Representing spectroscopy and the solar spectrum in atmospheric models

Eli Mlawer
Atmospheric and Environmental Research (AER)

AER contributors: Karen Cady-Pereira, Matt Alvarado, Rick Pernak, Mike Iacono
Non-AER contributors: Dave Turner (NOAA), Jen Delamere (Alpenglow), Scott Paine (SAO), Vivienne Payne (JPL), Luca Palchetti (CNR), Peter Norris (NASA), Jason Furtado (Univ. OK)

Topics

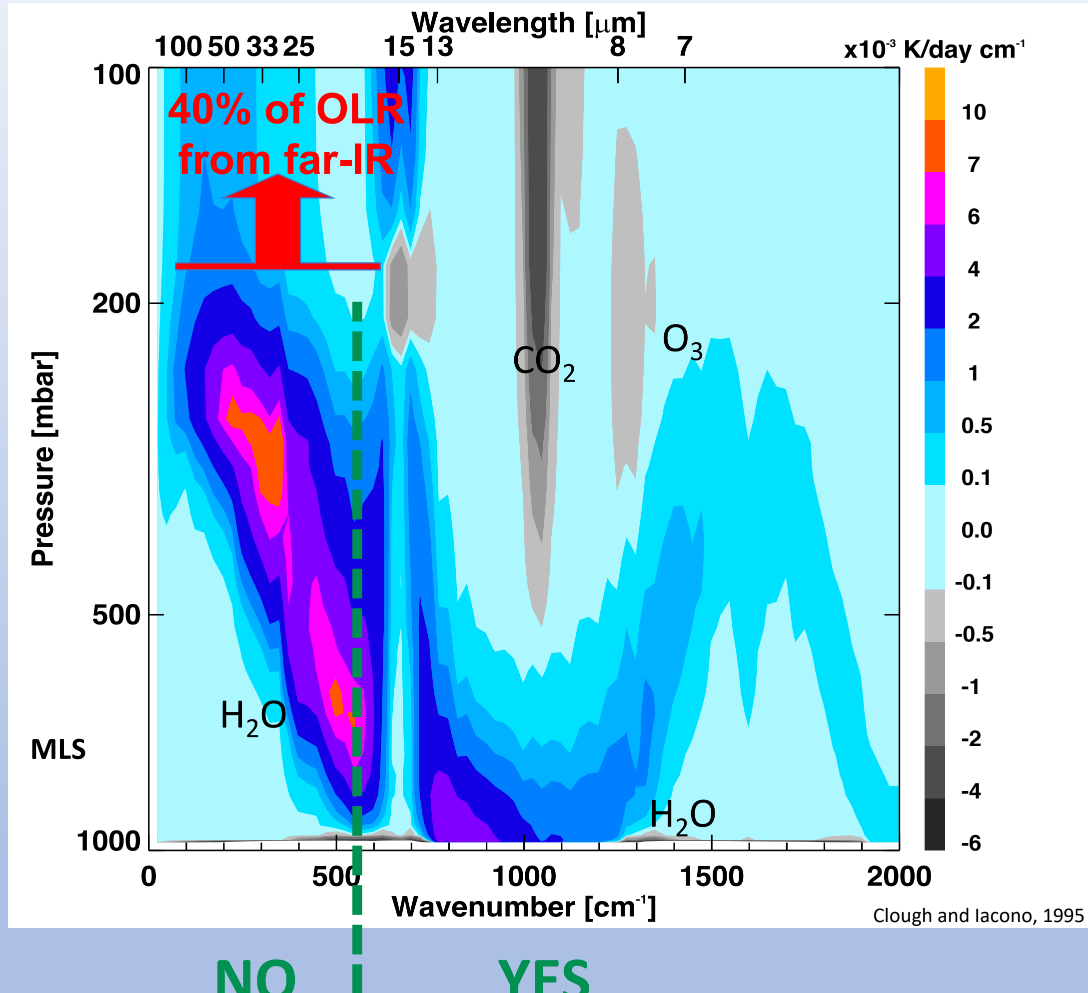
1) Far-infrared radiative closure study

2) Solar irradiance specification

The importance of the far-IR

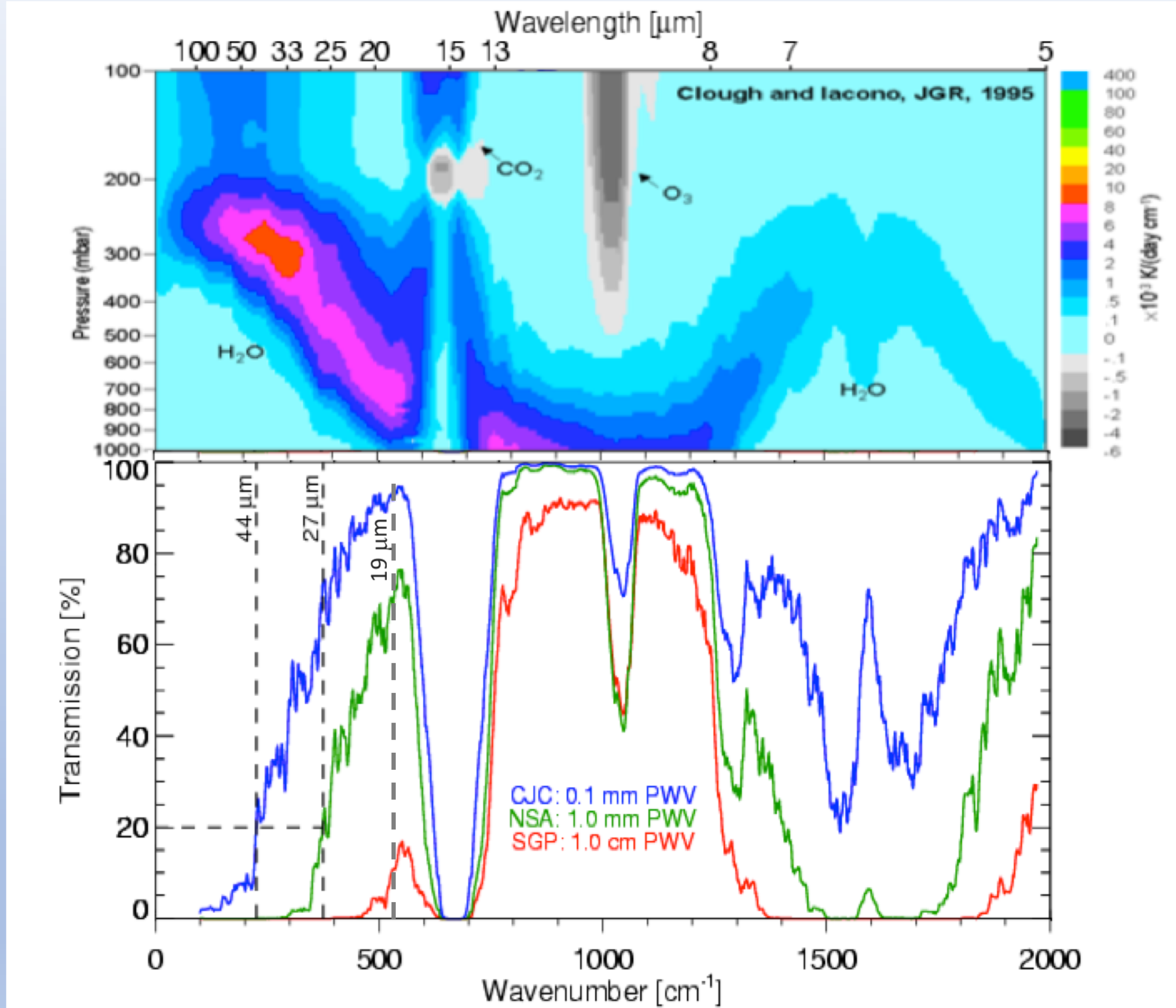
Spectral Cooling Rates (troposphere)

"Clough Plot"



As of ~10 years ago, had spectroscopic parameters been evaluated by field observations?

Dry locations needed to evaluate far-IR spectroscopy



Radiative Heating in Underexplored Bands Campaigns

Goal: Improve far-IR spectroscopy

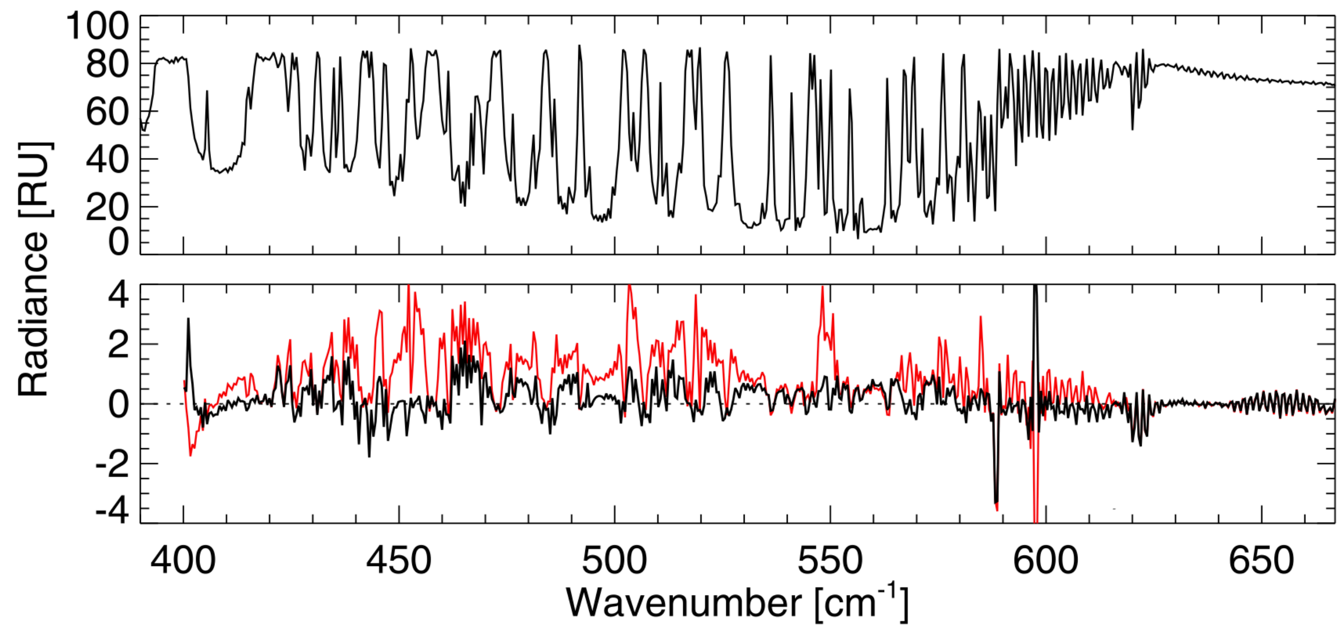
RHUBC-I

- ARM North Slope of Alaska Site, Barrow, AK
- February - March 2007, 70 radiosondes launched
- **Minimum PWV: 0.95 mm**
- 2 far-IR / IR interferometers
  - extended range AERI: > 400 cm^{-1}
- 3 sub-millimeter radiometers → determine PWV

RHUBC- I: Results

Spectroscopic modifications from RHUBC-I (Delamere et al., 2010)

- adjustments to water vapor foreign continuum
- foreign-broadened line widths for 42 H_2O lines were adjusted



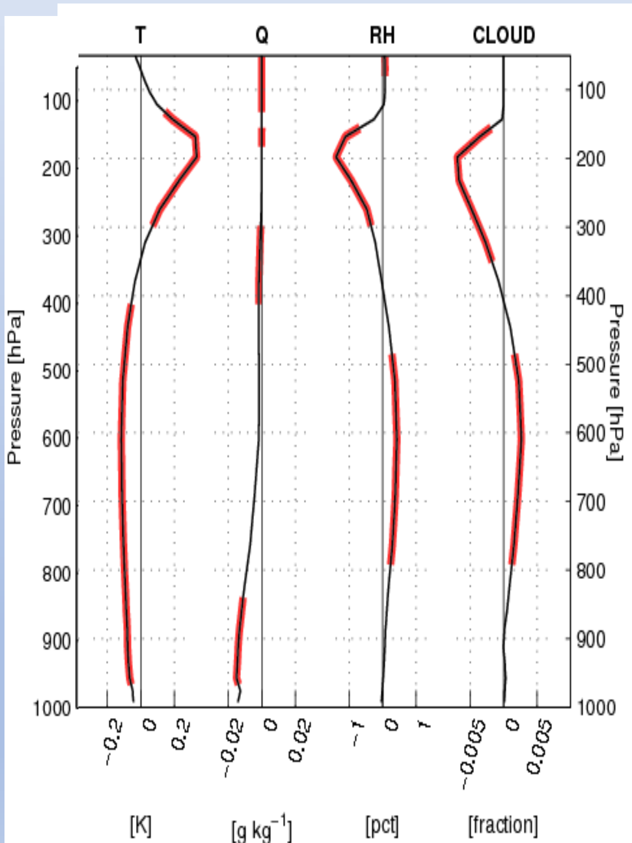
AERI_ER Measurements

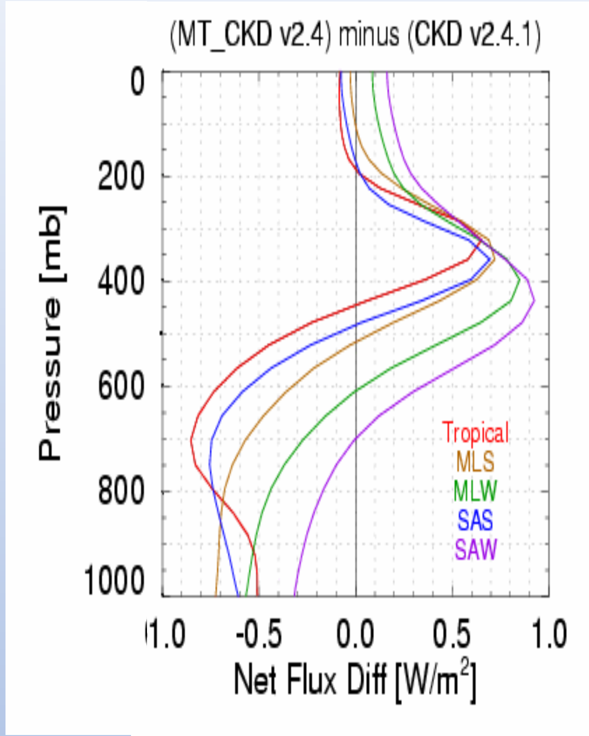
AERI_ER – LBLRTM residuals before RHUBC-I

Residuals after RHUBC-I

RHUBC- I: Results

Revised continuum and widths lead to significant changes in net flux





- RRTMG updated with revised continuum (MT_CKD_2.4)
- 20-yr simulation performed with CESM v1 (Turner et al., 2012)
  - statistically significant changes in temperature, humidity, and cloud fraction

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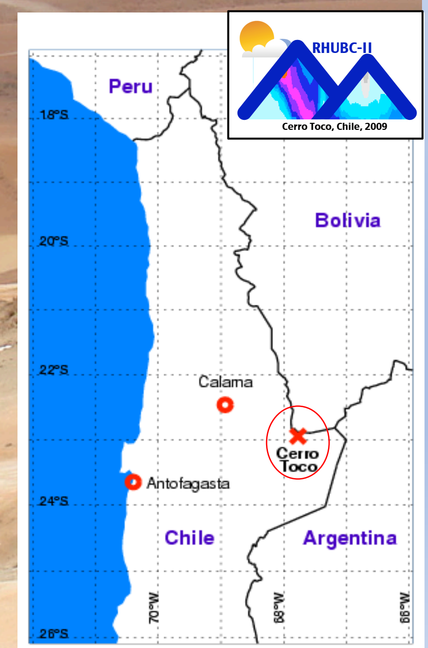
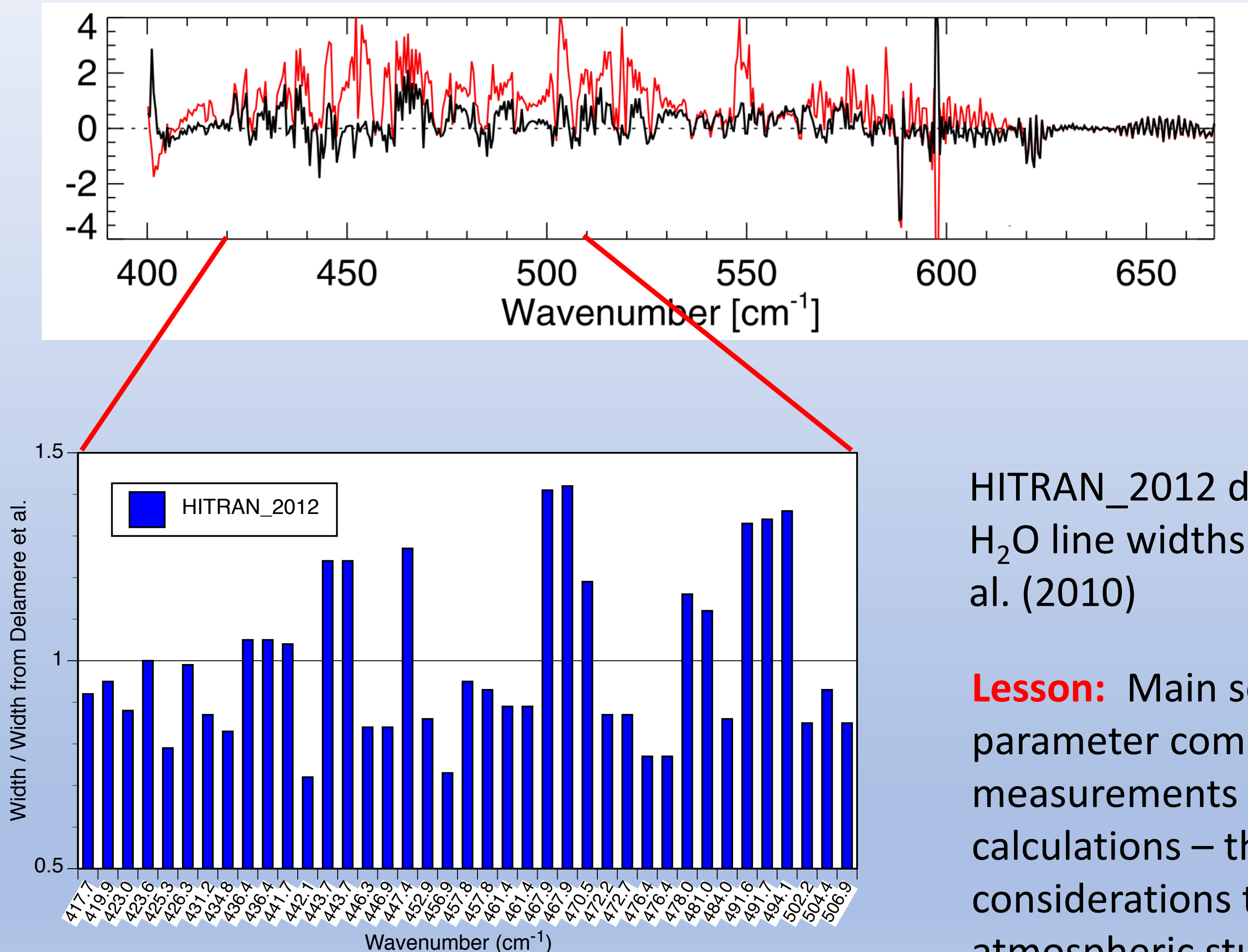
RHUBC-II

- Cerro Toco, Chile (23ºS, 68ºE, altitude - **5380 m**)
- August - October 2009, 144 radiosondes were launched
- **Minimum PWV: ~0.2 mm (5x drier than RHUBC-I)**
- 3 far-IR / IR interferometers
  - **REFIR-PAD (FTS) – 100-1400 cm^{-1}**
- 183 GHz radiometer for determining H_2O



Impact of RHUBC- I Results on Line Databases - **Nothing**



AERI – LBLRTM residuals before RHUBC-I

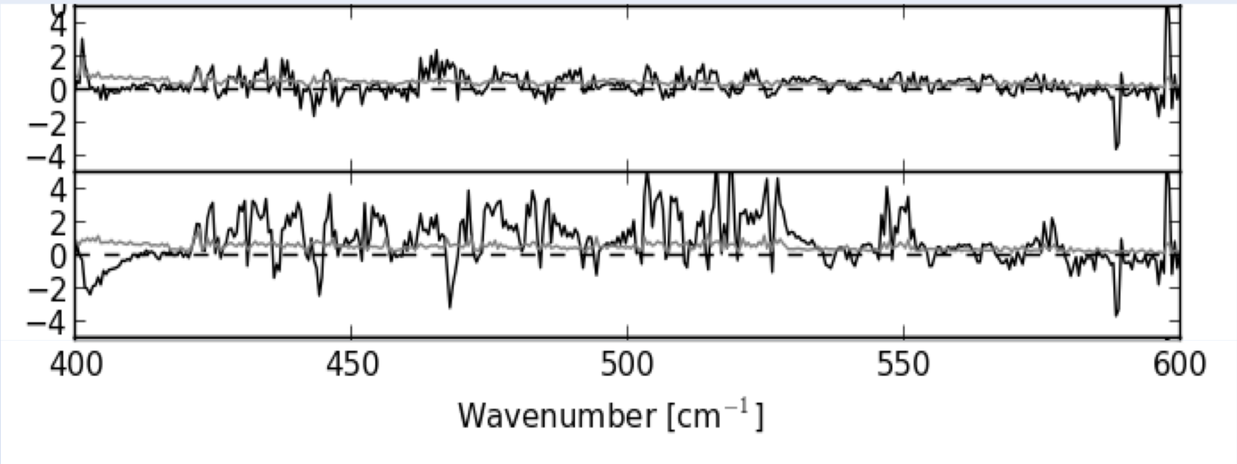
Residuals after RHUBC-I

HITRAN_2012 did not utilize the H_2O line widths from Delamere et al. (2010)

Lesson: Main sources for line parameter compilations are lab measurements and theoretical calculations – there are other considerations than accuracy in atmospheric studies

Impact of HITRAN widths on residuals

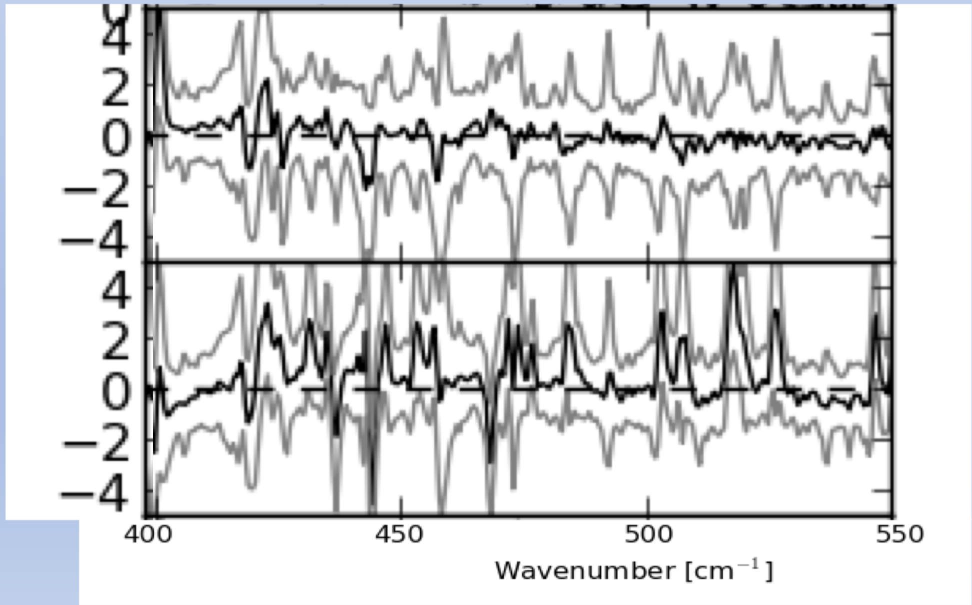
RHUBC-I



AERI – LBLRTM residuals with Delamere et al. widths

Residuals with HITRAN_2012 widths

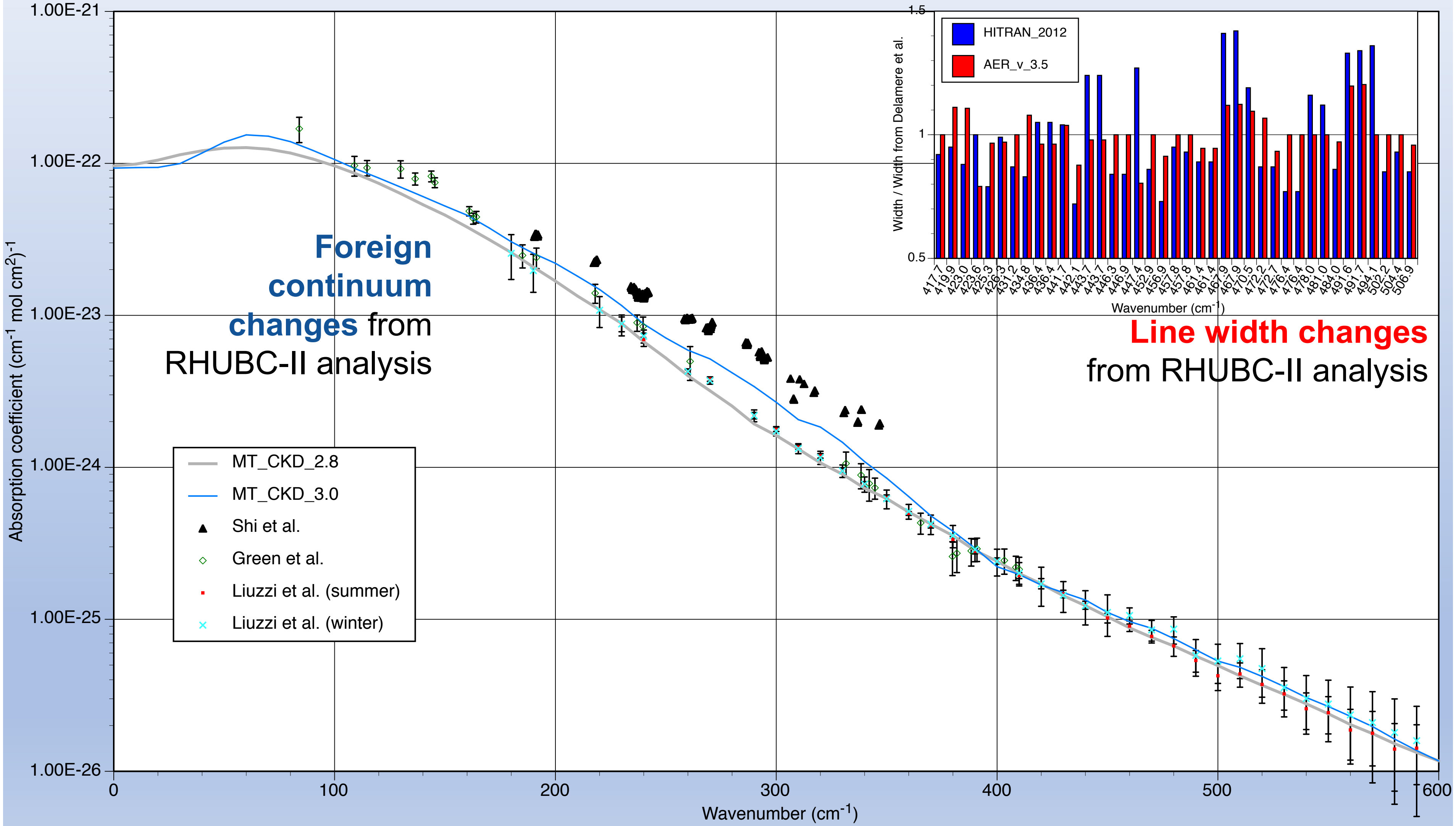
RHUBC-II



REFIR-PAD – LBLRTM residuals with Delamere et al. widths

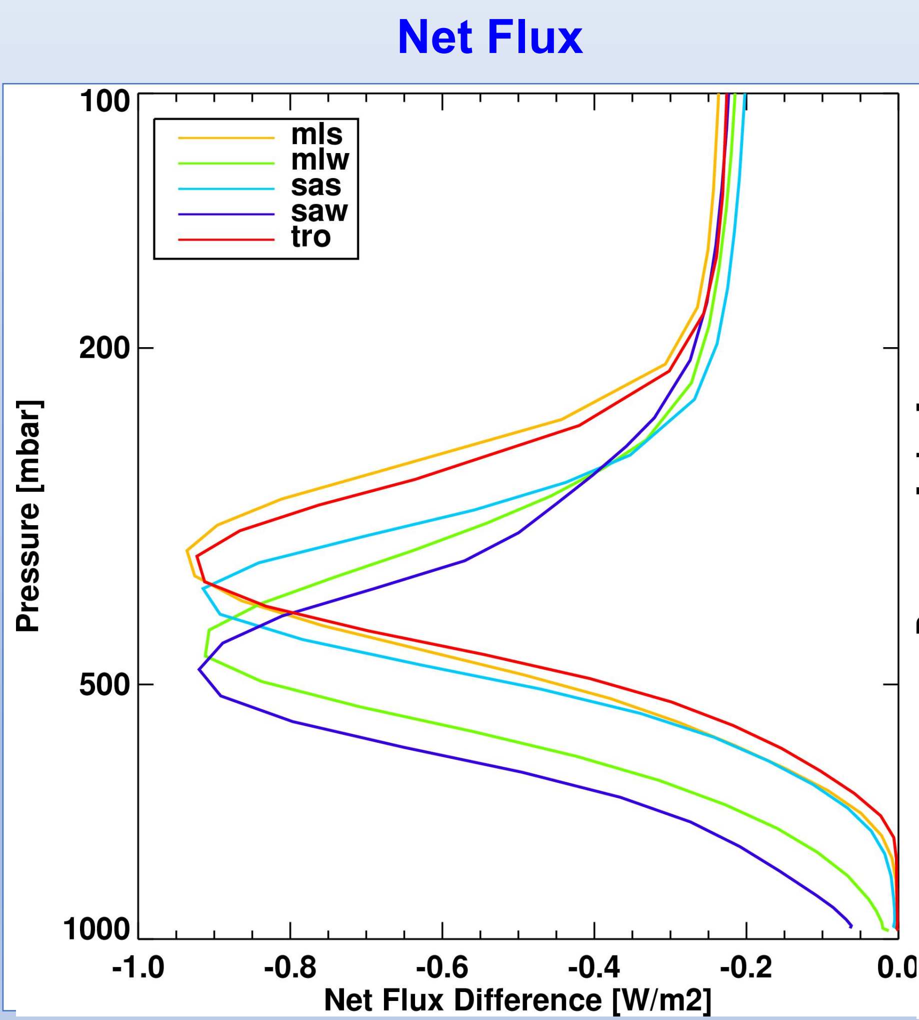
Residuals with HITRAN_2012 widths

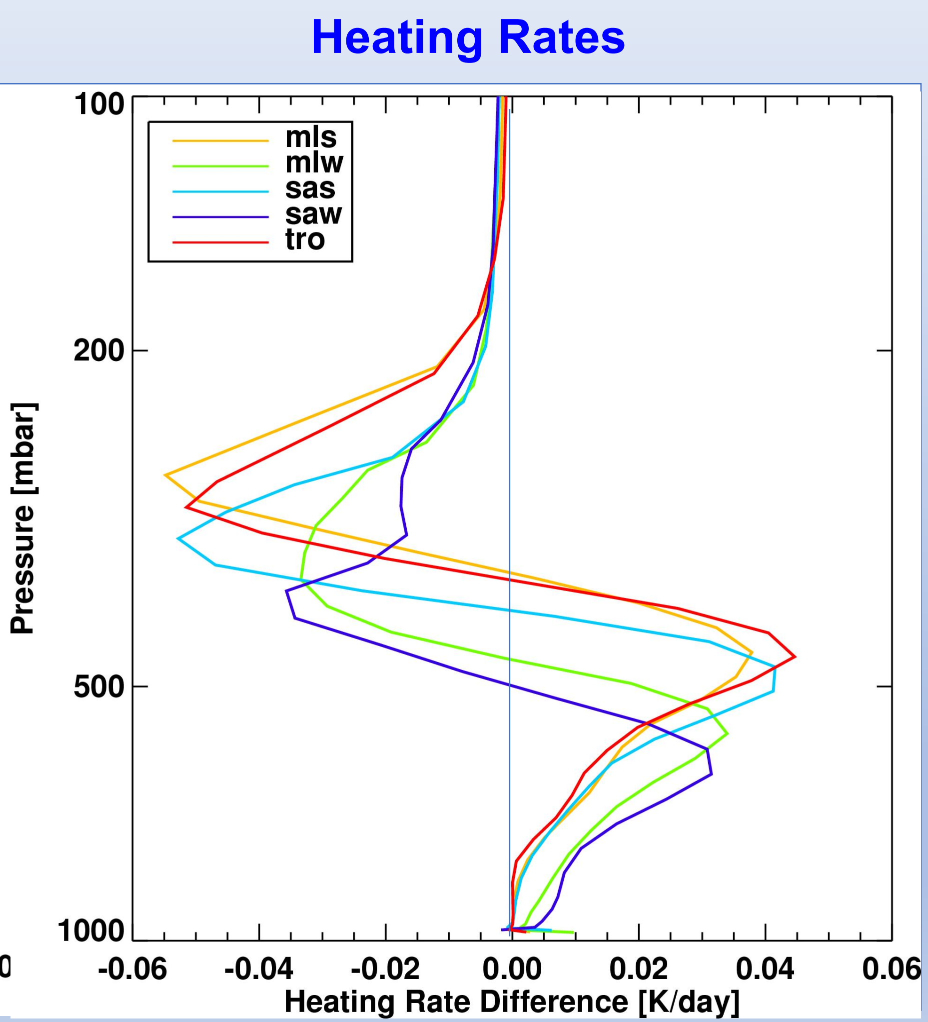
RHUBC-II spectroscopic improvements



RHUBC – II: Analysis

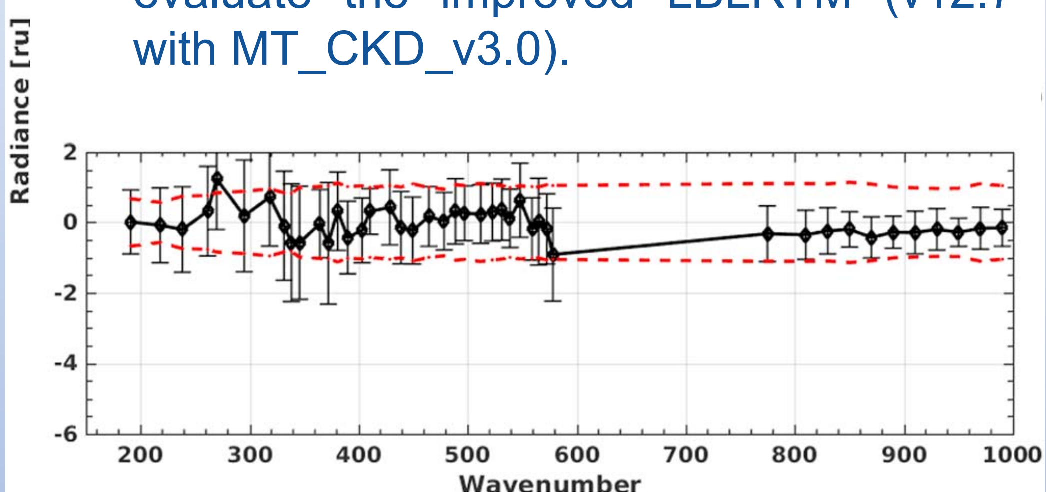
Effect of foreign continuum derived from RHUBC-II observations
(compared to previous version)





Independent evaluation

Rizzi et al. (2018) used REFIR-PAD measurements from Antarctica to evaluate the improved LBLRTM (v12.7 with MT_CKD_v3.0).



Winter cases from Rizzi et al. (2018)

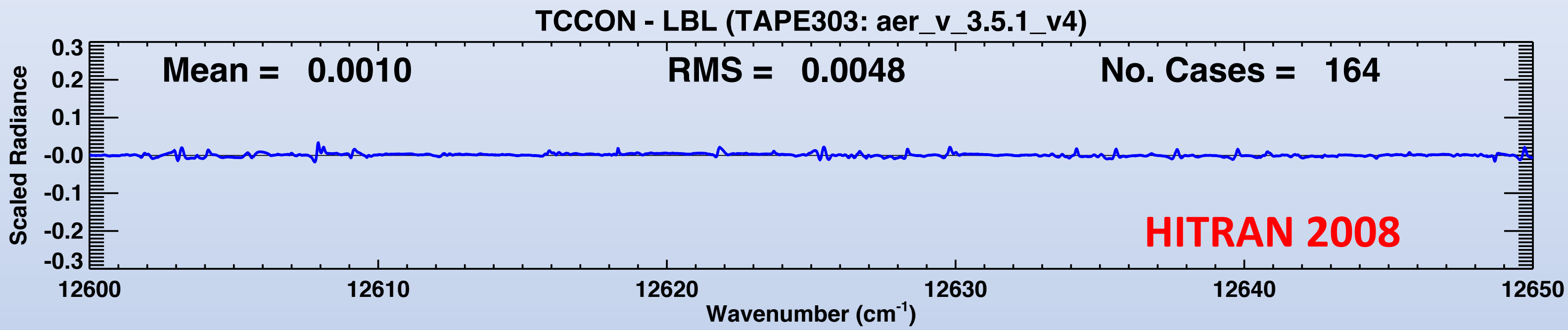
“The new simulations show that residuals between 200 and 400 cm^{-1} are much reduced with respect to (previous results) and are now within the combined error estimates ... average residuals for austral winter days are remarkably close to zero”

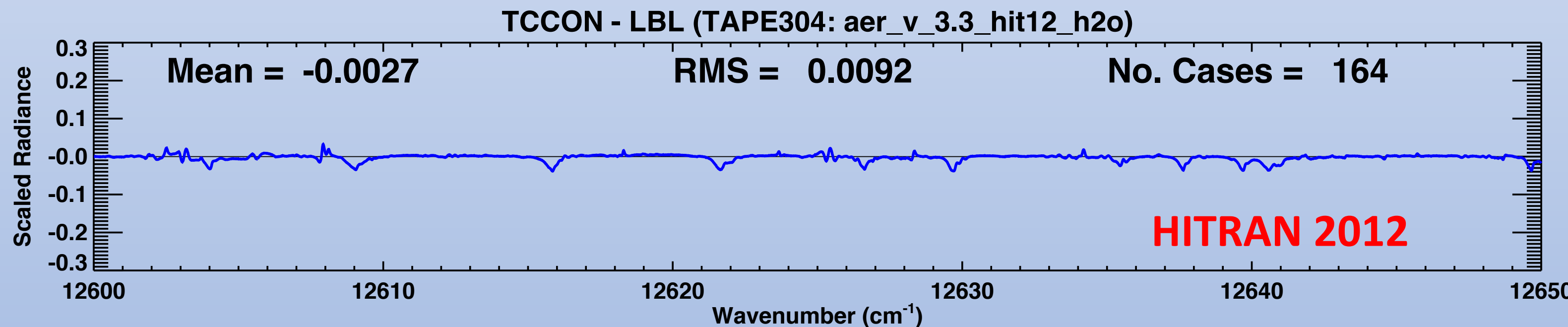
Main points

- **Radiative closure experiments continue to play an important role in improving and validating spectroscopic input to radiative transfer calculations**
  - e.g. Far-IR H2O line widths and continuum

Another example

Plot: Average residuals between direct beam measurements from solar FTS in Lamont, OK (TCCON), and LBLRTM calculations with different line parameters





Based on this analysis, NIR and visible H_2O widths in the AER_v_3.6 H_2O line file are:
< **6000 cm^{-1}** - HITRAN 2012; **6000-7925 cm^{-1}** - HITRAN 2012 with Mikhailenko;
7925-9395 cm^{-1} - HITRAN 2012 with Regalia; **9395-12000 cm^{-1}** - HITRAN 2012;
> **12000 cm^{-1}** : AER Version 3.3 (i.e. HITRAN 2008)

plus **numerous widths** manually changed to improve residuals

Main points

- Radiative closure experiments continue to play an important role in improving and validating spectroscopic input to radiative transfer calculations
  - e.g. Far-IR H2O line widths and continuum
  - e.g. NIR H_2O line widths

- **Line parameter databases should not be assumed to be improvements on previous versions or reflect atmospheric validation**

Main points so far

- Radiative closure experiments continue to play an important role in improving and validating spectroscopic input to radiative transfer calculations
  - e.g. Far-IR H_2O line widths and continuum
  - e.g. NIR H_2O line widths

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Our community is most interested in the "effective" accuracy for atmospheric conditions.

Is there a better strategy to address the need for atmospheric evaluation and improvement of spectroscopic parameters?

Somewhat haphazard right now

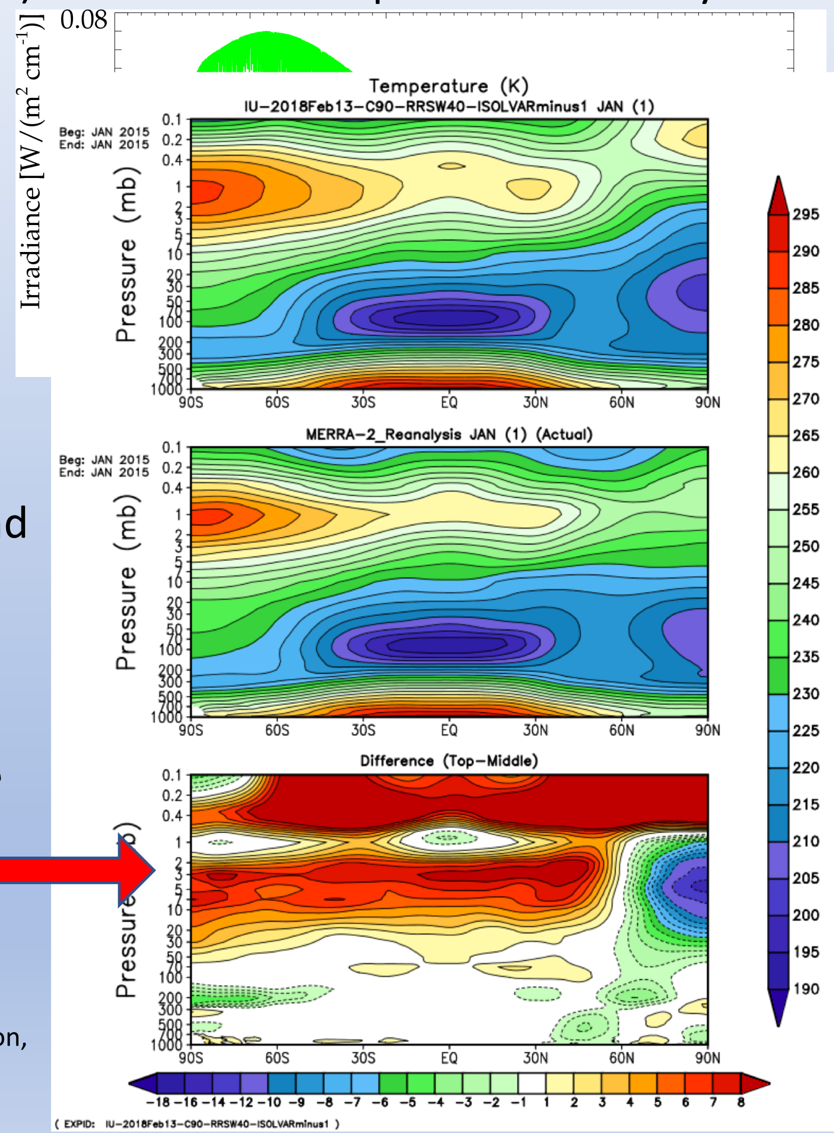
- Done well for specific instruments (e.g. OCO-2)
- Geoff Toon works with HITRAN
- AER does this when we can
- Increasing priority for GEISA

but overall this is not treated as a necessity by the community or funding agencies.

Moving onto solar irradiance

AER has used and distributed the Kurucz (1992) solar irradiance spectrum for ~20 years

- Formulation based on Kitt Peak Solar Flux Atlas and solar RT calculations
- At that time, used in MODTRAN
- Provided desired spectral range and high resolution for LBL calculations
- Used in RRTMG_SW



Issues:

- Disagrees with subsequent observations and analysis

  e.g. integrates to ~1368 W/m^2 (modern value - ~1361)

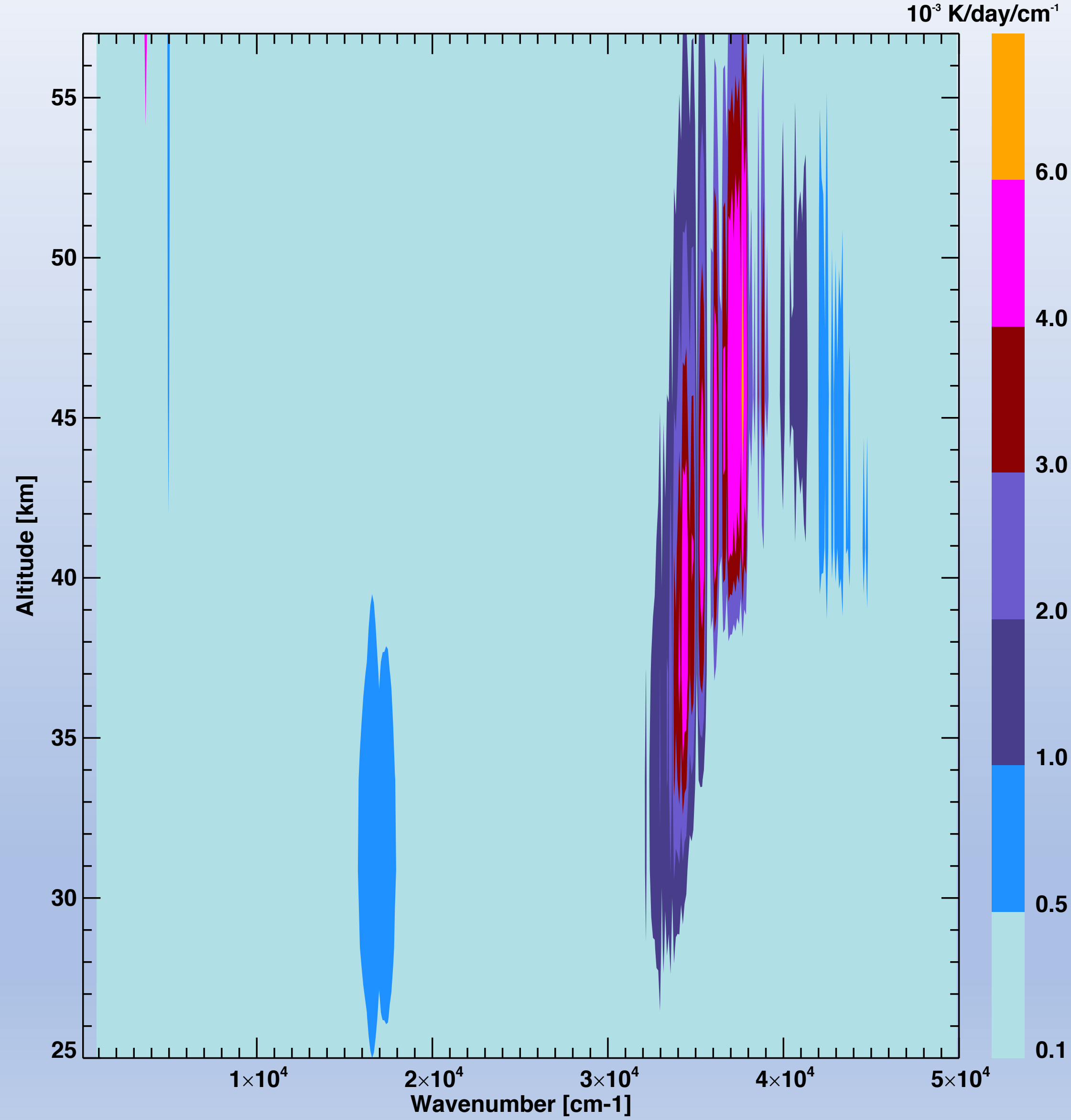
- GCMs using RRTMG_SW demonstrate large temperature biases in stratosphere

January 2015 zonal-height mean temperature for GEOS-5 with RRTMG SW (Kurucz w/ month-based solar constant) vs. **MERRA-2**.

(Acknowledgment: Peter Norris, Bill Putman, Matt Thompson, and Larry Takacz.)

Stratospheric heating rates (solar)

Clough plot for solar
heating rates in stratosphere



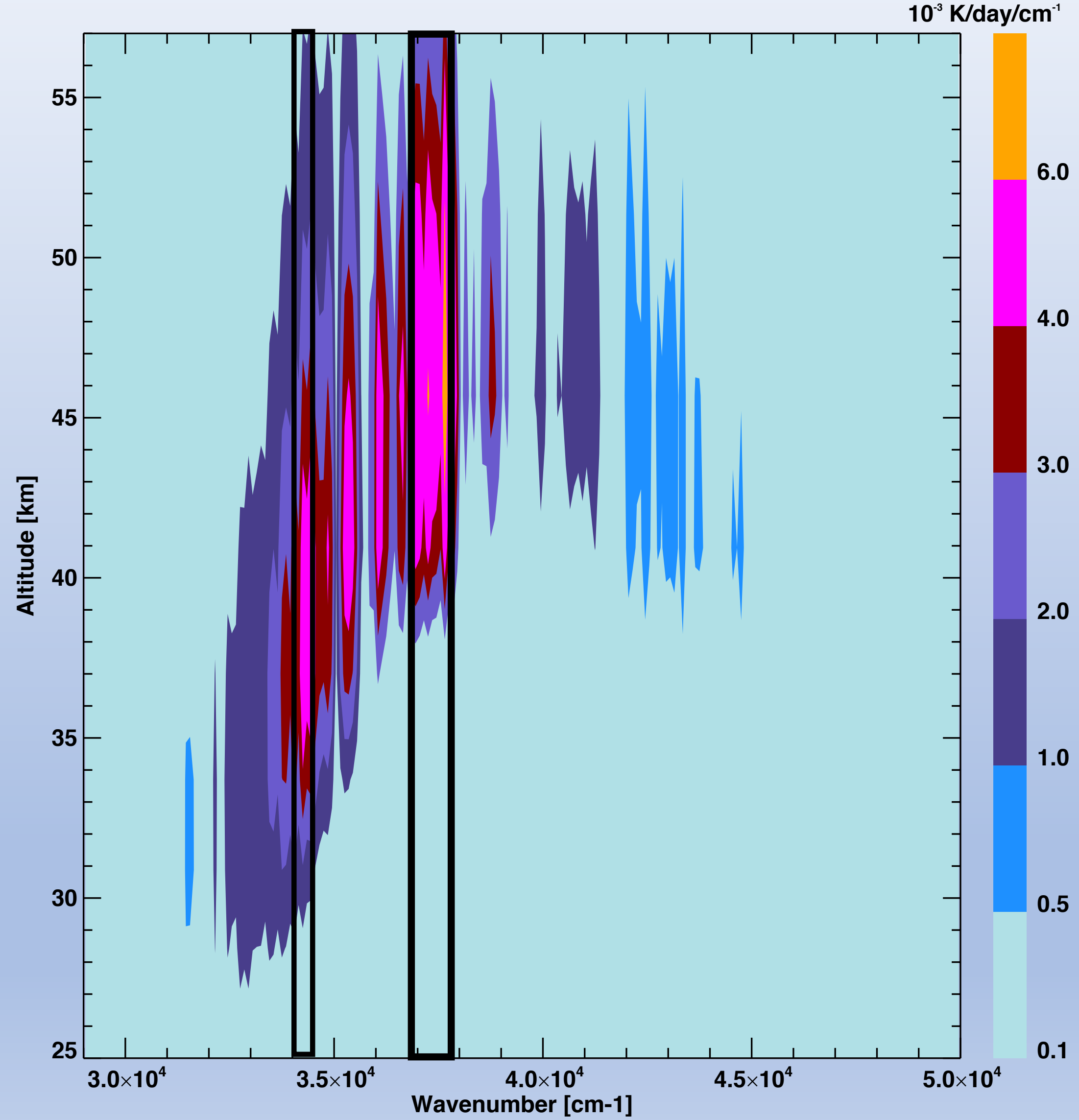
The UV is key to modeling the stratosphere.

UV stratospheric heating

Needed for accurate simulations in stratosphere:

- Accurate UV solar irradiance
- Sufficient spectral 'resolution' to resolve key heating features
- Correlation between spectral behavior of:
  - solar irradiance
  - absorption optical depth

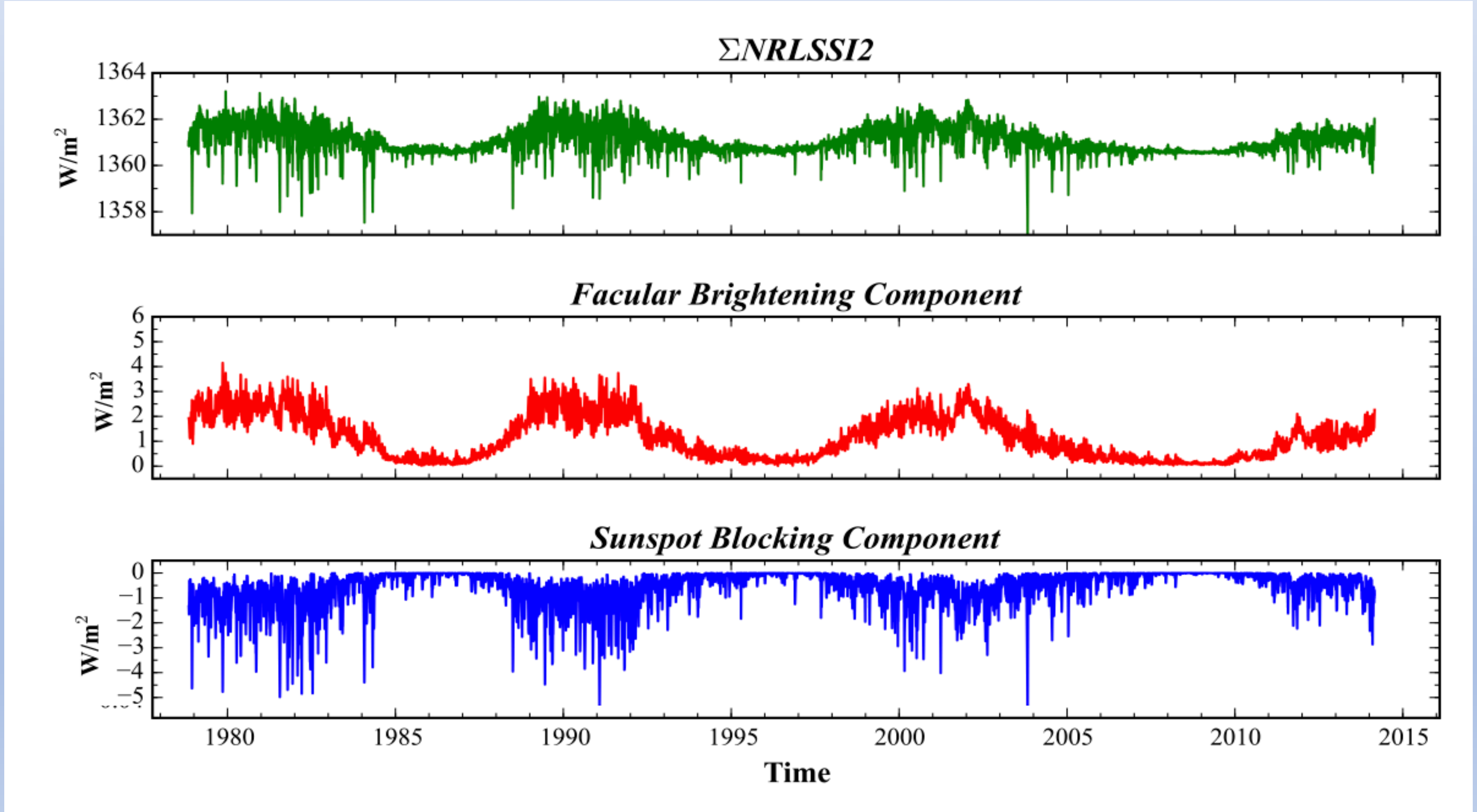
  must be respected.



Improvement to Kurucz: NRLSSI2

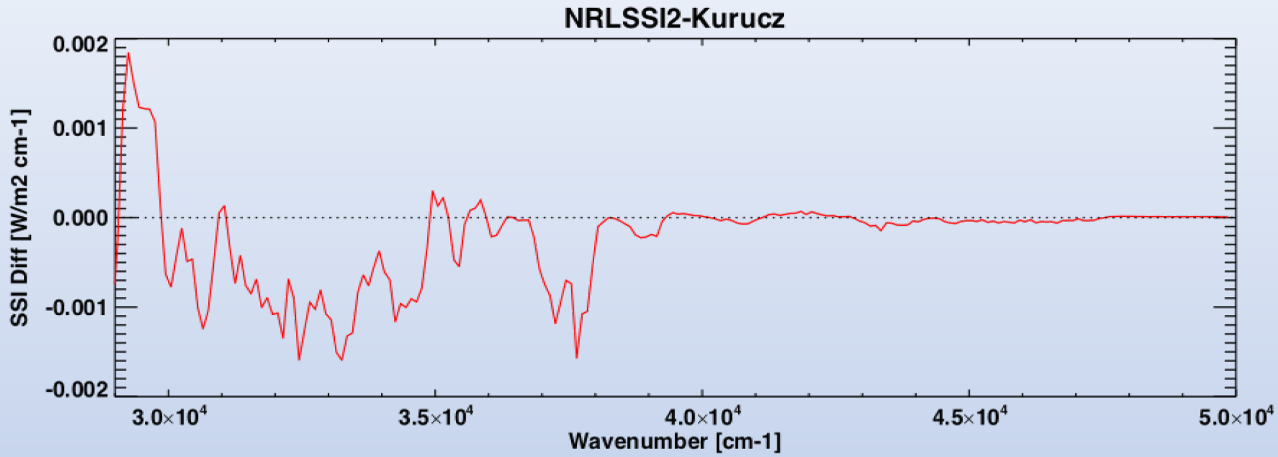
"The ...NRLSSI2 models compute ...SSI from the changes from quiet Sun conditions arising from bright faculae and dark sunspots on the solar disk using linear regression of proxies of solar sunspot and facular features with the approximately decade-long irradiance observations from the SOlar Radiation and Climate Experiment (SORCE)."

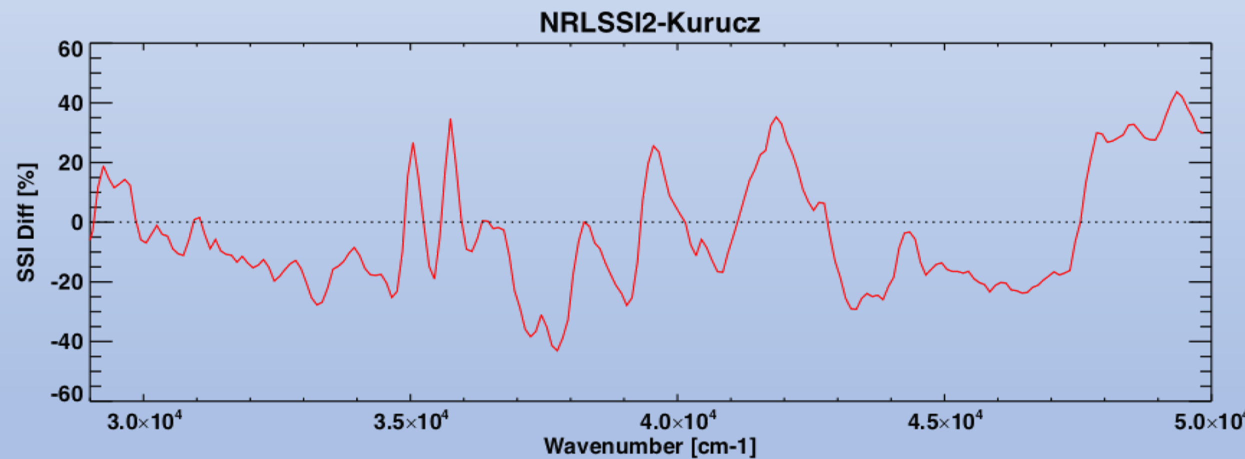
Coddington et al. (2016)
Lean (2012)



Improvement to Kurucz: NRLSSI2

- Very different in UV
- Note: AER constructed a high spectral resolution version of NRLSSI2, constraining higher resolution data sources (Toon transmittances, Kurucz) to NRLSSI2 values
  - available at rtweb.aer.com





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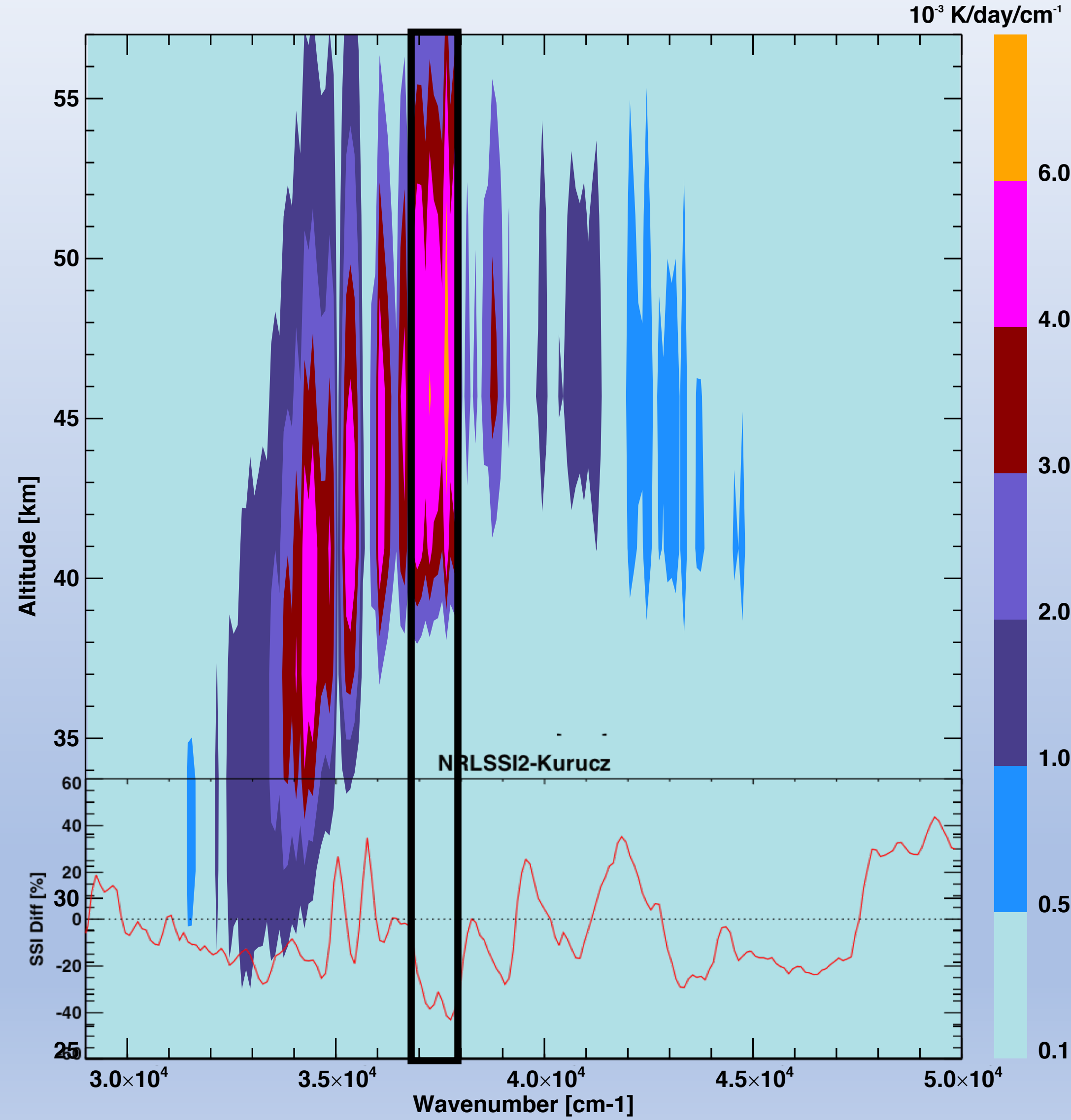

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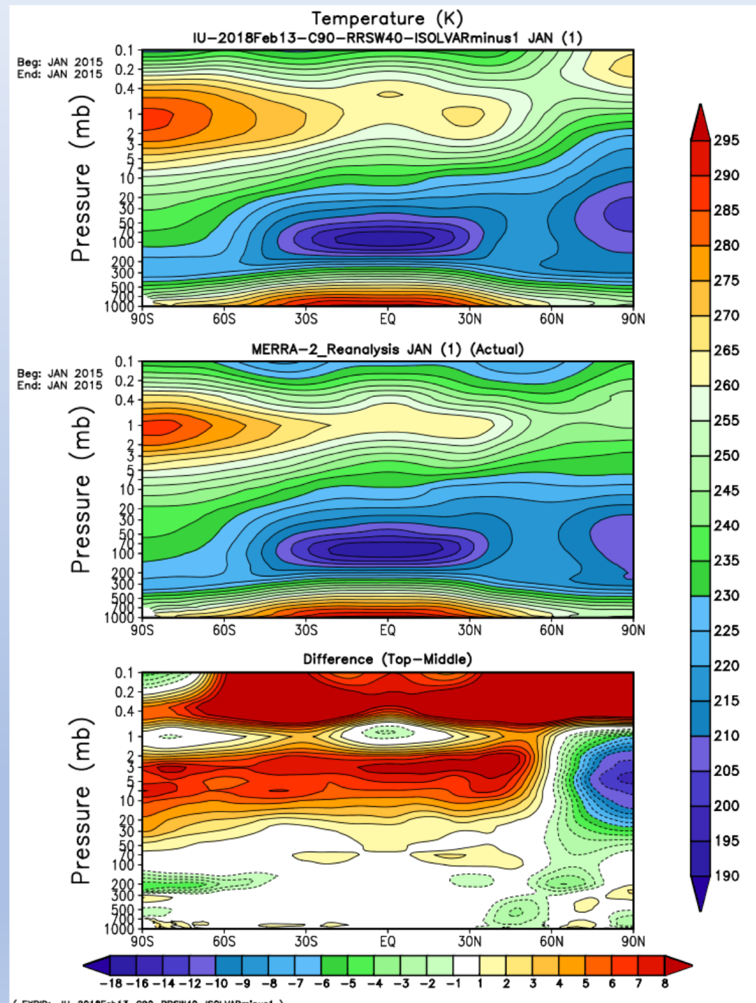
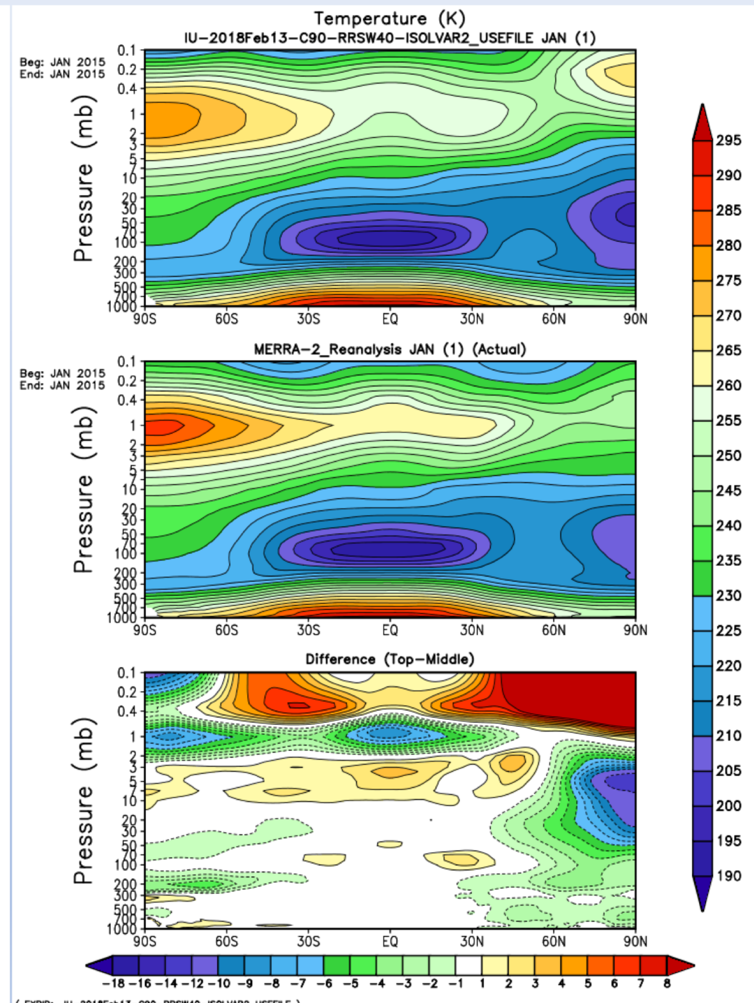
Improvement to Kurucz: NRLSSI2

Kurucz



NRLSSI2



January 2015 zonal-height mean temperature for GEOS-5 with RRTMG SW (month-based solar constant) vs. MERRA-2.

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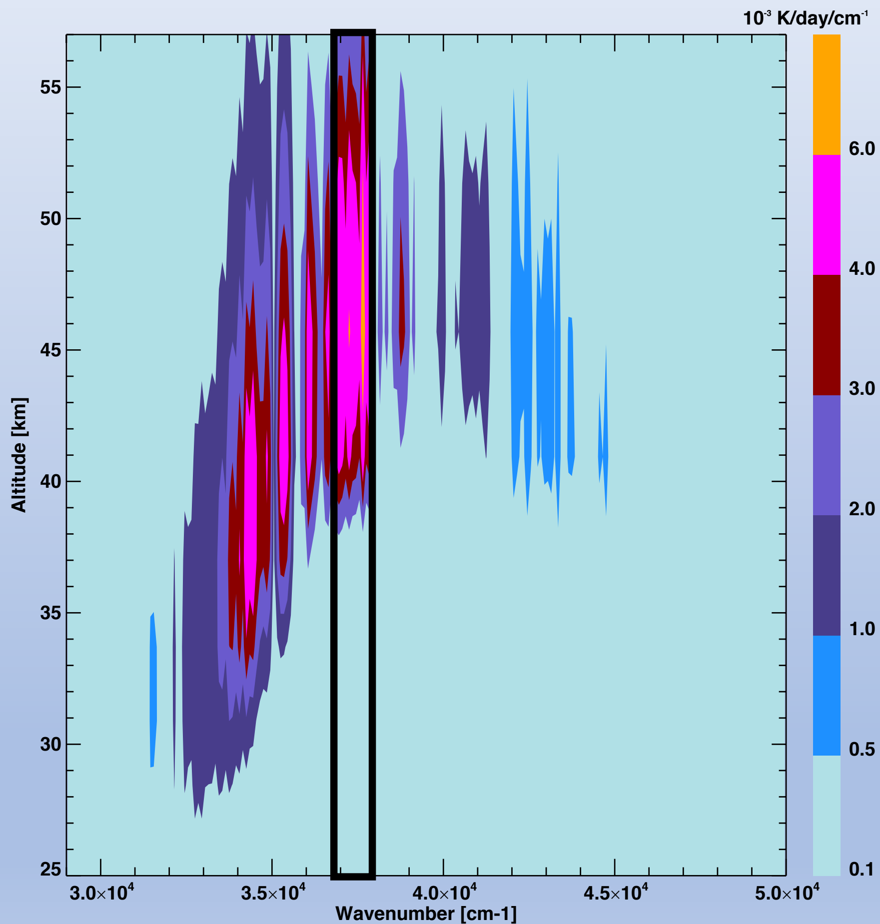
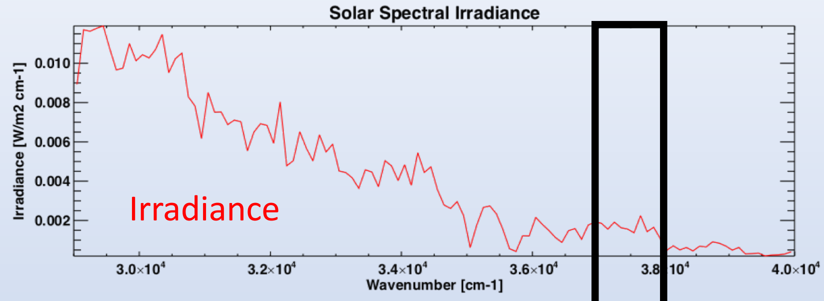
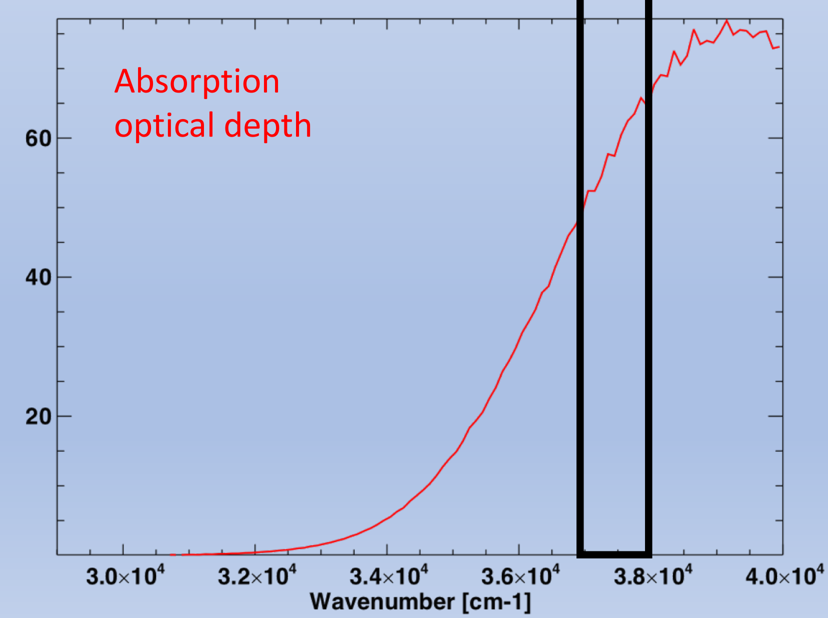
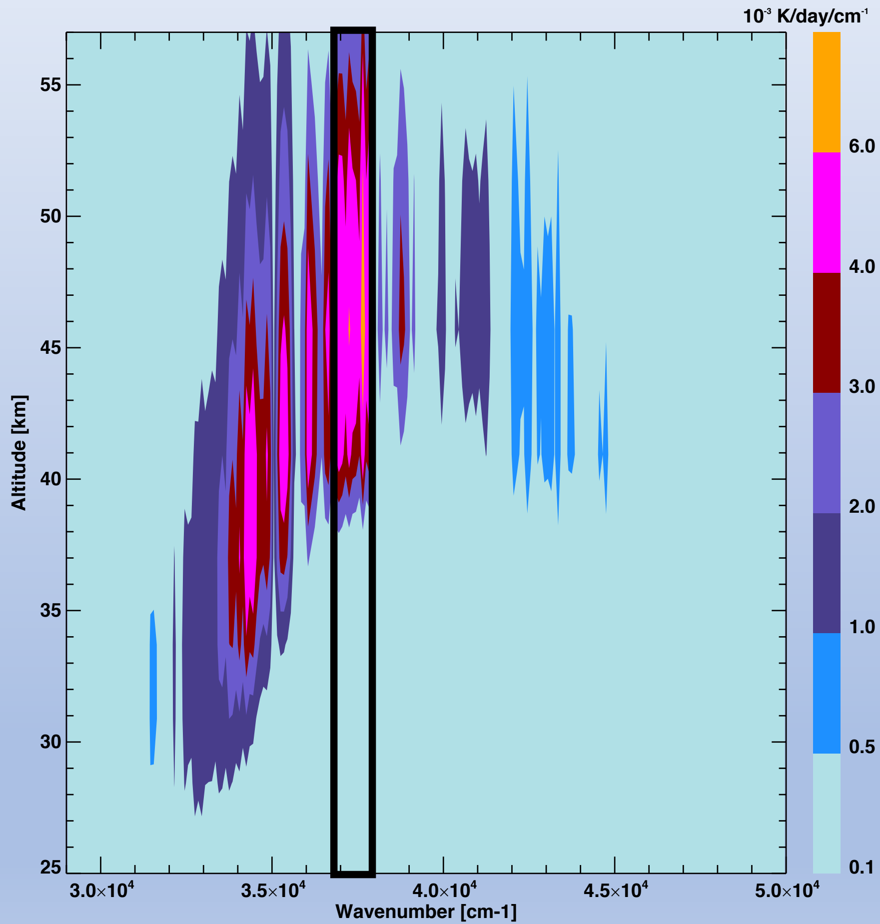
Spectral resolution and correlation

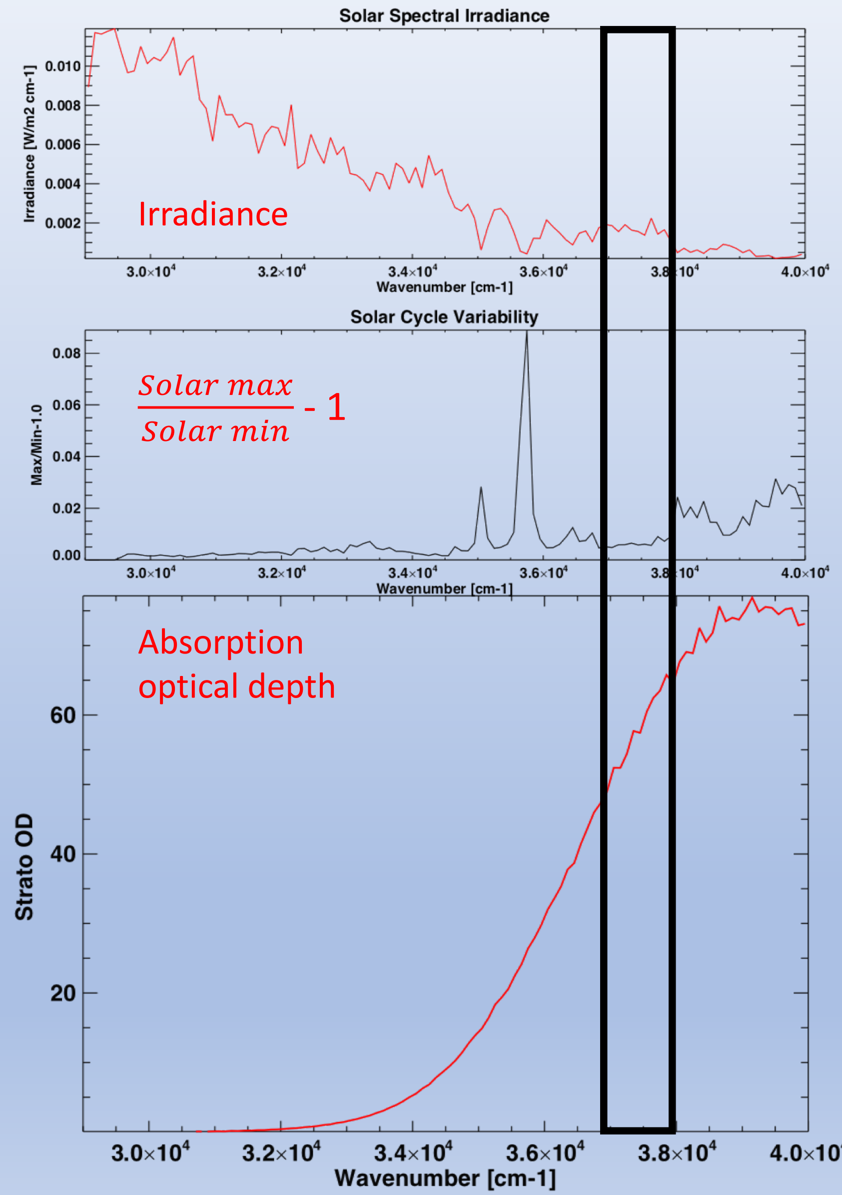




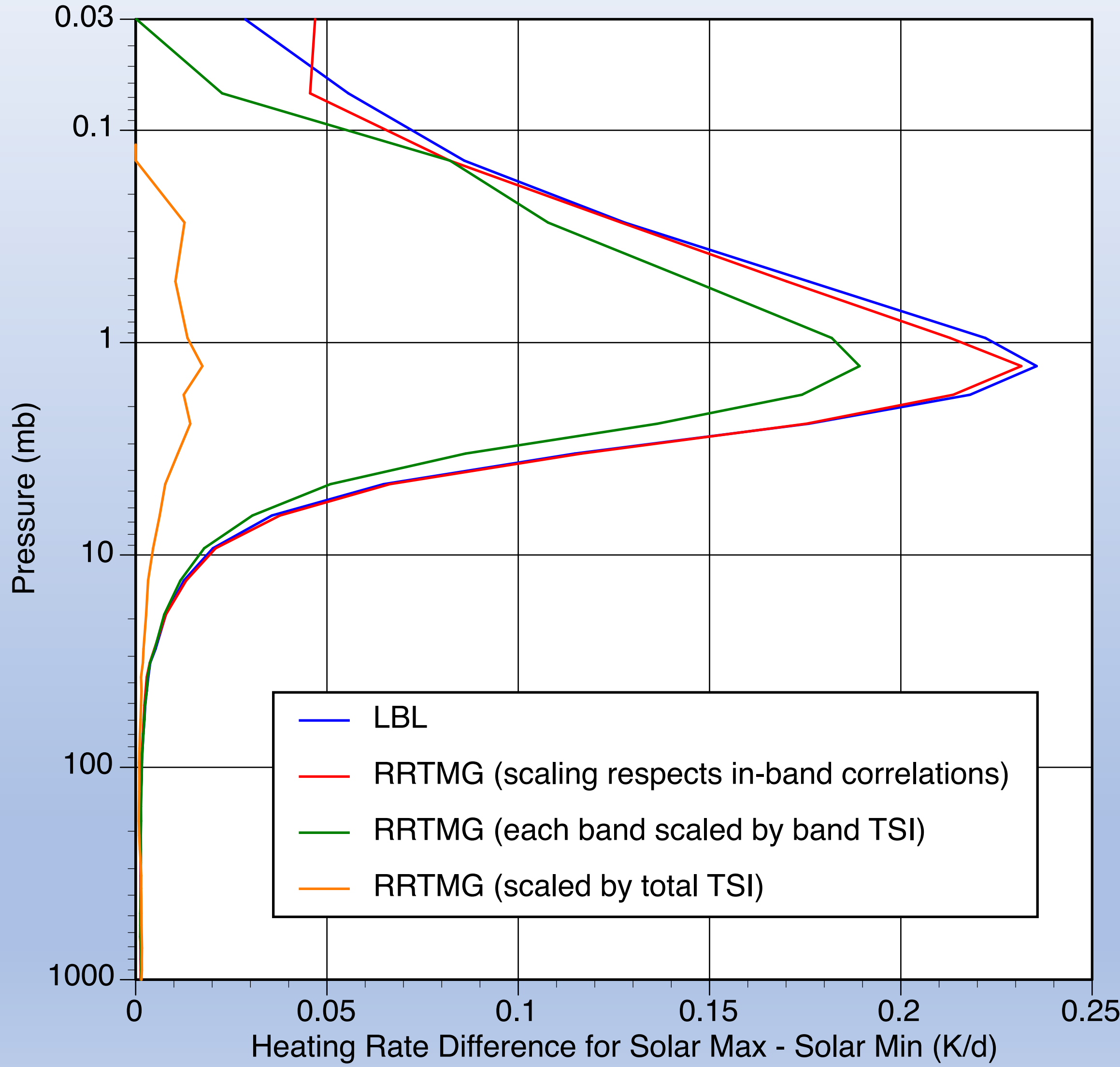


Spectral resolution and correlation





Impact of spectral correlation of solar variability



Note: RRTMG has (and RRTMGP will have) a number of options for the user to specify solar variability:

- No variability
- Typical variability
- Input TSI with typical variability
- Scaled typical variability
- Direct specification of Mg and SB indices

Main points

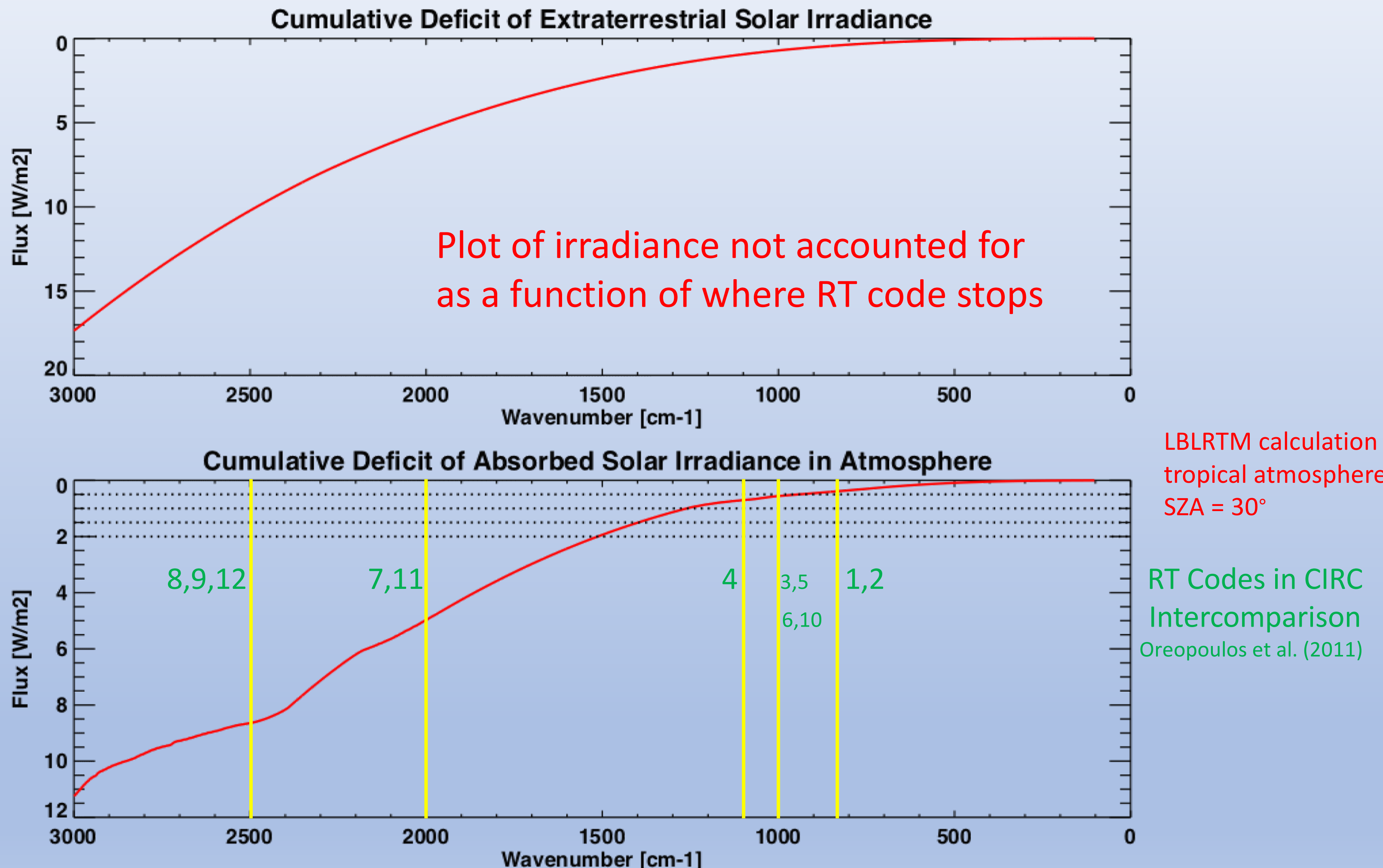
- Radiative closure experiments continue to play an important role in improving and validating spectroscopic input to radiative transfer calculations
  - e.g. Far-IR H_2O line widths and continuum
  - e.g. NIR H_2O line widths

- Line parameter databases should not be assumed to be improvements on previous versions

- **Spectral considerations are important for fast RT codes:**
  - **Spectral resolution**
  - **Spectral correlations**

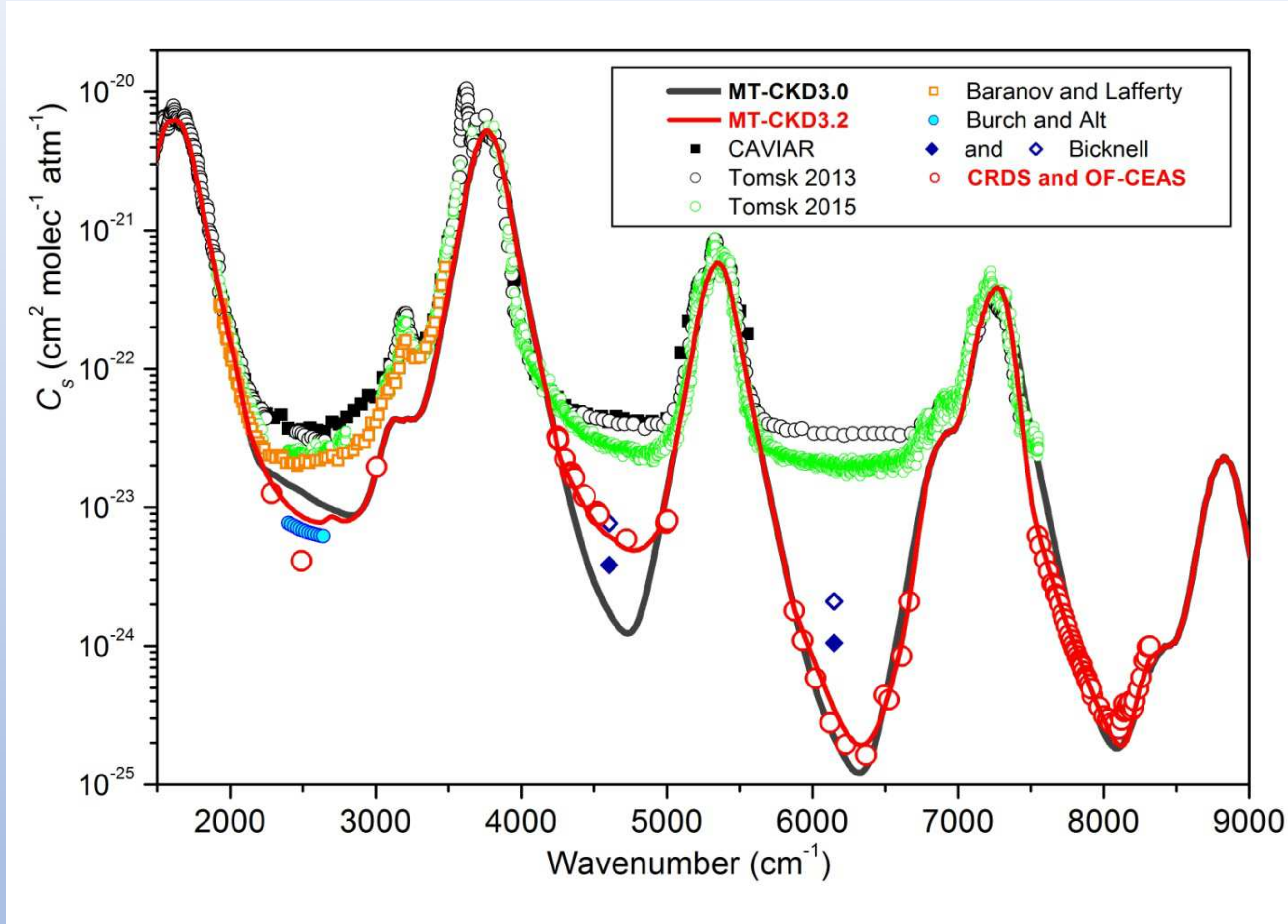
    - Possibly important for clouds (e.g Lu et al. (2011)), surface albedo, emissivity, ...

Solar radiation: spectral coverage



- Conclusion: Some radiation codes don't include a fair amount of solar absorption

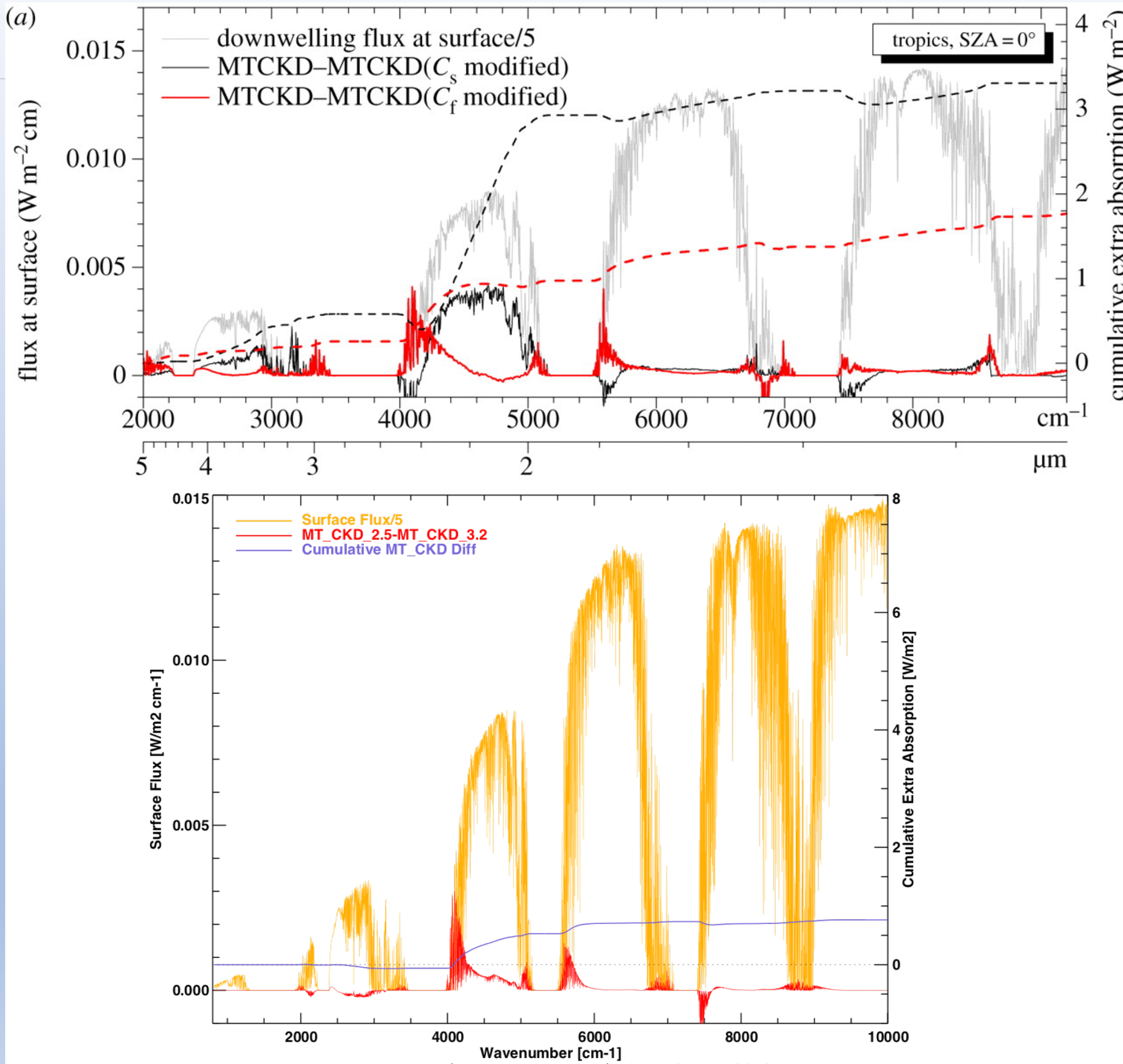
Near-IR water vapor self continuum laboratory measurements



From Lechevallier et al. (2018)

Fig. 8

Comparison of the MT_CKD3.0 and 3.2 models (black and red solid lines, respectively) (Mlawer et al. 2012) of the water vapor self-continuum cross-sections, C_S, in the 1500-9000 cm^{-1} range to an exhaustive collection of the experimental determinations: *(i)* FTS values reported by Baranov and Lafferty (2011) (orange squares); the CAVIAR consortium (Ptashnik et al., 2011a) (black full squares), from Tomsk2013 and Tomsk2015 experiments (Ptashnik et al., 2013, 2015) (black and green open circles, respectively); *(ii)* results by Bicknell et al. (2006) from calorimetric-interferometry in air at 4605 cm^{-1} (blue open diamond corresponds to a measurement in air, blue full diamond is an estimation of the self-continuum contribution) *(iii)* measurements by Burch and Alt (1984) near 2500 cm^{-1} using a grating spectrograph (open blue circles); *(iv)* present and previous measurements by CRDS and OFCEAS (red open circles).



Mlawer , Next gen. radiation, ECMWF, 2018

From Ptashnik et al. (2012)

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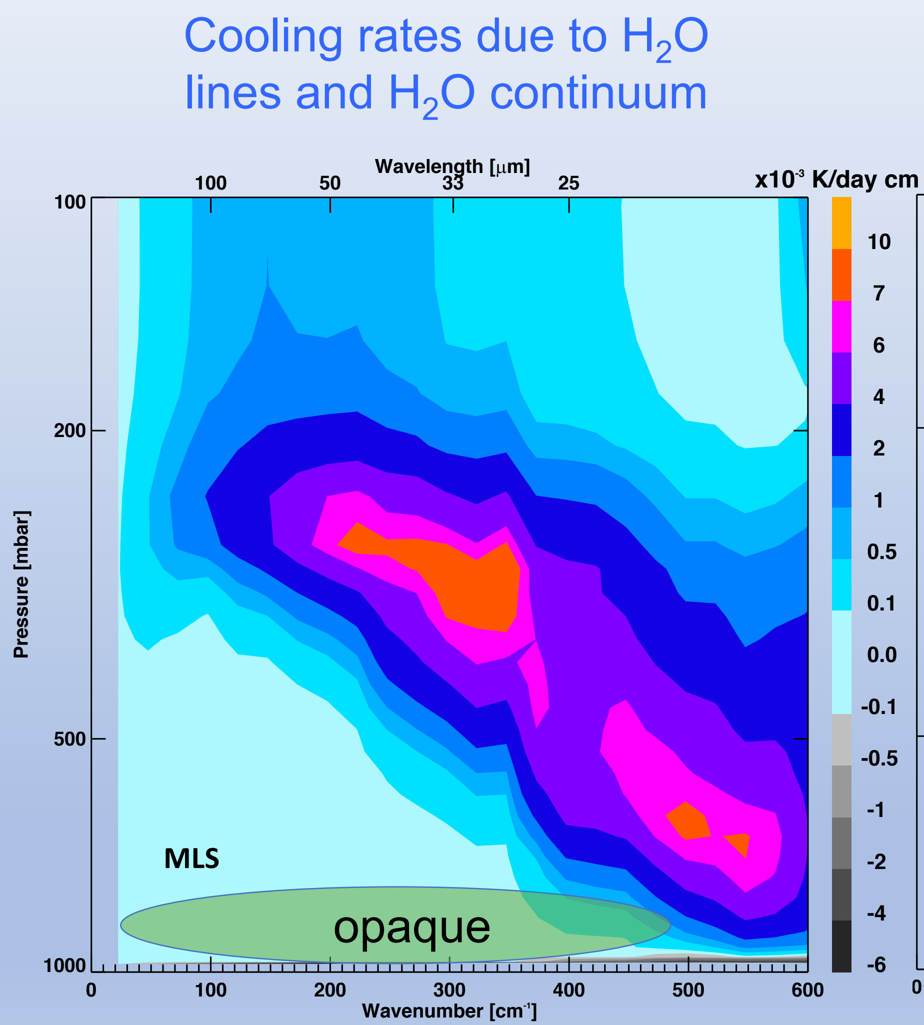
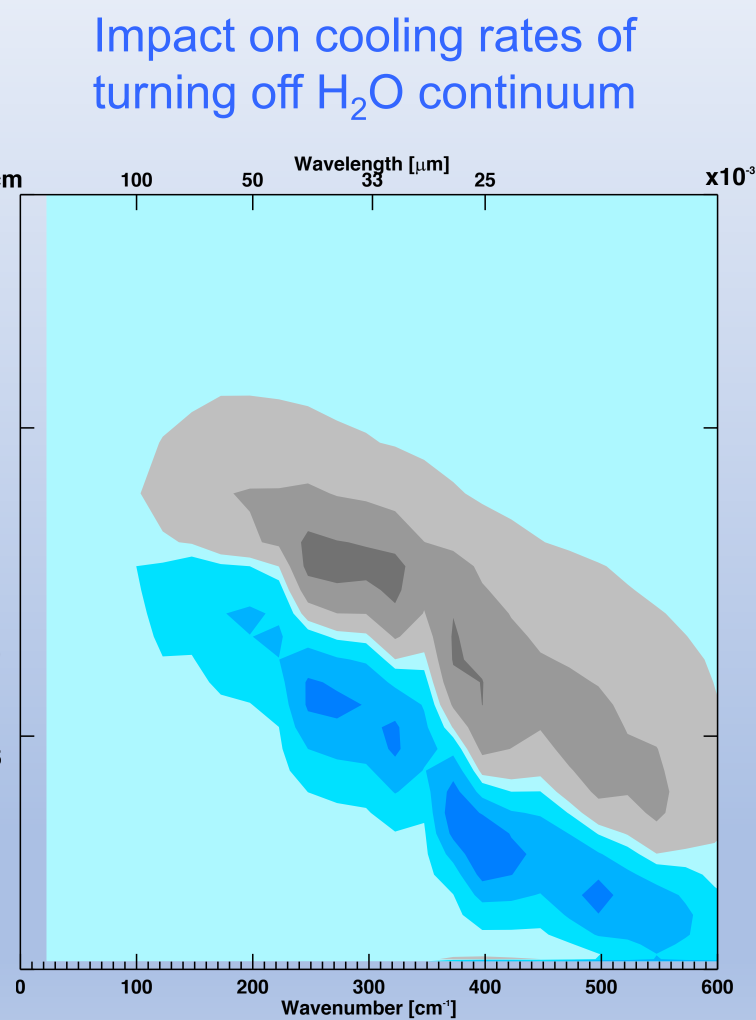
Extra slides

Far-Infrared Radiative Processes





RHUBC – II: Analysis

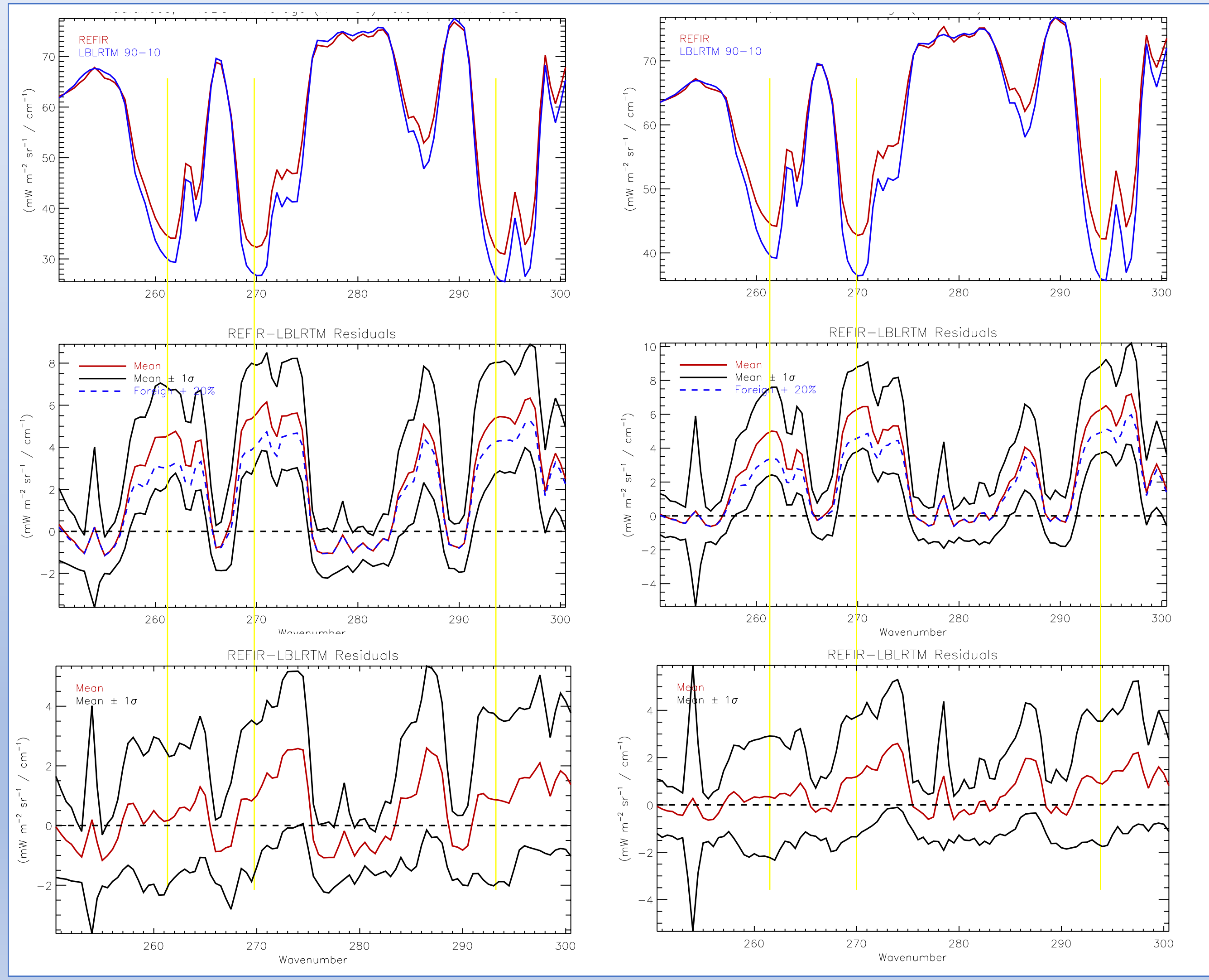
0.0 mm < PWV < 0.3 mm (34 cases)

0.3 mm < PWV < 0.5 mm (122 cases)

Observed radiances (REFIR)
LBLRTM calculation (MT_CKD_2.4)

Residuals (REFIR-LBLRTM)
+- 1 stdev
+20% foreign continuum

Residuals (REFIR-LBLRTM) with modified foreign continuum
+- 1 stdev



RHUBC – II: Analysis

RHUBC-II: the H_2O foreign continuum between 200-400 cm^{-1} is much larger than in recent versions of MT_CKD