Status of the LBLRTM Forward Model for Passive Remote Sensing

Mark Shephard, Vivienne Payne, Karen Cady-Pereira and Tony Clough

Workshop on Advanced High Spectral Resolution Infrared Observations
University of Wisconsin
26-28 April 2006

Topics

- Status of LBLRTM Analytic Jacobian
  - Temperature and Emissivity of the Surface
  - Temperature Profiles
  - Species Profiles
  - Upwelling/Downwelling

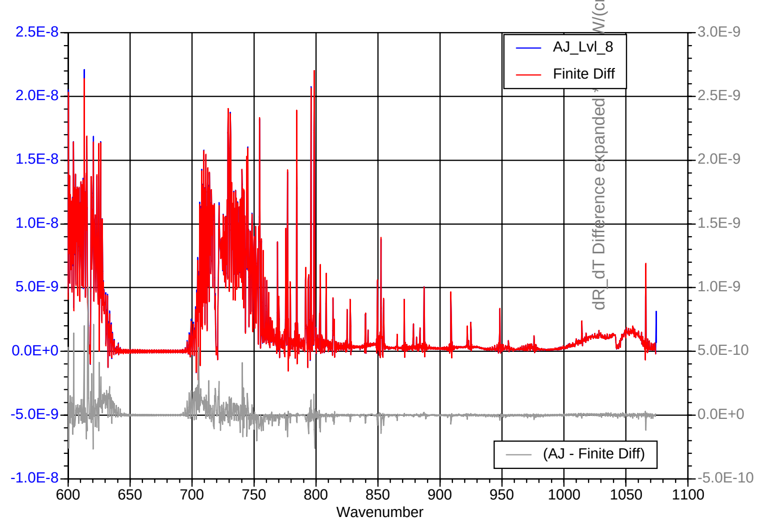
- Status of LBLRTM for Passive Remote Sensing
  - Temperature
  - Retrieval of Spectroscopic Parameters from High Resolution Spectral Observations
  - SHIS,TES, AIRS, AERI

Temperature Jacobians: Level 8

Upwelling at 20 km

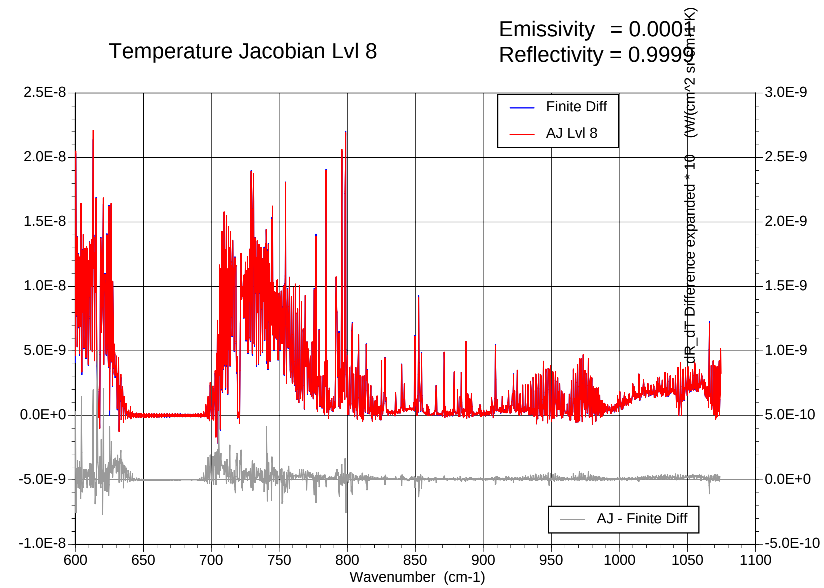
Temperature Jacobian Lvl 8

Emissivity = 0.9999
Reflectivity = 0.0001



Temperature Jacobian Lvl 8

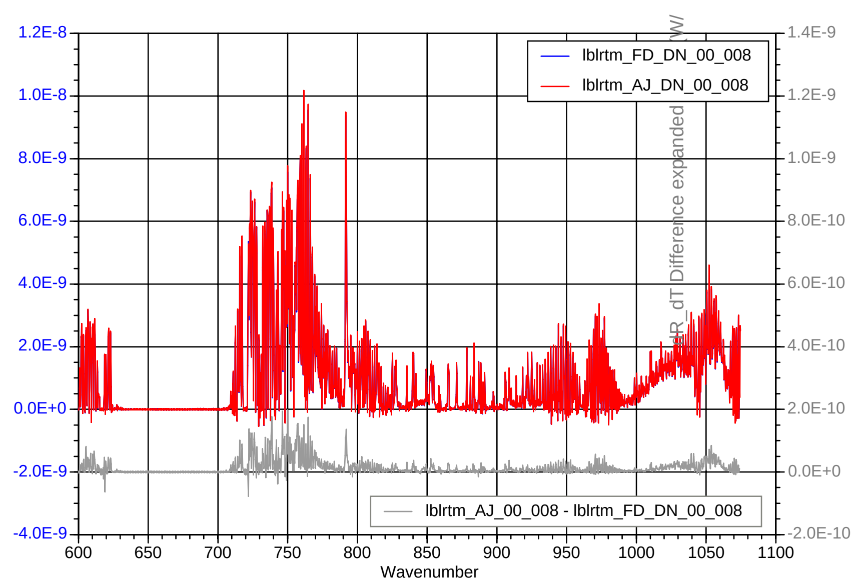
Emissivity = 0.0001
Reflectivity = 0.9999



Downwelling at the Surface

e.g. AERI

Temperature Jacobian Lvl 8



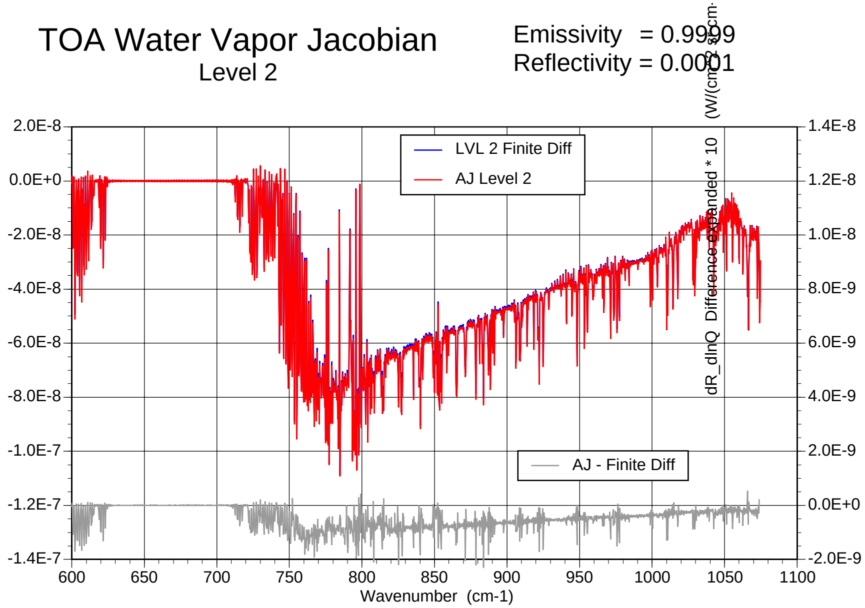
Atmosphere:
CAMEX Case
27 Levels
0-20 km

Water Vapor Jacobians: Level 2

Upwelling at 20 km

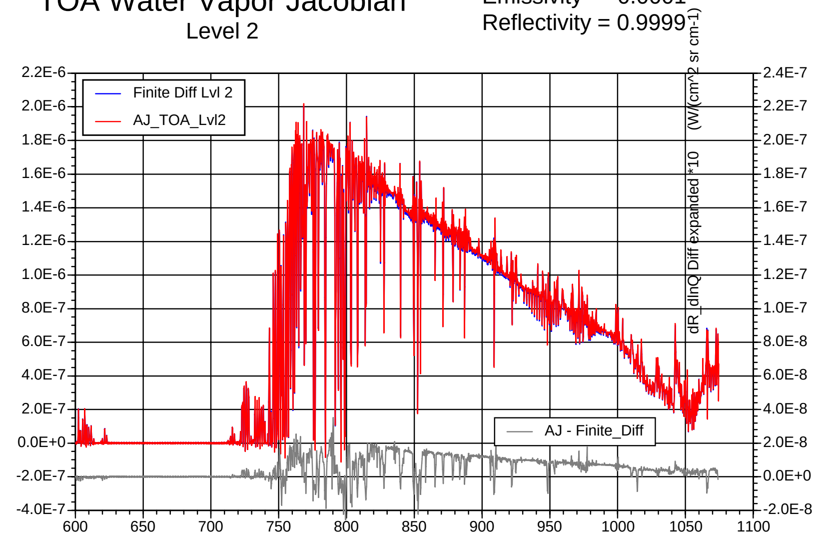
TOA Water Vapor Jacobian
Level 2

Emissivity = 0.9999
Reflectivity = 0.0001



TOA Water Vapor Jacobian
Level 2

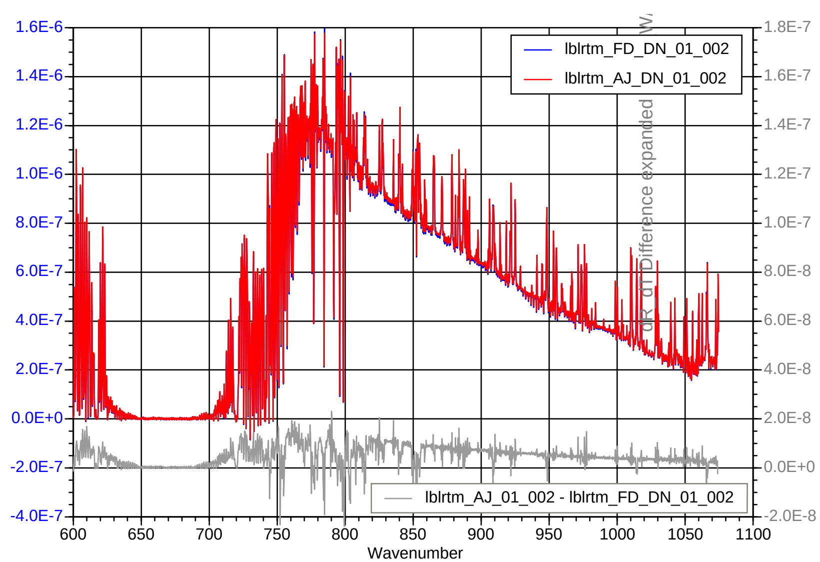
Emissivity = 0.0001
Reflectivity = 0.9999



Downwelling at the Surface

e.g. AERI

Water Vapor Jacobian



Atmosphere:
CAMEX Case
27 Levels
0-20 km

What is 'Truth'?

- **Spectral Residuals are Key!**

- **Consistency within a band system**
  - **Focus of this presentation**

- **Consistency between bands**
  - **AIRS ν_2 and ν_3 bands to investigate consistency for CO_2**

- **Consistency between species**
  - **TES: temperature from O_3 and H_2O consistent with CO_2 ; N_2O**

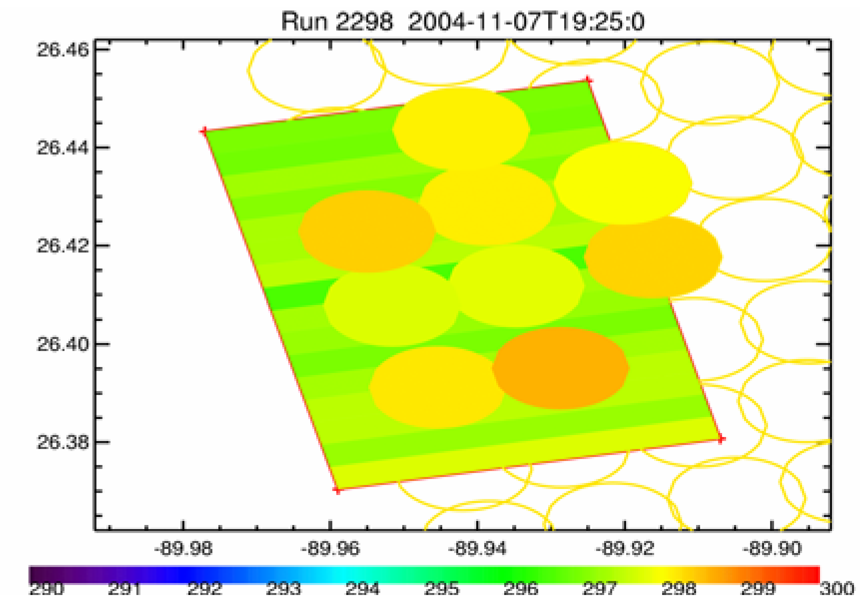
- **Consistency between instruments**
  - **SHIS**
  - **AIRS**
  - **TES**
  - **MIPAS**
  - **ACE**

Spectral Radiance Measurements

- **The retrieval of atmospheric parameters with InfraRed Remote Sensing is a Poorly Posed Problem**
- **High Accuracy in the Forward Model and the Measured Radiances is Essential**
- **Truth at the Level Required is not readily Available**
  - sonde accuracies; spatial and temporal sampling
  - laboratory measurements

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

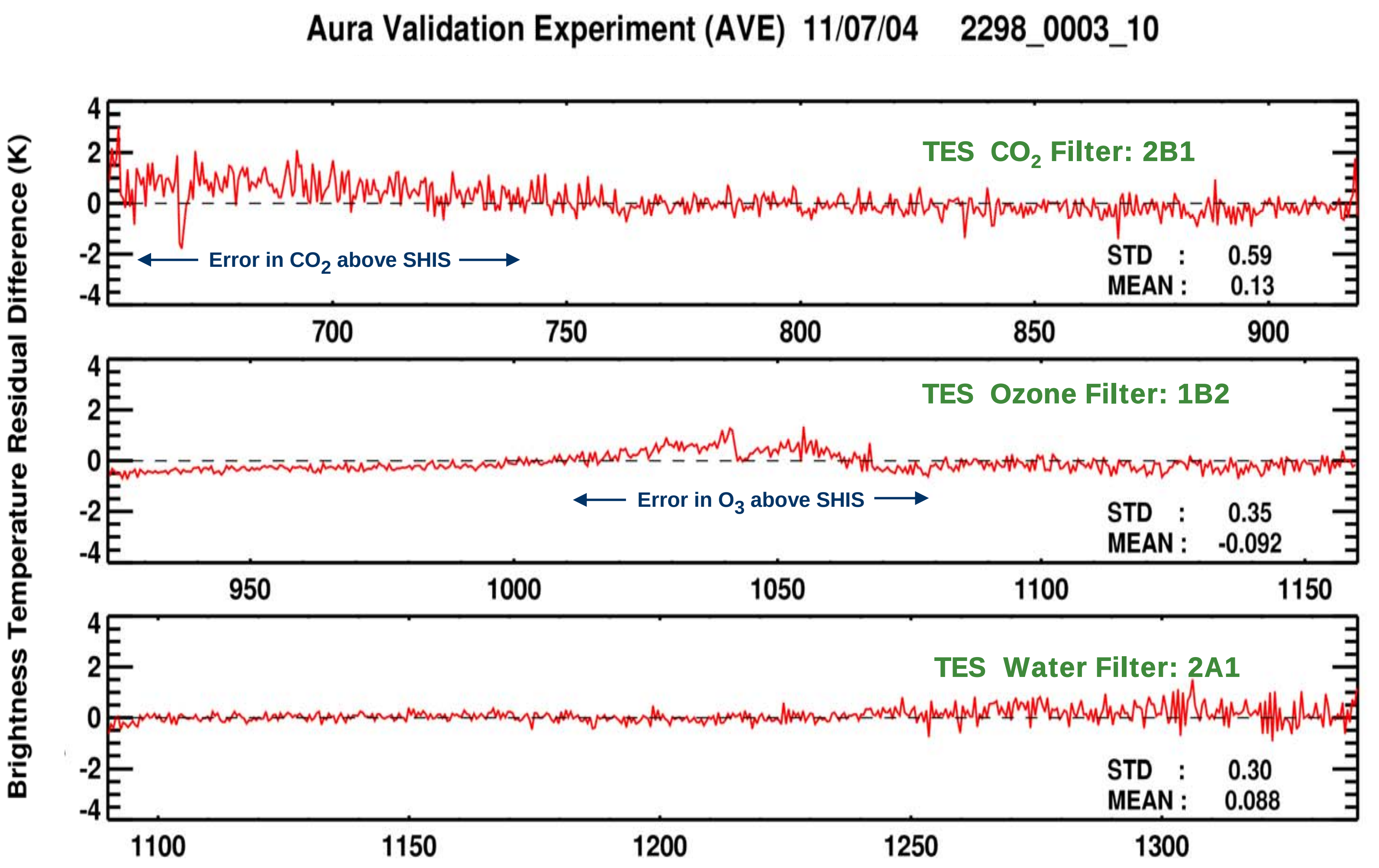
TES nadir scan - average of the sixteen 0.5 x 5km rectangular pixels from overpass

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)}



Reduction of Residuals in ν_2 Region

Simultaneous Retrieval of Temperature and Line Parameters

- **For each Vibration-Rotation Band (8 $\rightarrow$ 3)**
  - **Line Strength (3 parameters)**
  - **Line Width (2 parameters)**

- **Global**
  - **P - R Line Coupling *(Hartmann)* (scaling)**
  - **Q Line Coupling *(Hartmann)* (scaling)**
  - **Halfwidth Temperature Dependence**
  - **CO_2 Continuum (scaling)**

Corrections to CO_2 line intensities and widths

Linda Brown

- **Form of correction to line intensities:**

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

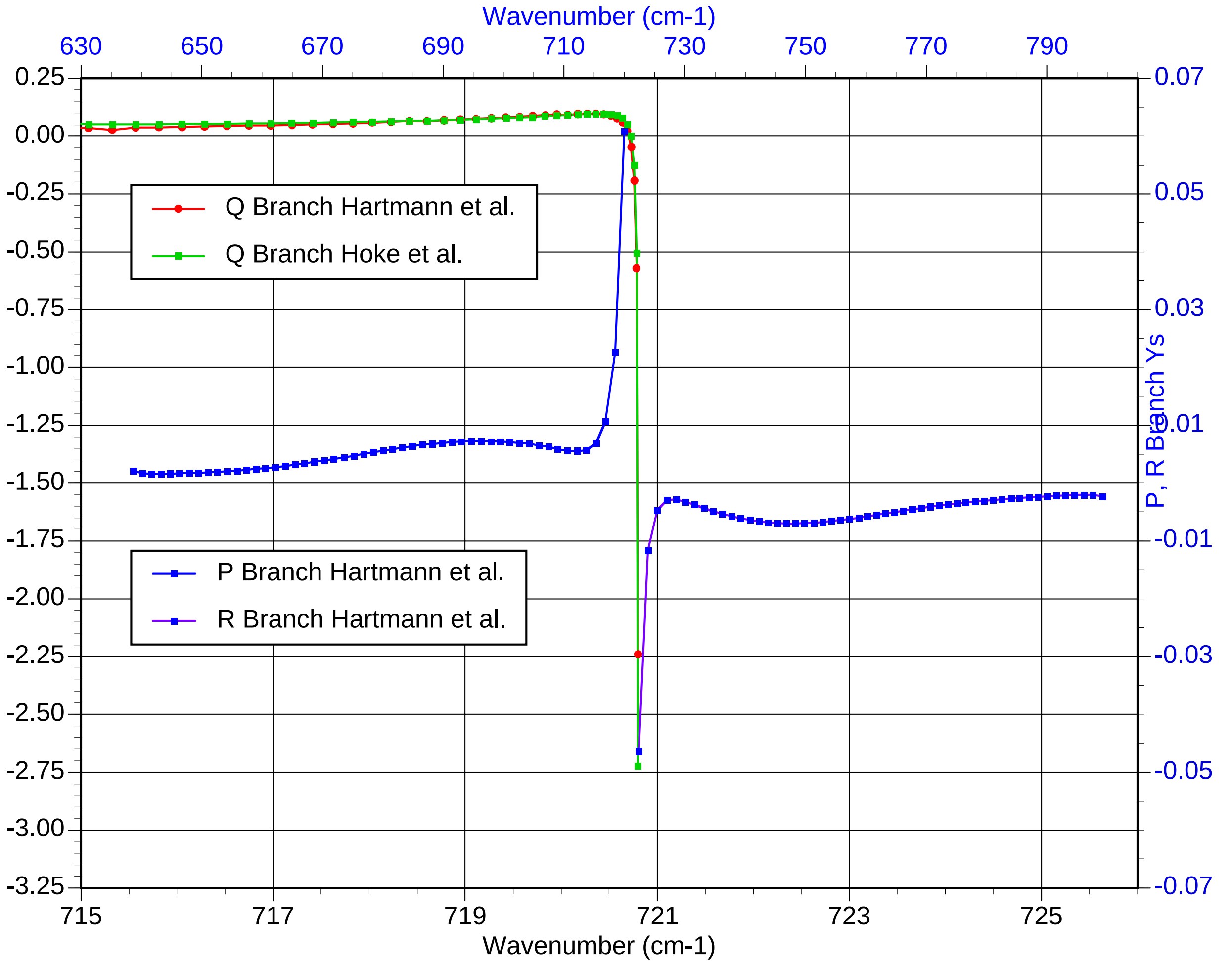
- **Form of correction to line widths:**

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

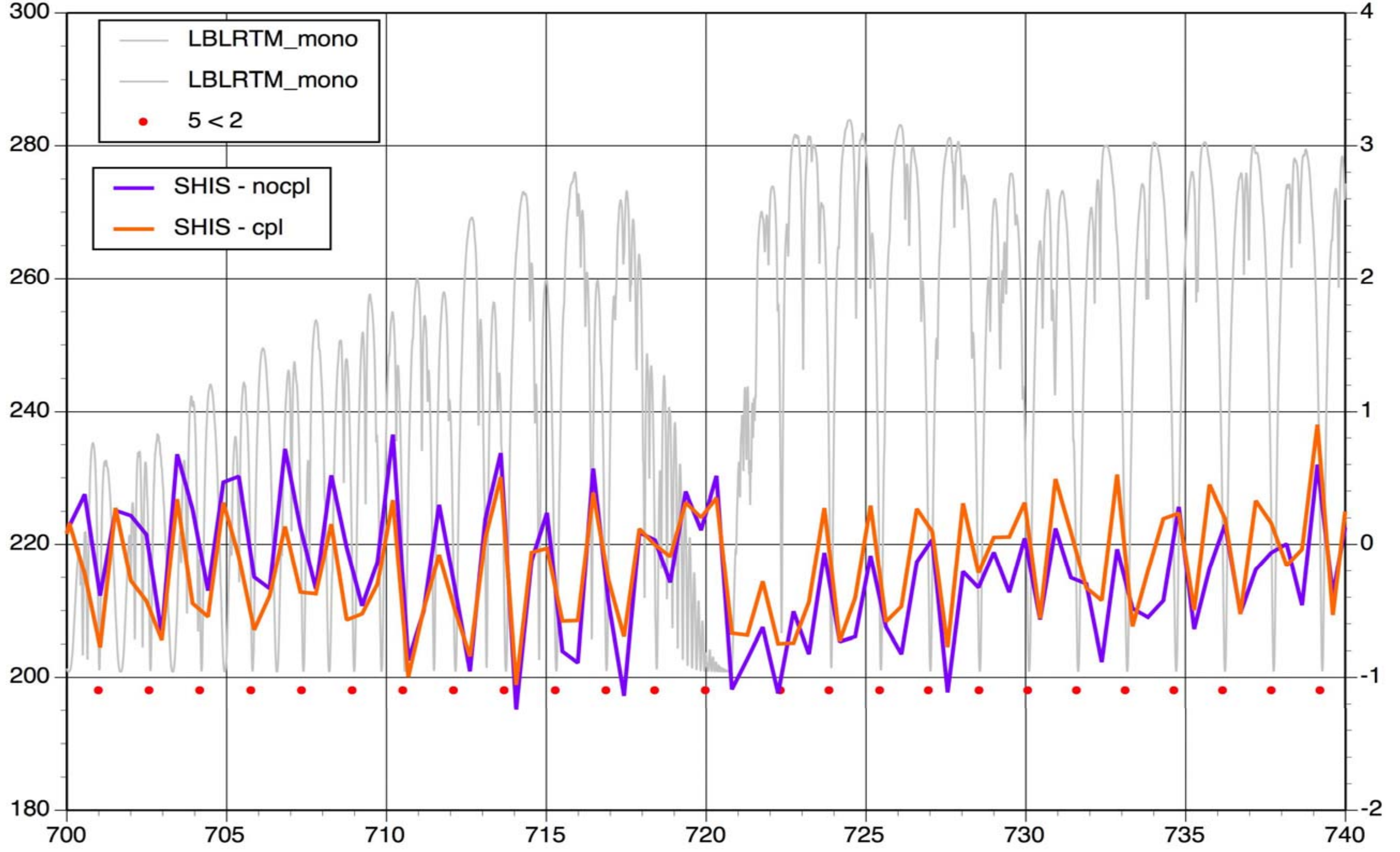
- ***m* is related to the upper state local quantum number.**
- **For the P branch** $m = -J''$ **For the R branch** $m = J'' + 1$

Retrieval parameters: a_0, a_1, a_2, b_0 , b_1

Line Coupling Parameters for the 5 < 2 Band



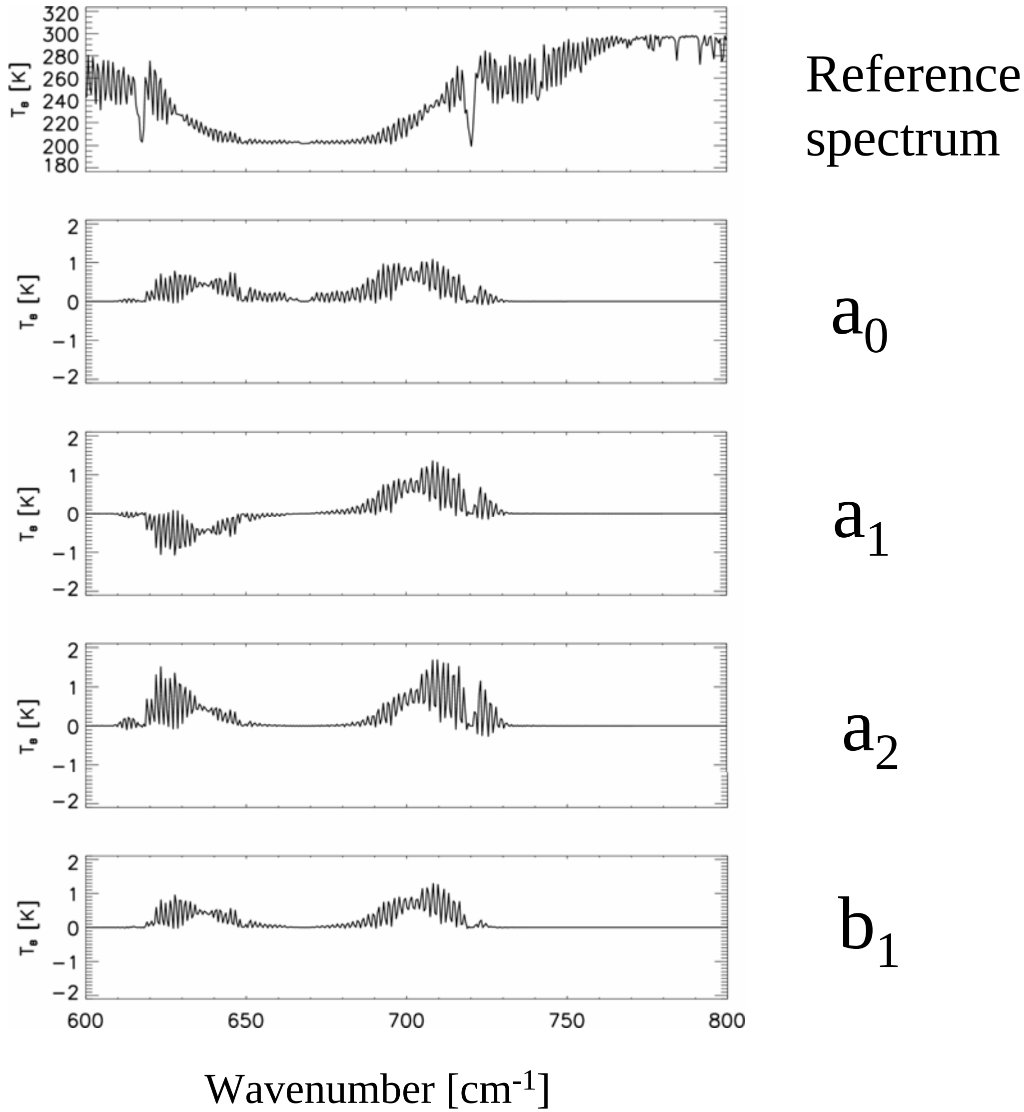
Effect of Line Coupling



Sensitivity Studies (Jacobians)

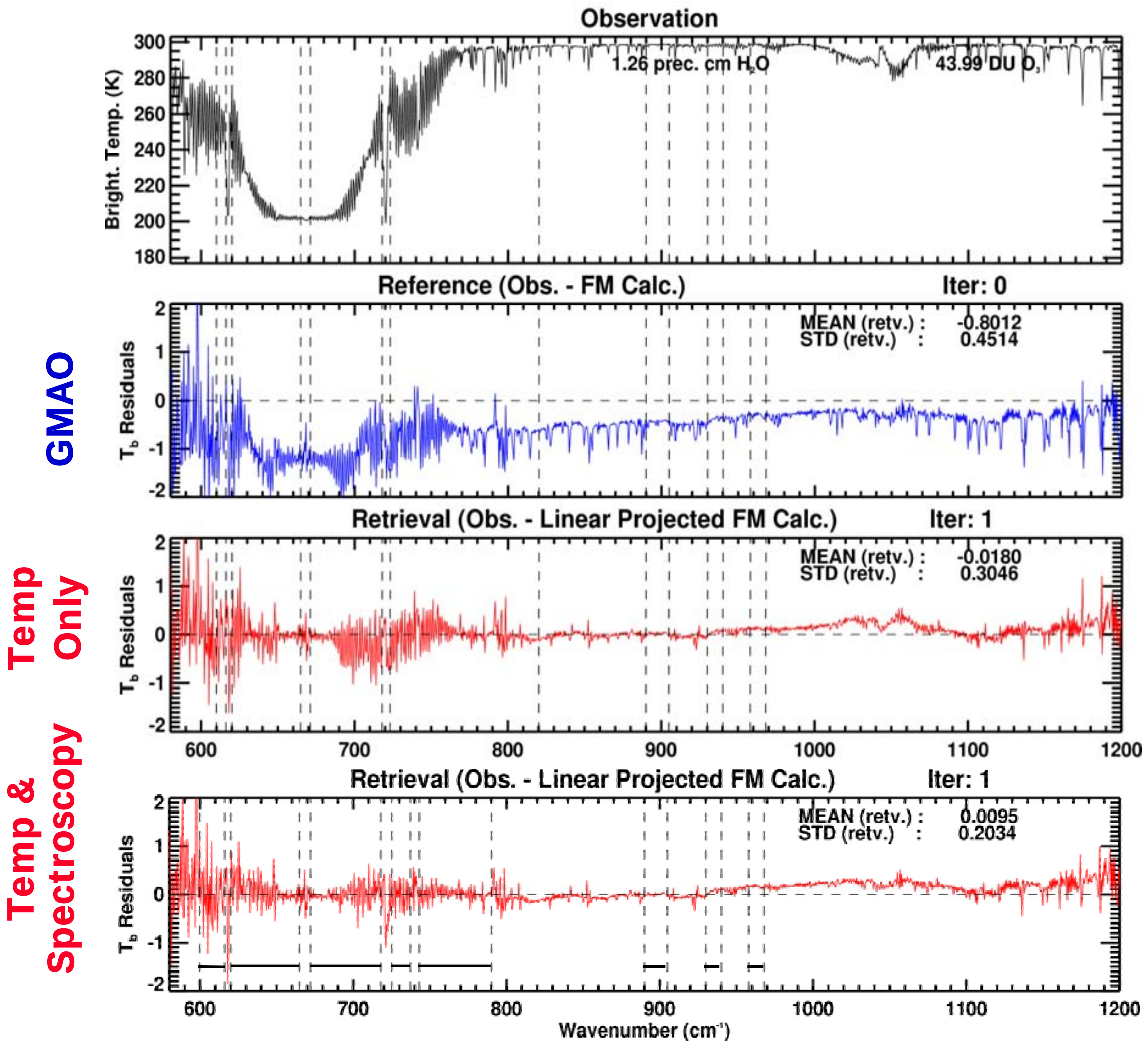
- a_0, a_1, a_2, b_1 perturbed to change intensities/widths in HITRAN line file.
- Values chosen to induce 10% change in intensity/width at J'' ~ 40.
- Perturbation spectra calculated for each parameter, each band.

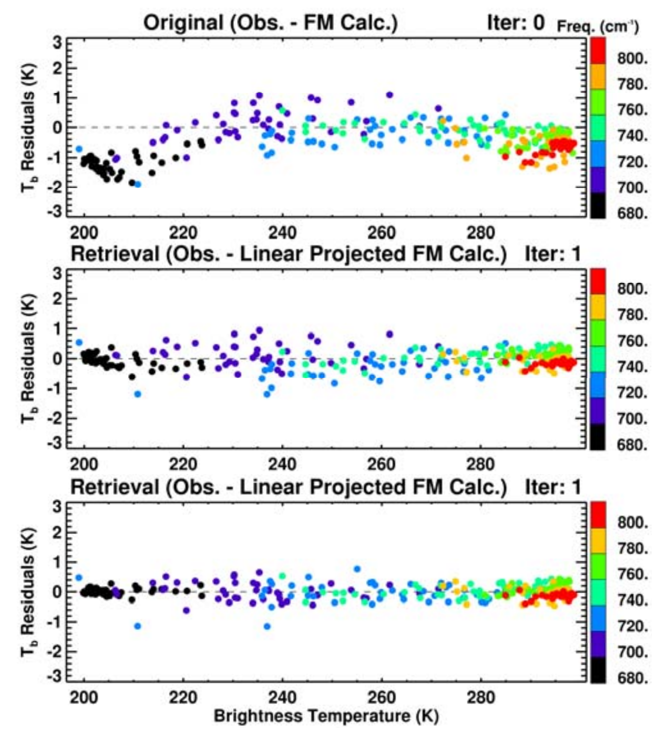
Example: 2←1 band



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

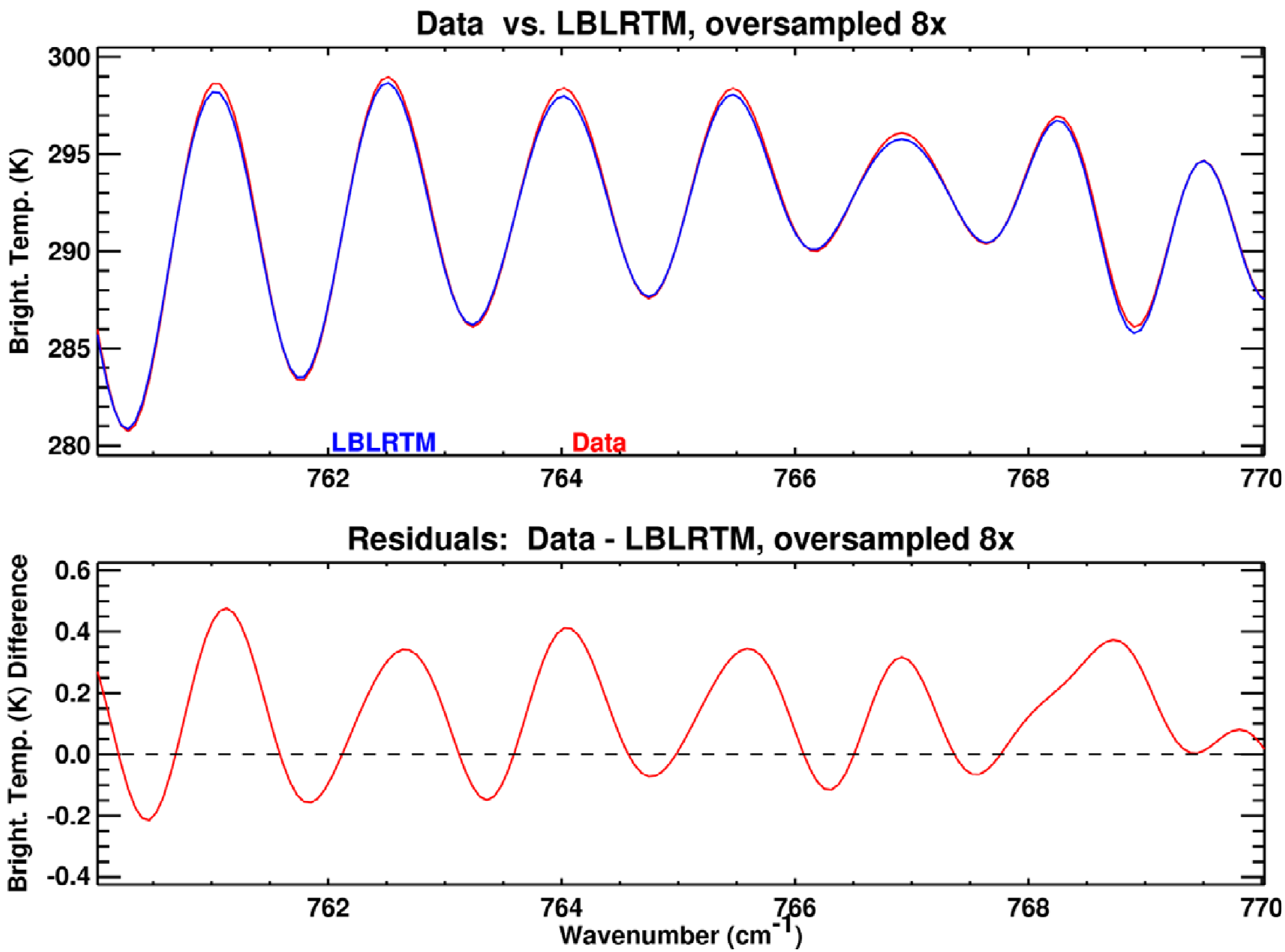




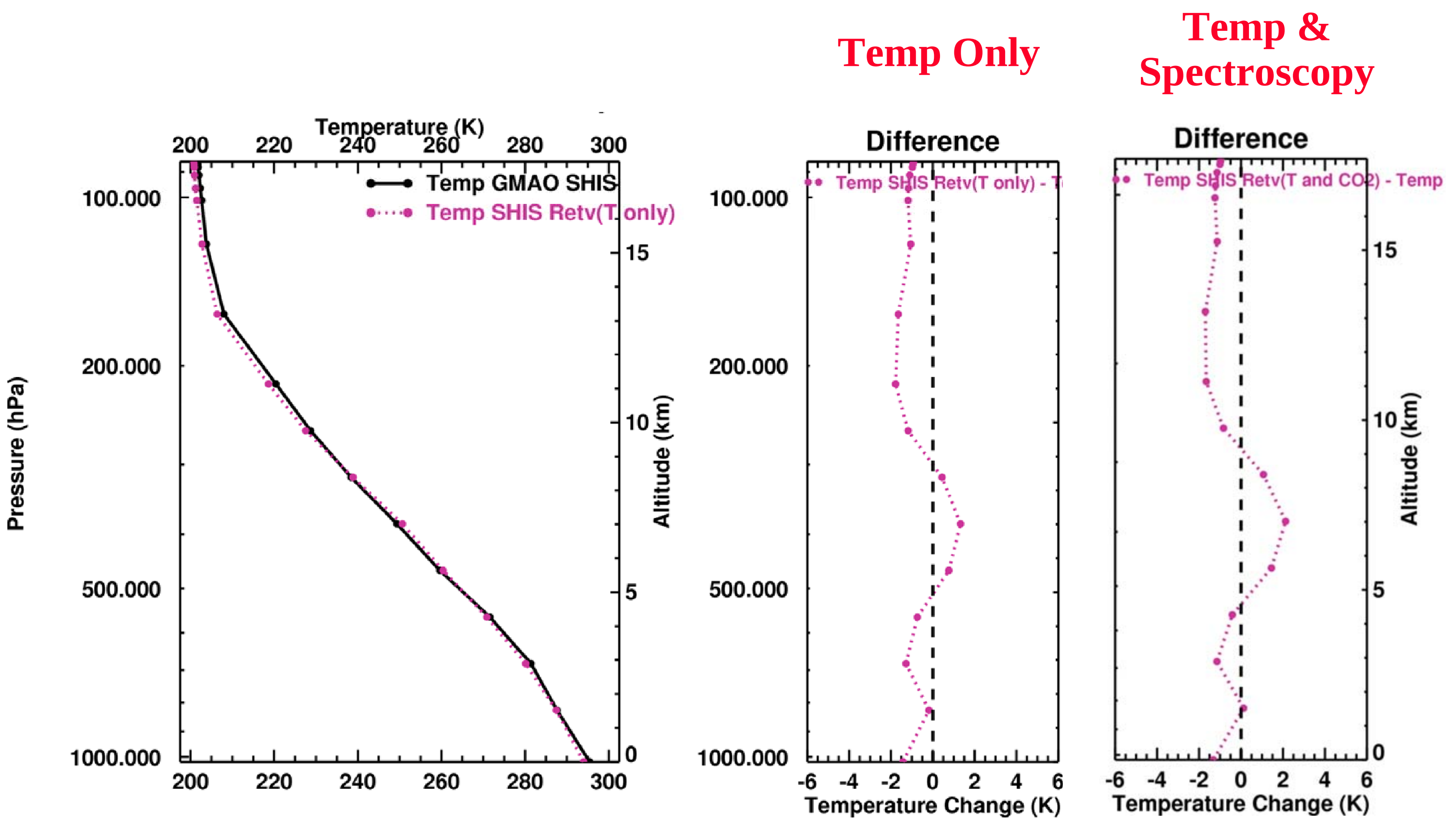
—— Retrieval Spectral Region

Detail View Before Spectroscopy

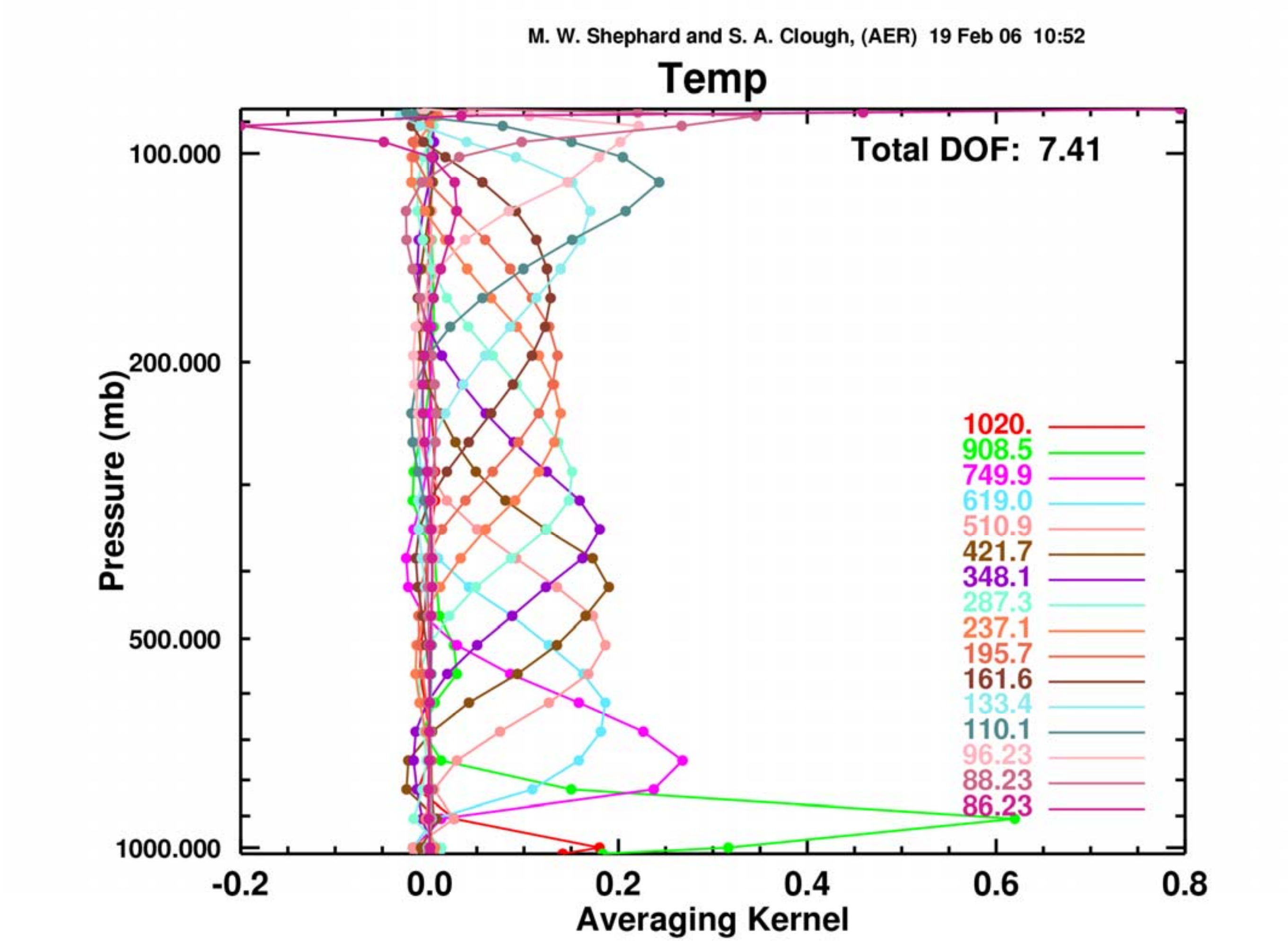
- **Further reduce residuals in the CO2 v2 spectral region**



SHIS AVE Temperature Retrieval Results



Averaging Kernels



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%

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

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

What is 'Truth'?

- **Spectral Residuals are Key!**

- **Consistency within a band system**
  - **Focus of this presentation**

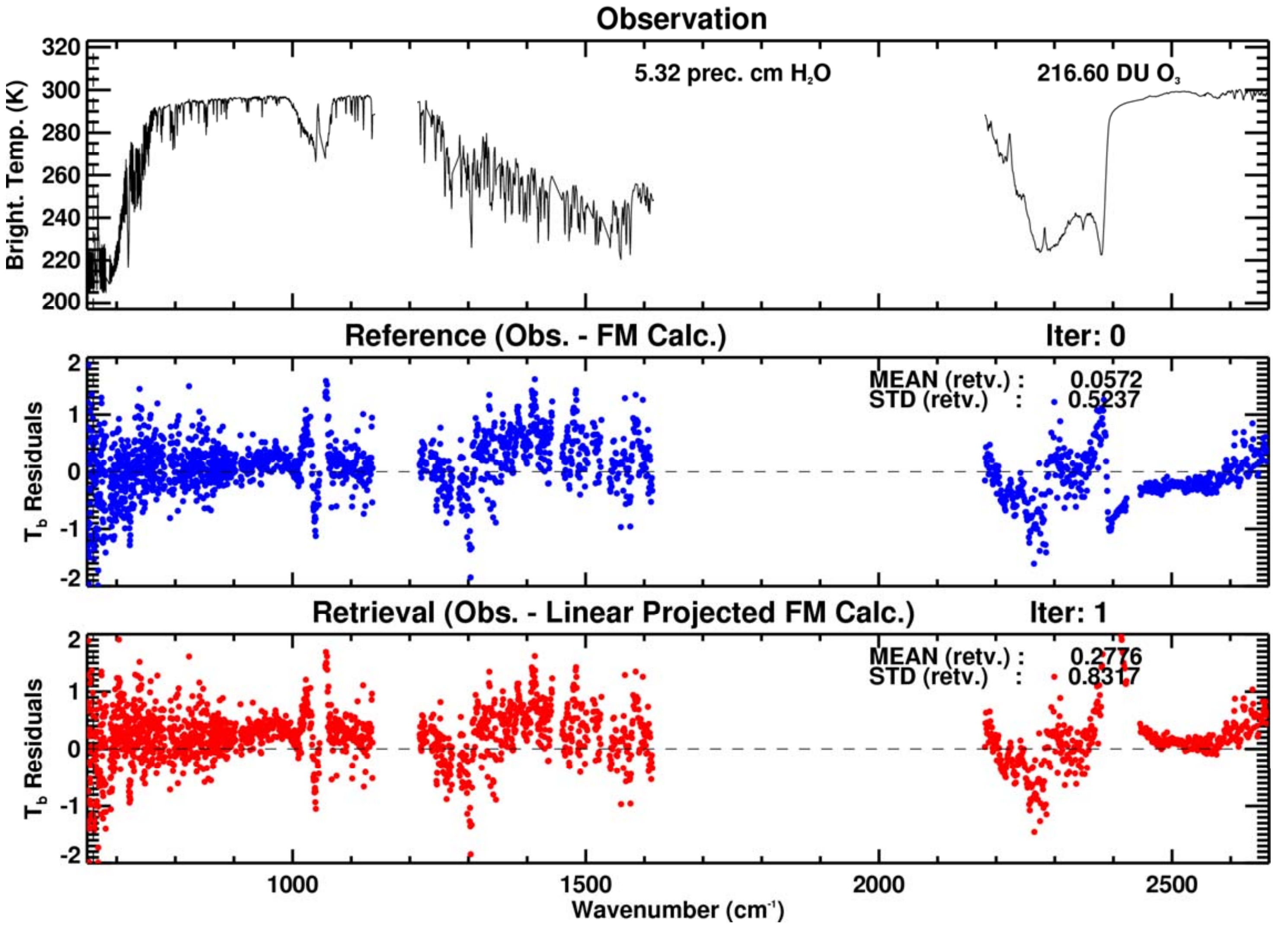
- **Consistency between bands**
  - **AIRS ν_2 and ν_3 bands to investigate consistency for CO_2**

- **Consistency between species**
  - **TES: temperature from O_3 and H_2O consistent with CO_2 ; N_2O**

- **Consistency between instruments**
  - **SHIS**
  - **AIRS**
  - **TES**
  - **MIPAS**
  - **ACE**

AIRS: new spectroscopy

Atmosphere: sonde/adjusted ecmwf



‘Truth’ isn’t ubiquitous- Yet!

- **Spectral Residuals are Key!**

- **Consistency within a band system**
  - **Focus of this presentation**

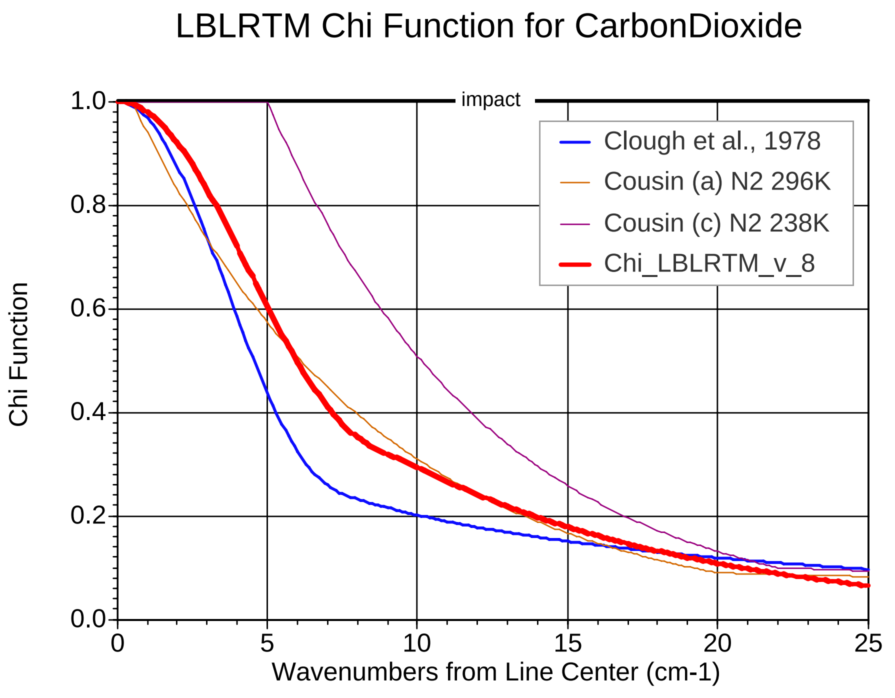
- **Consistency between bands**
  - **AIRS ν_2 and ν_3 bands to investigate consistency for CO_2**

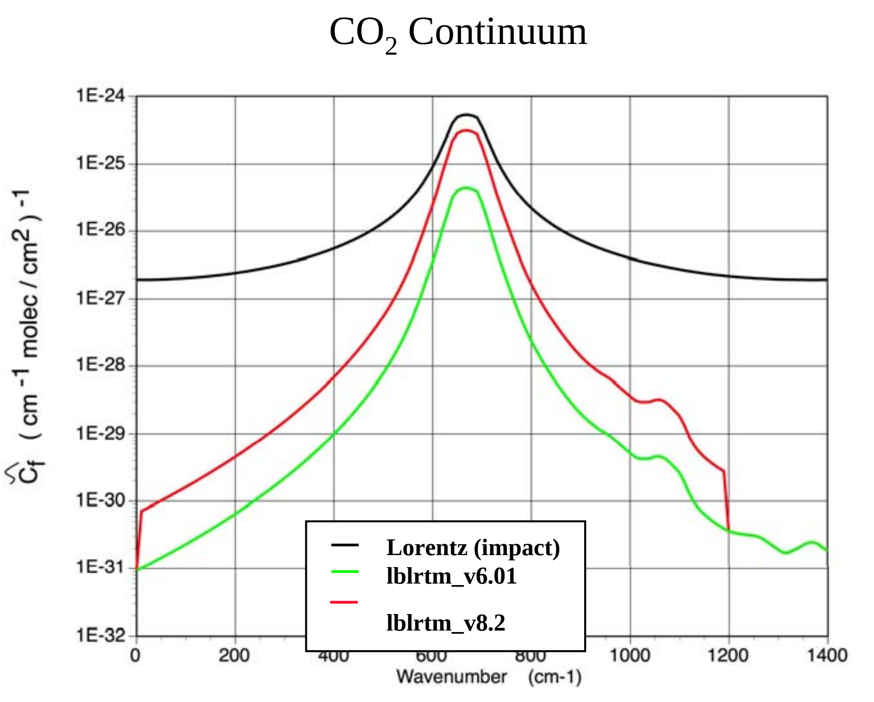
- **Consistency between species**
  - **TES: temperature from O_3 and H_2O consistent with CO_2 ; AIRS: CO_2 , N_2O**

- **Consistency between instruments**
  - **SHIS**
  - **AIRS**
  - **TES**
  - **MIPAS**
  - **ACE**

Back-up slides to follow………

CO_2 Line Shape

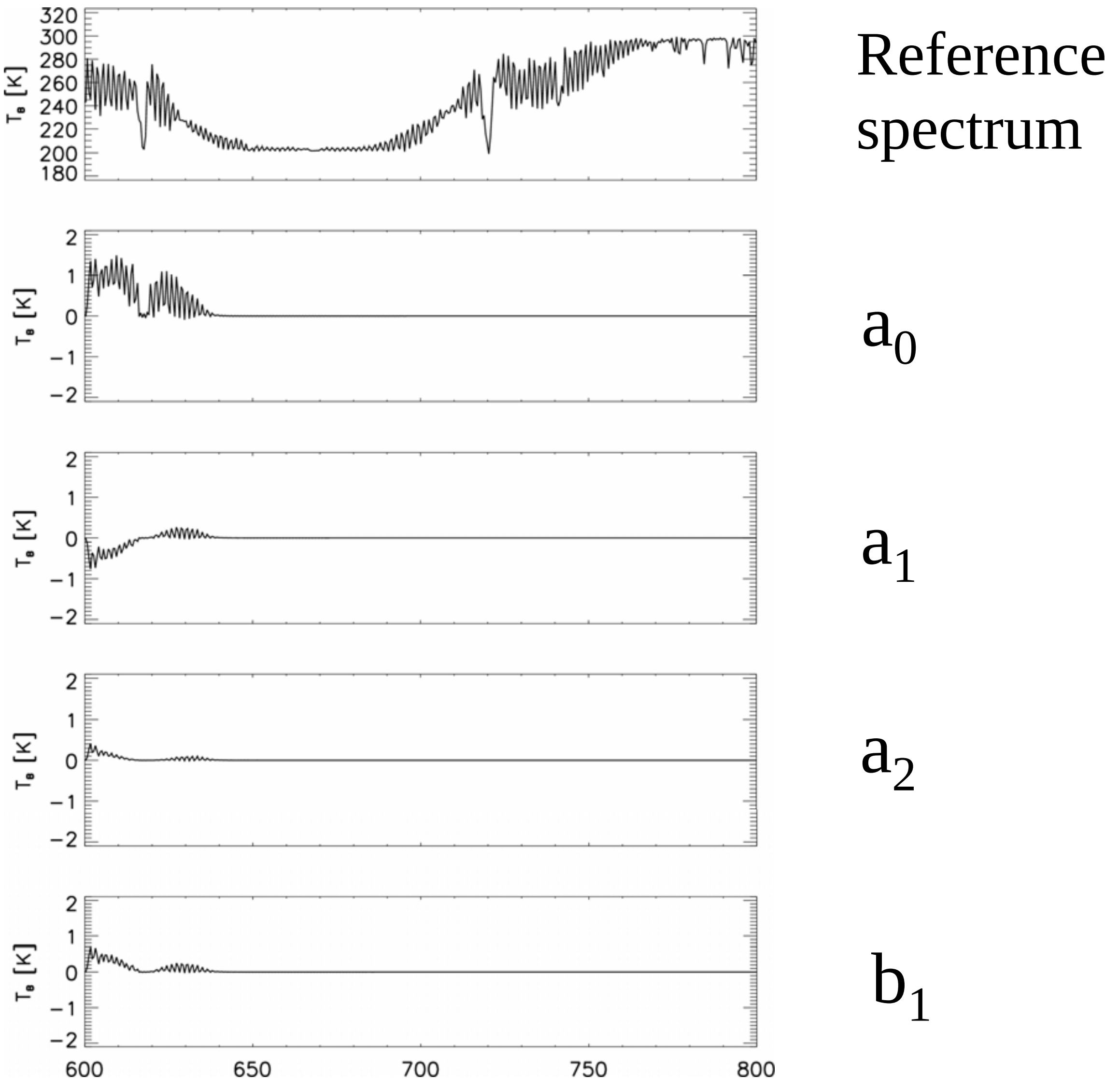




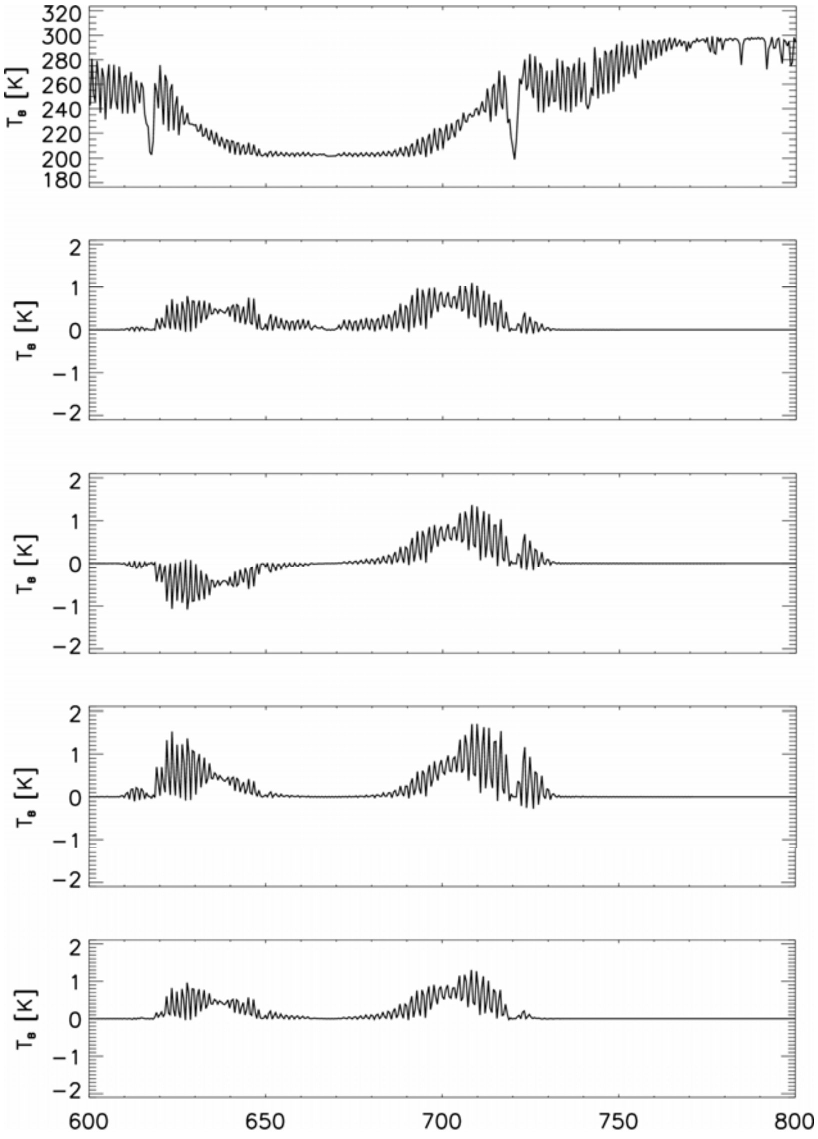
Chi function: The spectral function by which the Lorentz line shape (impact) must be multiplied to obtain the "true" line shape. Sub-Lorentzian chi function accounts for the duration of collision effects.

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

Perturbations to line intensities/widths: 3←2 band



Perturbations to line intensities/widths: 2←1 band



Reference spectrum

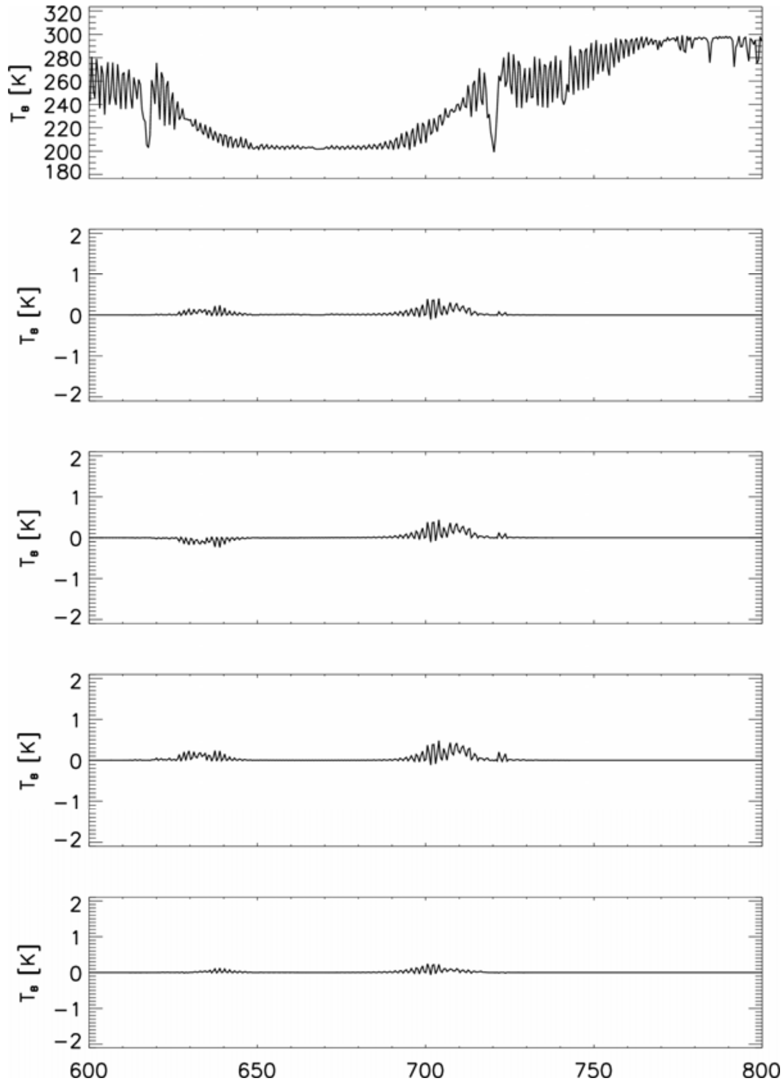
a_0

a_1

a_2

b_1

Perturbations to line intensities/widths: 4←2 band



Reference spectrum

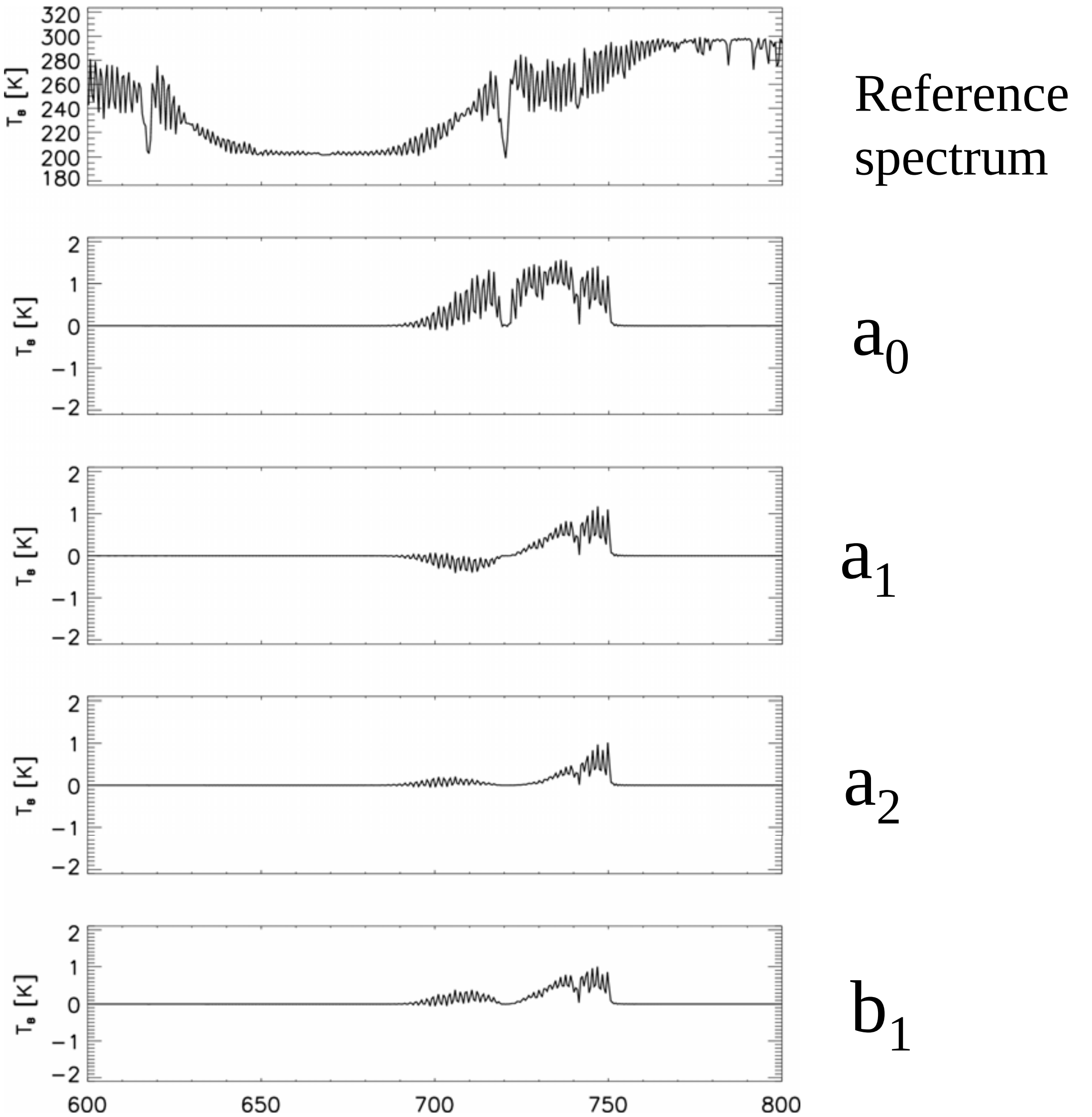
a_0

a_1

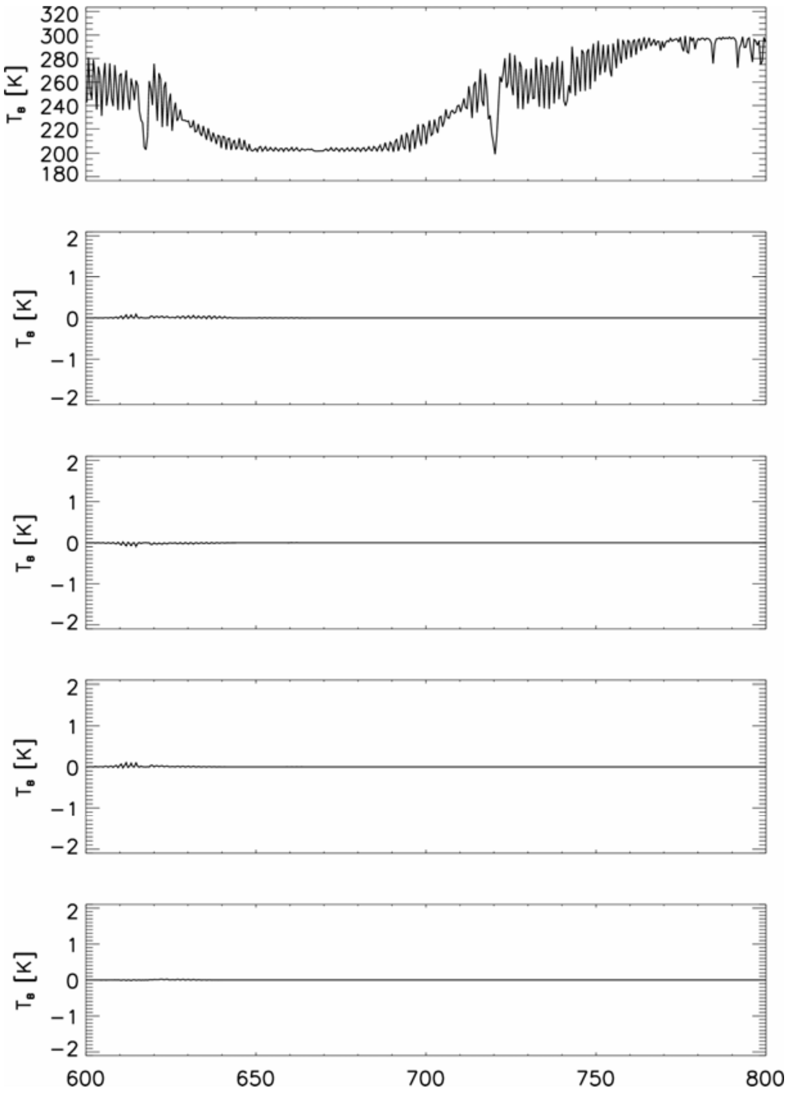
a_2

b_1

Perturbations to line intensities/widths: 5←2 band



Perturbations to line intensities/widths: 6←3 band



Reference spectrum

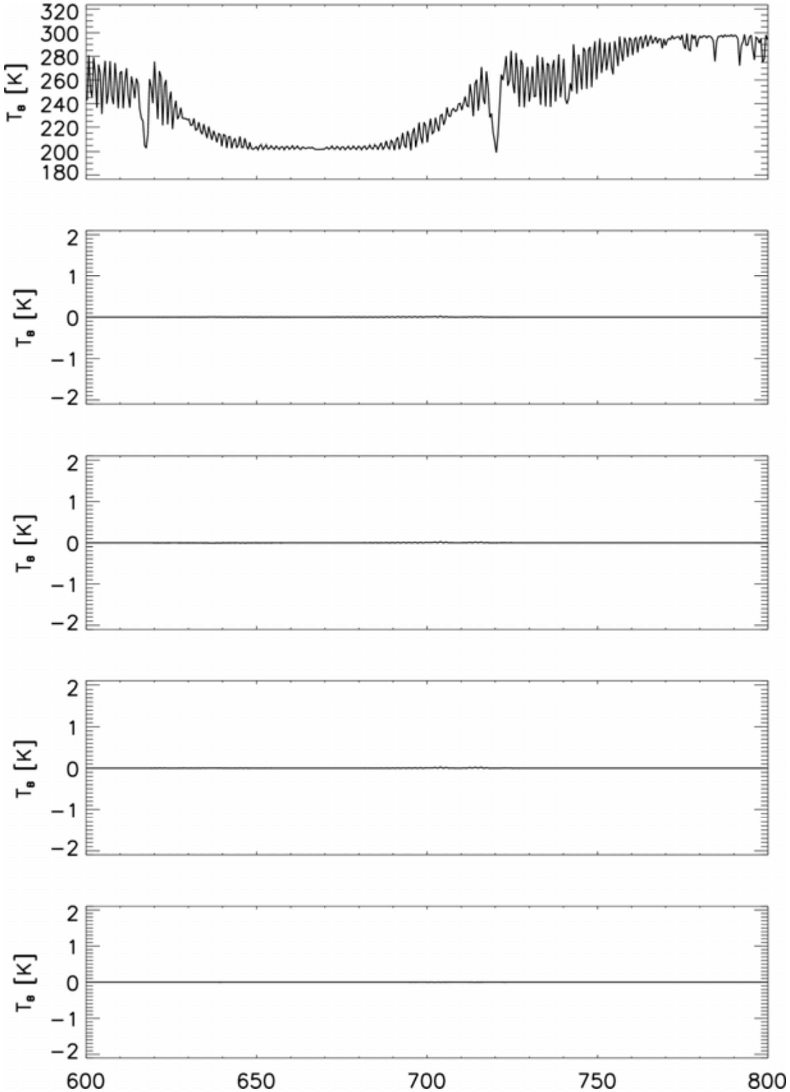
a_0

a_1

a_2

b_1

Perturbations to line intensities/widths: 7←4 band



Reference spectrum

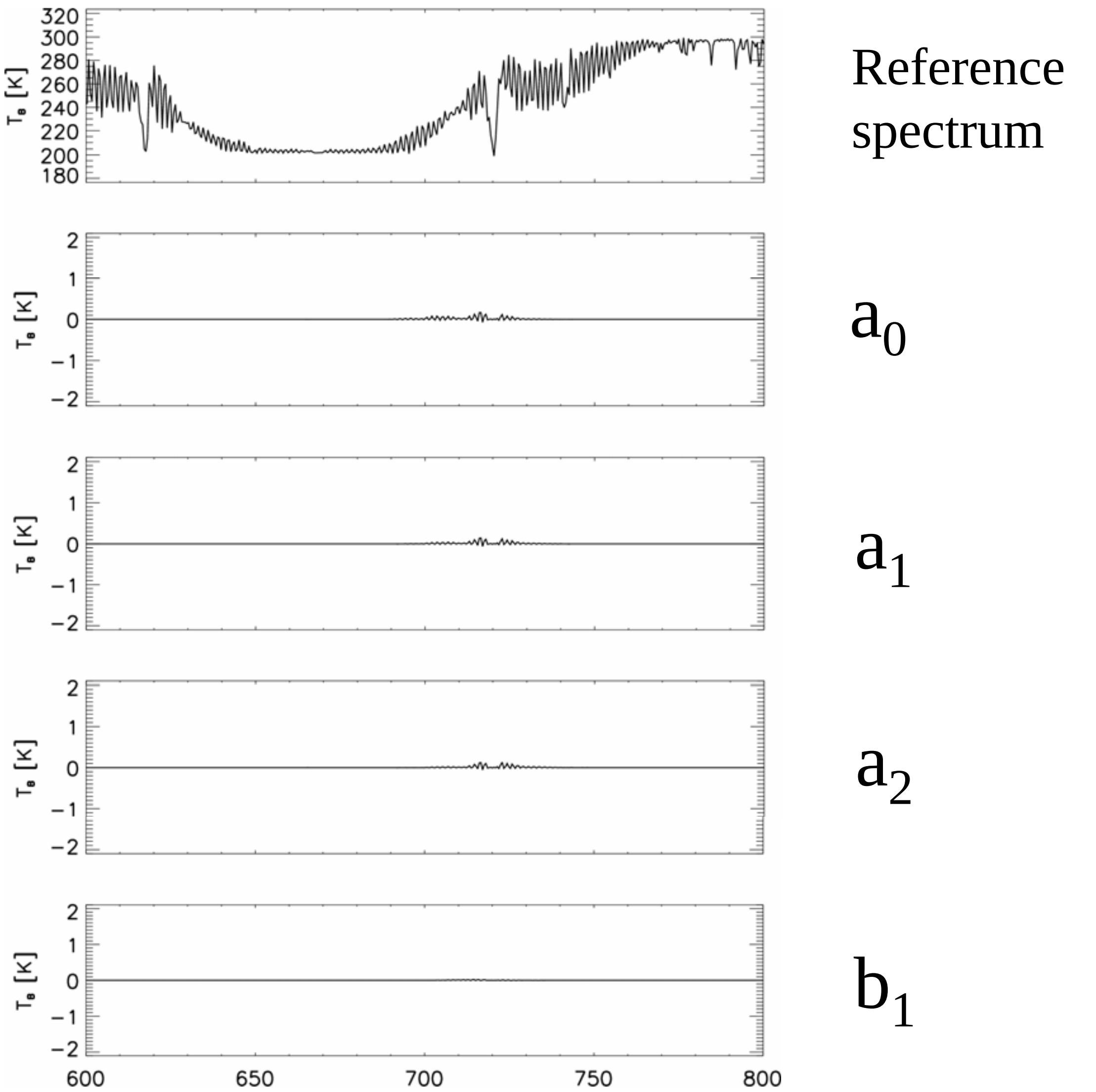
a_0

a_1

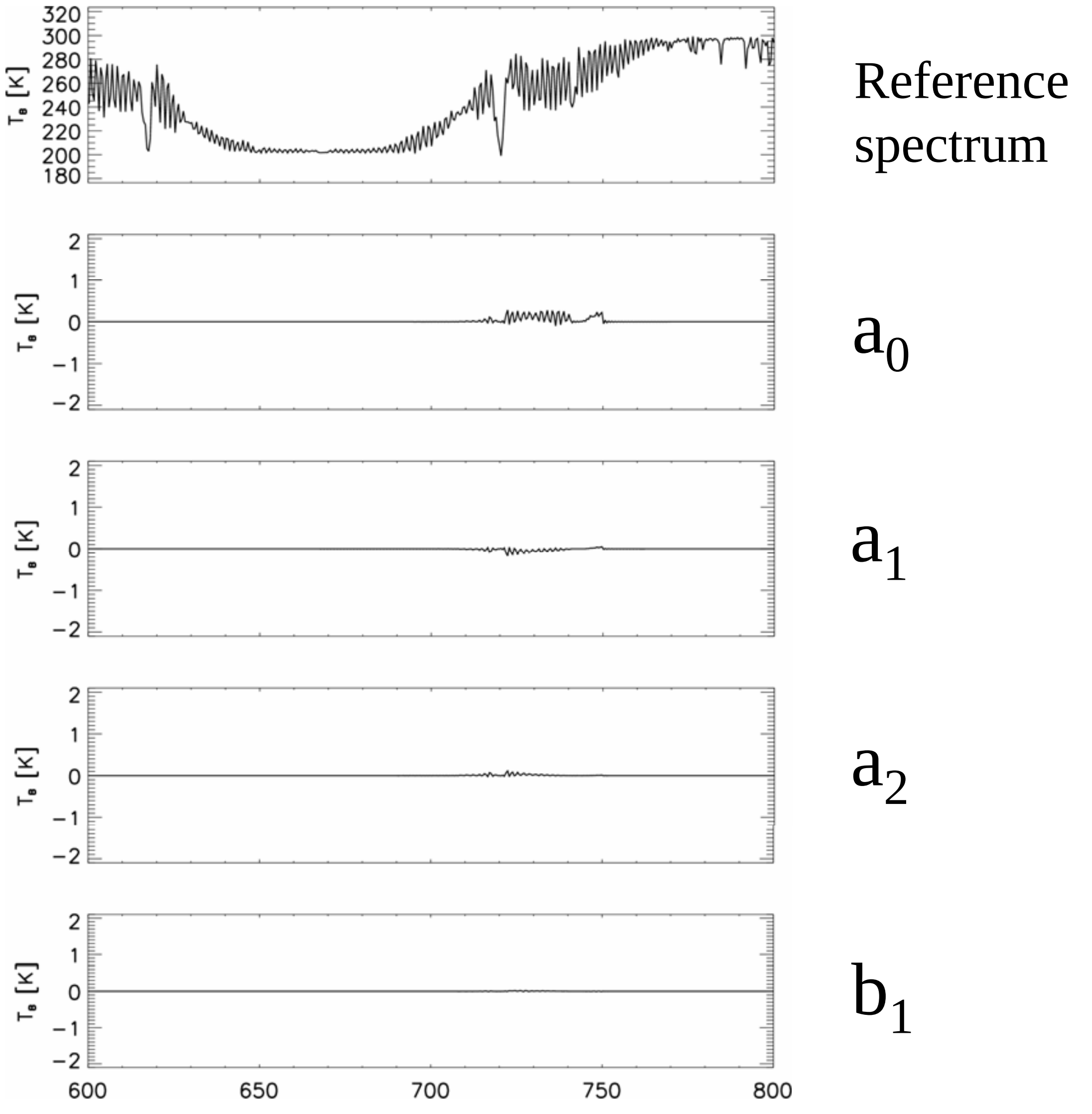
a_2

b_1

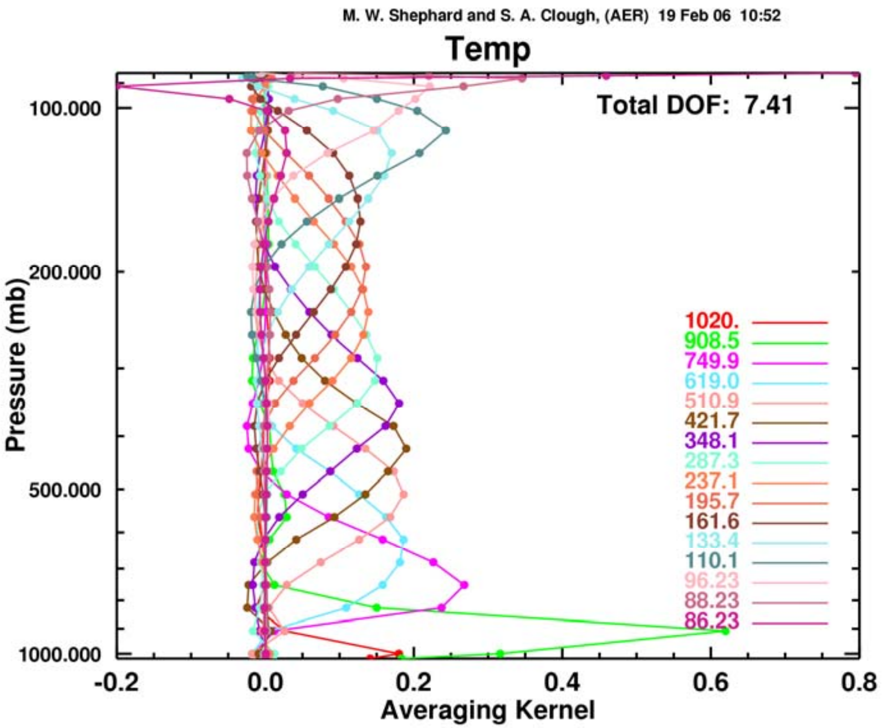
Perturbations to line intensities/widths: 8←5 band

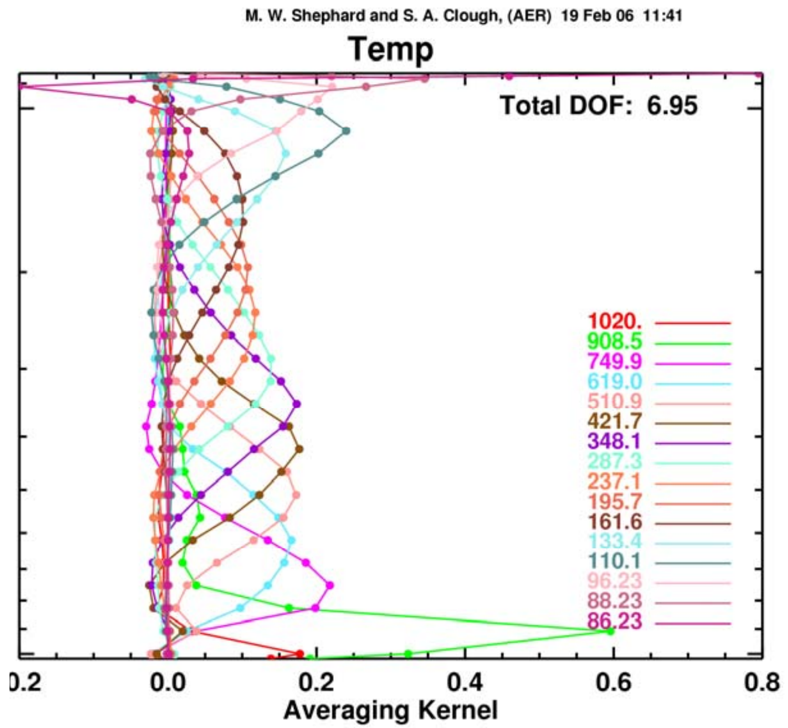


Perturbations to line intensities/widths: 8←4 band

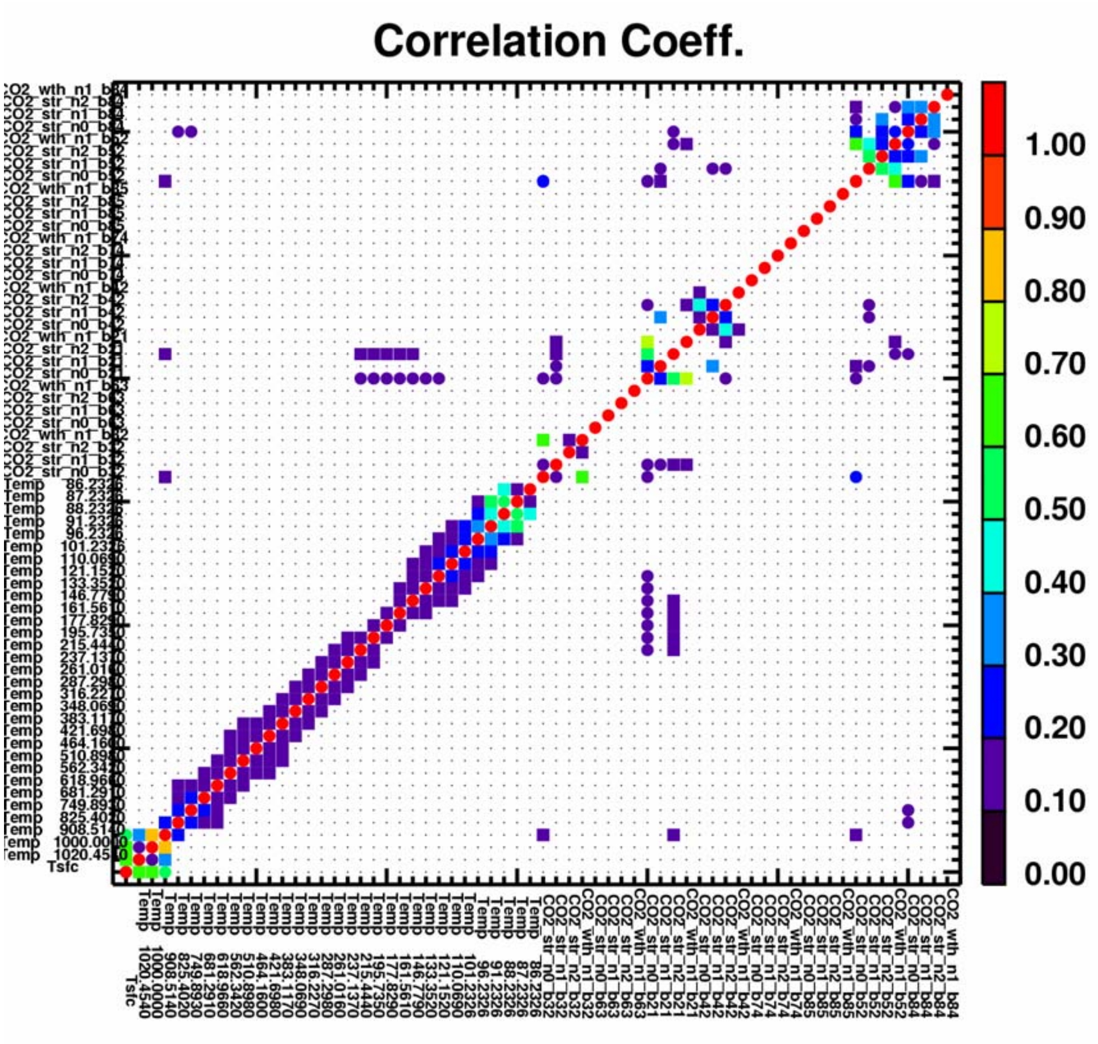


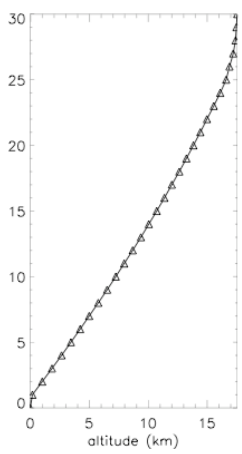
Averaging Kernels

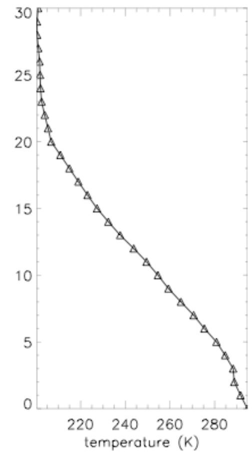




Correlation matrix (H^{-1})







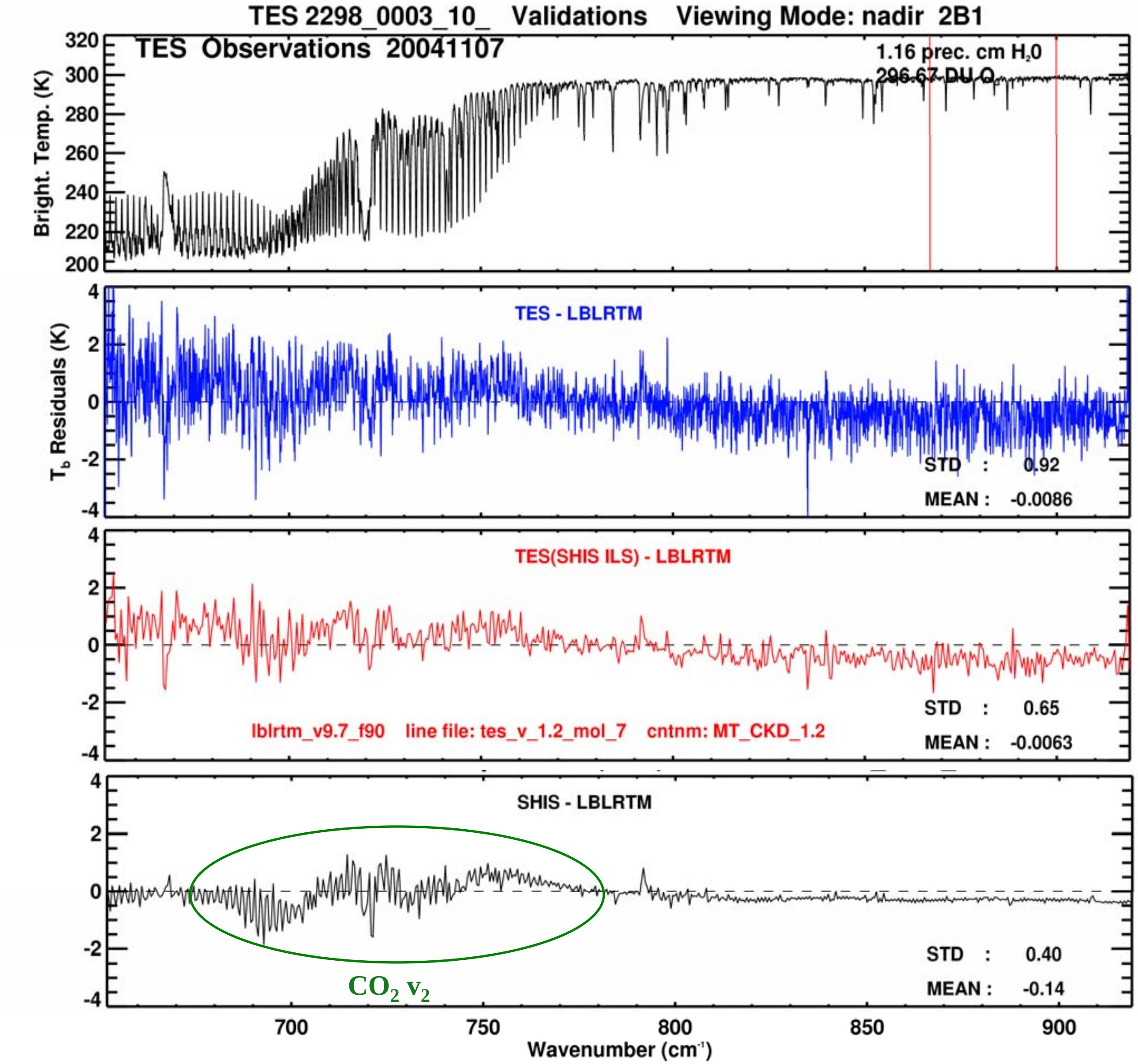
LBLRTM Validation : TES CO_2 v_2 Filter

TES Obs.

TES - LBLRTM

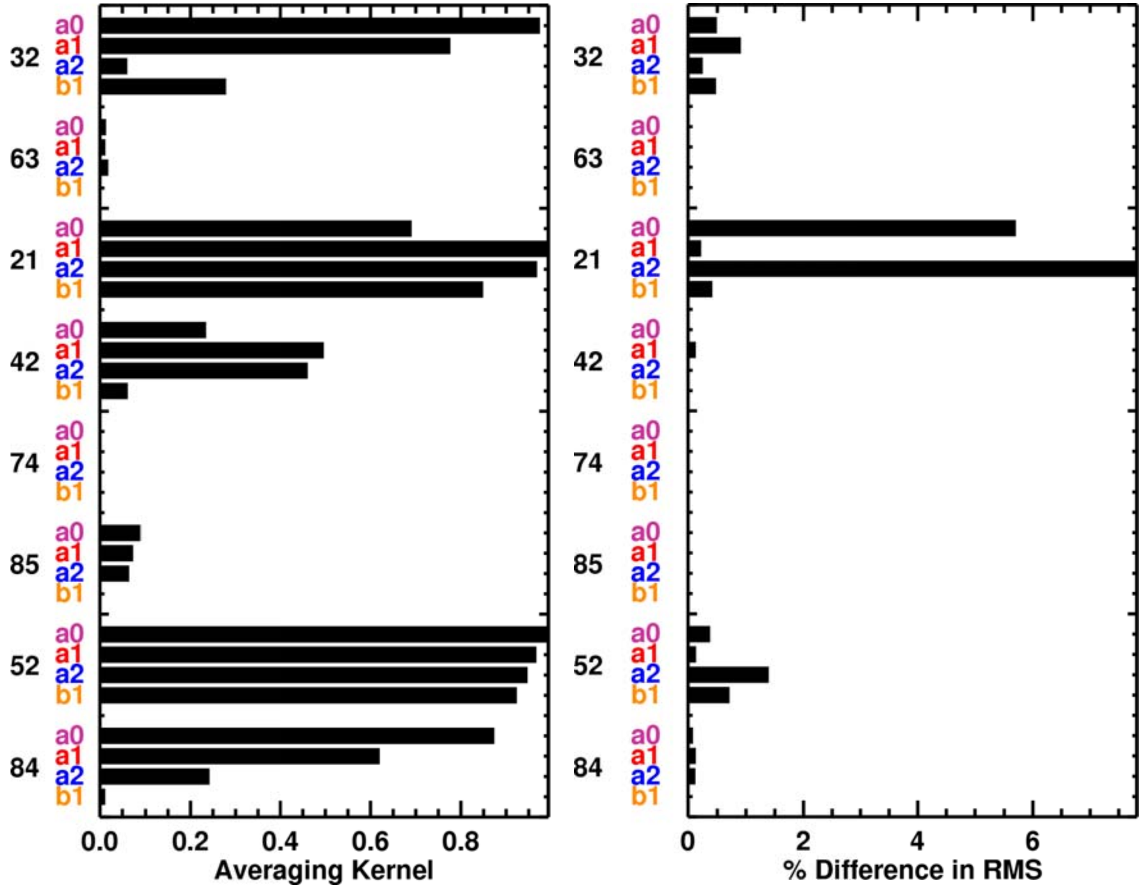
TES(SHIS ILS) - LBLRTM

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



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

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