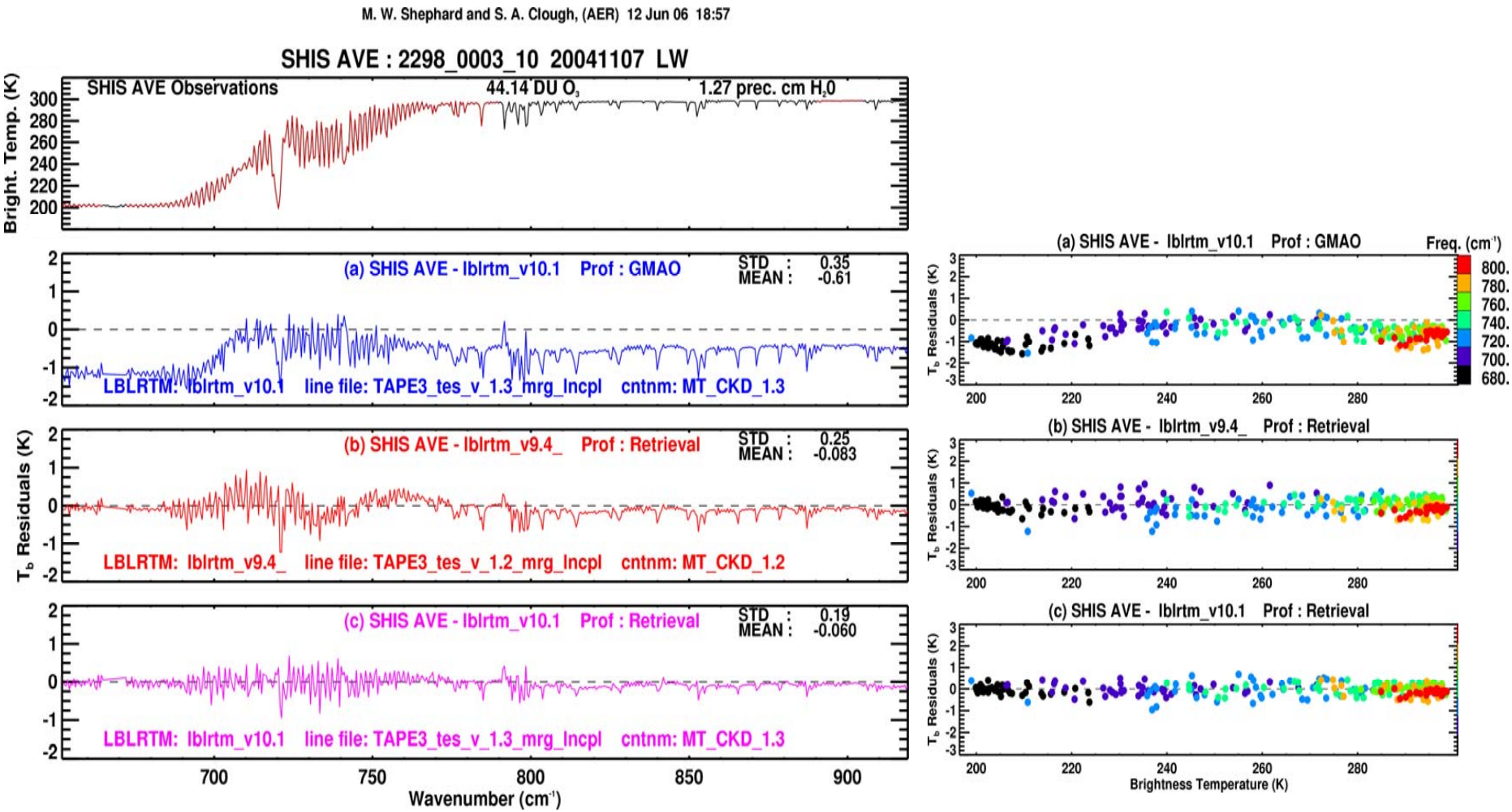
- Line Parameters
  - Stable at a high level of accuracy (esp. for most ARM objectives)

- MonoRTM
  - Improved oxygen spectroscopy
  - Stable at a high level of accuracy
  - Halfwidth of 183 GHz H_2O line to be modified
    - Based on GSR measurements at NSA
    - Important for PWV and CLW retrievals at NSA

- Excellent time to 'freeze' Models for
  RRTM, QMEs and PWV/CLW applications

Back-up slides to follow……

SHIS Analysis from AURA Validation Experiment
Gulf of Mexico - no sonde



Continuum: MT_CKD_1.3

- **Water Vapor**
  - Self / Foreign
  - Single Line Shape for each
- **Carbon Dioxide**
  - ν_2 Region Scaled based on this study
  - Continuing Research Focus
- **Nitrogen: Collision Induced**
  - 2330 cm-1 Region
  - Continuuing Research Focus
- **Oxygen: Collision Induced**
  - 1600 cm-1 Region Scaled

Monortm Spectroscopic Line Parameters

H04: hitran2004 (hoke et al.) **T05:Tretyakov et al.**

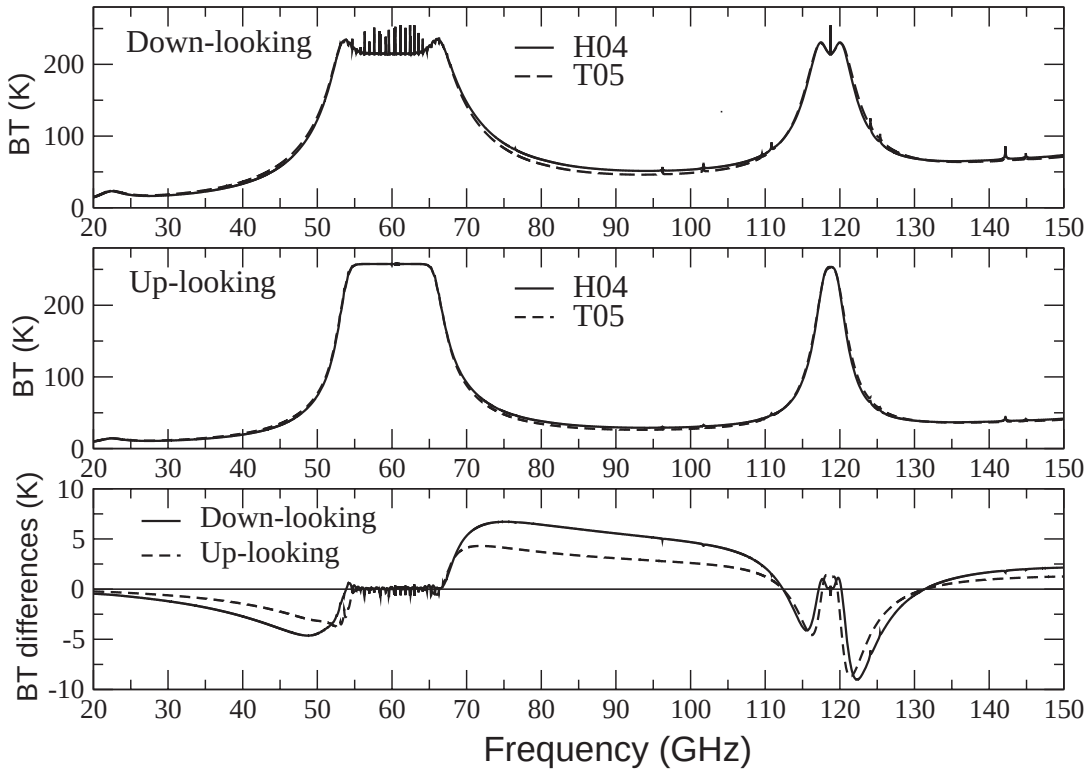
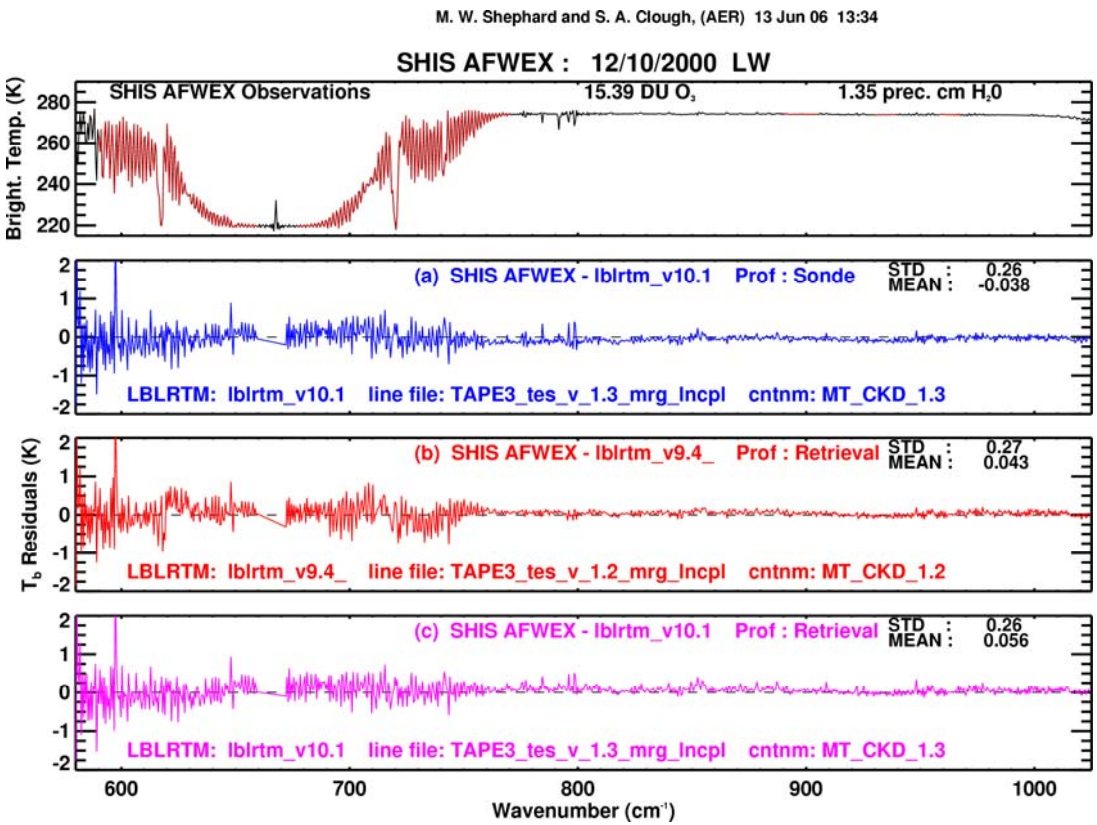
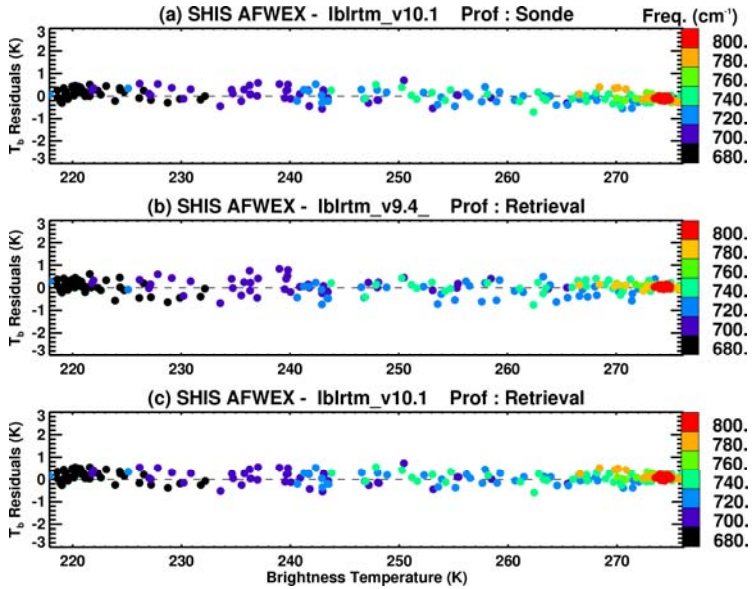


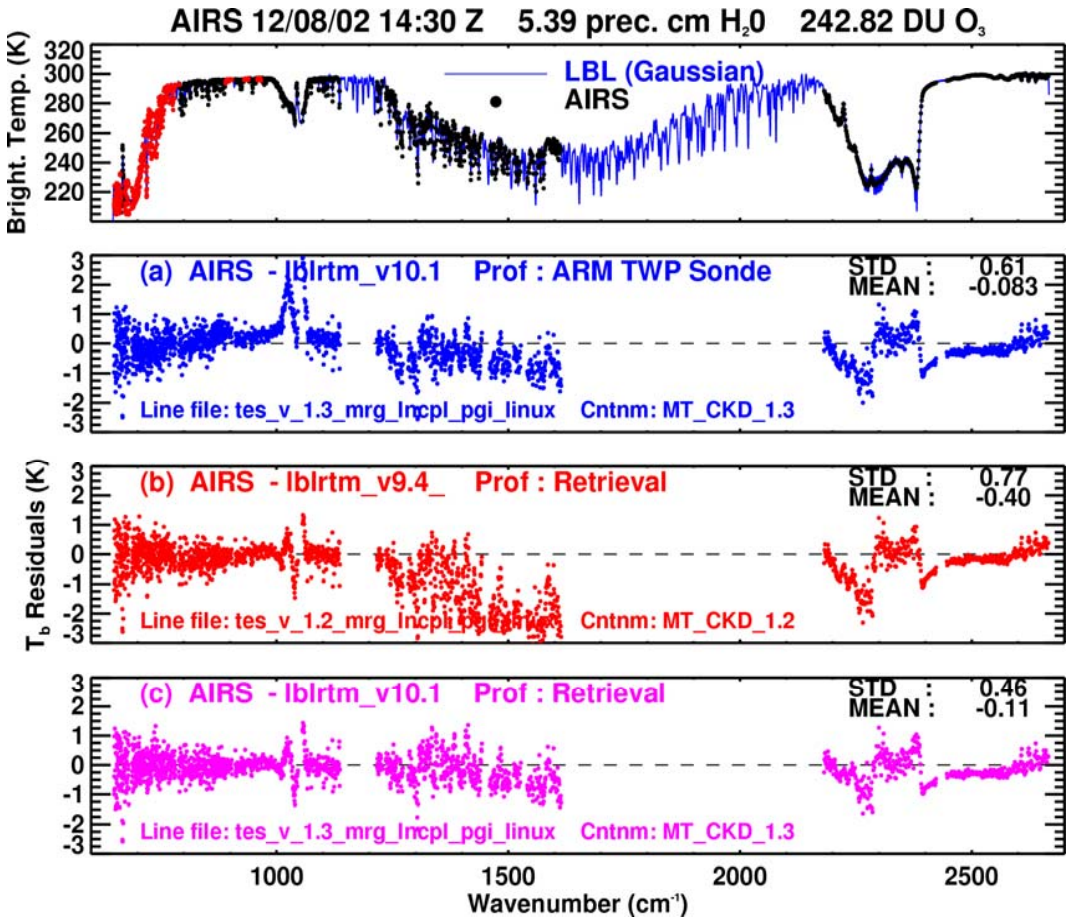
Fig. 7. Top two panels: Brightness temperature (BT) for a standard Arctic atmosphere simulated with H04 (solid) and T05 (dashed) parameters for a down-looking (top panel) and up-looking (middle panel) view. The bottom panel is the brightness temperature difference (H04-T05) for the down-looking (solid line) and up-looking (dashed line) view.

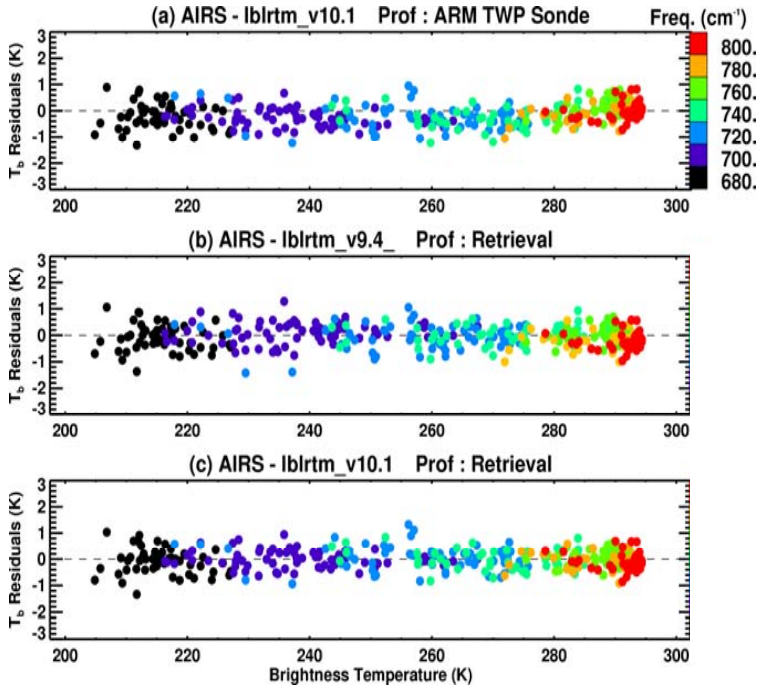
SHIS Analysis from AFWEX Experiment
Oklahoma SGP - sonde





AIRS Analysis
ARM Tropical Western Pacific site - sonde

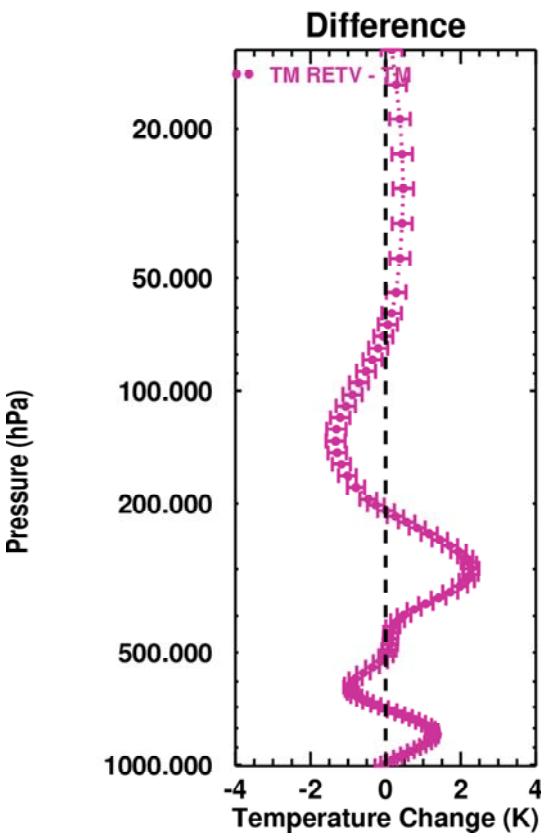




Impact on Temperature Profile

Reference: ARM TWP Sonde

Retrieved v9.4

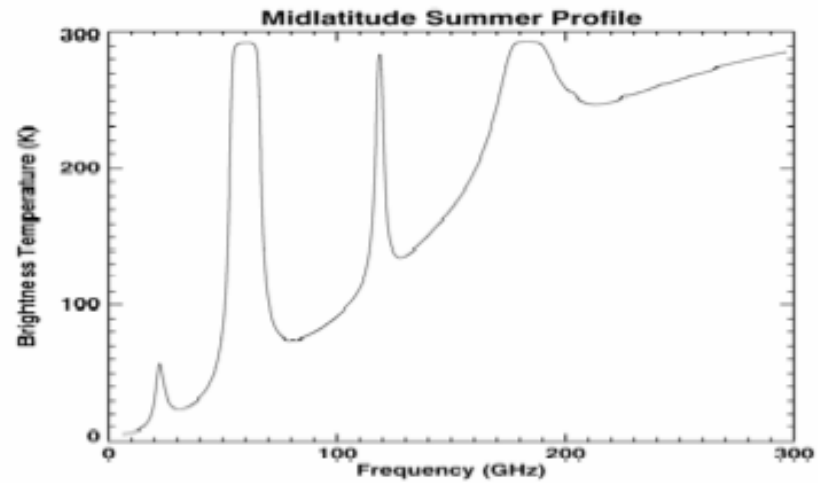


Retrieved v10.1

Accuracy and Computational Cost

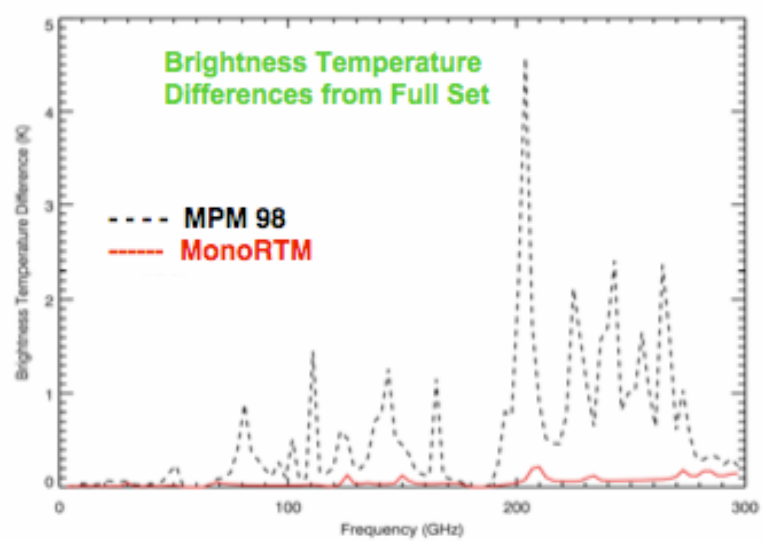
- Cost is proportional to the number of lines

Reduced Line Set for Accelerated Performance



Comparison: Number of lines used

	Full Set	Reduced Set	MPM 98 Set
H2O	517	40	15
O2	79	41	41
O3	421	32	0
N2O	28	4	0



LBLRTM Instructions

lblrtm_instructions

file:///Users/clough/Fortran/lblrtm_instructions/lblrtm_instructions_frame.html

CSB Apple Mac TES DocuShare AER_rtweb Yahoo! News (12719) MapQuest Mactopia Switchboard TitanIV Sagwa Home Amaz

Record 1.1 User Identification
Record 1.2 LBLRTM Control Variables
- Record 1.2a Continuum Factors
- Record 1.2b AJ: Variable Specification
- Record 1.2.1 LBL Parameter Specifications
- Record 1.3.a Profile Scaling Specification
- Record 1.3.b Profile Scaling Values

Record 1.4 Boundary Parameters
Record 1.6a Pathname for OD files
Record 1.6b, 1.6c, and 1.6d Pathname Options
Record 2.1 Molecular options
- Record 2.1.1 Layer input
- Record 2.1.2 Layer amounts
- Record 2.1.3

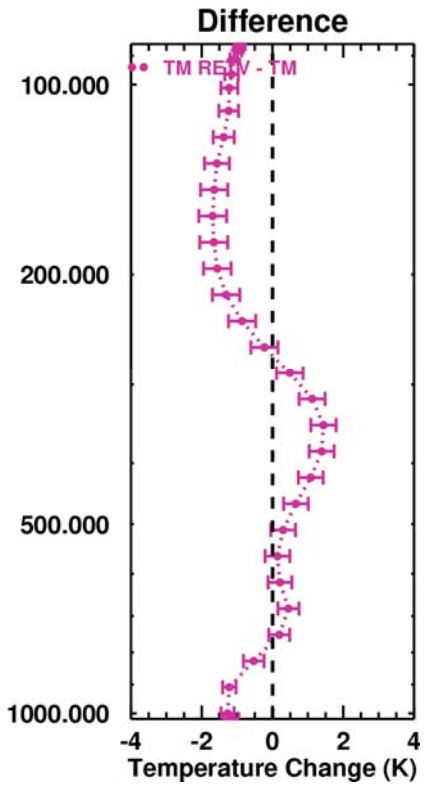
Record 2.2 Cross Sections options
- Record 2.2.1 Species selection
- Record 2.2.2 Control parameters
- Record 2.2.3 Layer input
- Record 2.2.4 Layer amounts
- Record 2.2.5

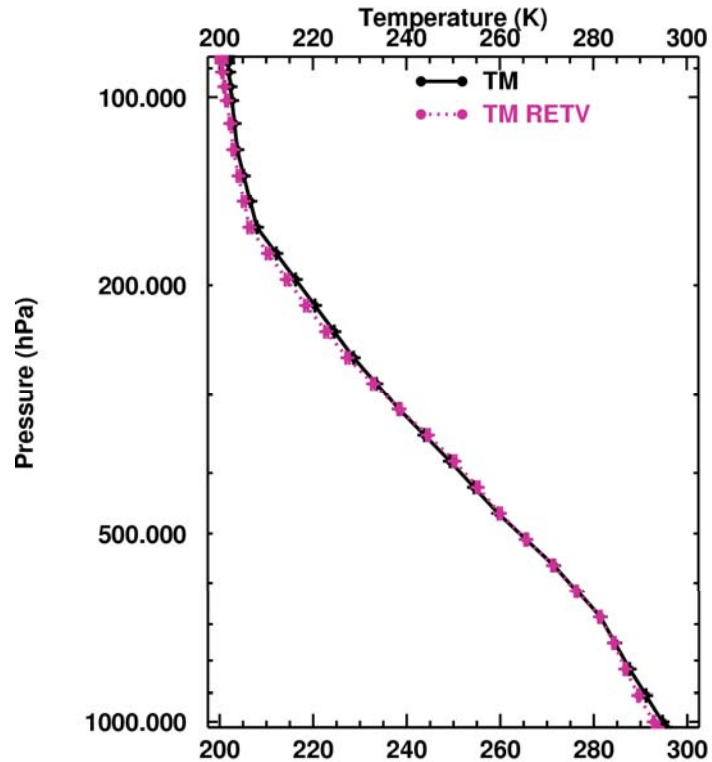
Record 3.1 LBLATM (atmosphere)
Record 3.2
Record 3.3A
Record 3.3B
Record 3.4
Record 3.5
Record 3.6.1...3.6.N
Record 3.2H
Record 3.3
Record 3.7


```
RECORD 1.2

 IHIRAC, ILBLF4, ICNTNM, IAERSL,  IEMIT,  ISCAN, IFILTR, IPLOT, ITEST,  IATM,  IMRG,  ILAS,   I

     5,     10,     15,     20,     25,     30,     35,     40,     45,     50, 54-55,     60,

 4X,I1,  4X,I1,  4X,I1,  4X,I1,  4X,I1,  4X,I1,  4X,I1, 4X,I1, 4X,I1, 4X,I1, 3X,A2, 4X,I1, 4X,

        IHIRAC   (0,1,2,3,4,9) selects desired version of HIRAC

                    = 0  HIRAC   HIRAC not activated; line-by-line calculation is bypassed
                                                      (skips to selected function)
                    = 1  HIRACI  (Voigt profile)
                    = 2  HIRACL  (Lorentz profile, not available in LBLRTM)
                    = 3  HIRACD  (Doppler profile, not available in LBLRTM)
                    = 4  NLTE Option (Non Local Thermodynamic Equilibrium)
                              -state populations as a function of altitude required on TAPE4
                    = 9  central line contribution omitted (functions 1-3)

        ILBLF4   (0,1,2) flag for LBLF4 (Line-By-Line Function 4)

                         (LBLF4 extends bound of line by line calculation beyond 64 halfwidths

                    = 0  LBLF4 not activated (line by line bound is 64 halfwidths)
                           (Note: if IHARAC>0 and line coupling is used in generating the inpu
                    = 1  line by line bound is 25 cm-1 for all layer pressures (altitudes)
                    = 2  line by line bound is 25 cm-1 for layers with pressures .GT. 0.5 mb
                                          and 5 cm-1 for layers with pressures .LE. 0.5 mb
                         (ILBLF4 = 2 saves computational time above 50 km with minimal loss of

        ICNTNM   (0,1,2,3,4,5,6) flag for continuum (CONTNM)
                    = 0  no continuum calculated
                    = 1  all continua calculated, including Rayleigh extinction where applicab
                    = 2  H2O self not calculated, all other continua/Rayleigh extinction calcu
                    = 3  H2O foreign not calculated, all other continua/Rayleigh extinction ca
                    = 4  H2O self and foreign not calculated, all other continua/Rayleigh exti
                    = 5  Rayleigh extinction not calculated, all other continua calculated
                    = 6  Individual continuum scale factors input (Requires Record 1.2a)
```

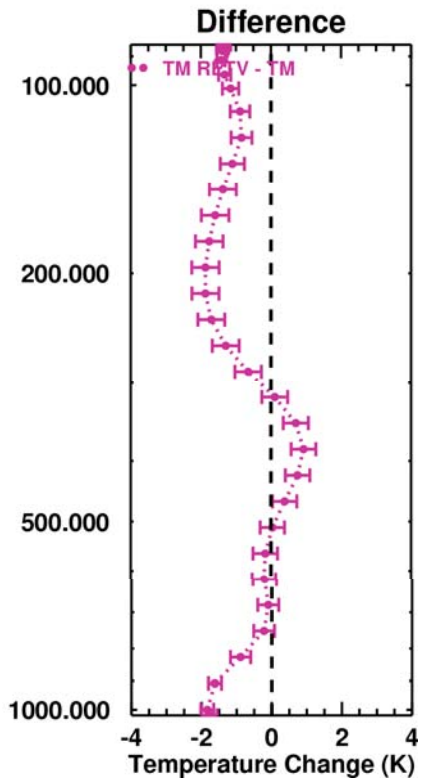
Impact on Temperature Profile
Reference: GMAO

Retrieved v9.4



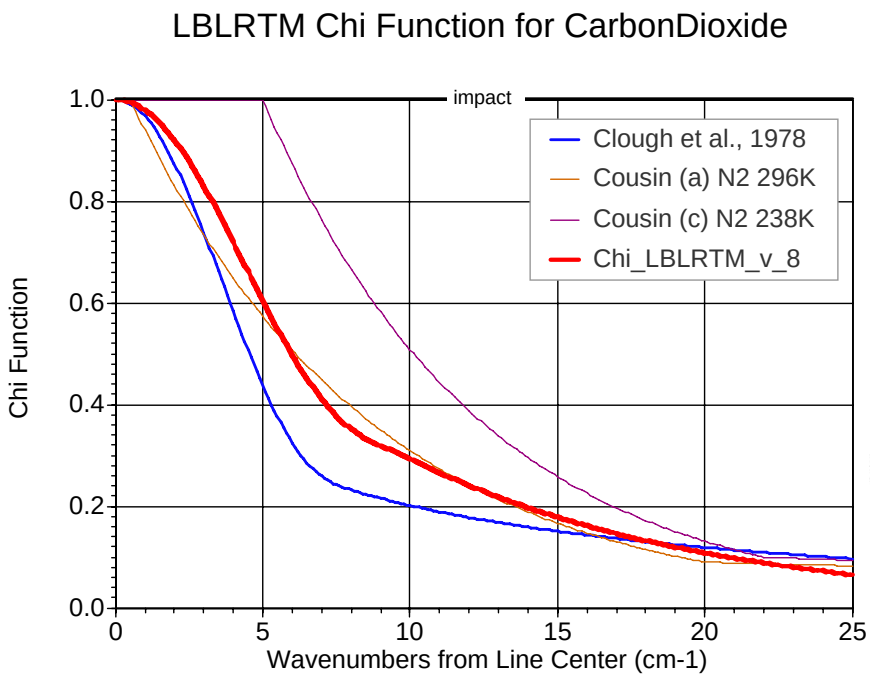


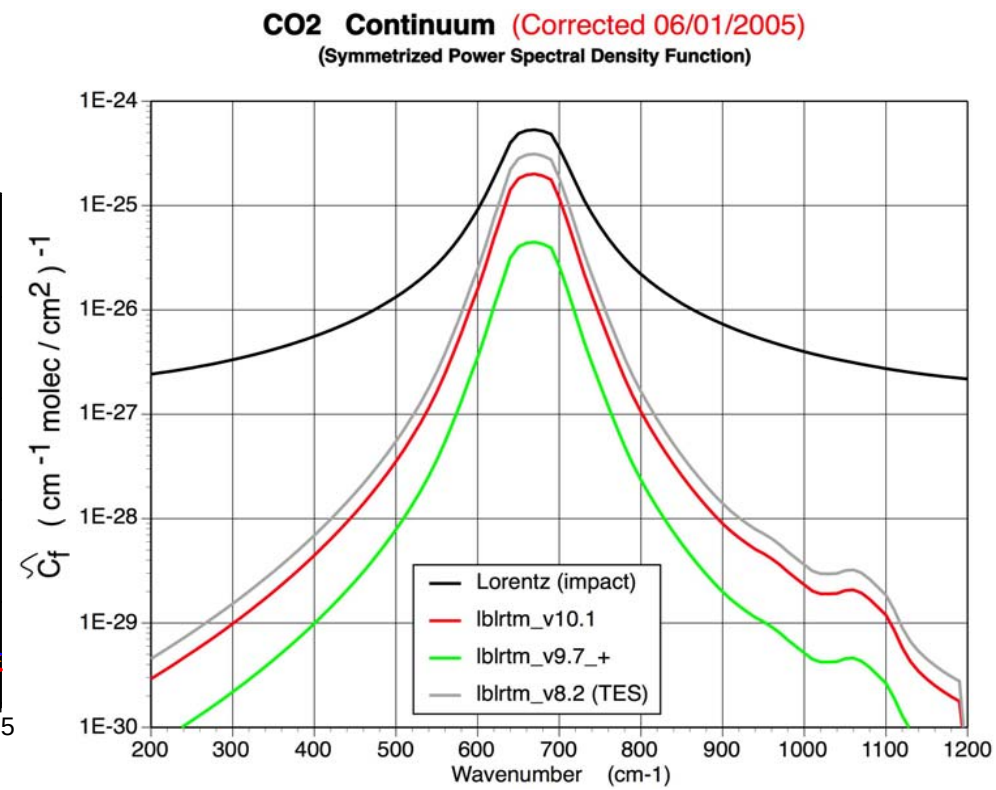
Retrieved v10.1



monotonic

CO_2 Line Shape





Chi function: Multiplies Lorentz function to account for duration of collision effects.

Continuum: Line contributions 25 cm^{-1} beyond line center

Topics

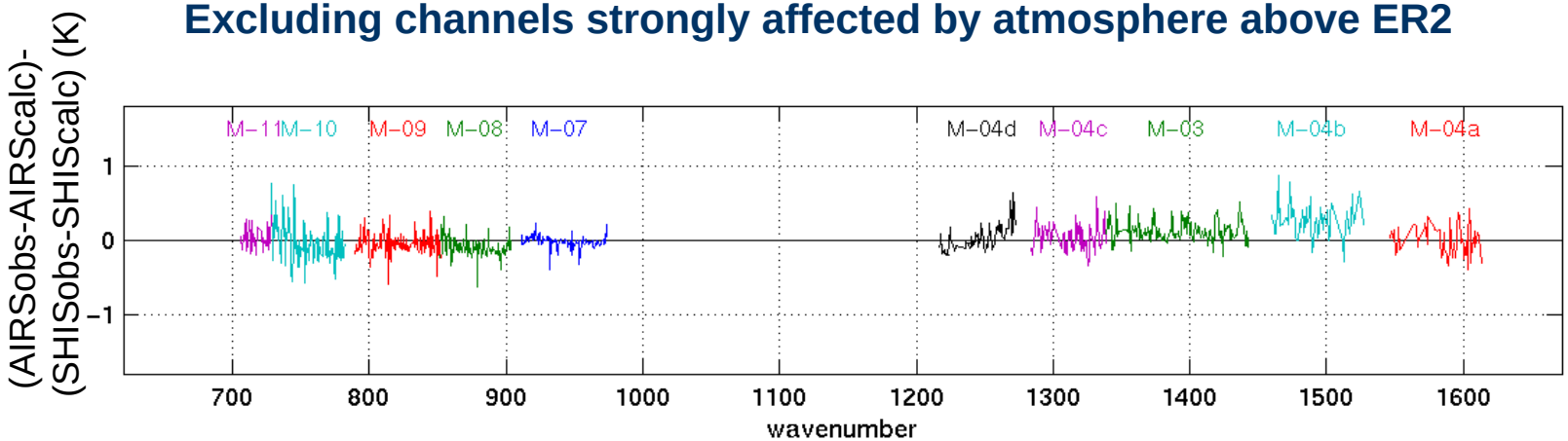
- **Forward Model**
  - Atmospheric State
    - Layering, Pressure, Temperature and Column Amounts
  - Layer Optical Depths
    - Line Parameters (Line Coupling)
    - Line Shape
    - Continuum
  - Radiative Transfer
  - Instrument Function

- **Model/Measurement Comparisons**
  - Truth ?

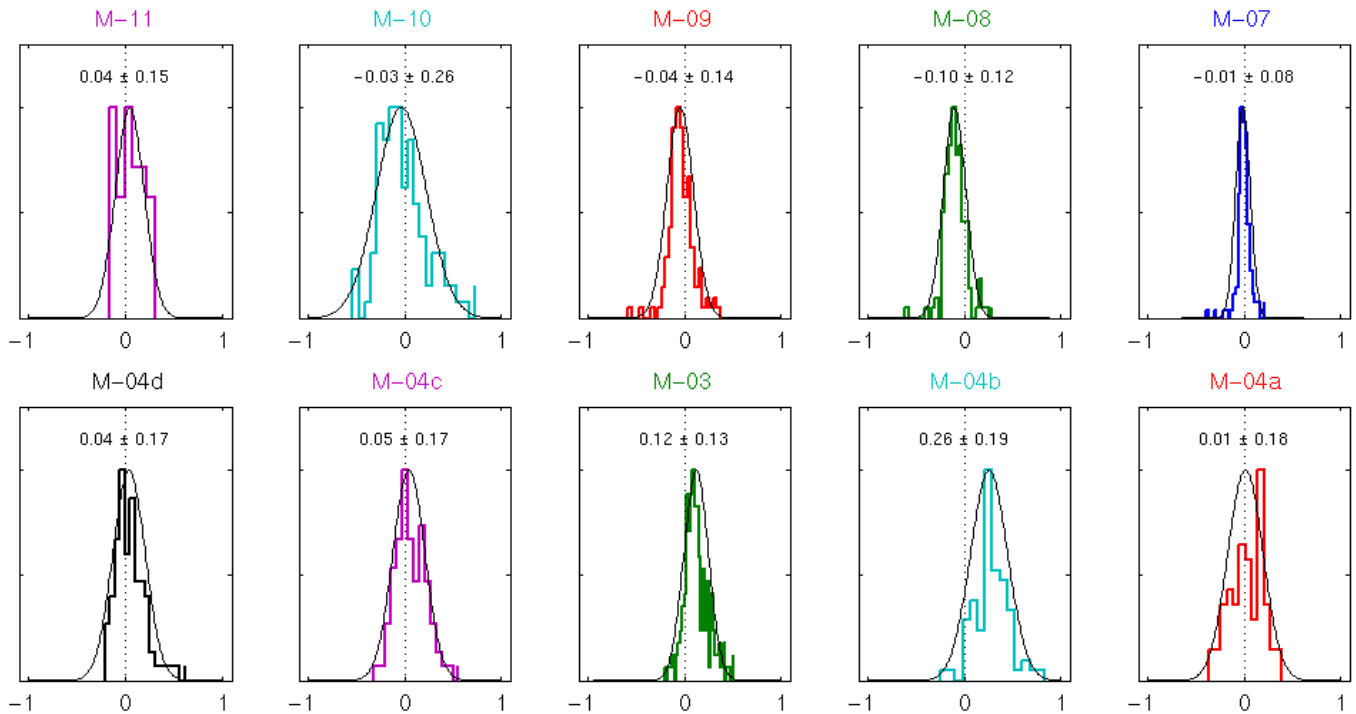
- Temperature / Clear Sky

AIRS / SHIS Brightness Temperature Comparison

Excluding channels strongly affected by atmosphere above ER2

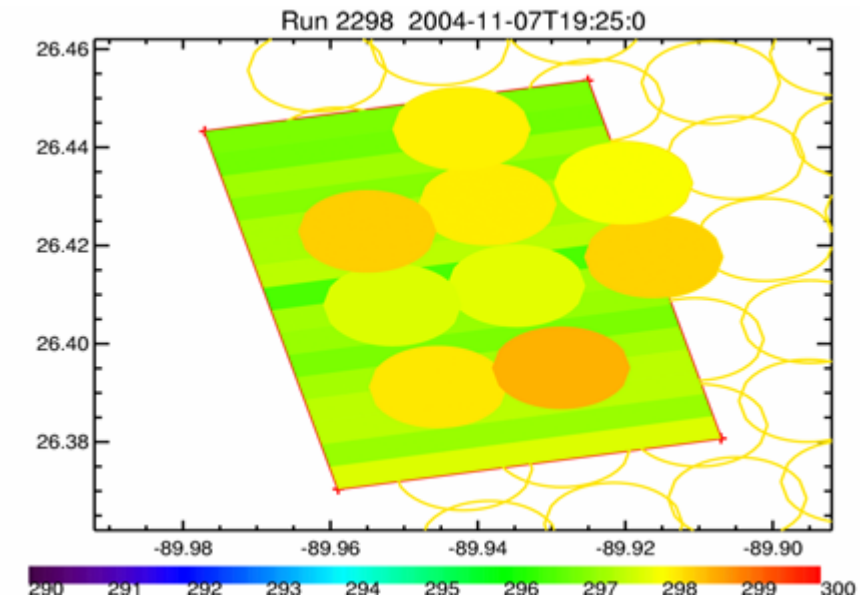


Histograms



Aura Validation Experiment: Nov. 7, 2004 : Gulf of Mexico

AVE Observations to Investigate Line-by-line Calculations



Brightness Temperature (K) @ 1105 cm $^{-1}$

SHIS scans - averaged nine ~2 km circles

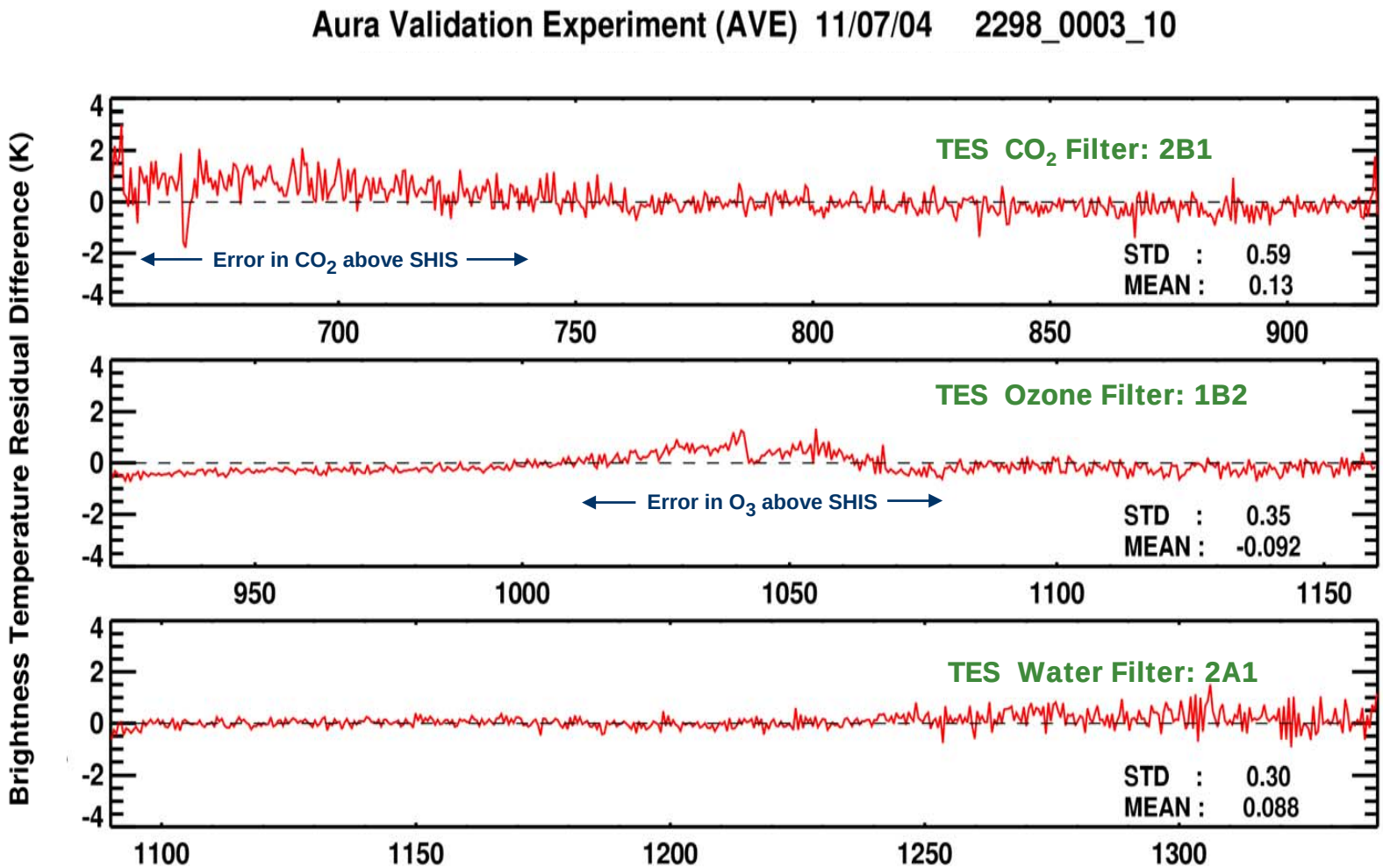
TES nadir scan - average of the sixteen 0.5 x 5km rectangular pixels from overpass

SHIS : ~ 2 km
Spectral resolution: 0.48 cm^{-1}
TES Underflight
Altitude of 18 km

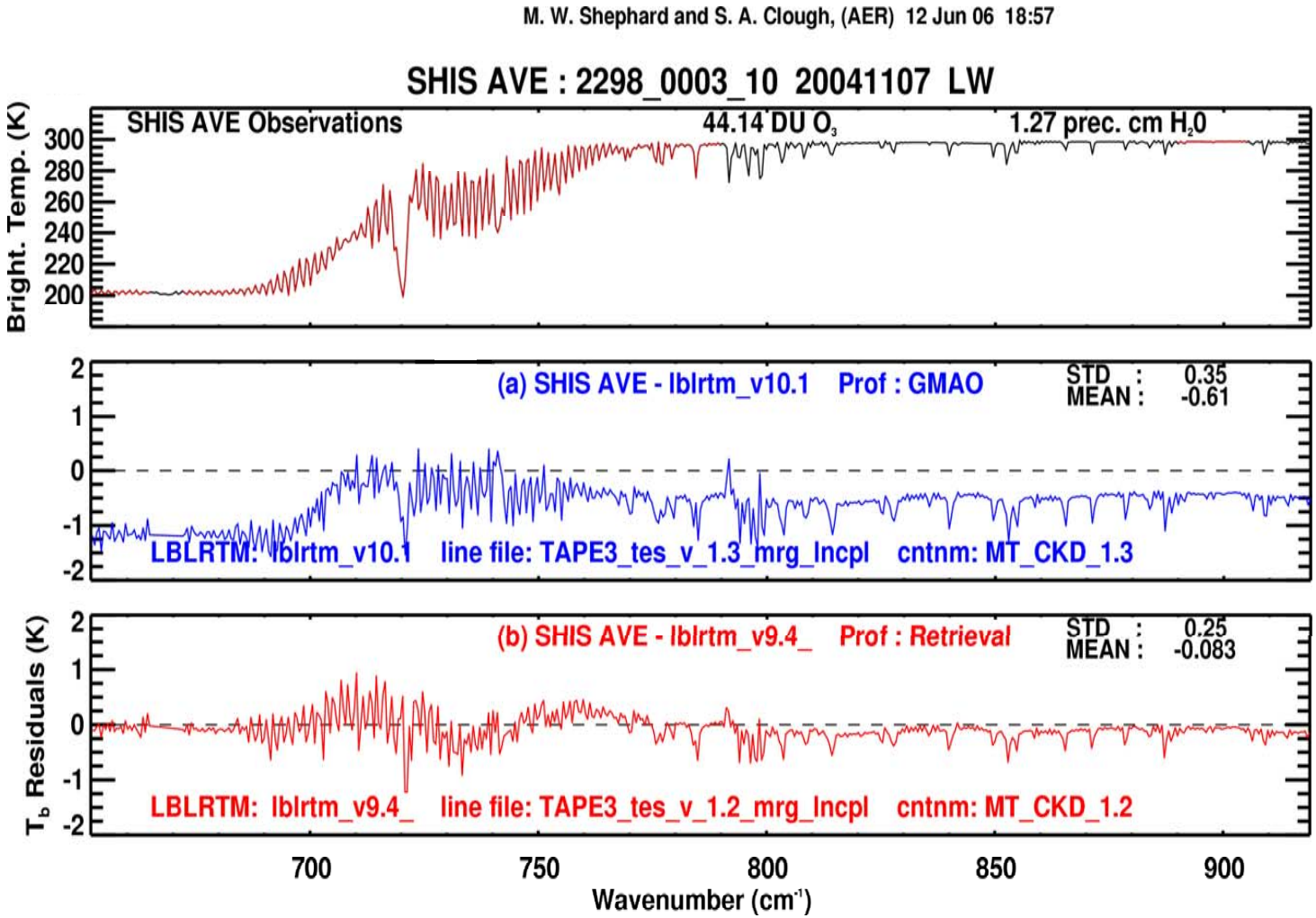
TES : 8 x 5 km
Spectral resolution: 0.06 cm^{-1}
Nadir
19:25 UTC

TES - SHIS Radiance Comparison

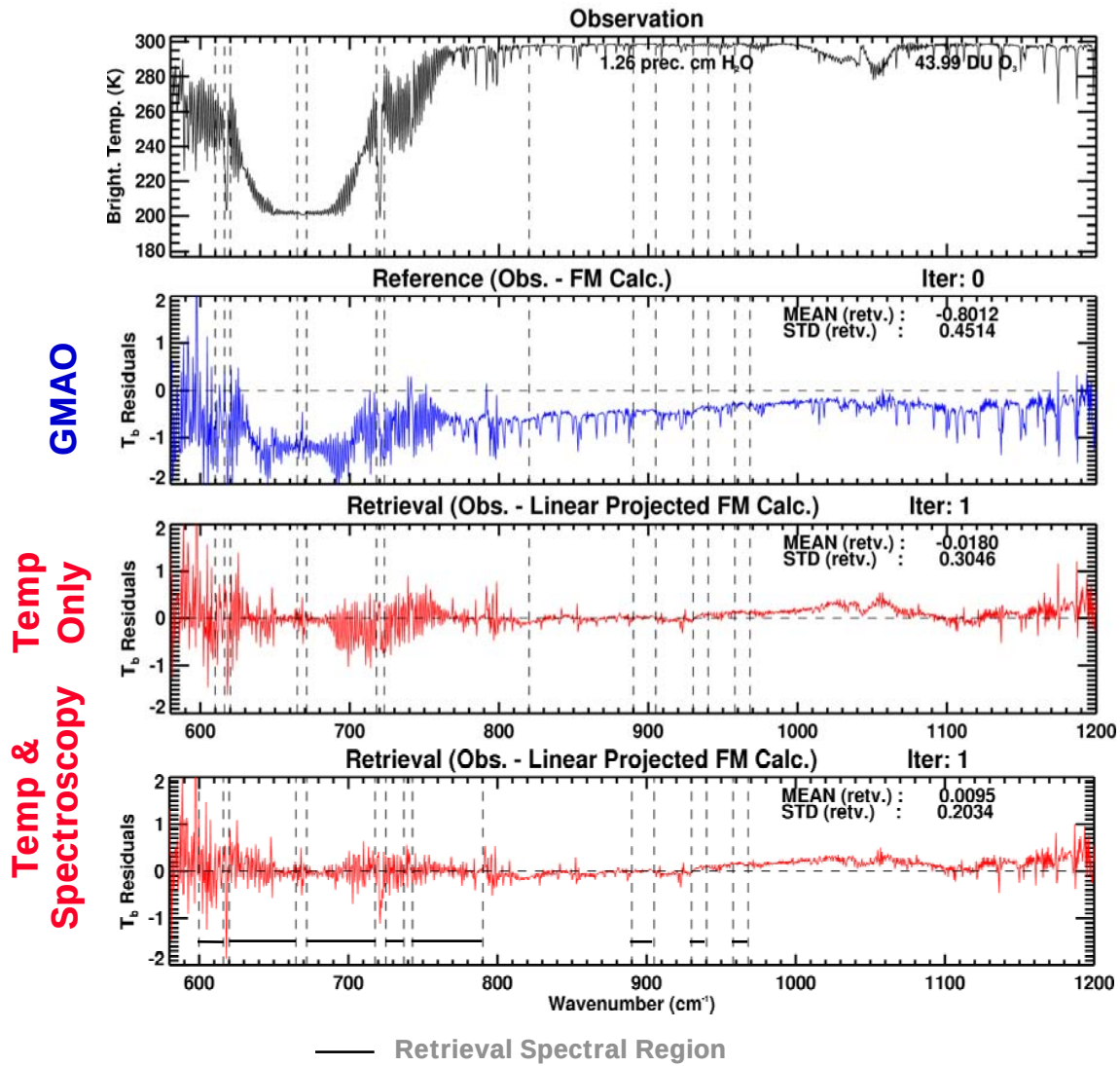
- TES Convolved to SHIS ILS
- {TES - LBLRTM(TES Geometry)} - {SHIS - LBLRTM(SHIS Geometry)}



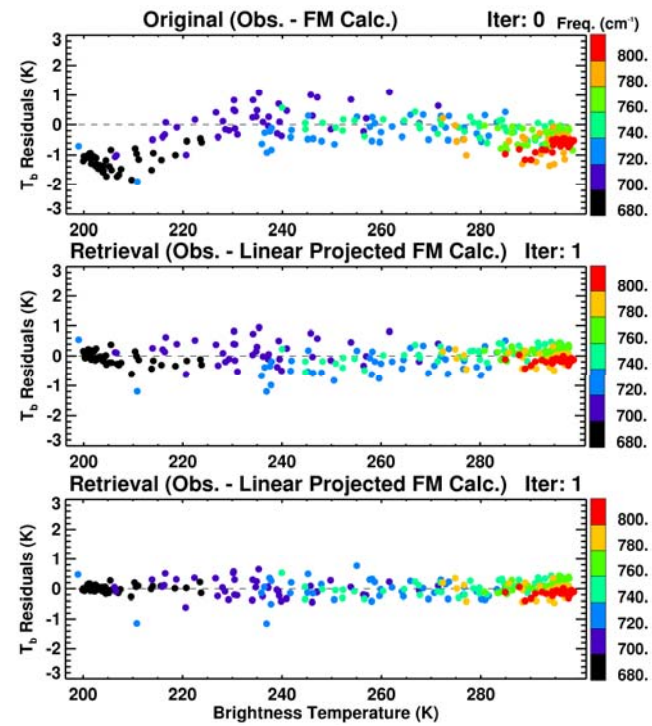
SHIS Analysis from AURA Validation Experiment
Persistent Spectral Residuals



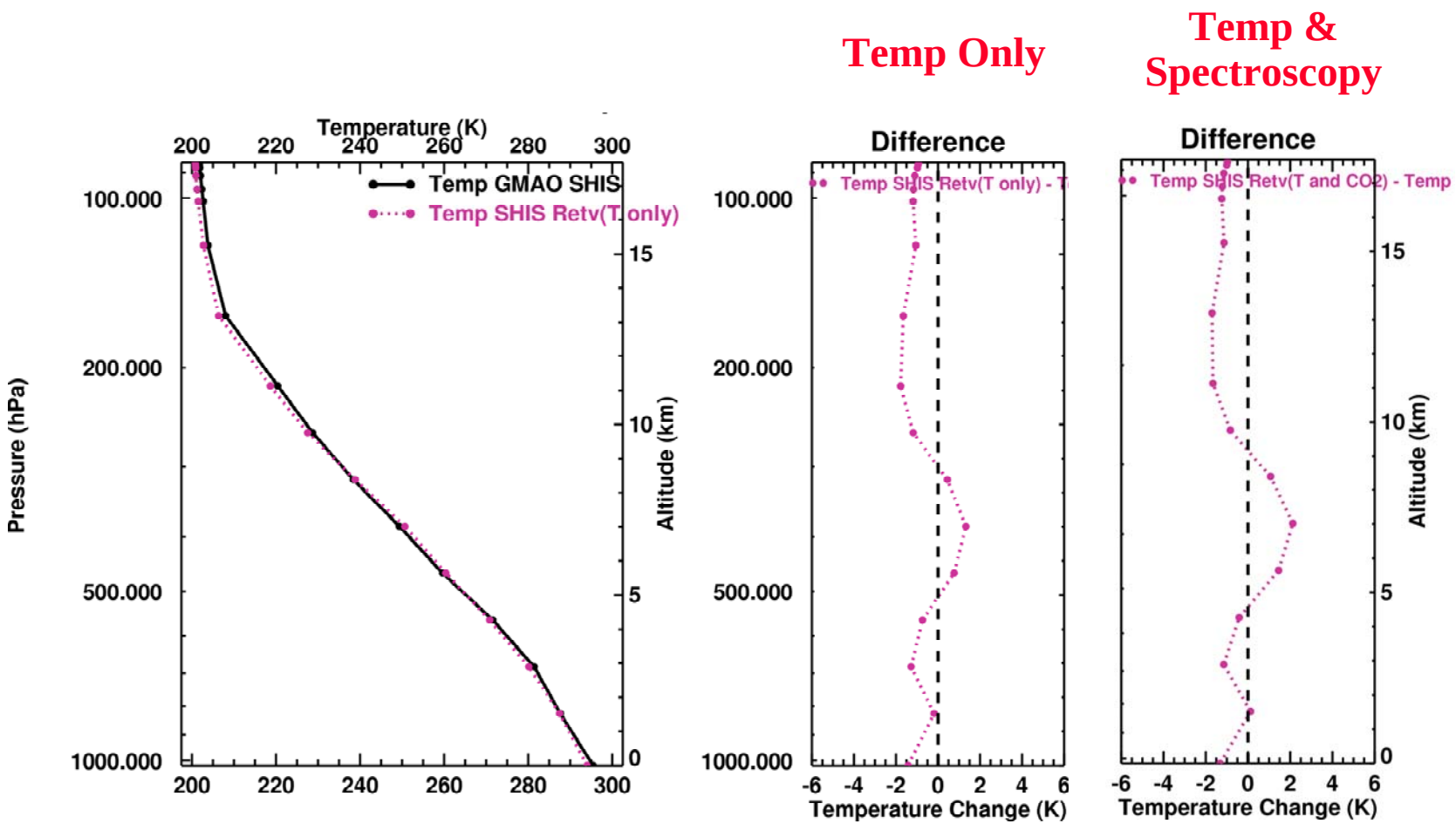
SHIS AVE Retrieval Results



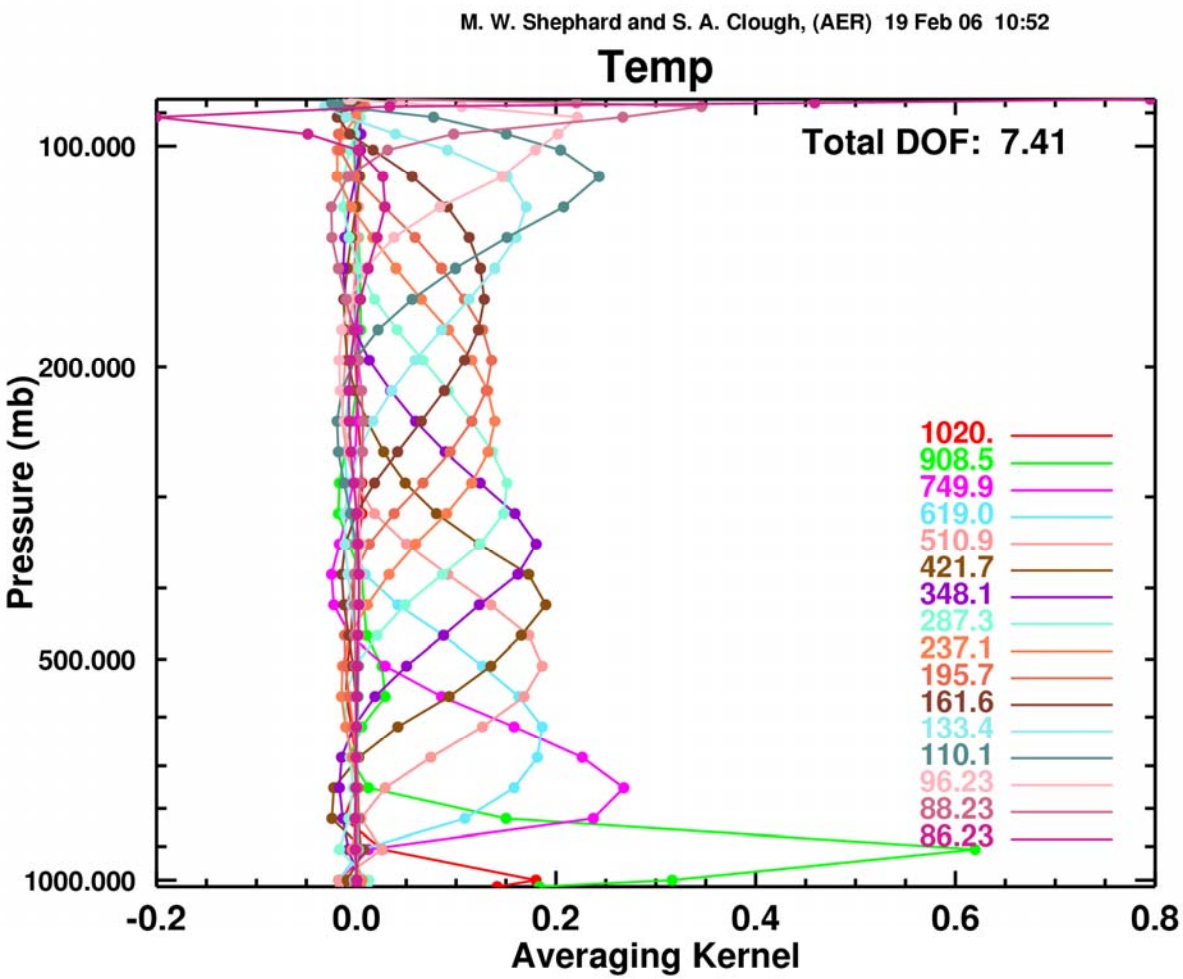
Scatter plots of Brightness Temperature vs. Residuals (Obs - Calc.) binned in 20 cm^{-1} intervals from the CO_2 v_2 region



SHIS AVE Temperature Retrieval Results



Averaging Kernels for S-HIS



SHIS AVE CO_2 Retrieved Parameters

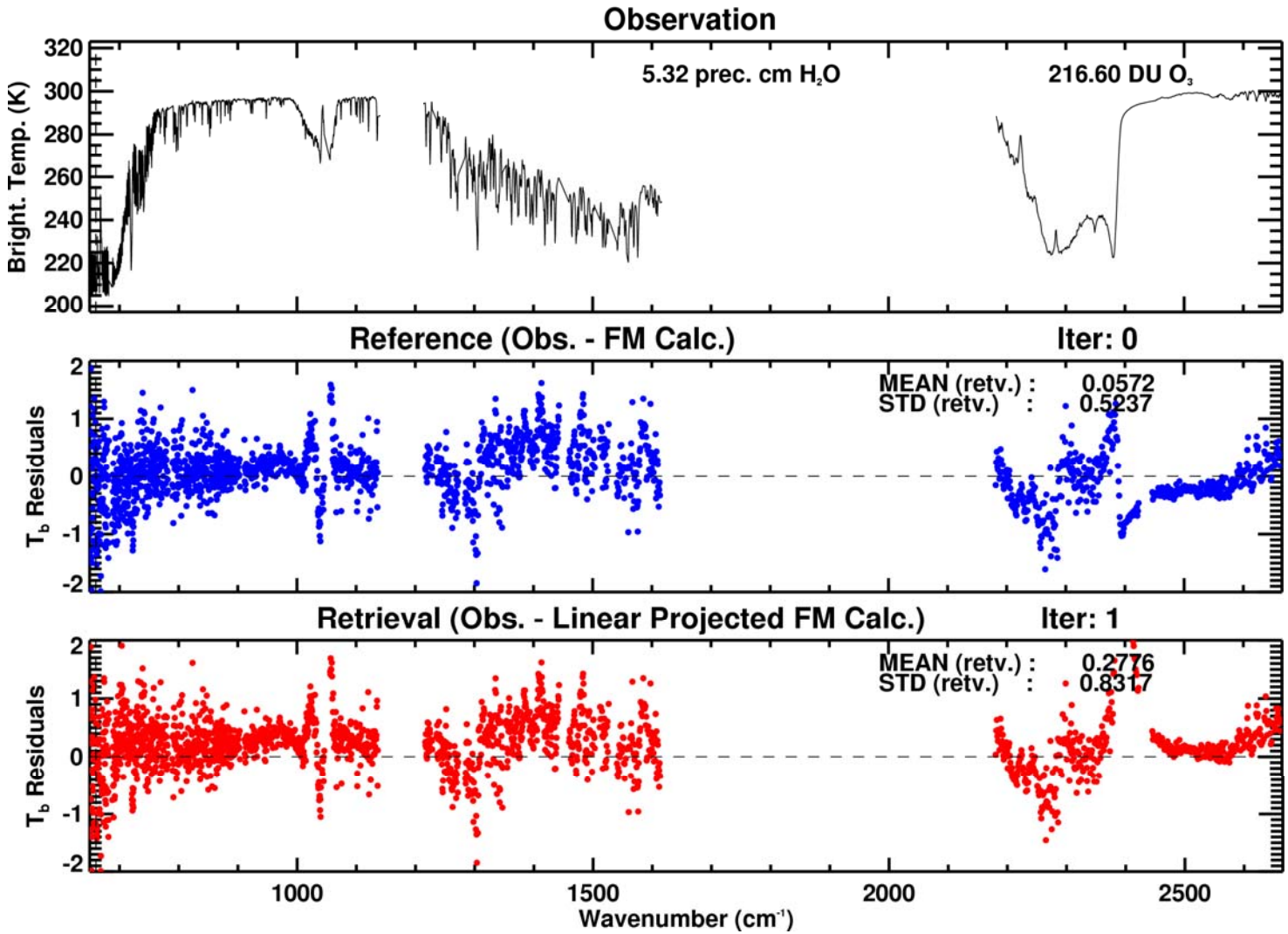
Band	Band center (cm^{-1})	Retrieved Parameter	
3 2	618.03	a_0 b_0	1% 1%
2 1	667.38	a_2	- 2%
5 2	720.81	a_2 b_0	- 4% 3%
ALL Bands		CO_2 CNTMN	2x
P/R Line Coupling			- 50%

$$S_{ret} = S_{HITRAN}\,(1 + a_0)\,(1 + a_1 m + a_2 m^2)^2$$

$$W_{ret} = W_{HITRAN}(1 + b_0 + b_1\,|m|)$$

AIRS: new spectroscopy

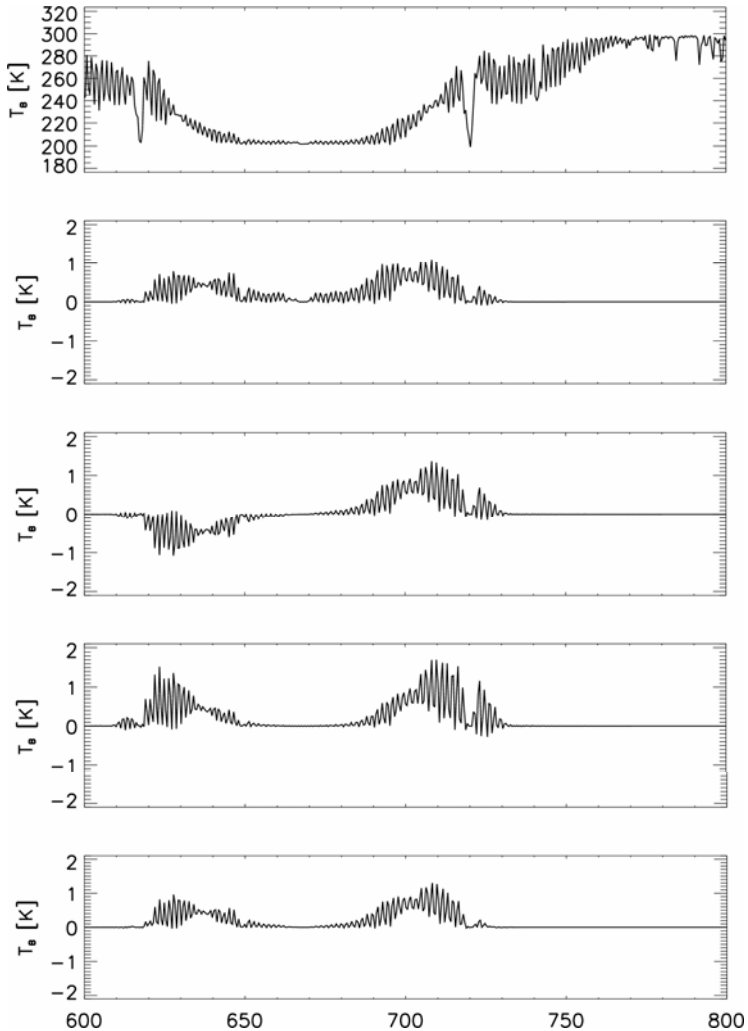
Atmosphere: sonde/adjusted ecmwf



Sensitivity Studies (Jacobians)

- **a_0, a_1, a_2, b_1 perturbed to change intensities/widths in HITRAN line file.**
- **Values chosen to induce 10% change in intensity/width at J'' ~ 40.**
- **Perturbation spectra calculated for each parameter, each band.**

Example: 2←1 band



Reference spectrum

a_0

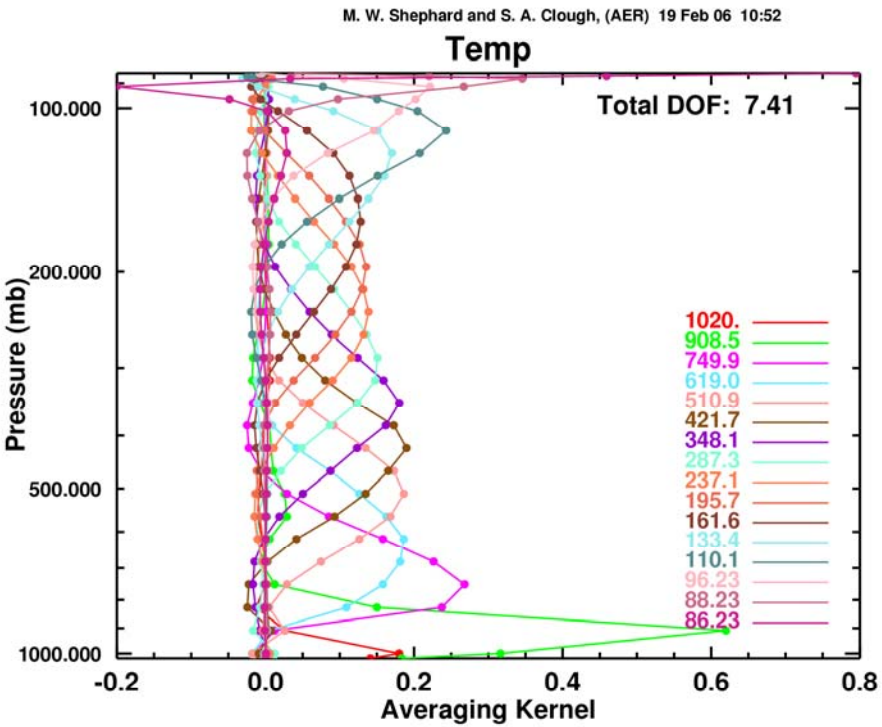
a_1

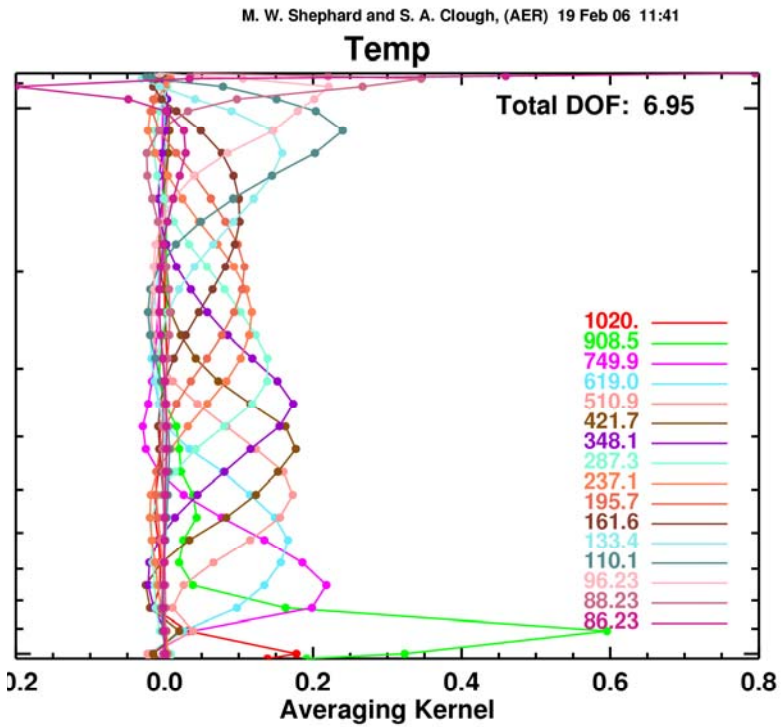
a_2

b_1

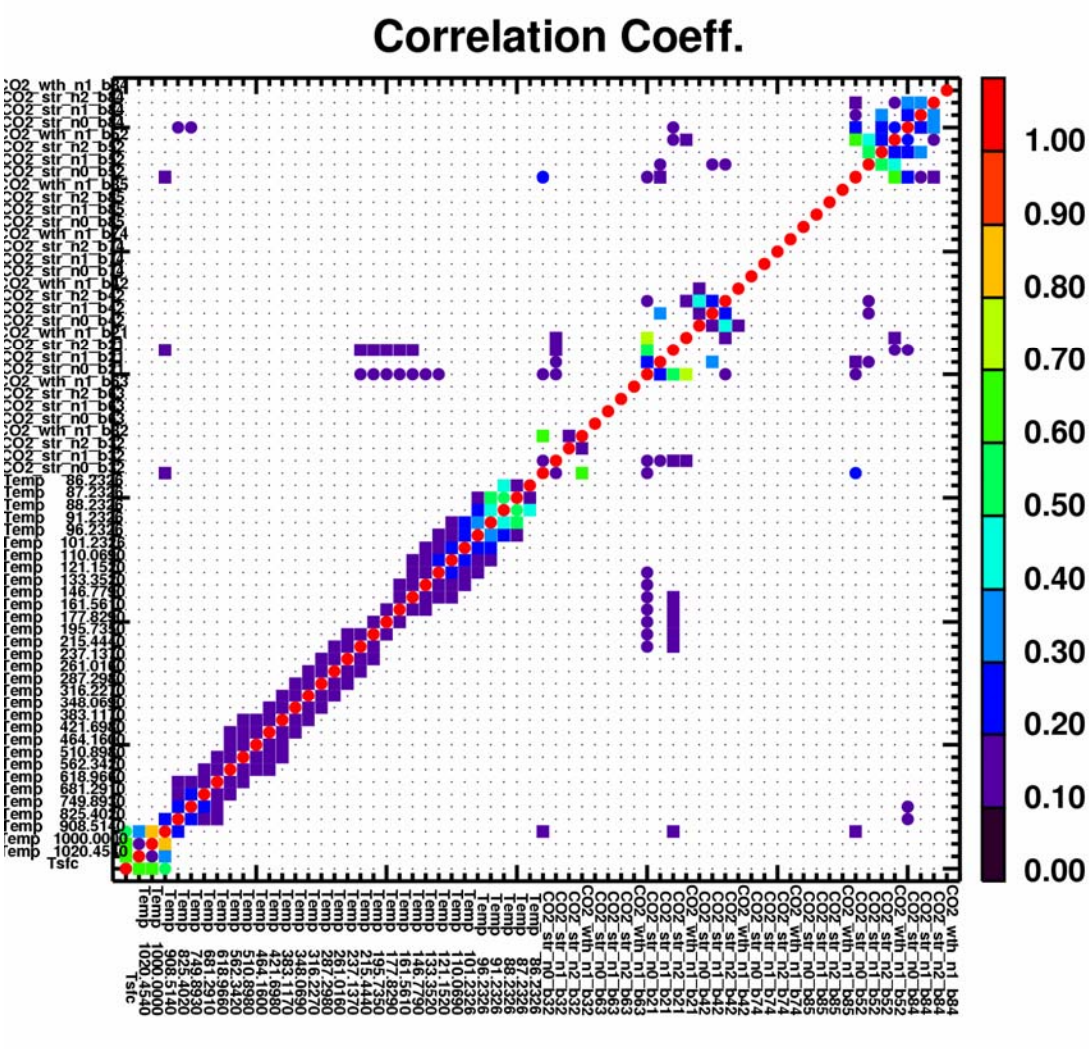
Wavenumber [cm^{-1}]

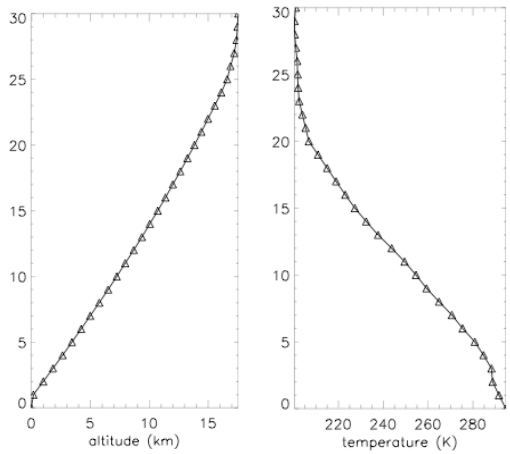
Averaging Kernels





Correlation matrix (H^{-1})





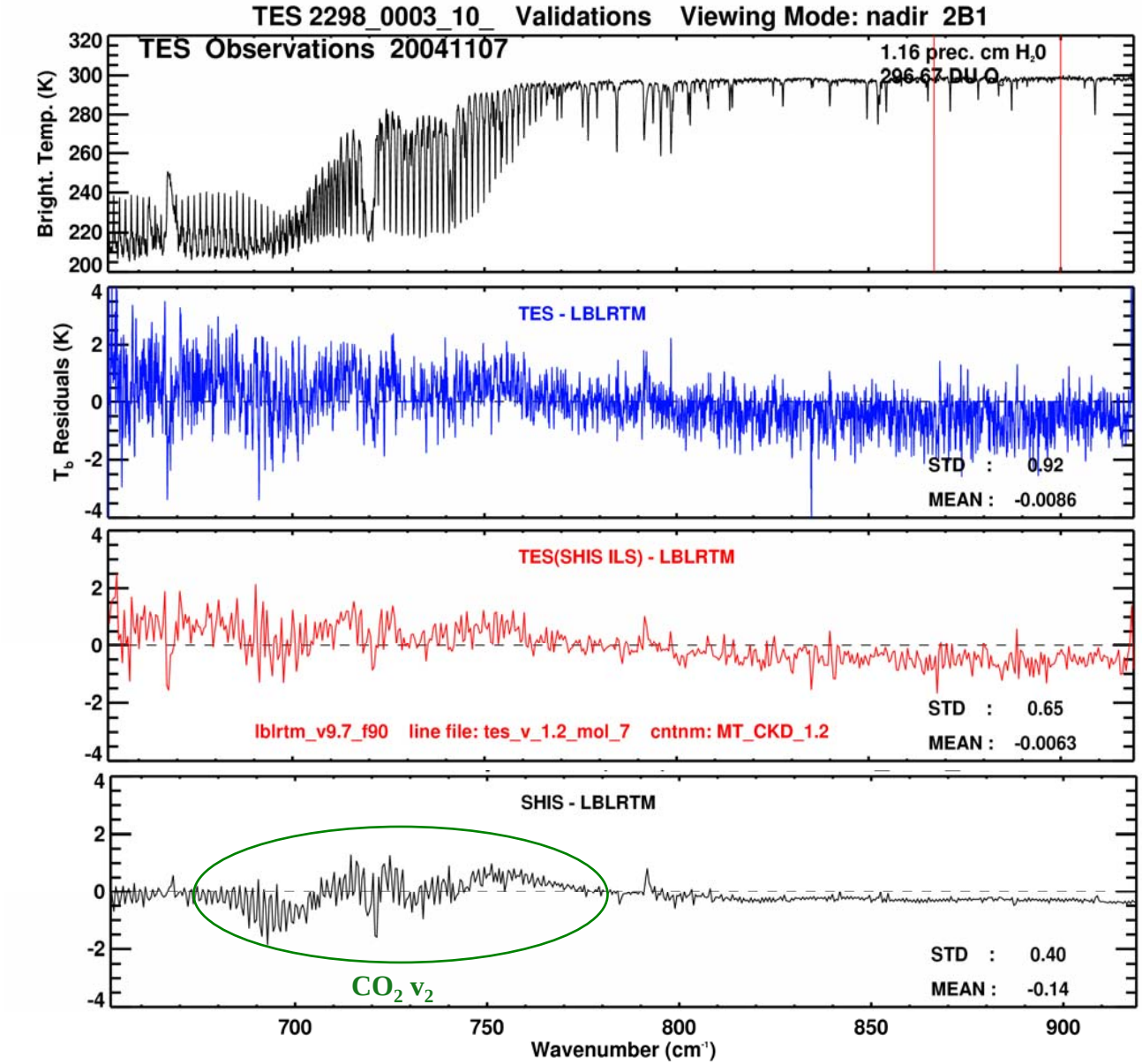
LBLRTM Validation : TES CO_2 v_2 Filter

TES Obs.

TES - LBLRTM

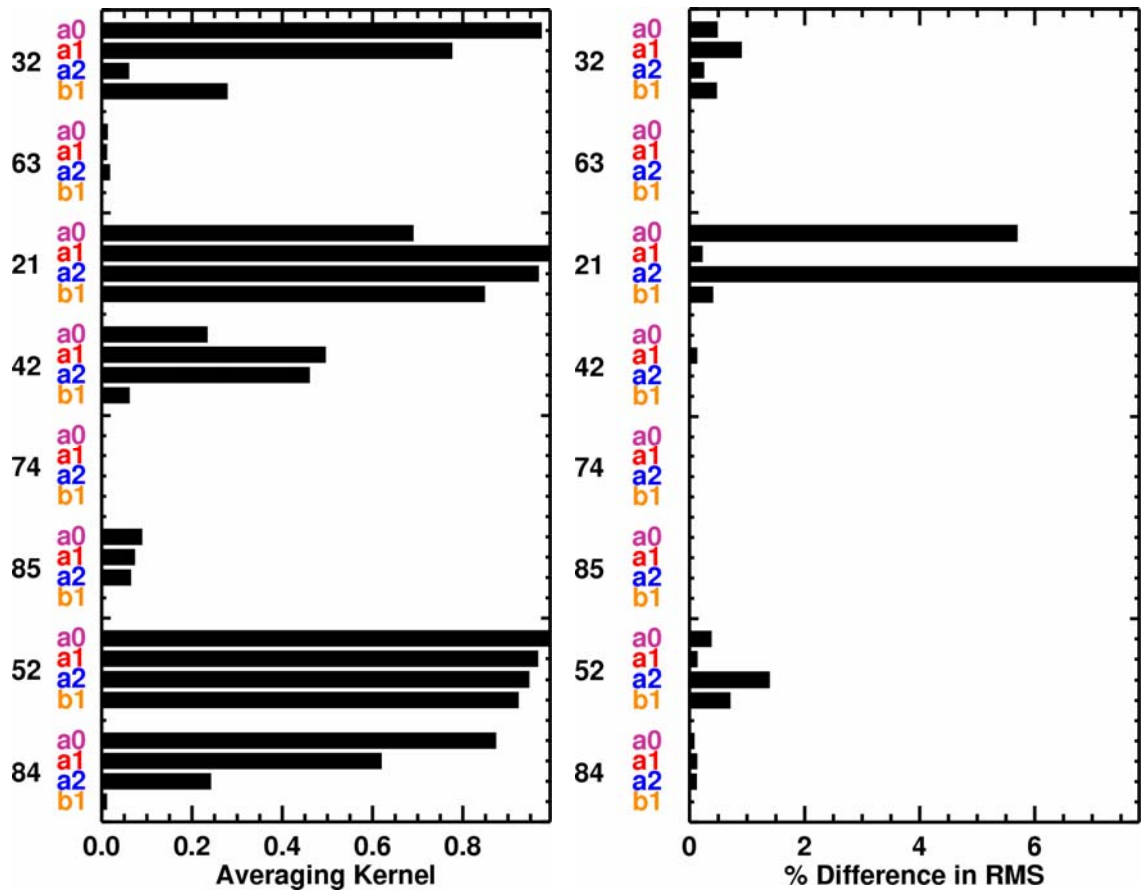
TES(SHIS ILS) - LBLRTM

SHIS - LBLRTM



SHIS AVE CO_2 Width and Intensity Retrieval Results

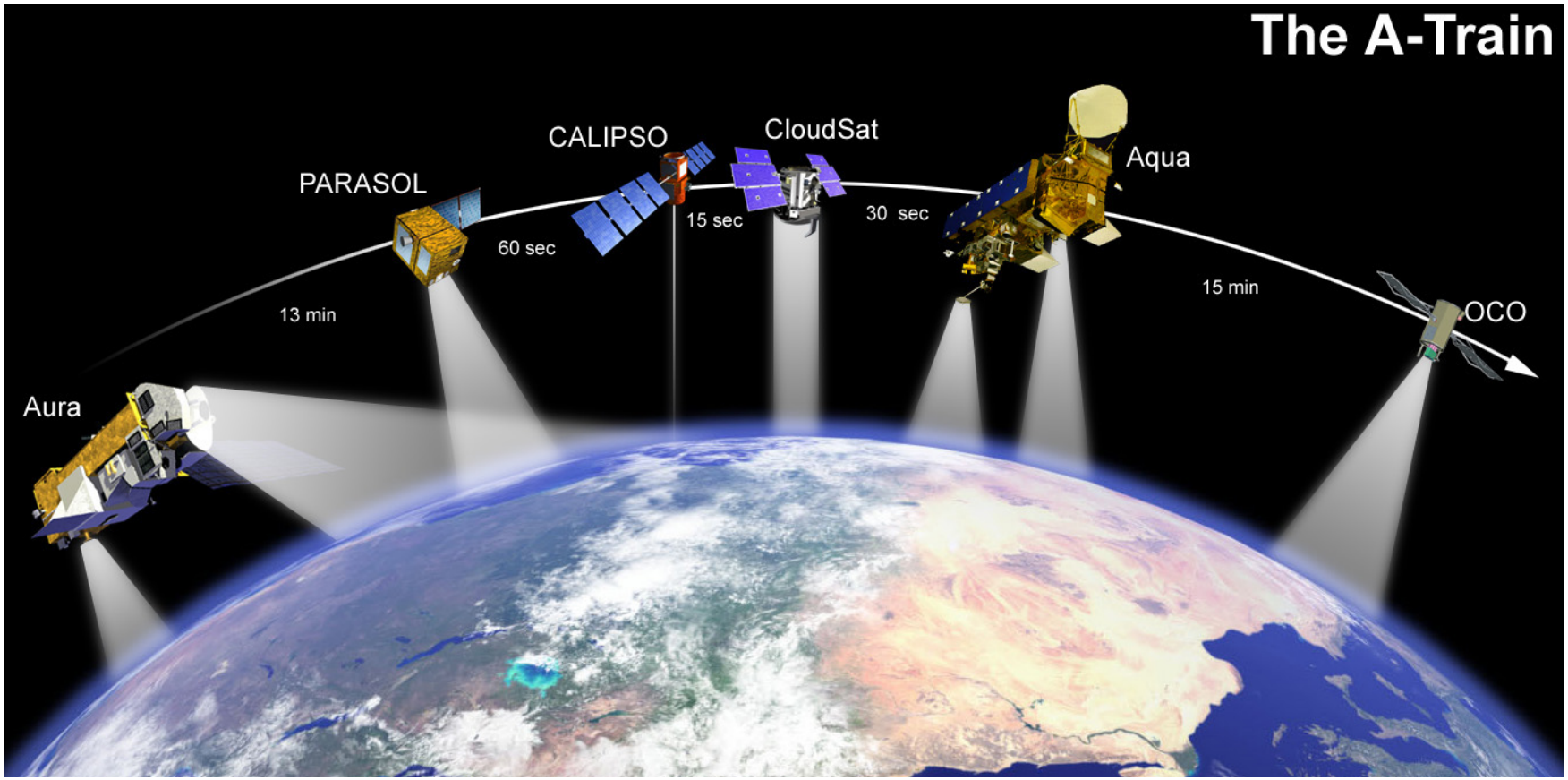
Band	Band center (cm^{-1})	Retrieved value	
3 2	618.03	a_0	-0.0053
		a_1	-0.00051
		a_2	0.000004
		b_1	0.00055
2 1	667.38	a_0	0.077
		a_1	0.00022
		a_2	-0.000039
		b_1	-0.00077
5 2	720.81	a_0	0.015
		a_1	0.00028
		a_2	-0.000016
		b_1	-0.00075

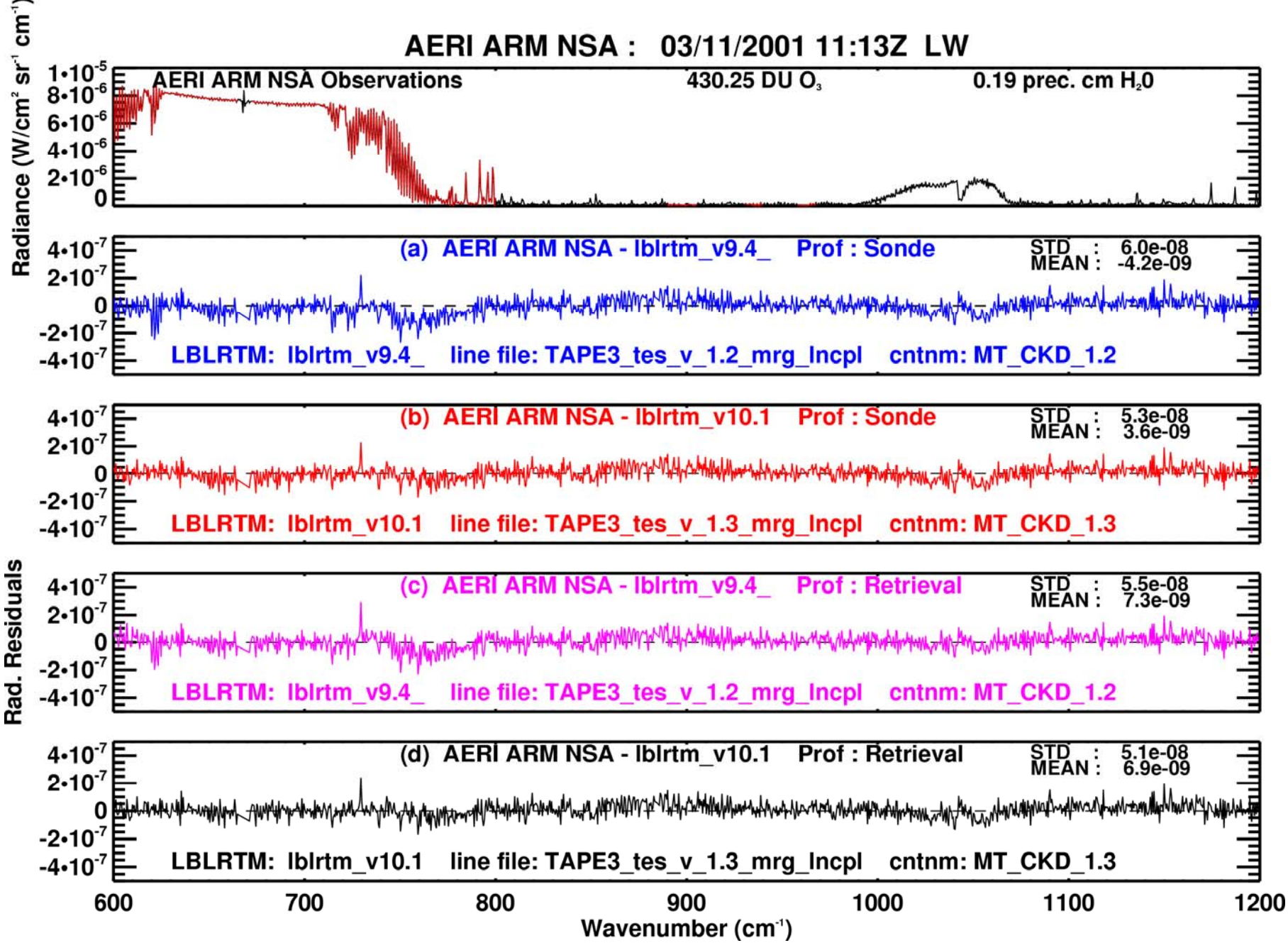


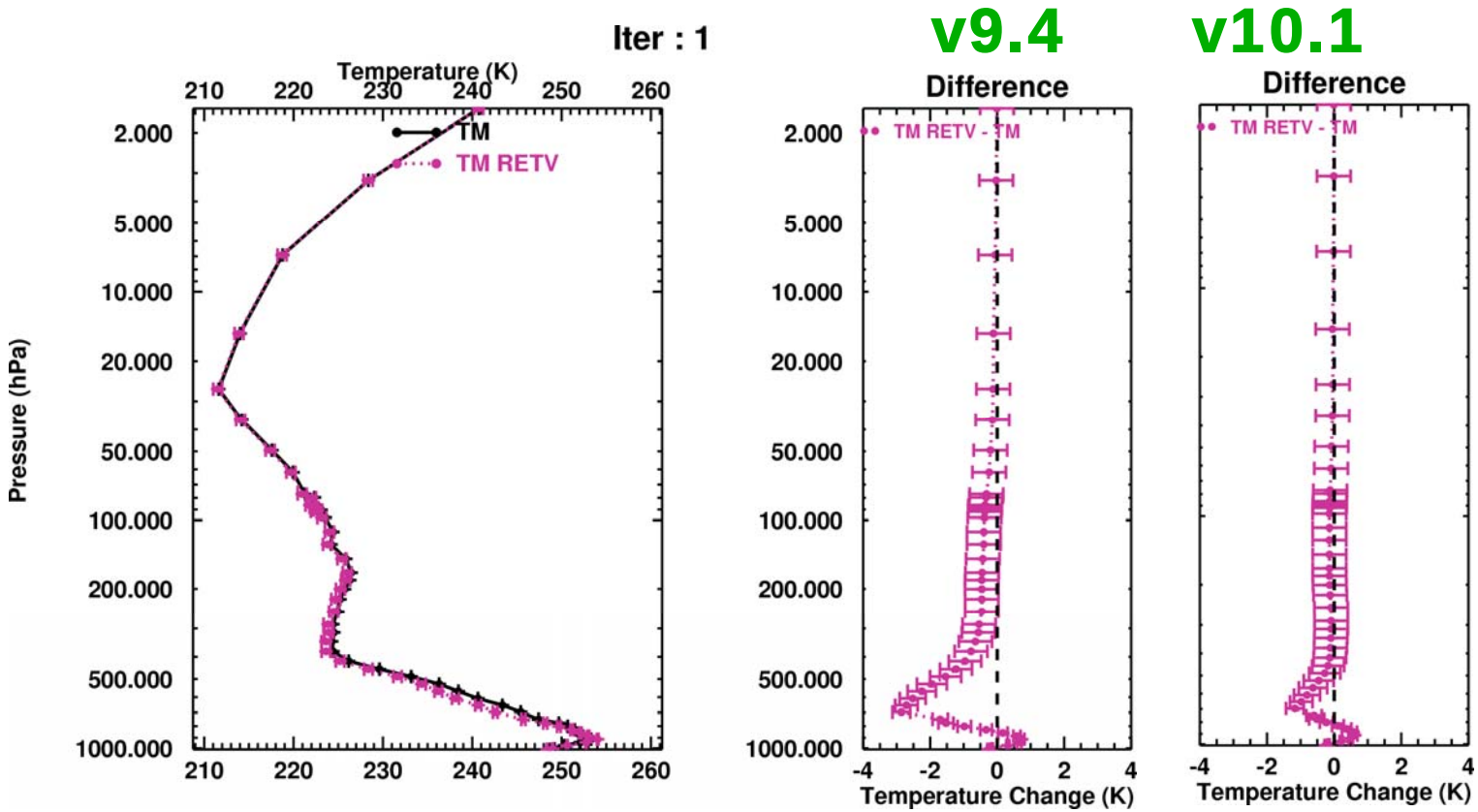
$$S_{ret} = S_{HITRAN}\,(1 + a_0)\,(1 + a_1 m + a_2 m^2)^2$$

$$W_{ret} = W_{HITRAN}(1 + b_1 |m|)$$

A TRAIN


The A-Train
Aura
PARASOL
CALIPSO
CloudSat
Aqua
OCO
13 min
60 sec
15 sec
30 sec
15 min


AERI ARM NSA : 03/11/2001 11:13Z LW
AERI ARM NSA Observations
430.25 DU O3
0.19 prec. cm H20
Radiance (W/cm2 sr-1 cm-1)
(a) AERI ARM NSA - lblrtm_v9.4_ Prof : Sonde
STD : 6.0e-08
MEAN : -4.2e-09
LBLRTM: lblrtm_v9.4_ line file: TAPE3_tes_v_1.2_mrg_lncpl cntnm: MT_CKD_1.2
(b) AERI ARM NSA - lblrtm_v10.1 Prof : Sonde
STD : 5.3e-08
MEAN : 3.6e-09
LBLRTM: lblrtm_v10.1 line file: TAPE3_tes_v_1.3_mrg_lncpl cntnm: MT_CKD_1.3
(c) AERI ARM NSA - lblrtm_v9.4_ Prof : Retrieval
STD : 5.5e-08
MEAN : 7.3e-09
LBLRTM: lblrtm_v9.4_ line file: TAPE3_tes_v_1.2_mrg_lncpl cntnm: MT_CKD_1.2
(d) AERI ARM NSA - lblrtm_v10.1 Prof : Retrieval
STD : 5.1e-08
MEAN : 6.9e-09
LBLRTM: lblrtm_v10.1 line file: TAPE3_tes_v_1.3_mrg_lncpl cntnm: MT_CKD_1.3
Rad. Residuals
Wavenumber (cm-1)

Result after Performing a Retrieval

Reference: sonde