Implications for ν_2 and ν_3 CO_2 Spectroscopic Parameters from Atmospheric Remote Sensing

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Temperature field must be as accurate as possible for passive infrared atmospheric species retrievals

- **Errors in the Forward Model, including spectroscopy, play a significant role in the retrieval error**
- **The CO_2 ν_2 (600-800 cm^{-1}) and ν_3 (2150 - 2450 cm^{-1}) spectral regions are commonly used for the remote sounding of atmospheric temperature profiles**

What is Truth for Temperature Comparisons?

- **"Truth" at the level required is not readily available**
  - **Radiosonde accuracies; spatial and temporal sampling**
- **Spectral Residuals are Key!**
  - **Consistency within a band system (shown here)**
    - **Forward model improvements across the CO2 v2 band show consistency within a band**
  - **Consistency between bands (shown here and present work)**
    - **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 CO2 and N_2O**
  - **Consistency between instruments**
    - SHIS - AERI
    - AIRS - ACE
    - TES - MIPAS

Instruments Used in Comparisons

- **AERI Atmospheric Emittance Radiometric Interferometer**
  - U. of Wisconsin — Interferometer
  - Downwelling Radiance — ARM/Surface — Resolution: 0.5 cm^{-1}
- **(S)HIS (Scanning) High-resolution Interferometer Sounder**
  - U. of Wisconsin — Interferometer
  - Upwelling Radiance — ER-2/WB-57 — Resolution: 0.5 cm^{-1}
- **TES Tropospheric Emission Spectrometer**
  - JPL — Interferometer
  - Upwelling Radiance — AURA — Resolution: 0.06 cm^{-1}
- **AIRS Atmospheric InfraRed Sounder**
  - JPL/NASA — Grating Array
  - Upwelling Radiance — AQUA — Resolution: 0.5 - 2 cm^{-1}

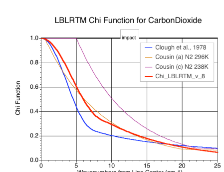
Forward Model (Including Spectroscopy)

LBLRTM

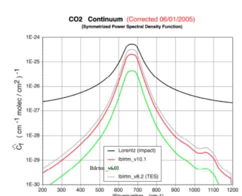
- **Input Atmospheric State**
  - **Radiosonde and NWP profiles (GMAO)**
  - **Surface parameters**
- **Layer Optical Depths**
  - **Line Shape:**
    - CO2 has a sub-Lorentzian line shape that accounts for duration of collision effects

$$k_i(\nu) = \frac{1}{\pi}\frac{S_i}{(\nu-\nu_i)^2+\alpha_i^2}\left[\chi(\nu-\nu_i)\right]$$

Lorentz — χ_i*: duration of collision*



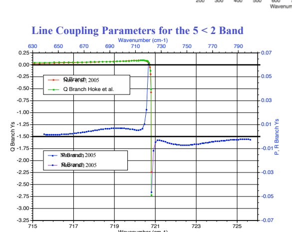
  - **CO2 Continuum:**
    - Line contributions 25 cm^{-1} beyond line center
    - LBLRTM_v9.4 : MT_CKD_1.2
    - LBLRTM_v10.1: MT_CKD_1.3 (based on retrieved results shown below)

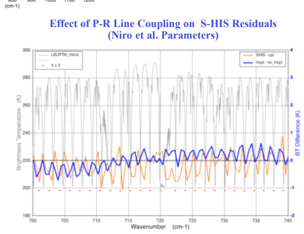


  - **CO2 Line Coupling (Mixing)**
    - Implemented CO2 v2 P/R branch line coupling (Niro et al., 2005)

$$k_i(\nu) = \frac{1}{\pi}\frac{S_i}{(\nu-\nu_i)^2+\alpha_i^2}\left[1+y_i(\nu-\nu_i)\right]$$

Lorentz — y_i*: line coupling coefficient*





  - **Spectroscopic Line Parameters:**
    - tes_v_1.2 -> CO2 parameters from HITRAN2000
    - tes_v_1.3 -> tes_v_1.3 modified with retrieved parameters (see below)
- **Radiative Transfer**
- **Instrument Function**

Physical Retrieval of CO_2 ν_2 Parameters

The form of the retrieved CO_2 parameters reflect the underlying physics (semi-empirical)

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

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

- **Hermann-Wallis-type parameters (i.e. a_1 and a_2)** (e.g. Rothman et al., 1992)
  - Accounts for the dependence on the upper state rotational quantum number *J*
    P-Branch : *m = -J* R-branch : *m = J + 1*
- **Simple scaling parameters (a_0 and b_0)**

Table of Retrieved Semi-Empirical Line Parameter Modifications

Band	Band center (cm^{-1})	Retrieved CO_2 Parameters: Parameter		Retrieved Value	Resultant change at J=40
2 1	667.38	Intensity	a_0 a_1 a_2	+0.01 +0.0002 -0.00002	-3%
		Width	b_0 b_1	+0.03 +0.0003	+4%
5 2	720.81	Intensity	a_0 a_1 a_2	-0.008 -0.0004 0.000004	-5%
		Width	b_0 b_1	+0.004 +0.0004	+2%
All Bands in v2		CO_2 Continuum	4.5x		
		Implemented			
3 2, 2 1, 5 2, 8 4		P/R Line Coupling	Niro et al., 2005		

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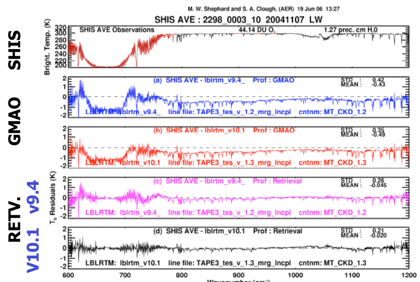
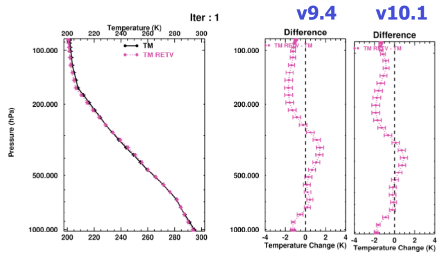
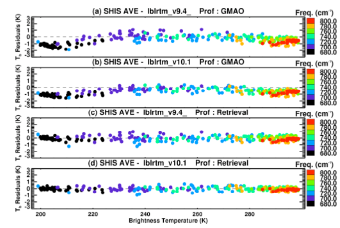
LBLRTM Comparisons With Observations (CO2 ν_2 Band)

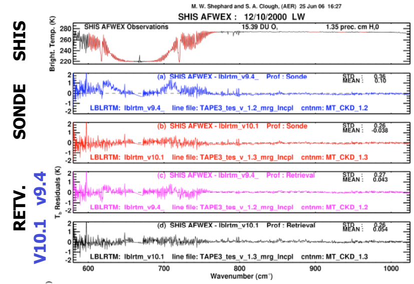
Impact on Temperature Retrievals

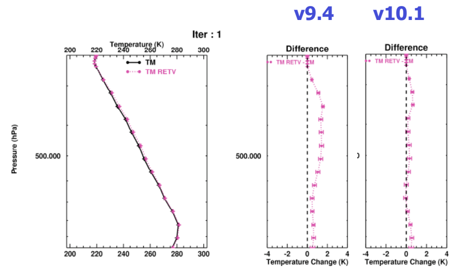
Scatter plots of Brightness Temperature vs. Residuals (Obs - Calc.) binned in 20 cm-1 intervals from the CO_2 ν_2 region

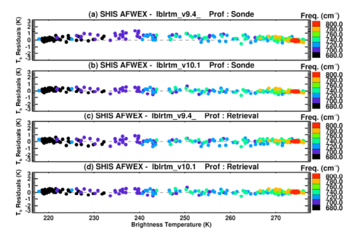


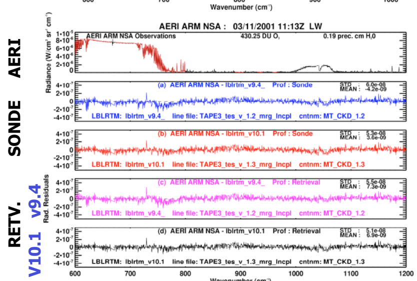


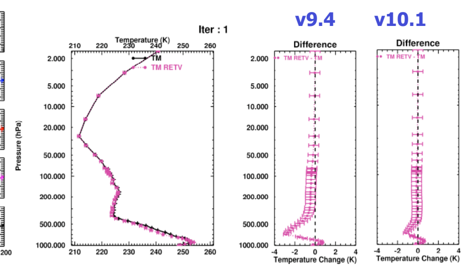






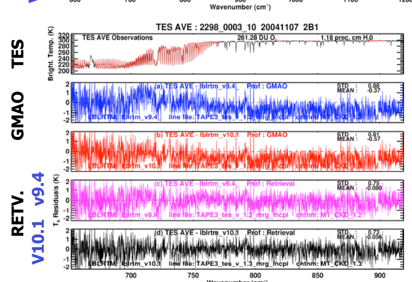


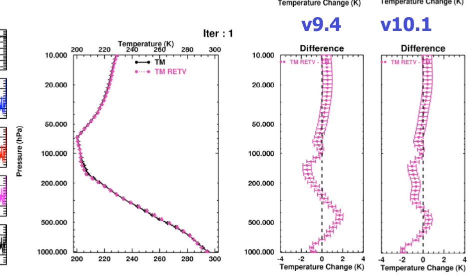




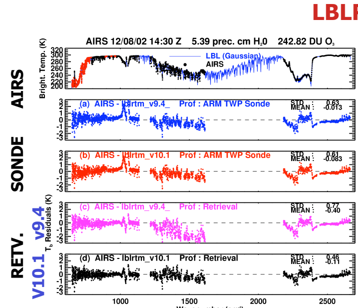
General Remarks on CO2 ν_2

- **LBLRTM_v10.1 :**
  - Implementation of P/R branch line coupling
  - Retrieval of a new CO2 continuum
  - Retrieval of CO2 line intensities and widths
    - tes_v_1.3
- **LBLRTM_v10.1 with tes_v_1.3 show an improvement in Obs. - LBLRTM residuals in the CO_2 ν_2**
- **This improvement impacts the temperature retrievals ~1-2 K in the troposphere**

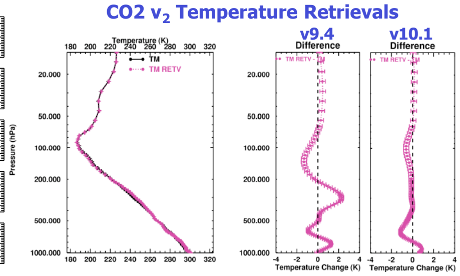




LBLRTM Comparison with Observations (CO_2 ν_2 and ν_3)

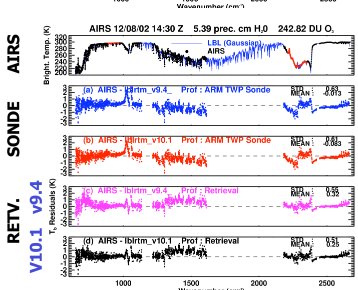


CO2 ν_2 Temperature Retrievals



General Remarks on CO_2 ν_2 and ν_3

- **The CO_2 ν_2 region improvements made to LBLRTM_v10.1 and tes_v_1.3 provide more consistency between the CO_2 ν_2 and ν_3 spectral regions, and thus the retrieved temperature profiles**
- **However, the CO2 ν_2 and ν_3 still are not consistent….Yet!**
- **Start working on the CO_2 ν_3 spectral region in conjunction with the CO_2 ν_2 region:**
  - Implement P/R line coupling in the CO_2 ν_3 spectral region
  - Further investigate the χ factor and continuum by taking into consideration both CO_2 ν_2 and ν_3



CO2 ν_3 Temperature Retrievals