Performance of the line-by-line radiative transfer model (LBLRTM) for satellite retrievals of temperature and water vapor: Recent spectroscopy updates evaluated using IASI case studies

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Joint Center for Satellite Data Assimilation Workshop
October 10, 2012

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 Research supported by JCSDA external research program through NASA contract NNH11CD78C – "Maintaining High Quality Spectroscopy for the Community Radiative Transfer Model"

Poster Alert

P19. Development of an OSS version of the CRTM (CRTM-OSS)

J.-L. Moncet – AER

Improving Spectroscopy for Satellite Data Assimilation

- **Satellite data assimilation depends on accurate IR spectroscopy**
  - Reducing uncertainties in spectroscopic line parameters and continua is critical to improving the use of satellite data in numerical weather prediction (NWP) and climate models.
- **AER's Line-by-Line Radiative Transfer Model (LBLRTM, Clough *et al.,* 2005)**
  - Traces its heritage to FASCODE, developed for Air Force by Clough and collaborators
  - Reference standard for model intercomparisons in the thermal IR (*e.g.*, CCMVal, CIRC)
  - Basis of retrieval algorithms for AERI, IASI, and TES
  - Used to train fast models in the Joint Center for Satellite Data Analysis Community Radiative Transfer Model (*e.g.*, OPTRAN, OSS)
- **Here we present the results of a rigorous validation of recent spectroscopic updates to LBLRTM against a global dataset of 128 near-nadir measurements from IASI.**
  - Expands JAIVEx study of Shephard *et al*., ACP, 2009
- **We compare the performance of LBLRTM v12.1 to a previous version (LBLRTM v9.4+) to test the impact of the latest updates to the line parameters and the CO_2 and H_2O continua (including the addition of P- and R-branch line coupling for CO_2).**

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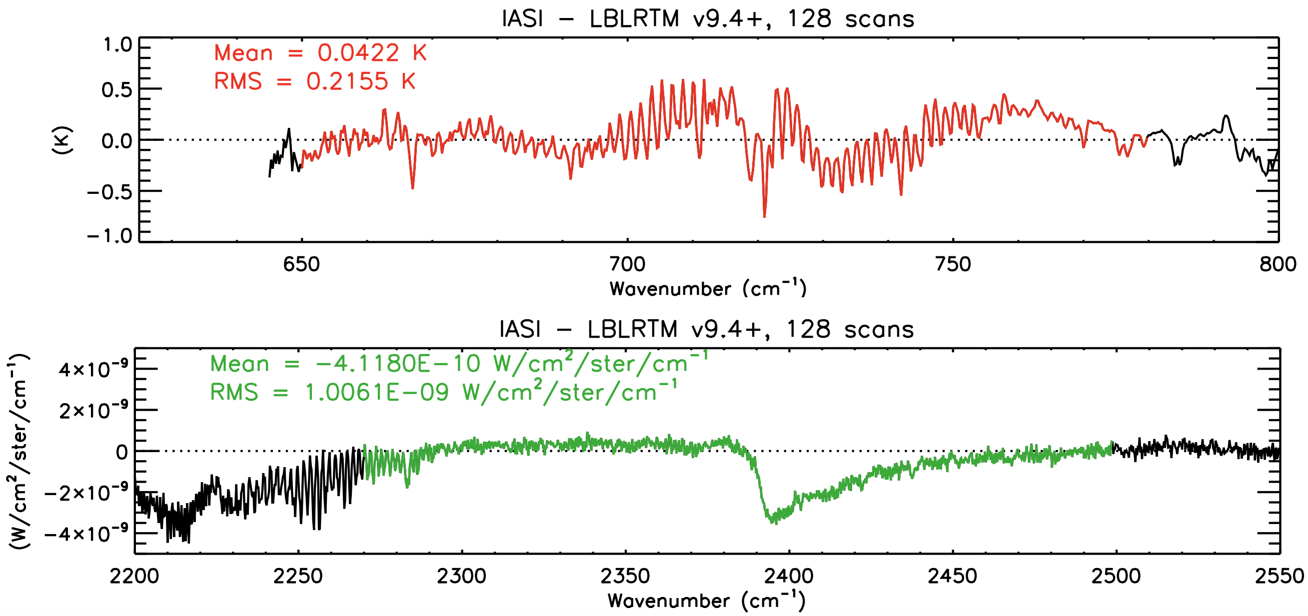
Spectroscopy in LBLRTM v9.4+
(released January 2005)

HITRAN 2000 (Rothman *et al*., 2003) along with:

- **CO_2** Q-branch line coupling based on Hoke *et al*. (1989) and Strow *et al*. (1994).
- **CH_4** (922.65-1678.33 cm^{-1}) and **CO** supplied by Linda Brown (JPL)
- **O_3** from Wagner *et al*., 2002.
- **MT_CKD v1.2 Continuum**

LBLRTM v9.4+ had significant problems in the CO_2 ν_2 band (top) as well as at the ν_3 bandhead (bottom).



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Spectroscopy in LBLRTM v12.1
(released November 2011, available at rtweb.aer.com)

HITRAN 2008 (Rothman *et al*., 2009) along with:

- **CO_2**
  - Lamouroux *et al*. (2010) first order line coupling parameter (P-,Q-, and R-branches).
  - Line intensities and positions (597-2500 cm^{-1}) from the Carbon Dioxide Spectral Database (Tashkun *et al*., 2003; Flaud *et al*., 2003).
- **H_2O**
  - Positions and intensities (10-2500 cm^{-1}): Coudert *et al*. (2008).
- **CH_4**
  - HITRAN 2008 with first-order line coupling for ν_4 and ν_3 bands: Tran *et al*., 2006
- **MT_CKD v2.5.2 Continuum**
  - Updates to CO_2 and self-broadened H_2O in the 2400 cm^{-1} region: Mlawer *et al*., 2012

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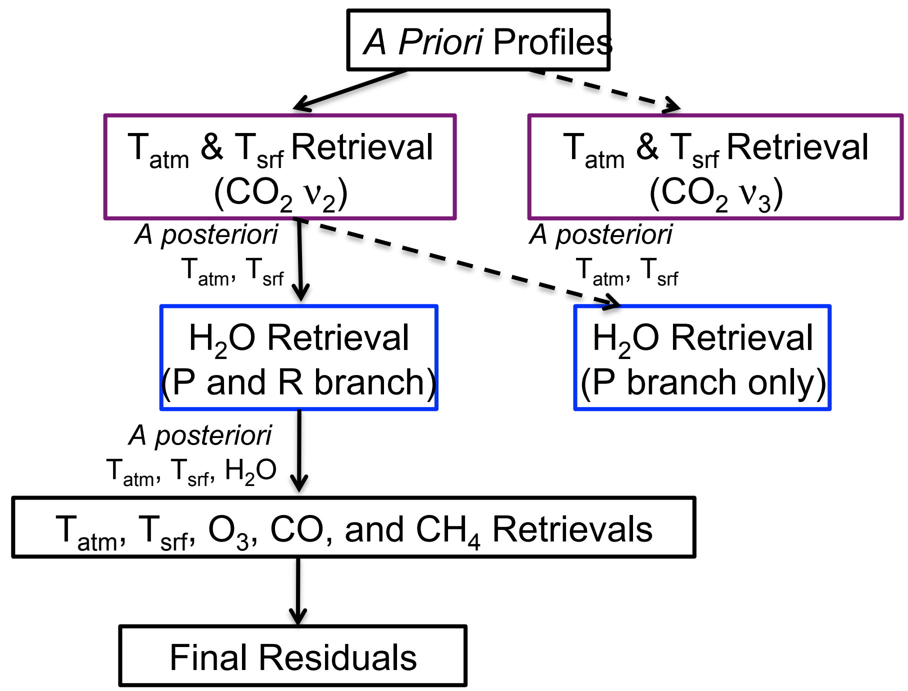
IASI Closure Study Methodology

We use 128 clear-sky, nighttime, over ocean IASI profiles (a subset of Matricardi, 2009) to minimize potential errors from clouds, surface emissivity, and NLTE effects.

Systematic spectral residuals after retrievals indicate errors in the spectroscopy.

***A priori* profiles:**

- Temperature: ECMWF adjusted between 10 mbar and 0.1 mbar (Masiello *et al.*, 2011).
- H_2O: ECMWF model.
- O_3: ECMWF model scaled by OMI.
- CO_2, N_2O, CH_4, and CO: Aura TES climatology



Schematic of the retrieval procedure. The dashed arrows show additional retrievals performed to assess the consistency of CO_2 in the IASI spectral range.

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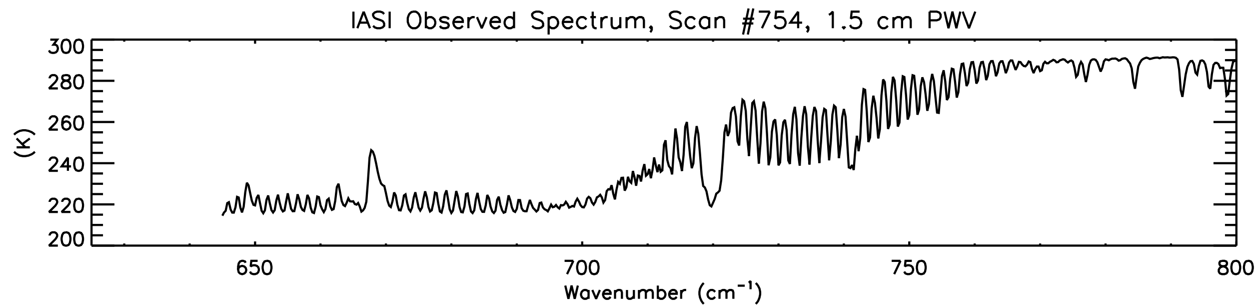
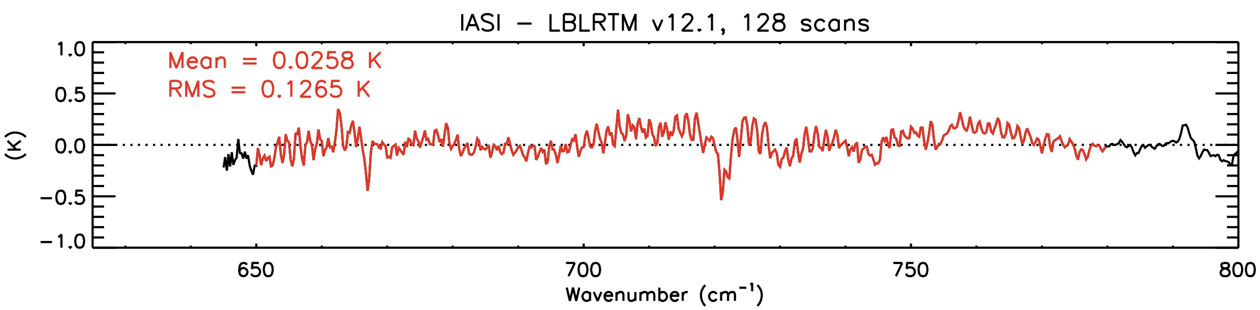
The addition of P- and R-branch line coupling improved performance in the ν_2 band of CO_2

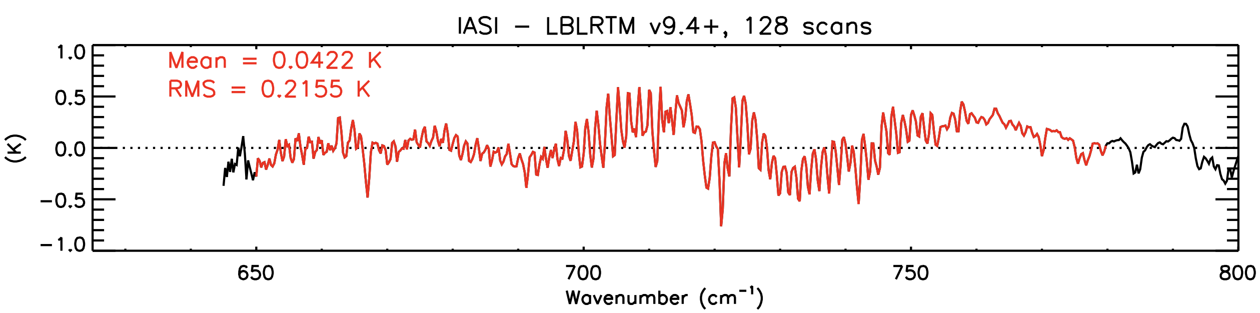
IASI Scan #754



Mean Residuals
LBLRTM v12.1



Mean Residuals
LBLRTM v9.4+



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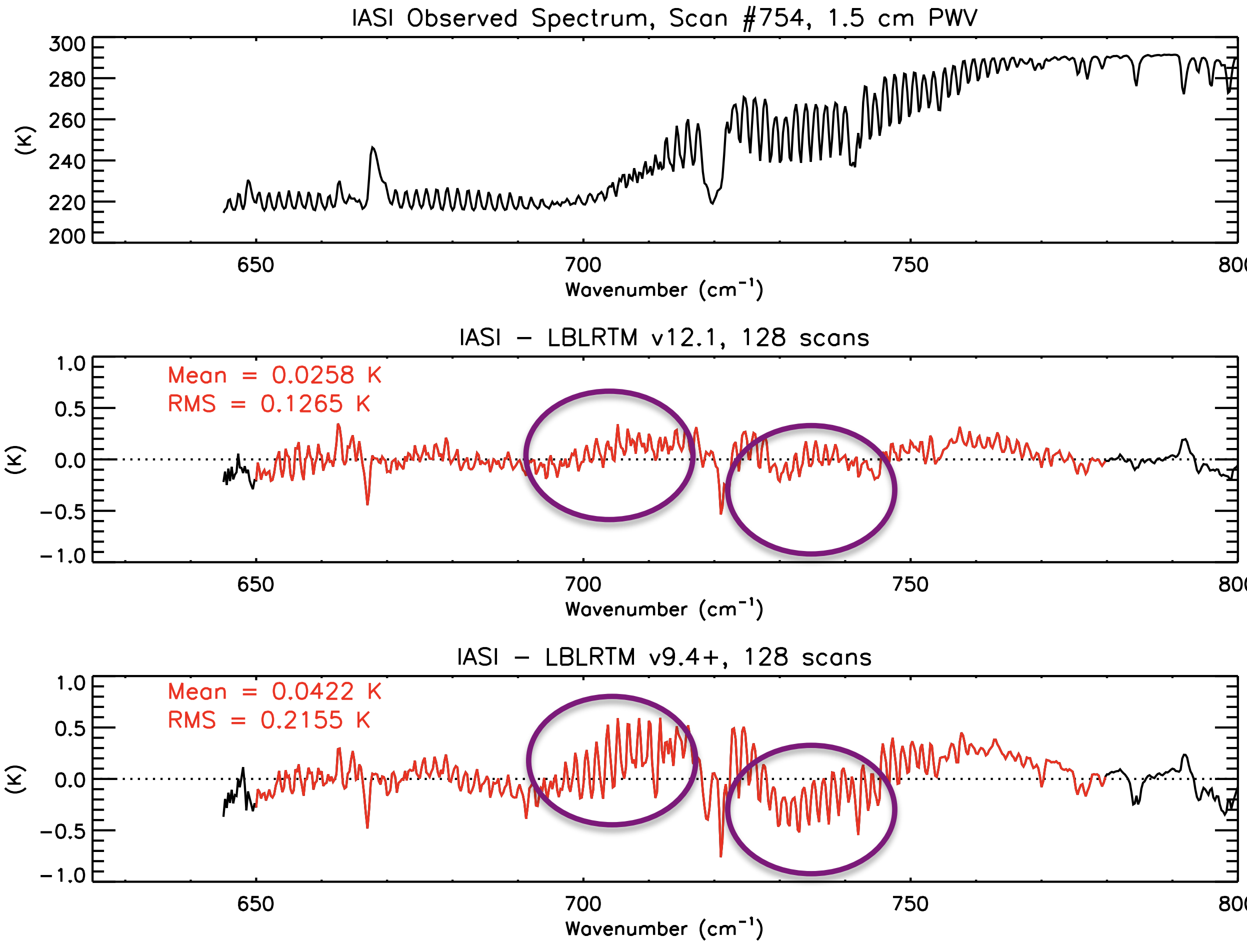
The addition of P- and R-branch line coupling improved performance in the ν_2 band of CO_2

IASI Scan #754

Mean Residuals LBLRTM v12.1

Mean Residuals LBLRTM v9.4+



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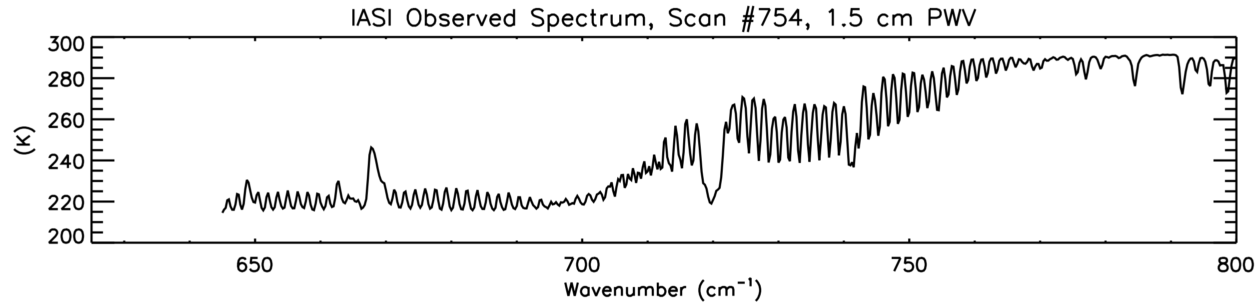
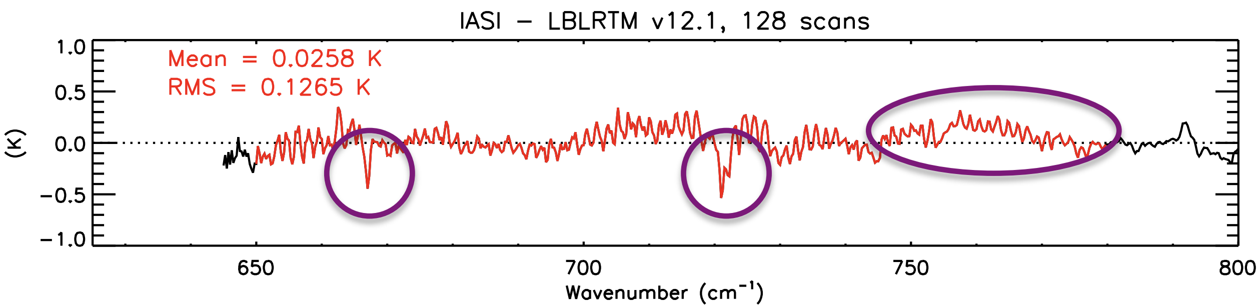
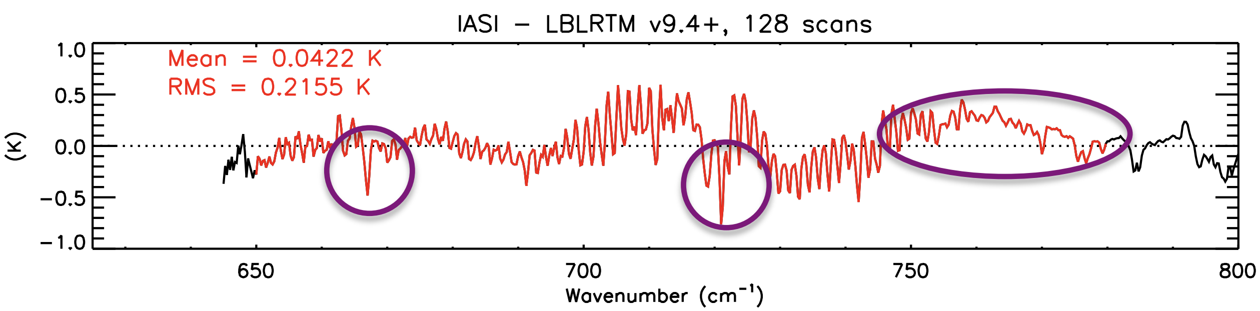
IASI Scan #754



Mean Residuals
LBLRTM v12.1

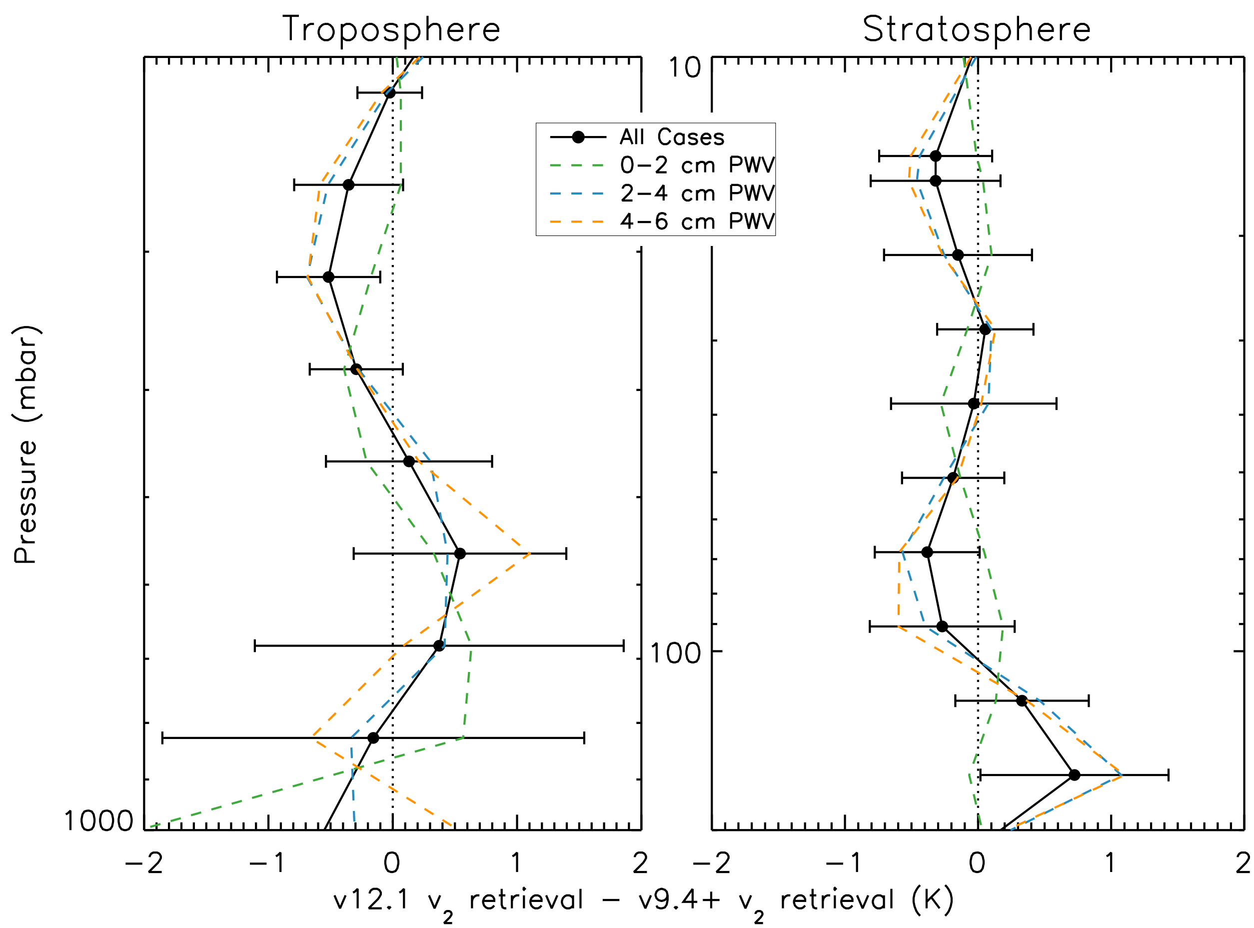


Mean Residuals
LBLRTM v9.4+



These spectroscopy updates alter the temperature profiles retrieved using the ν_2 band

Right: Mean and std. dev. of the differences between the temperature profiles retrieved with LBLRTM v12.1 and v9.4+. *Only the 123 cases that converged for all four model/band combinations are included.*



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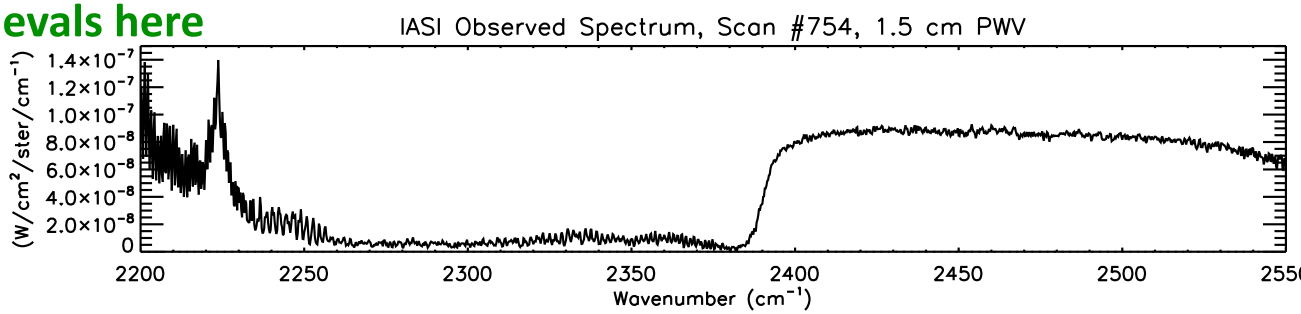
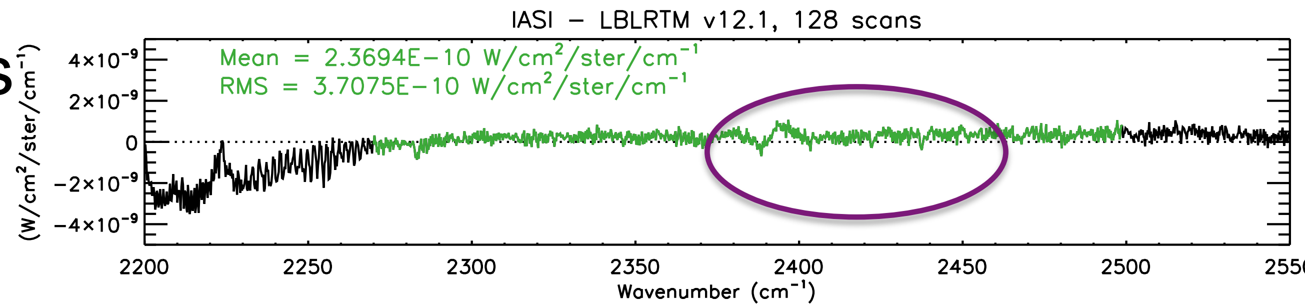
Updates to the MT_CKD continuum have improved performance at the ν_3 bandhead

Note that green ν_3 region was not used in temperature retrievals here

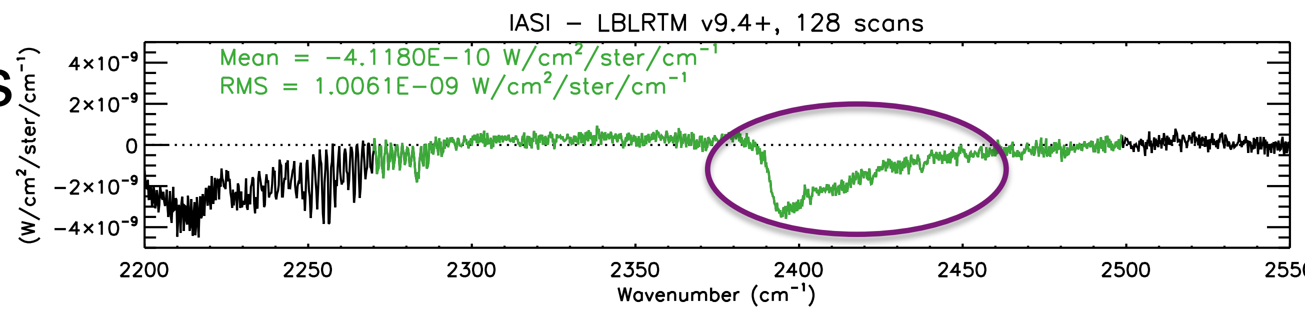
IASI Scan #754



Mean Residuals LBLRTM v12.1



Mean Residuals LBLRTM v9.4+



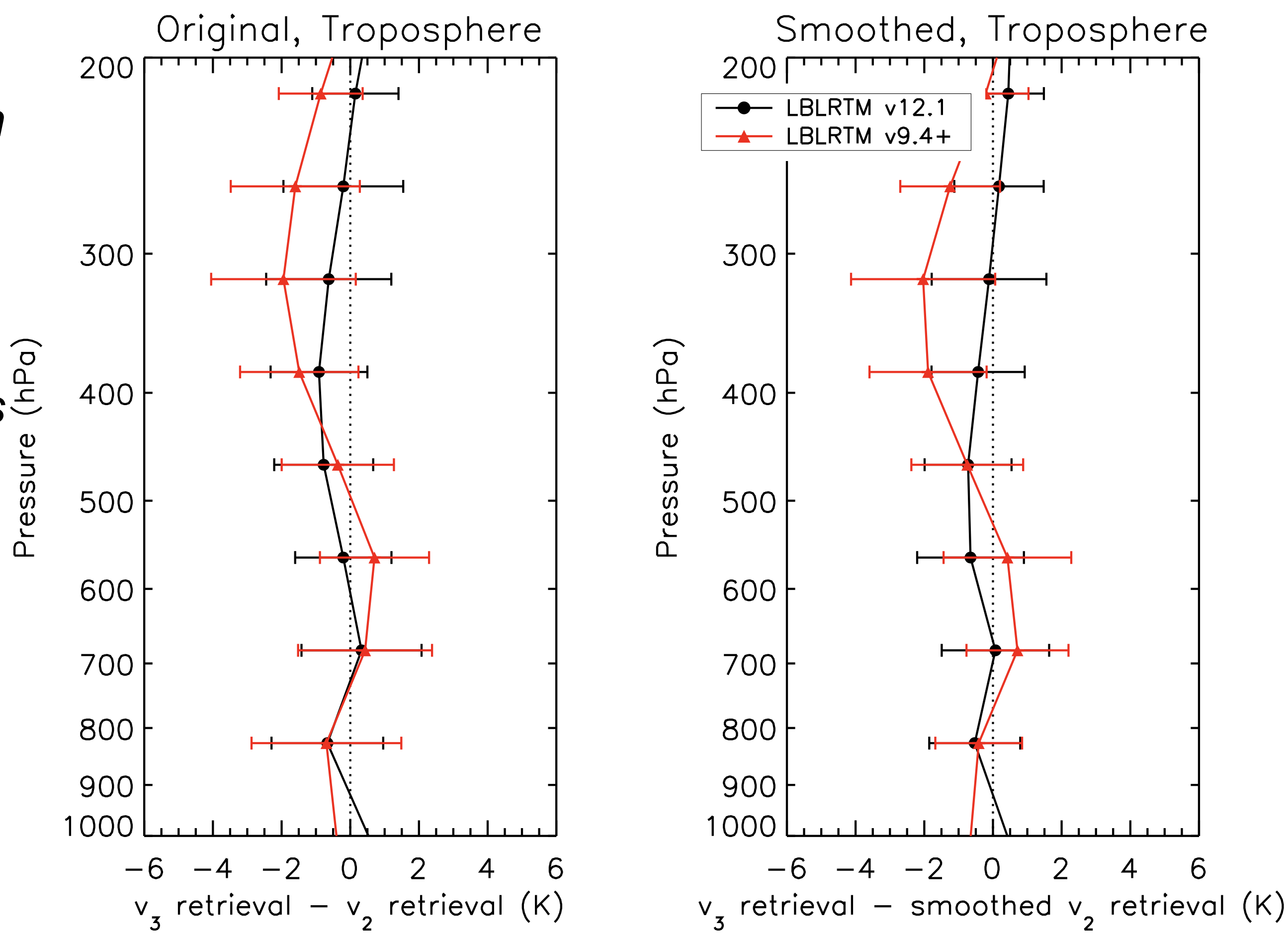
The ν_2 and ν_3 temperature retrievals in LBLRTM v12.1 are remarkably consistent.

$$\hat{\mathbf{x}}_{\text{smooth } \nu_2} = \hat{\mathbf{x}}_{\nu_3} + \mathbf{A}_{\nu_3}\left(\hat{\mathbf{x}}_{\nu_2} - \hat{\mathbf{x}}_{\nu_3}\right)$$

Mean and std. dev. of the differences between the retrieved temperature profiles.

Only the 123 cases that converged for all four model/band combinations are included.

Right panel: the ν_2 retrieval was smoothed with the ν_3 averaging kernel and retrieval(Rodgers and Connor, 2003).



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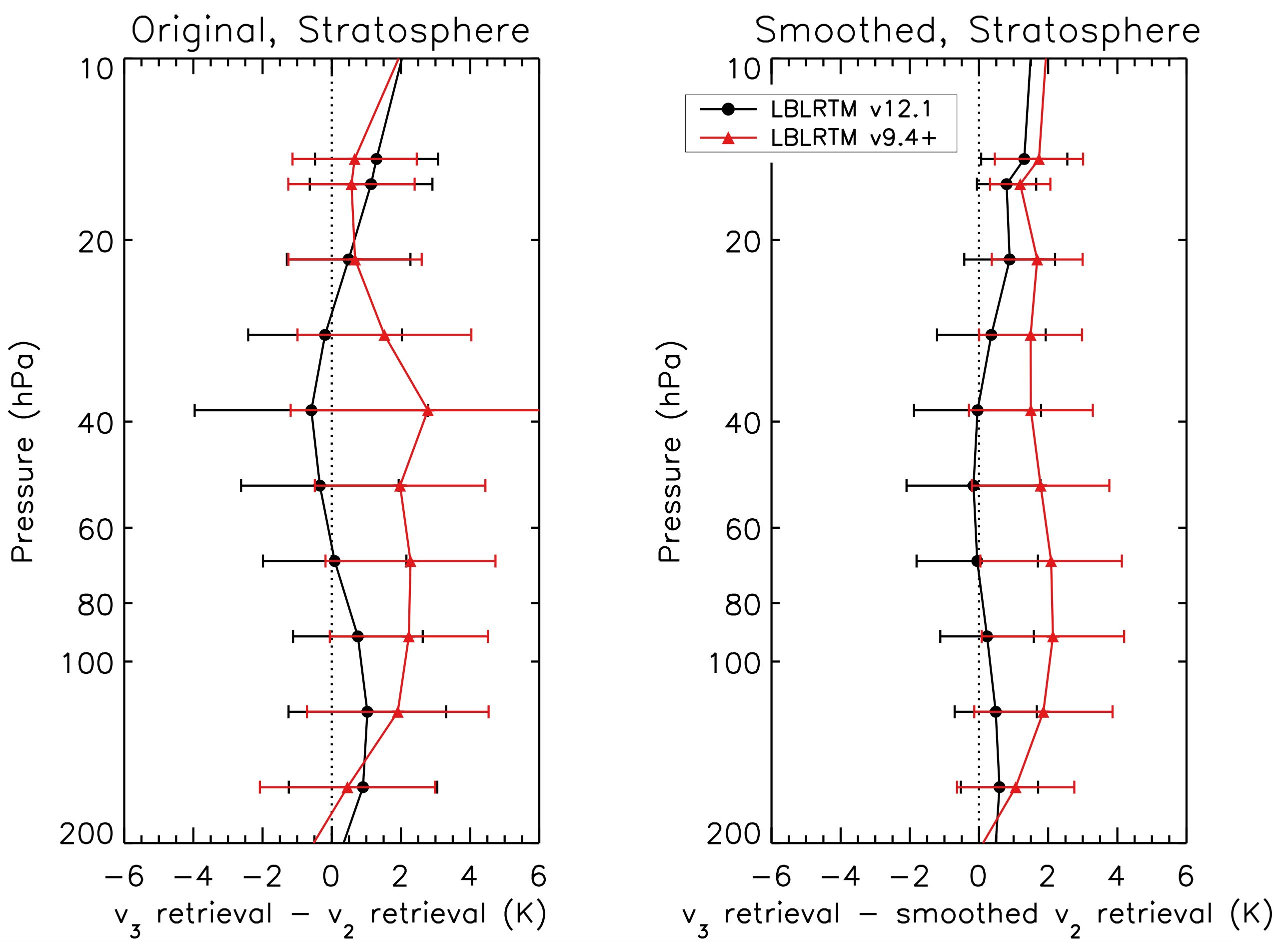
Right panel: the ν_2 retrieval was smoothed with the ν_3 averaging kernel and retrieval(Rodgers and Connor, 2003).

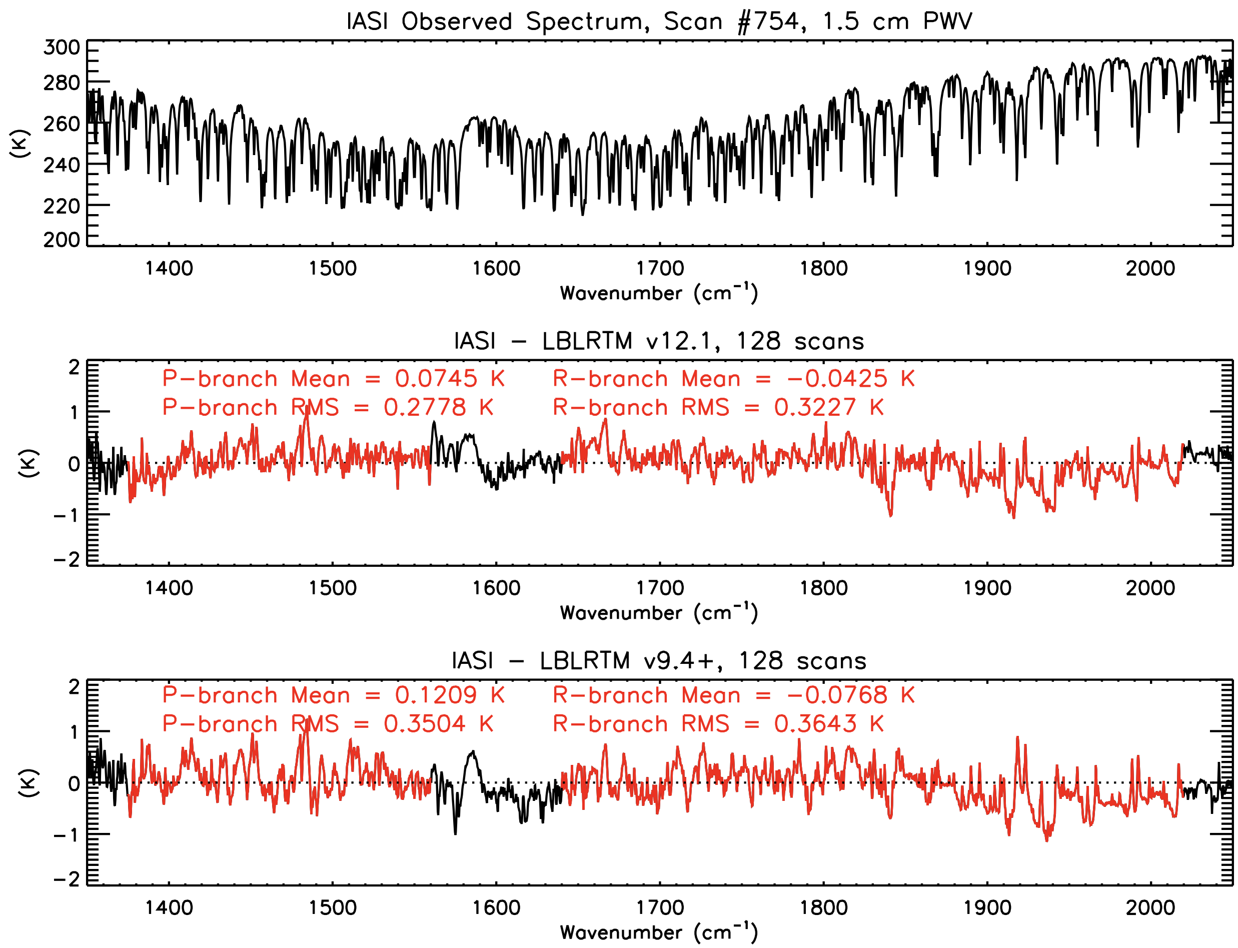


Residuals in the H_2O ν_2 band are improved, especially in P-branch

IASI Scan #754

Mean Residuals LBLRTM v12.1

Mean Residuals LBLRTM v9.4+



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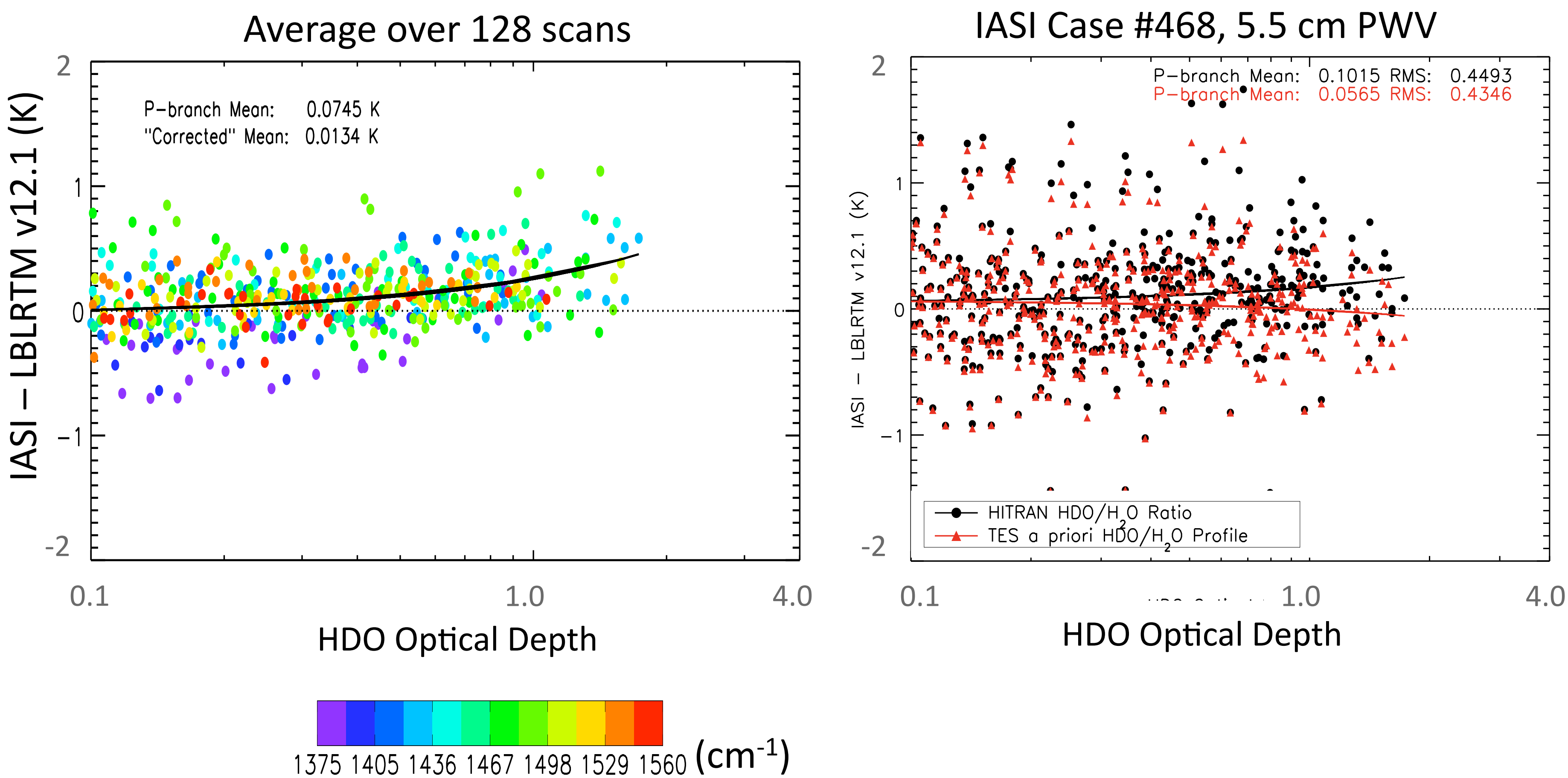
Constant HDO/H_2O ratio creates bias in P-branch residuals for high water vapor cases



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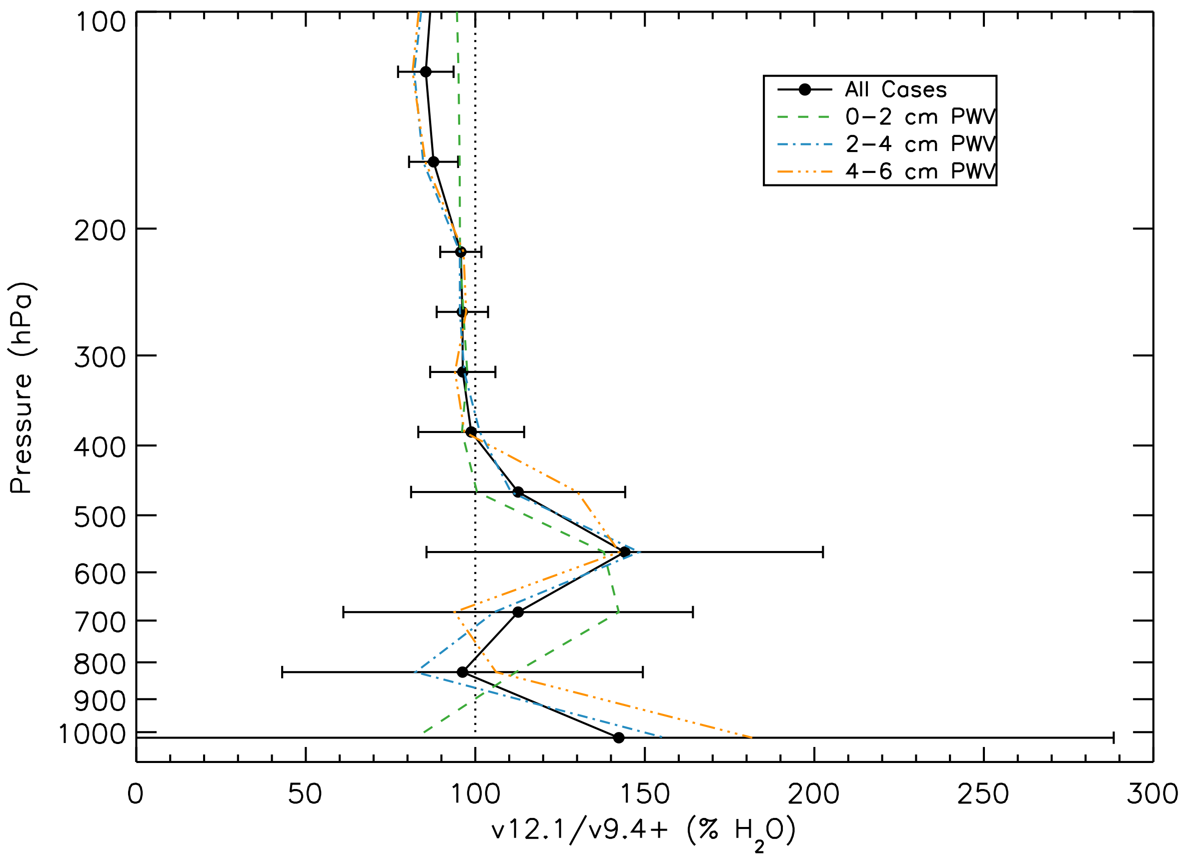
Updated H_2O spectroscopy in LBLRTM v12.1 impacts retrieved H_2O profiles

Right: Mean and std. dev. of the ratio between the H_2O profiles retrieved with LBLRTM v12.1 and v9.4+. *Only the 122 cases that converged for temperature and H_2O in both models are included.*



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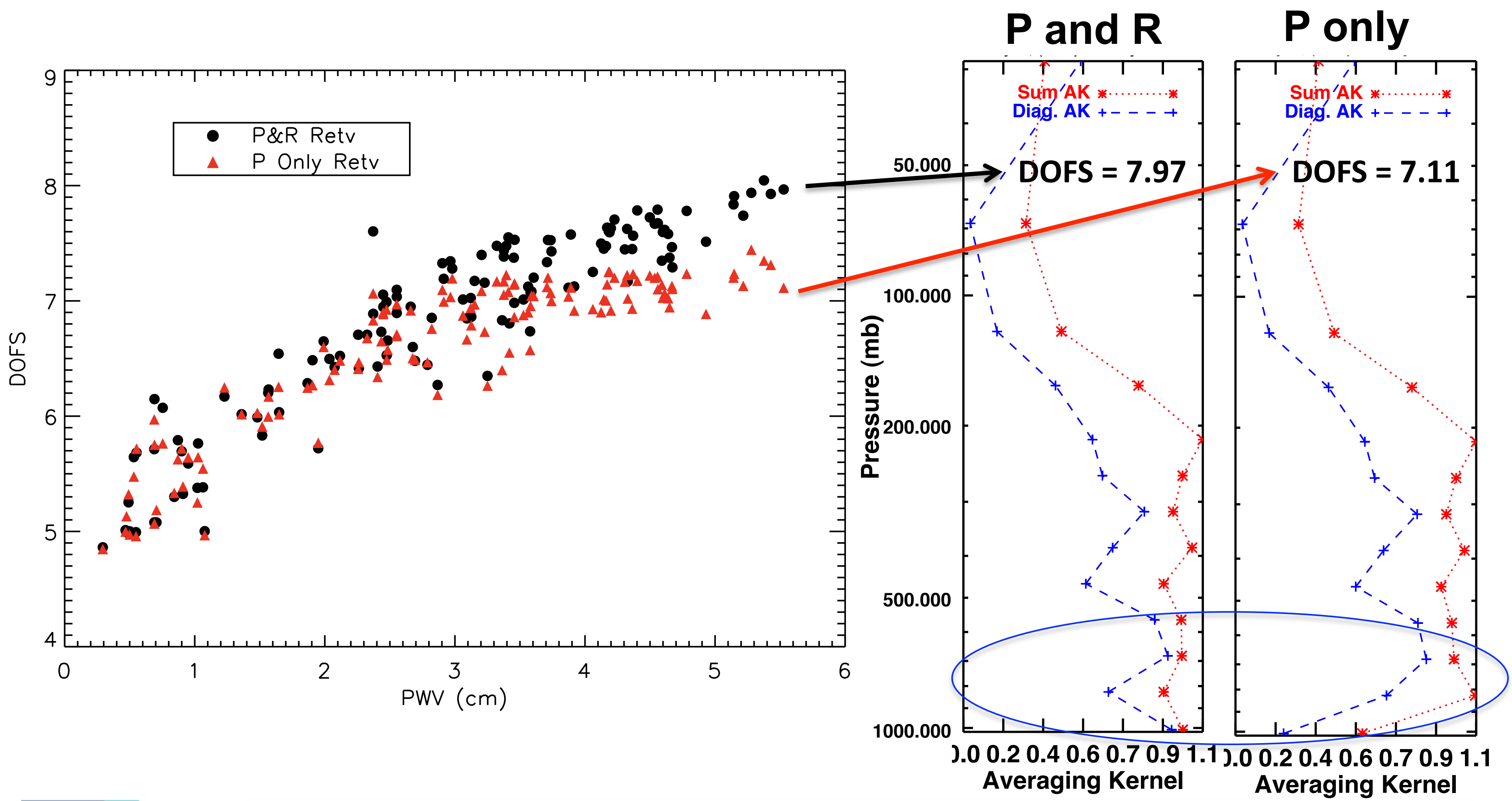
R-branch provides more information about near-surface H_2O for moist atmospheres



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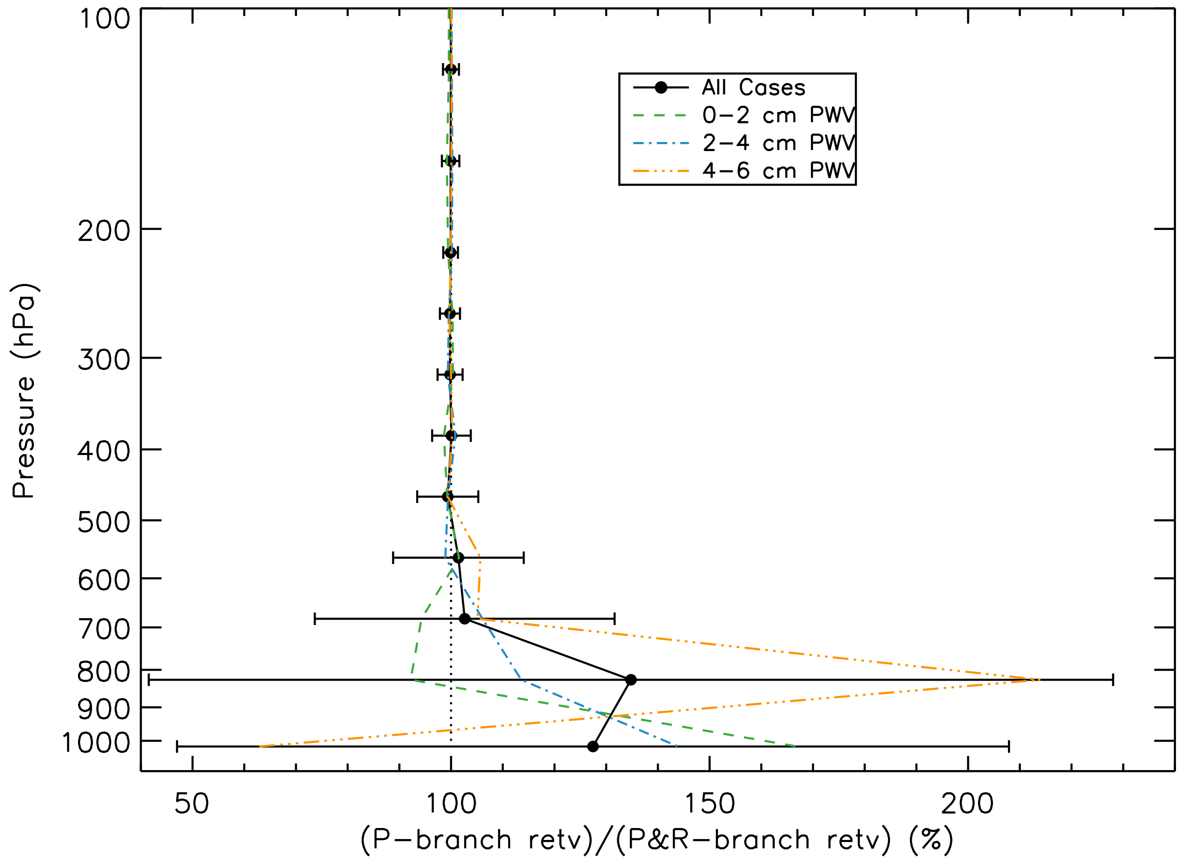
Additional information from R-branch only alters retrieved profile near surface

Mean and std. dev. of the ratio between the LBLRTM v12.1 retrieved H_2O profiles when P-branch alone is used versus when P- and R-branch are used. *All 128 cases are included.*

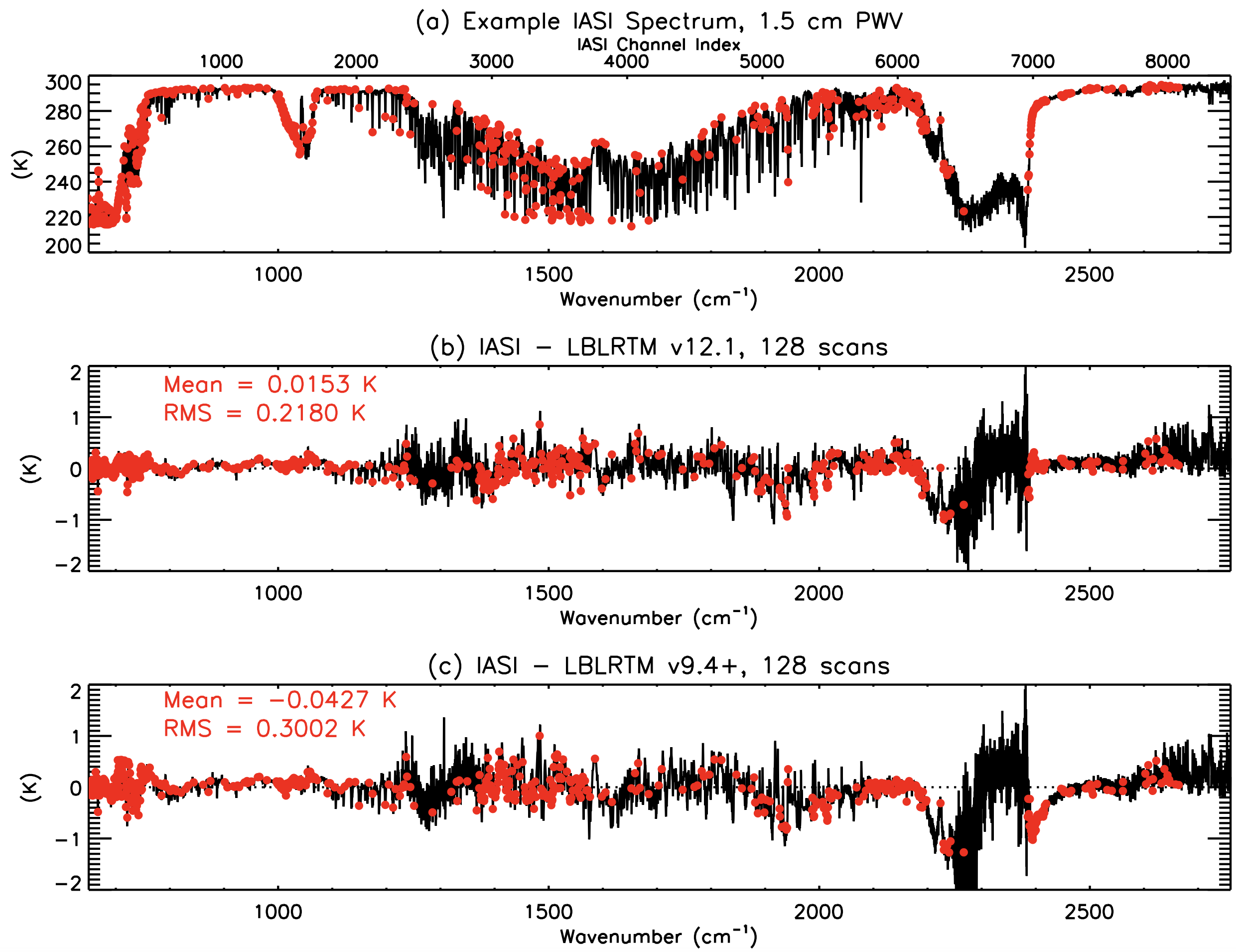


Residuals in the 616 JCSDA assimilated IASI channels are substantially improved

IASI Scan #754

Mean Residuals LBLRTM v12.1

Mean Residuals LBLRTM v9.4+



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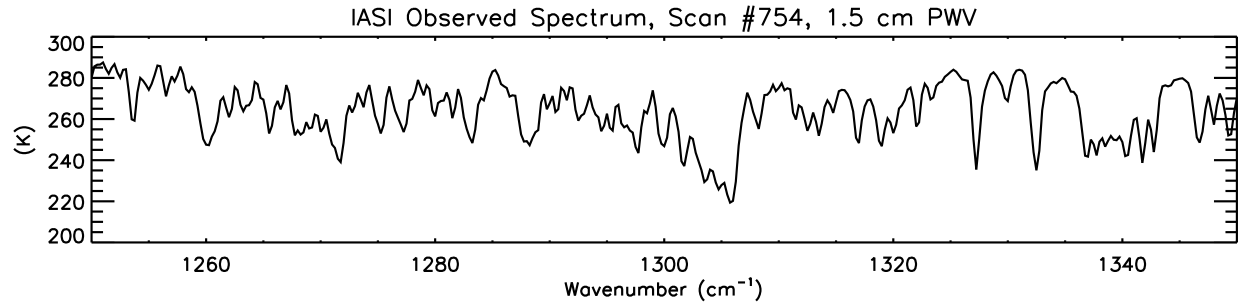
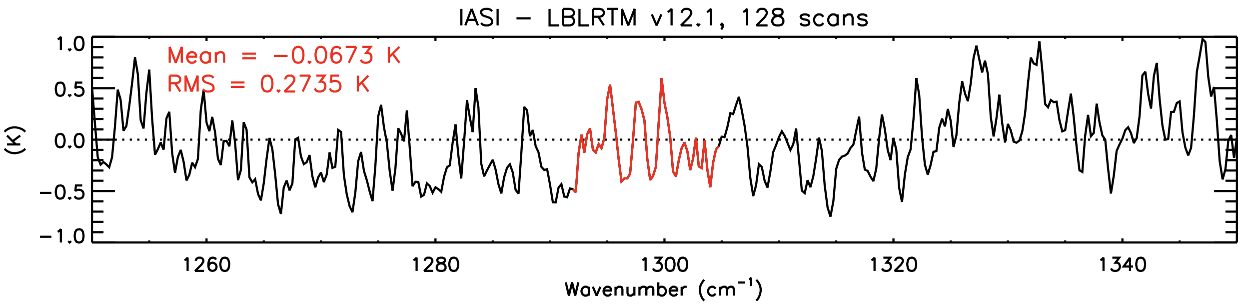
Updates in CH_4 spectroscopy don't clearly improve residuals

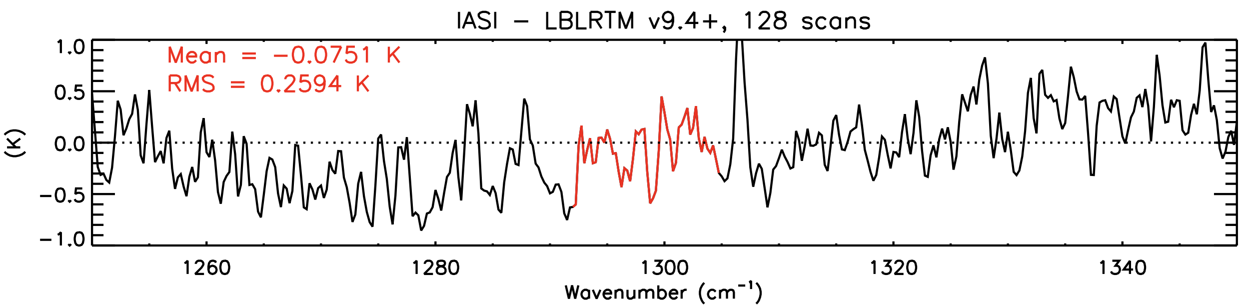
IASI Scan #754



Mean Residuals LBLRTM v12.1



Mean Residuals LBLRTM v9.4+



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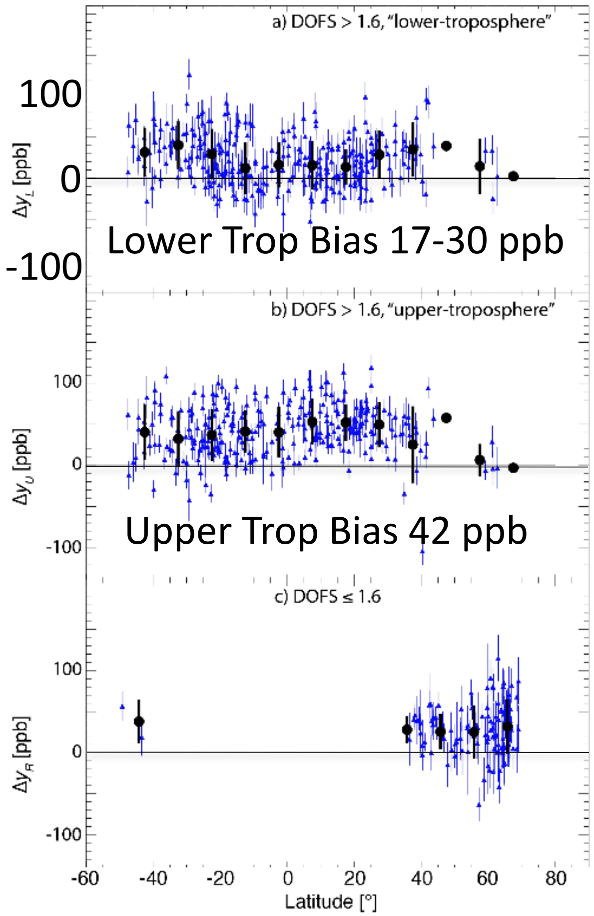
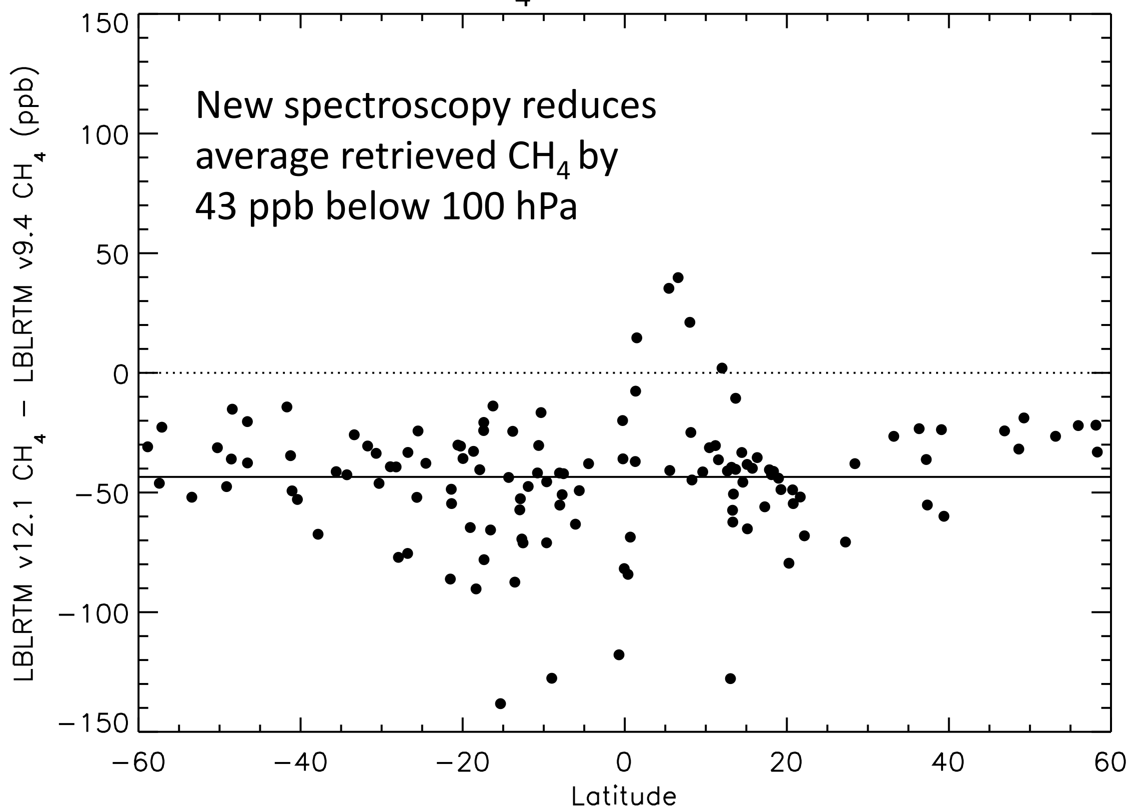
New spectroscopy reduces the bias in retrieved CH_4 profiles

TES V005 – HIPPO CH_4 (ppb)
Wecht et al., ACP, 2012

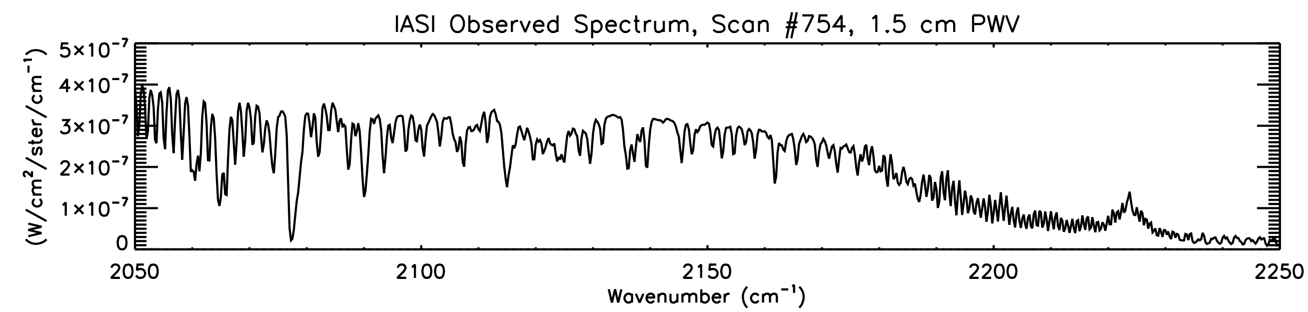


Retrieved CH_4: LBLRTM v12.1 – v9.4+

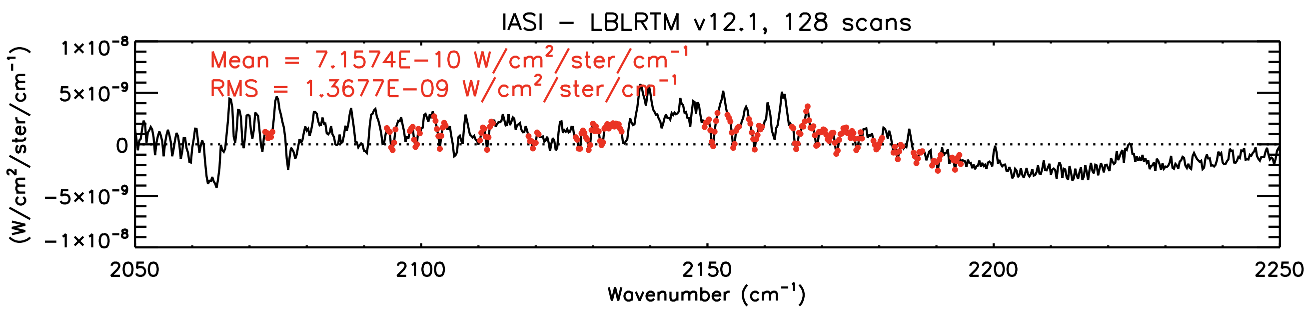


Increases in the H_2O self continuum degrade performance in the CO fundamental band

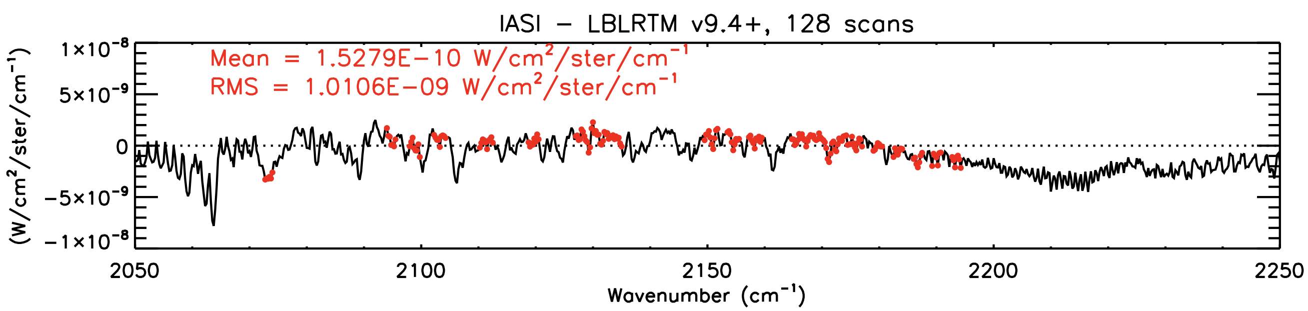
IASI Scan #754



Mean Residuals
LBLRTM v12.1



Mean Residuals
LBLRTM v9.4+



Conclusions

- **The improved CO_2 spectroscopy in LBLRTM v12.1 can alter the retrieved temperature profiles by 0.5 K or more.**
- **The LBLRTM v12.1 CO_2 spectroscopy is remarkably consistent between the CO_2 v_2 and v_3 bands.**
  - Systematic residuals remain in the v_2 Q-branches and at the v_3 bandhead.
- **The H_2O spectroscopy is improved in both the P- and R-branches of the v_2 band in LBLRTM v12.1, but significant systematic residuals remain.**
  - Using a more realistic, vertically-varying HDO profile may reduce the P-branch mean residuals for scans with high water vapor.
- **The LBLRTM v12.1 CH_4 spectroscopy reduces the high bias in the retrieved profiles, but does not clearly improve the spectral residuals.**
- **Increases in the H_2O self continuum in LBLRTM v12.1 lead to degraded performance in the CO fundamental band.**

Acknowledgements

- S. A. Clough, Clough Radiation Associates
- Marco Matricardi, ECMWF
- Robert Gamache, U. Mass. Lowell
- Jean-Michel Hartmann, CNRS
- Linda Brown, JPL
- Kevin Wecht, Harvard
- Joint Center for Satellite Data Assimilation (JCSDA)
- NASA
- Tropospheric Emission Spectrometer (TES) Science Team