Atmospheric and Environmental Research, Inc.

Improved Spectroscopy for Microwave and Infrared Satellite Data Assimilation

Vivienne Payne, Jean-Luc Moncet, Tony Clough

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Acknowledgements

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Overview

- **Microwave**
  - **MonoRTM**
  - **Comparisons with Rosenkranz model**
  - **Validation with ground-based instruments**

- **Infrared**
  - **Updates to LBLRTM**
    - » **CO_2 line mixing**
    - » **CO_2 continuum**
  - **Validation with aircraft and satellite instruments**

- **Summary**

What is 'Truth'?

- **'Truth' at the Level Required is not readily available**
  - **sonde accuracies; spatial and temporal sampling**
  - **laboratory measurements**

- **Spectral Residuals are Key!**

- **Consistency within a band system**

- **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**

- **Consistency between infrared and microwave**

Microwave

Microwave topics

- MonoRTM
- Recent updates to MonoRTM
  - Water vapor
  - Oxygen
- Differences from the Rosenkranz model
- Validation against ground-based measurements

MonoRTM

- **Microwave monochromatic radiative transfer model**
  - **"laser" - i.e. single frequency - version of LBLRTM**
- **Developed at AER**
- **Useful range**
  - **0-1648 GHz**
- **Spectroscopic parameters from external line file**
  - **HITRAN 2000 with specific updates/modifications**
    - » **22 GHz and 183 GHz line intensities from Clough et al (1973)**
    - » **Recent updates:**
      - **Other 22 GHz and 183 GHz line parameters from R. R. Gamache (2007)**
      - **Oxygen widths, line coupling parameters from Tretyakov et al (2005)**
- **Lineshape**
  - **Van-Vleck Weisskopf**
- **Continuum: CKD_2.4**
  - **Identical to MT_CKD in this region**

MonoRTM and the Rosenkranz model: Differences

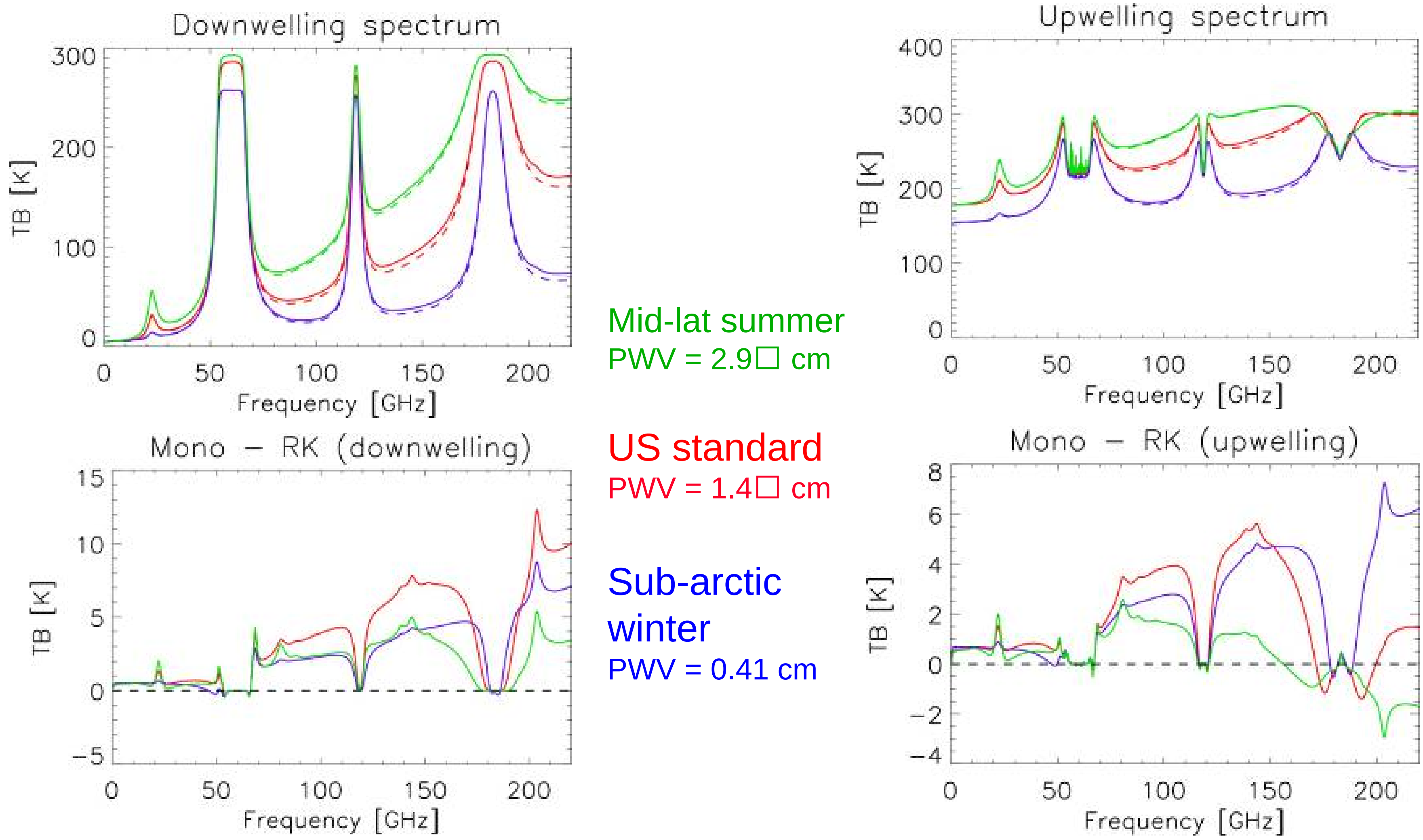
- **Rosenkranz has made recent updates**
  - **Oxygen parameters**
  - **183 GHz line width**
  - **Can now include certain ozone lines**

- **Updates in MonoRTM and Rosenkranz models bring results closer**

- **Important remaining differences:**
  - **Spectroscopic parameters**
    - » **Width of the 22 GHz water vapor line**
    - » **Temperature dependencies of widths**
  - **Continuum**
    - » **Foreign broadening**
    - » **Self broadening**
  - **Number of lines**
    - » **Rosenkranz does not include all lines or all species**
    - » **MonoRTM: line info from external file**
      - **Can include/exclude lines according to speed/accuracy requirements**
      - **Weak water vapor lines can have non-negligible effect**

Brightness temperature comparisons: MonoRTM vs RK

- Same RT code used (different models used for optical depth calculations).
- No ozone in either simulation.



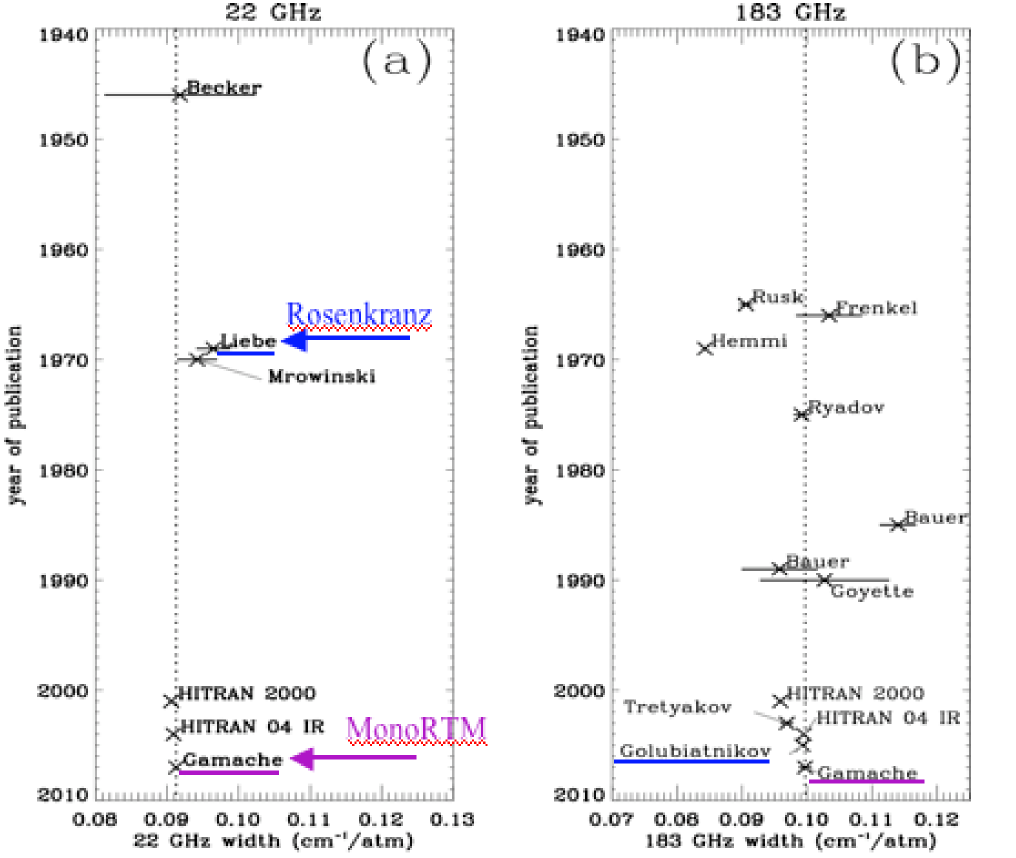
Water vapor line parameters

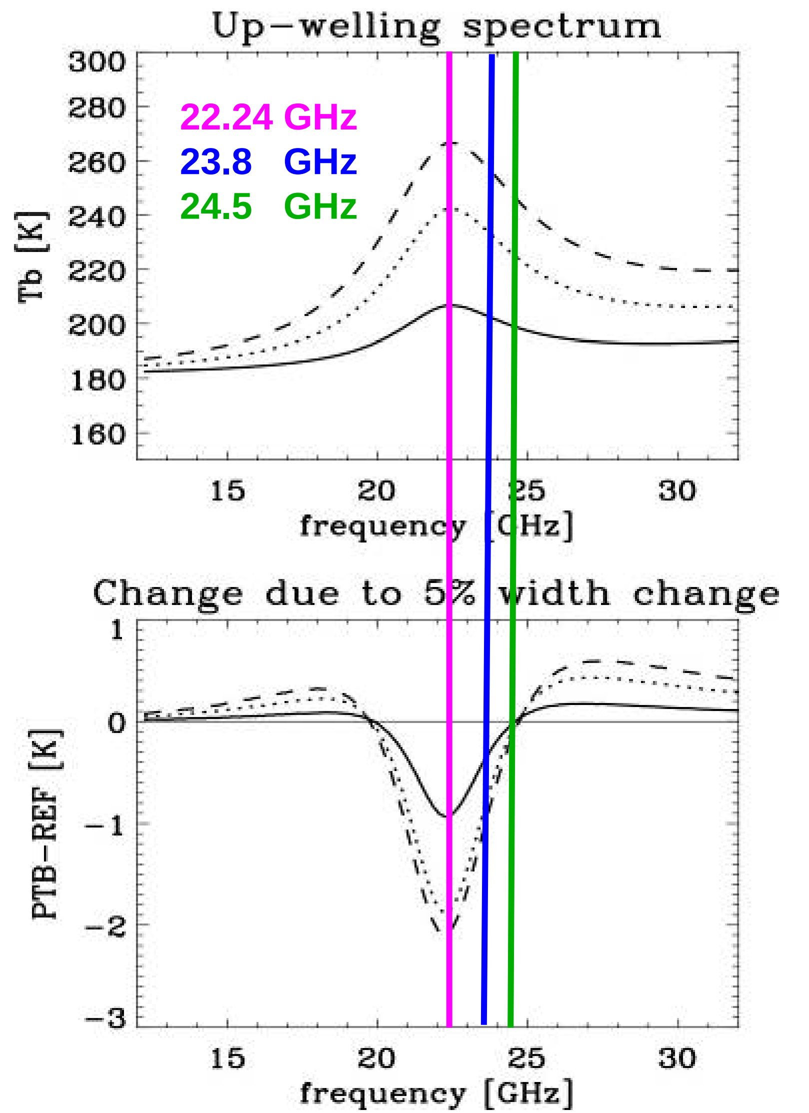
22 GHz line	α_f	X_f	α_s	X_s	S	E”	shift
MonoRTM 2007	0.0913	0.76	0.44	0.76	4.438E-25	446.511	-0.000088
Rosenkranz 2007 (HITRAN units)	0.0959	0.69	0.46	0.61	4.319E-25	447.047	-0.000084
Rosenkranz 1998 (HITRAN units)	0.0959	0.69	0.46	0.61	4.319E-25	447.047	**0**

183 GHz line	α_f	X_f	α_s	X_s	S	E”	shift
MonoRTM 2007	0.0997	0.77	0.45	0.77	7.691E-23	136.164	-0.00269
Rosenkranz 2007 (HITRAN units)	0.0993	0.64	0.51	0.85	7.646E-23	139.285	-0.00238
Rosenkranz 1998 (HITRAN units)	**0.0959**	0.64	0.51	0.85	7.646E-23	139.285	**-0.00163**

Water vapor: Line widths

Dotted line shows MonoRTM value for purposes of comparison





Incorrect specification of the 22 GHz width will lead to inconsistency between eg AMSU/AMSR-E and SSMIS!

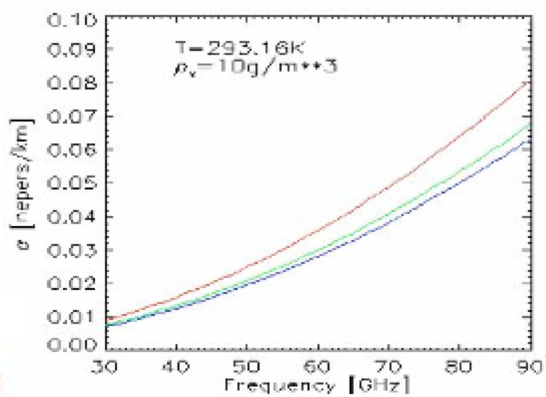
Water vapor continuum

Ratios of absorption in models (Rosenkranz=1.0)

Thomas Meissner (RSS)

	FB T = 298 K	FB T = 278 K	SB T = 298 K	SB T = 278 K
Rosenkranz	1.00	1.00	1.00	1.00
MonoRTM	1.27	1.27	0.56	0.53
RSS	1.08	1.04	0.64	0.56

Foreign broadening (FB)

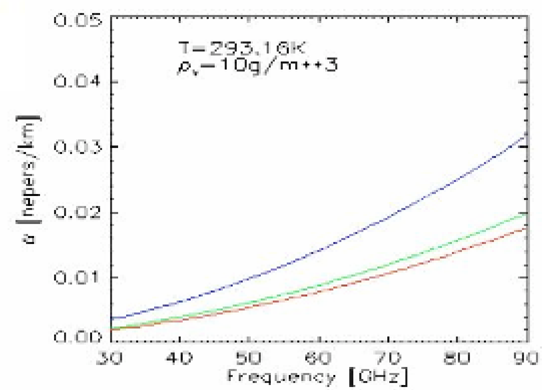


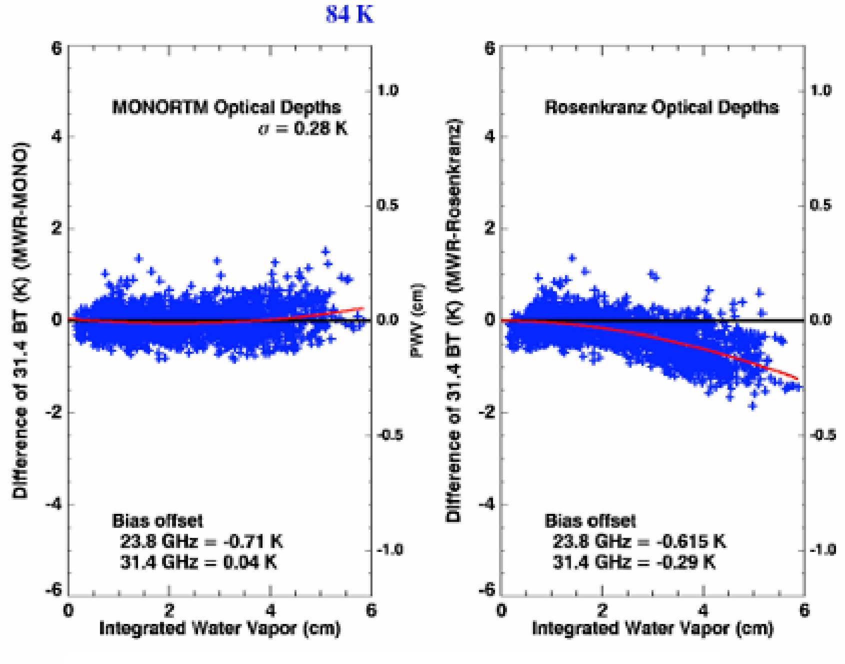
Rosenkranz

AER MonoRTM

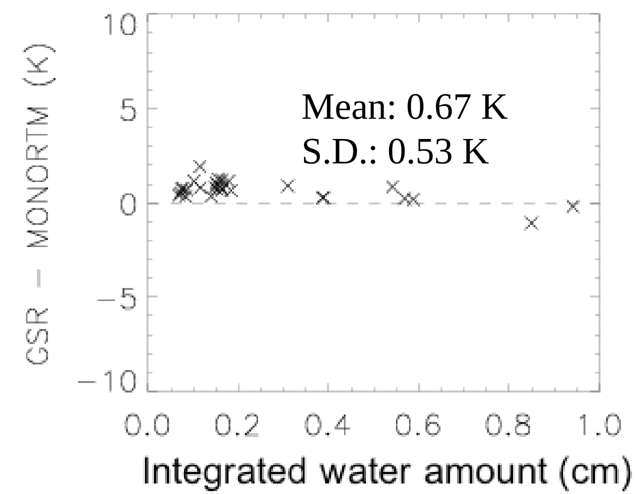
RSS (ATBD)

Self broadening (SB)





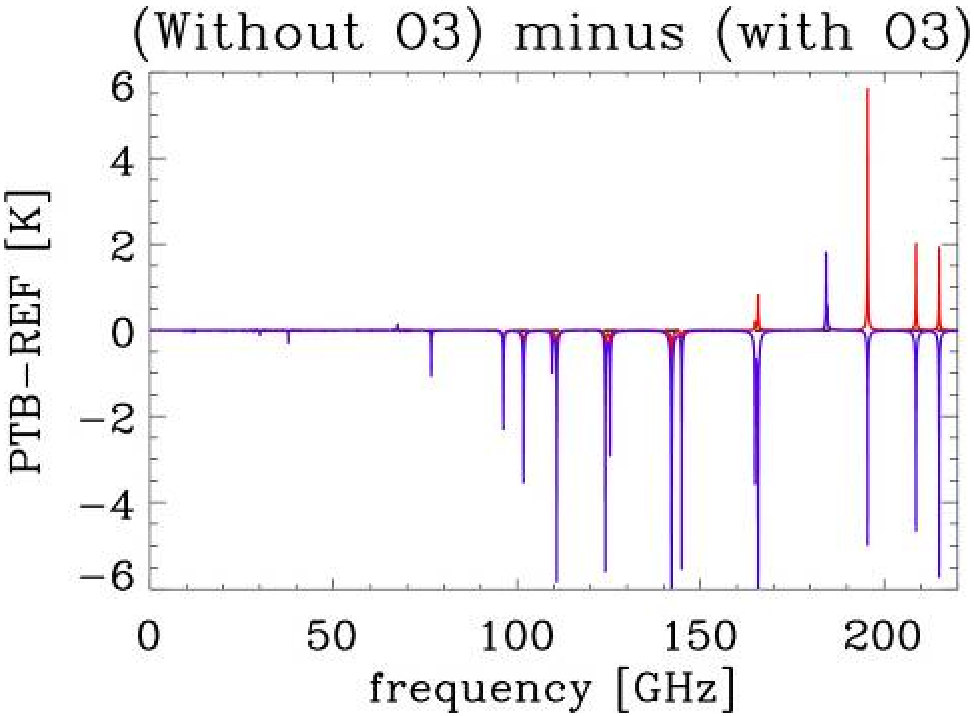
GSR 89 GHz



Ozone: Difference in upwelling spectra

US standard
PWV=1.4 cm

Sub-arctic winter
PWV = 0.41 cm

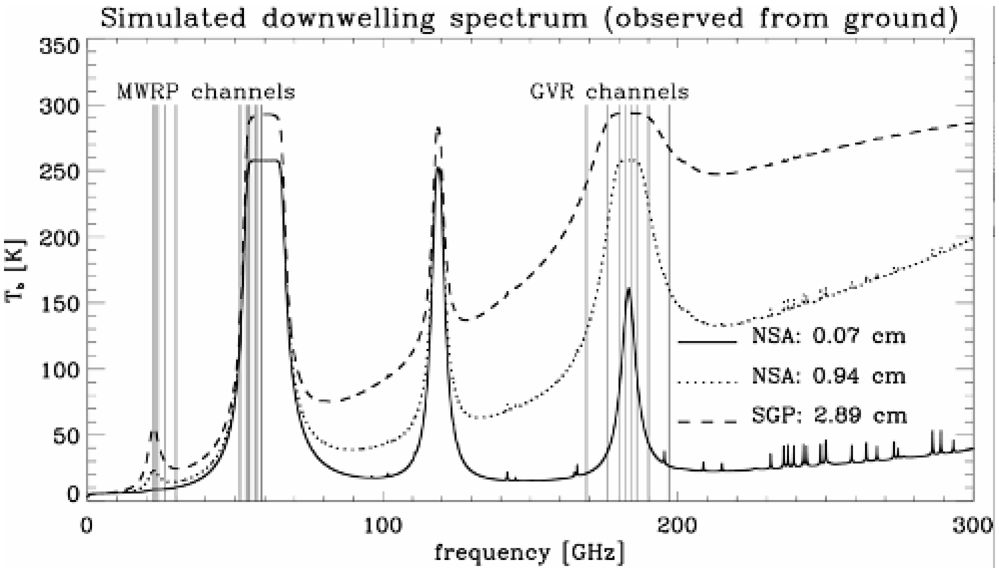


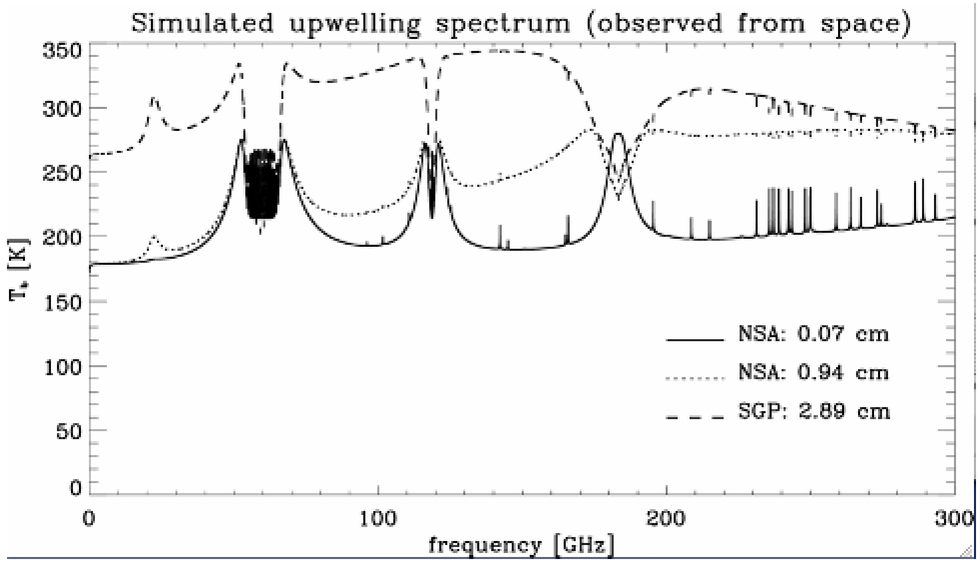
Impact on AMSU 183+/-1 GHz channel

Validation of microwave spectroscopy using ground-based radiometers

ARM sites

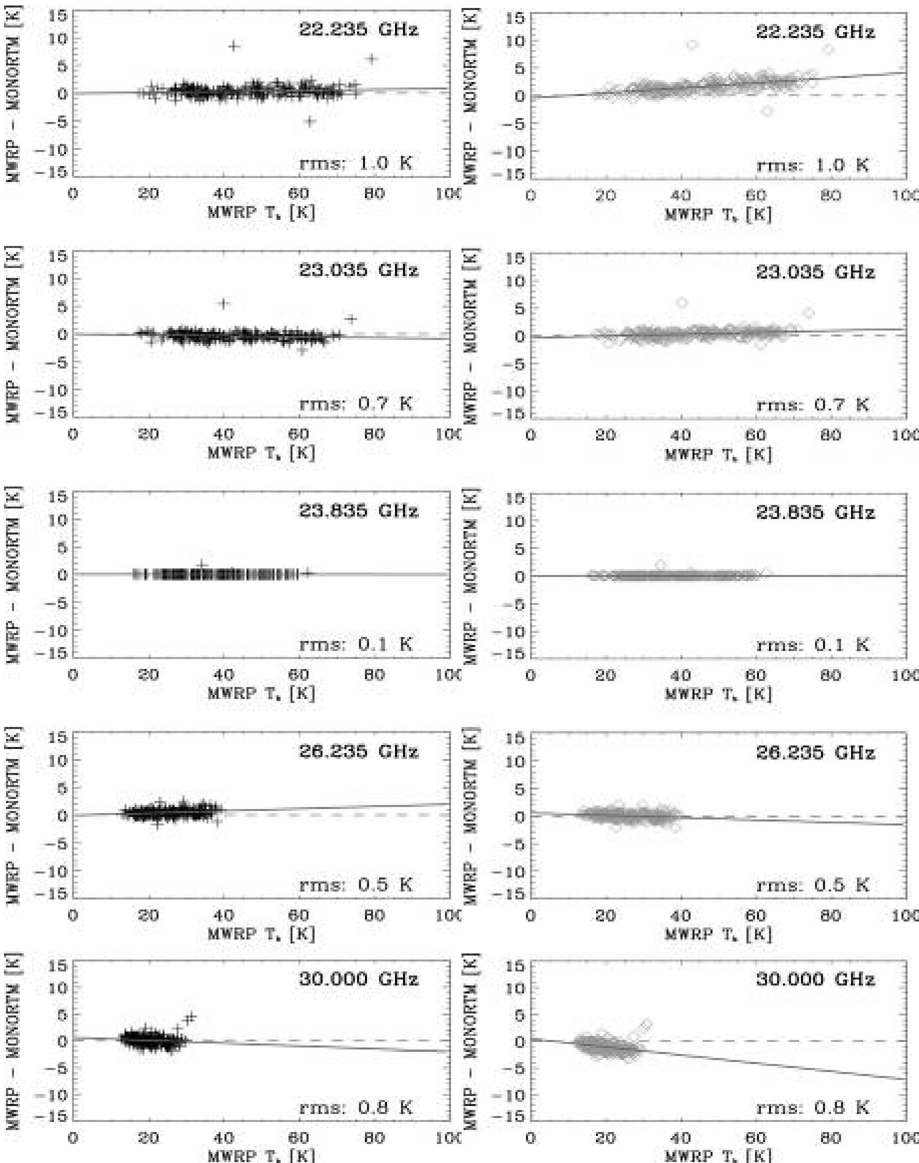
- MWRP at NSA
  - Oxygen band
- MWR and MWRP at SGP
  - 22 GHz water vapor line
  - Water vapor continuum
- GVR at NSA
  - 183 GHz water vapor line
  - Oxygen band
- GSR at NSA
  - Water vapor continuum

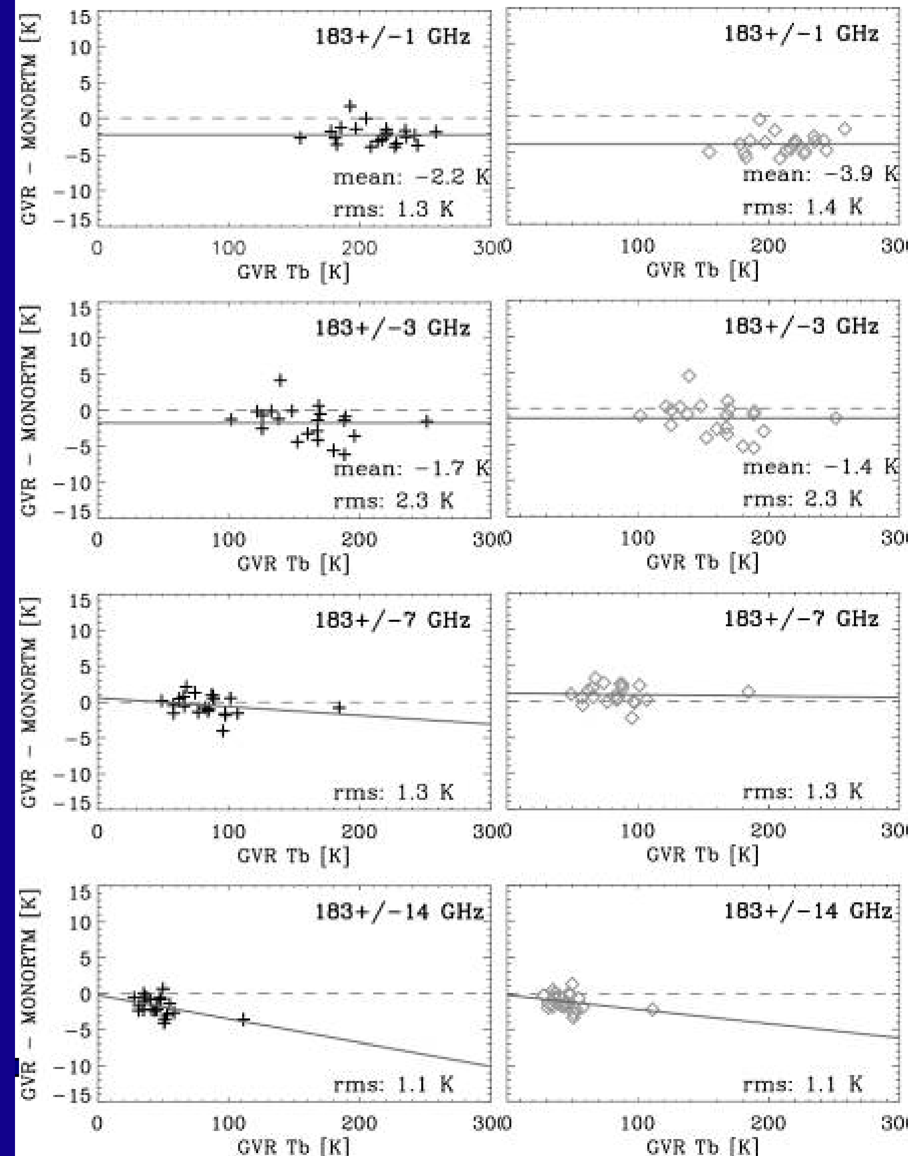




Water vapor line widths: comparisons with data

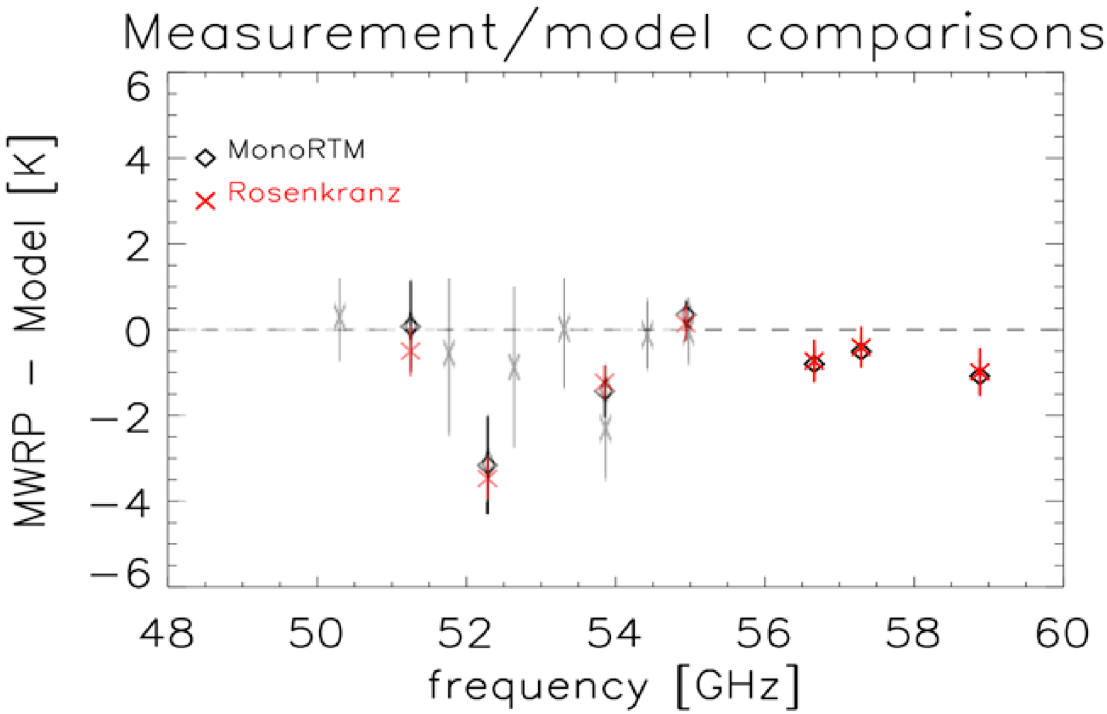
MonoRTM width (scaled sondes) | Rosenkranz width (scaled sondes) | MonoRTM (raw sondes) | HITRAN 2000 (raw sondes)





Oxygen region: model/measurement comparisons

- **Mean and SD of measurement/model differences from the NSA site**
- **14 months of data from MWRP**
  - **Channels at 51.25, 52.28, 53.85, 54.94, 56.66, 57.29, 58.88 GHz**
- **1 month of data from GSR (larger standard deviations)**
  - **Channels at 50.3, 51.76, 52.725, 53.29, 53.845, 54.4, 54.94 GHz**
- **Large differences at 52.28 GHz believed to be due to instrument calibration**



Microwave Summary

- **Recent updates in MonoRTM and Rosenkranz bring results closer**

- **Main differences between MonoRTM (2007) and Rosenkranz (2007):**
  - **Width of 22 GHz water vapor line**
  - **Water vapor continuum**

- **Ground-based validation supports MonoRTM water vapor parameters**

- **Inclusion of ozone can be important**

- **Future work:**
  - **Continued validation at ARM sites**
  - **Consistency between microwave and infrared (AERI instrument at NSA)**
  - **Zeeman line splitting**

Infrared

LBLRTM

Line-by-line radiative transfer model

- **Recent updates to LBLRTM**
- **Validation against measurements**

Line Parameters

- HITRAN: reference source for 'AER' Line Parameters
- Substitutions are only made for very specific reasons and only with extensive validation
- aer_v_1.0 (0 -122,656 cm-1)
- tes_v_1.3 (500 - 3500 cm-1)

1. Water Vapor
   - HITRAN 2000 + Update 1.1 (Toth et al.)
2. Carbon Dioxide
   - HITRAN 2000
   - Line Coupling (Hartmann et al.)
3. Ozone
   - MIPAS (Wagner at al.; Flaud et al.)

Continuum: MT_CKD_1.3

- **Water Vapor**
  - Self / Foreign
  - Single Line Shape for each
- **Carbon Dioxide**
  - ν_2 and ν_3 regions scaled based on this study
  - Continuuing Research Focus
- **Nitrogen: Collision Induced**
  - 2330 cm-1 Region
  - Continuuing Research Focus
- **Oxygen: Collision Induced**
  - 1600 cm-1 Region Scaled

Line Coupling

Lorentz

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

y_i: line coupling coefficient

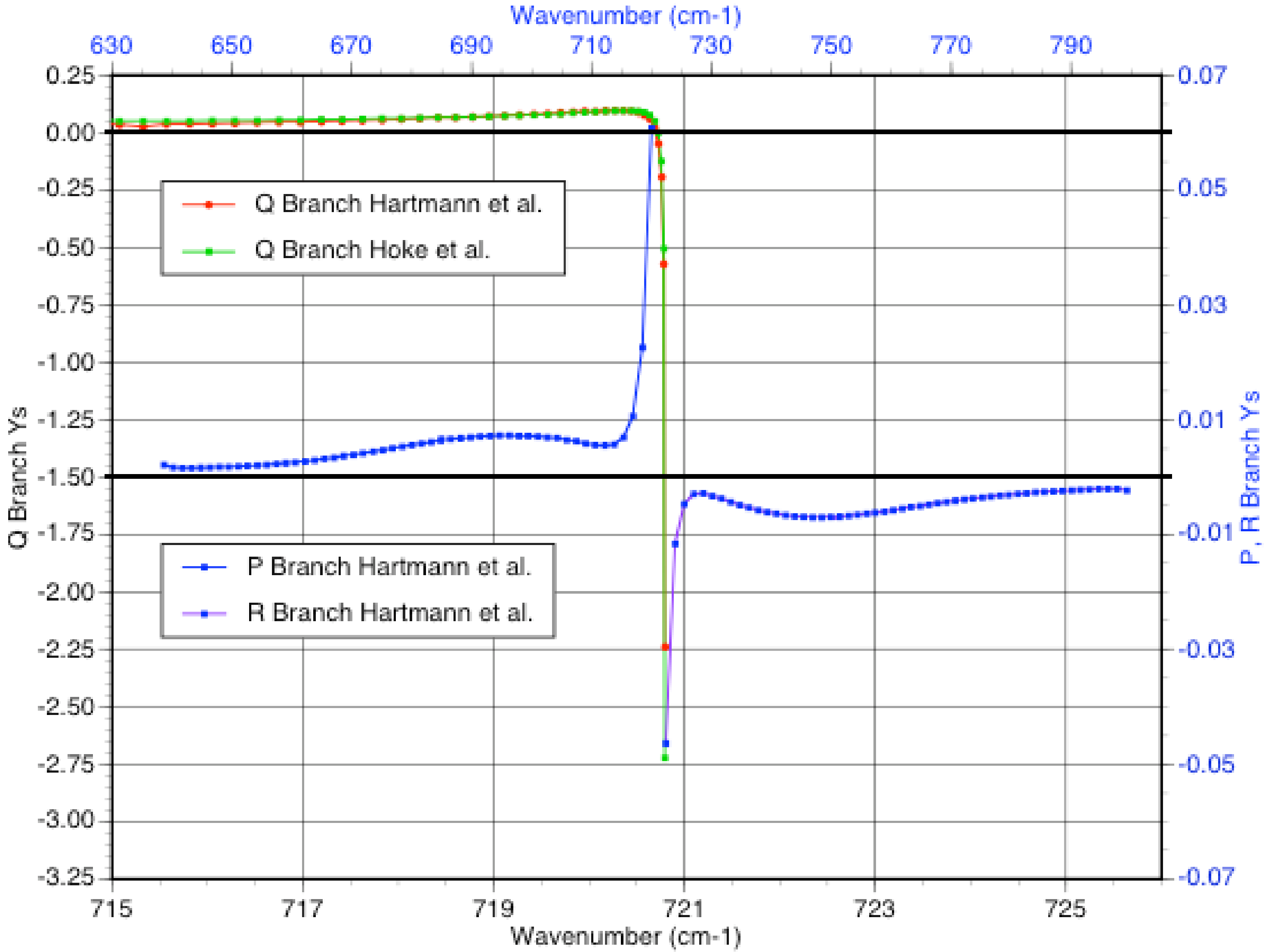
Up to now in LBLRTM:

- Q branch line coupling modeled explicitly
- P & R branch line coupling accounted for in CO_2 continuum and in duration of collision effects

Update to LBLRTM:

- P & R branch line coupling for CO_2 from Jean-Michel Hartmann's group

Line Coupling Parameters for the 5 < 2 Band



Duration of Collision Effects

Lorentz

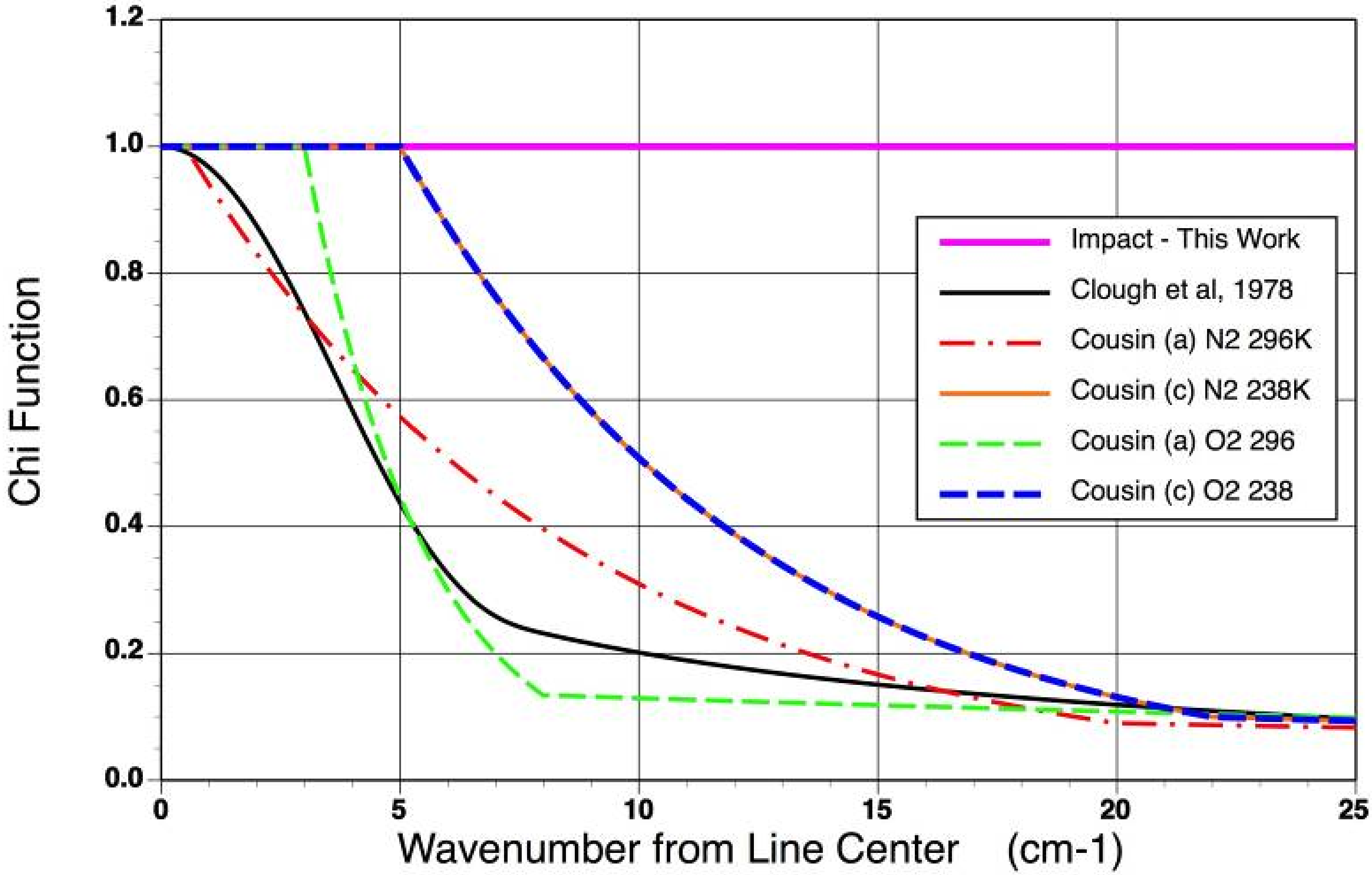
$$k_i(\nu) = \frac{1}{\pi} \frac{S_i}{(\nu - \nu_i)^2 + \alpha_i^2} \quad [\chi(\nu - \nu_i)]$$

χ_i: **duration of collision**

LBLRTM Chi Factor for CarbonDioxide

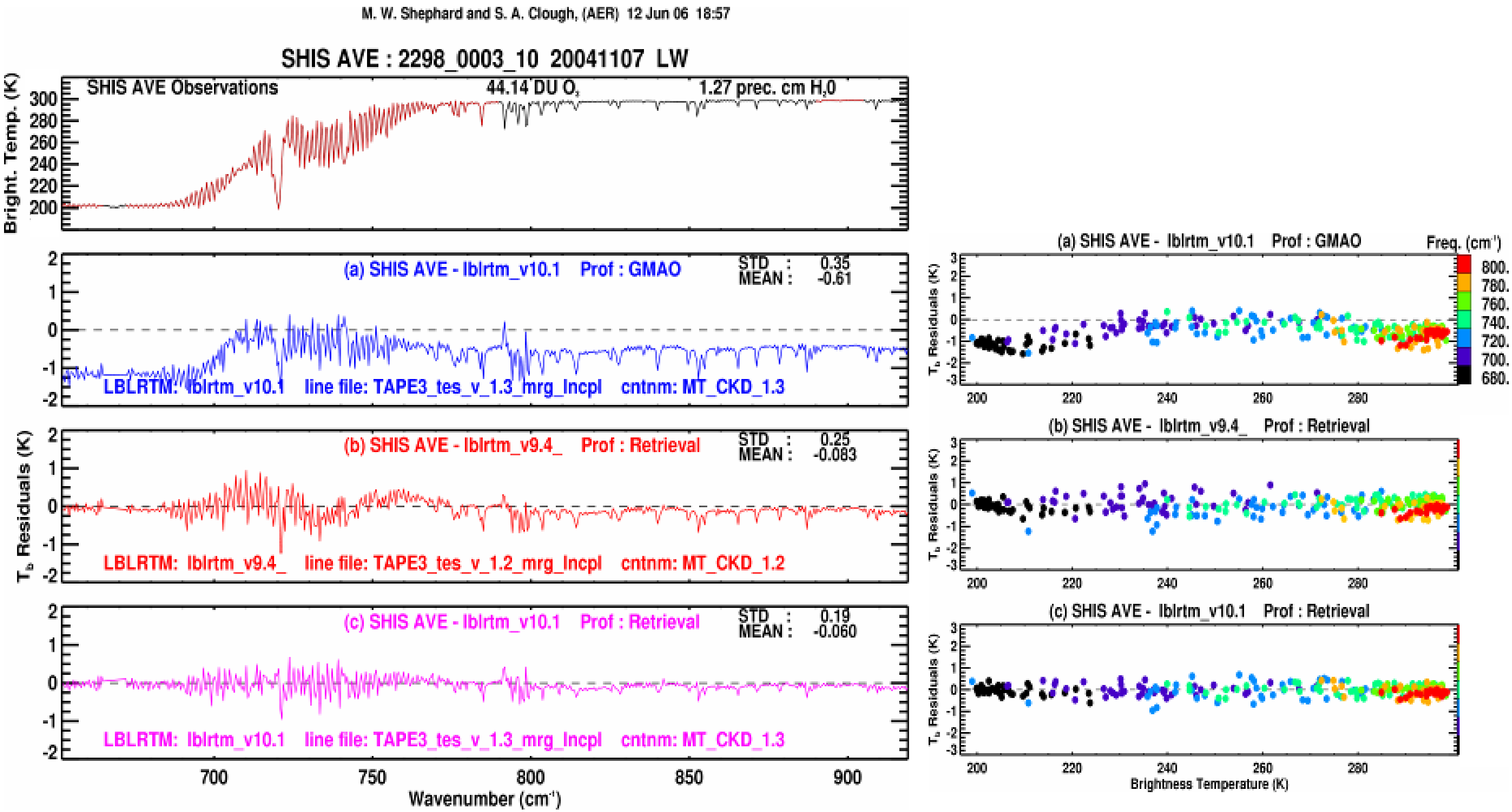
Line Coupling - Duration of Collision

Clough/Burch/Benedict based on ν3 band



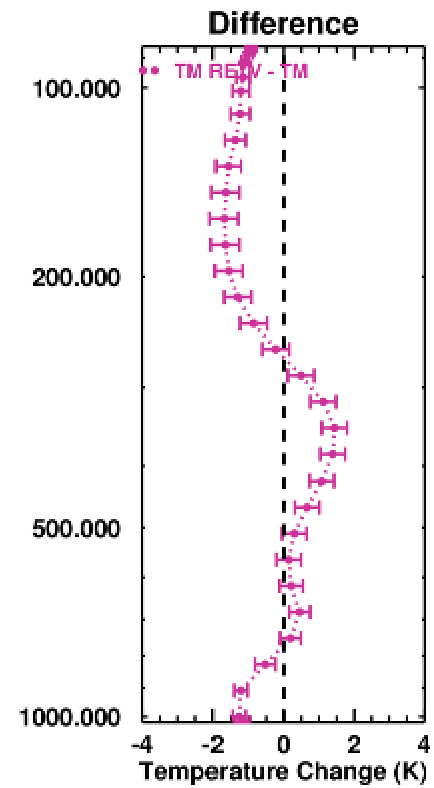
SHIS Analysis from AURA Validation Experiment

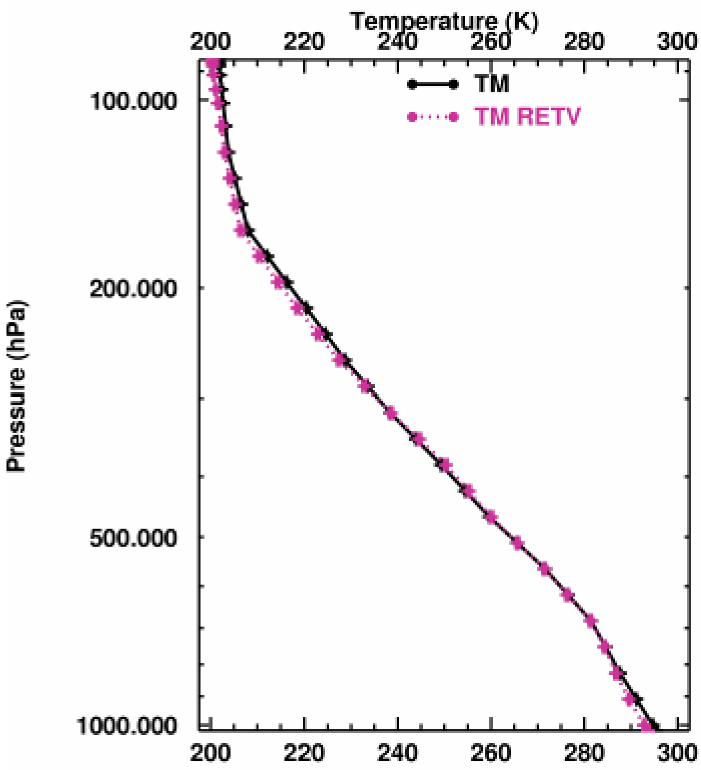
Gulf of Mexico - no sonde



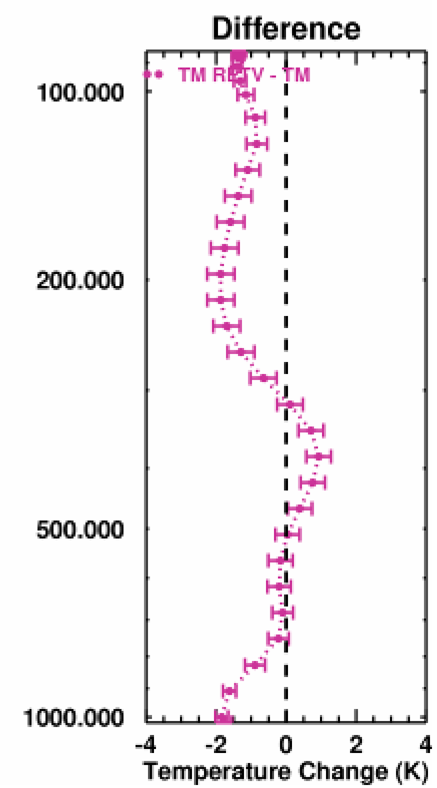
Impact on Temperature Profile
Reference: GMAO

Retrieved v9.4



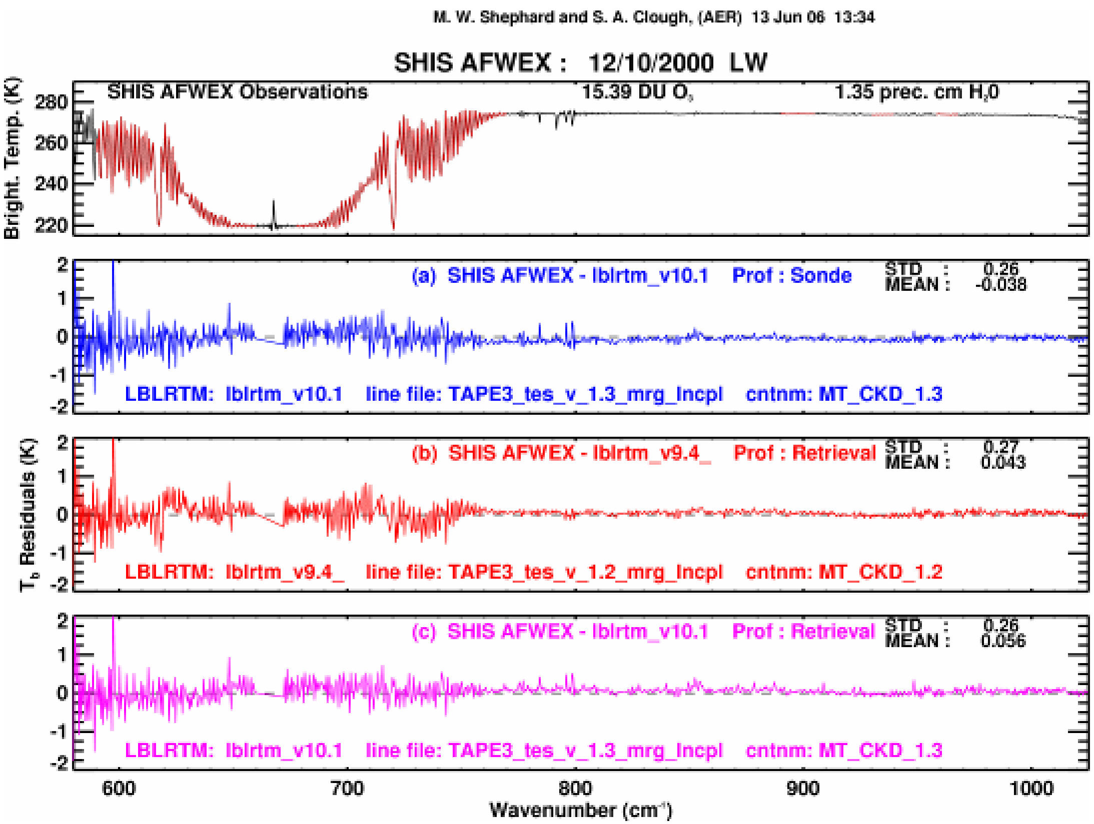


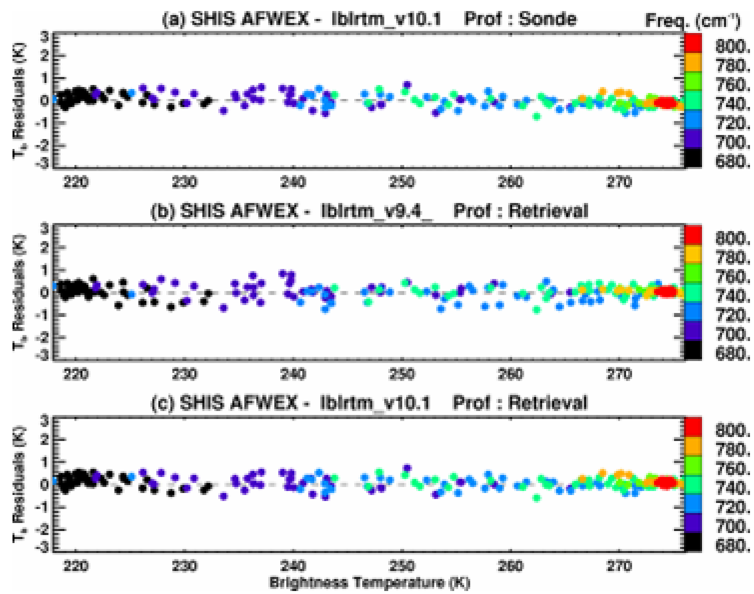
Retrieved v10.1



monotonic

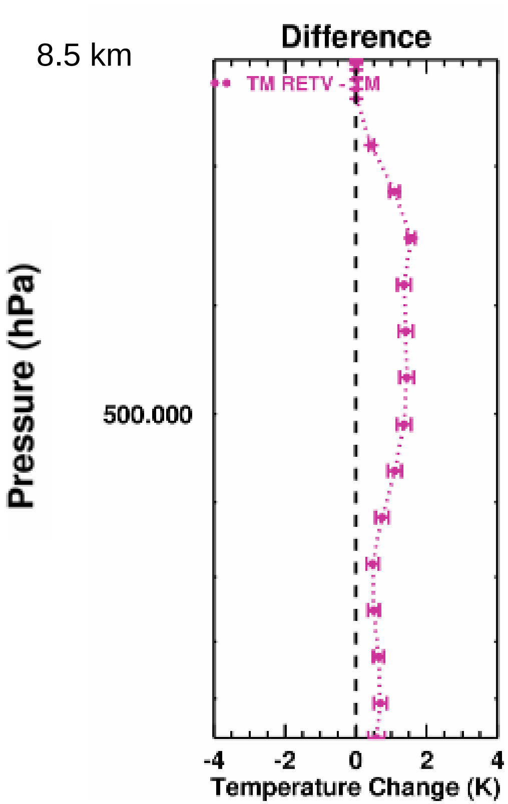
SHIS Analysis from AFWEX Experiment
Oklahoma SGP - sonde





Impact on Temperature Profile
Reference: Radiosonde

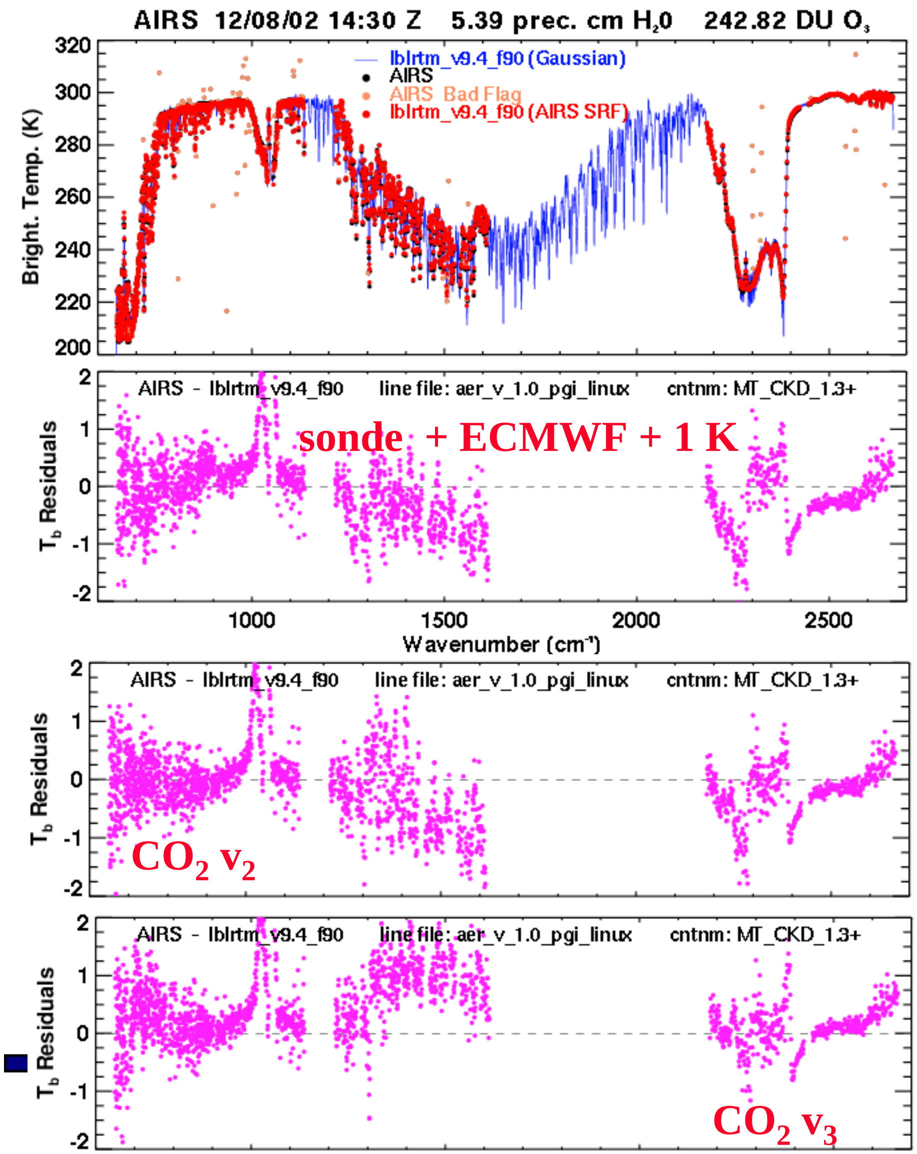
Retrieved v9.4



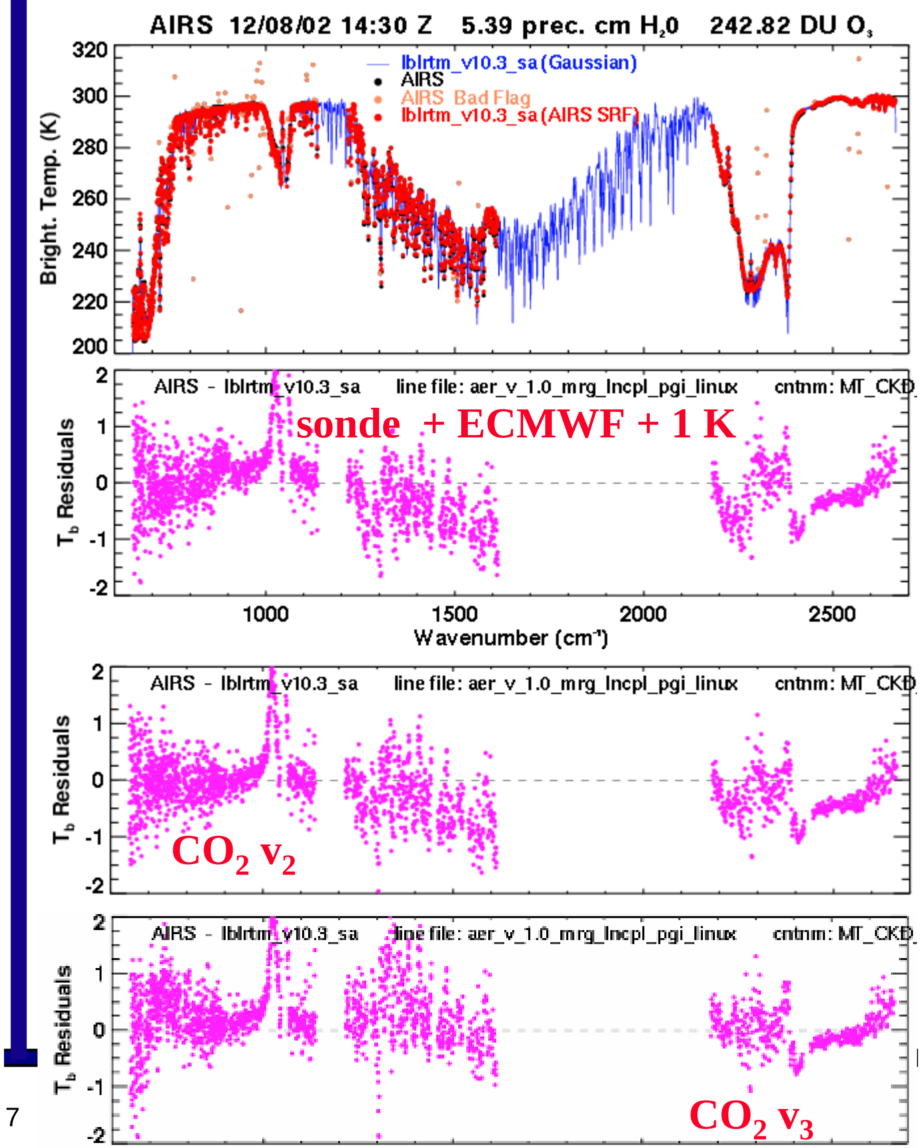
Retrieved v10.1

ARM TWP case

LBLRTM v9.4
Q branch line coupling only

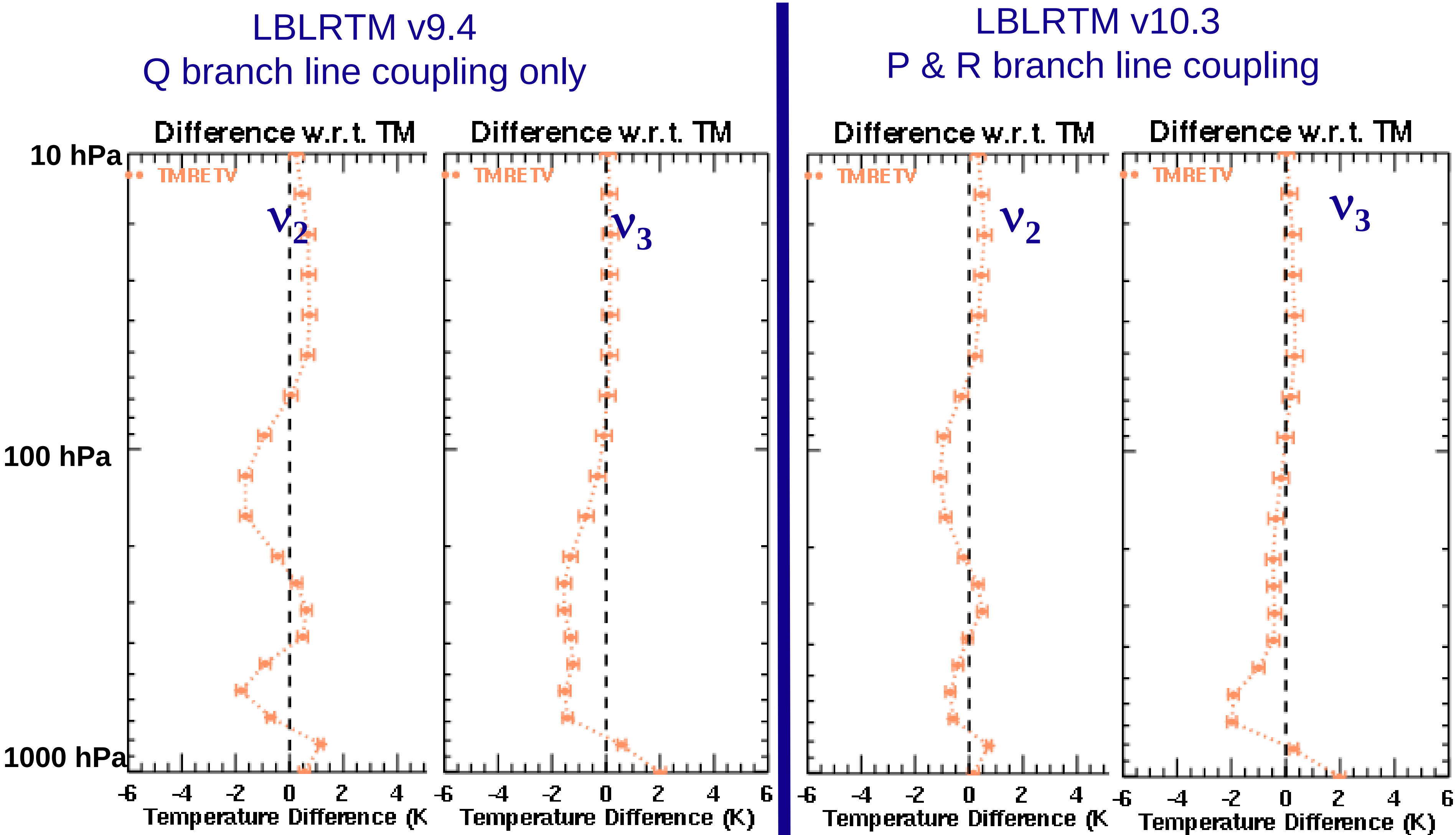


LBLRTM v10.3
P & R branch line coupling



Impact on Temperature Profile

Reference: ARM TWP Sonde



Recent updates to LBLRTM: Summary

- **Forward Model for Temperature Retrievals significantly improved**
  - **P-R line coupling is a key element**
- **Carbon Dioxide:**
  - **χ factor and continuum strongly influenced by line coupling**
  - **need to introduce small χ factor for duration of collision effects**
  - **CO_2 Continuum has been reduced by 25% for best fit at bandhead**
- **ν_2 and ν_3 are apparently not yet fully consistent**
- **Updated Code and Line Parameters to be made public**
  - **separate Line Coupling file (Hartmann) available: TAPE2**
- **Spectral Residuals will likely become the validation criterion**

Future Plans

- **Further work on CO_2 continuum**
- **Line Coupling for N_2O**
- **Line Coupling for CH_4**

- **Work with Larrabee Strow on LBLRTM/SARTA comparisons**

Improved Spectroscopy for Microwave and Infrared Satellite Data Assimilation

J.-L. Moncet, S. A. Clough and V. Payne, AER, Inc.

Summary of Accomplishments

- **Microwave**
  - Updates to O_2 line widths and line coupling in MonoRTM
  - Updates to water vapor line parameters in MonoRTM
  - Validation of updates using ground-based measurements
- **Infrared**
  - Implementation of P&R line coupling in CO_2 ν_2 and ν_3 regions
  - Updates to CO_2 continuum
  - Improvements in consistency between ν_2 and ν_3 regions

Future Work

- **Microwave**
  - Implementation of Zeeman line splitting
  - Continued validation at ARM sites
  - Infrared/Microwave consistency
- **Infrared**:
  - Further improvements to CO_2 continuum
  - P&R branch line coupling for CH_4 and N_2O
  - Work with Larrabee Strow on LBLRTM/SARTA comparisons

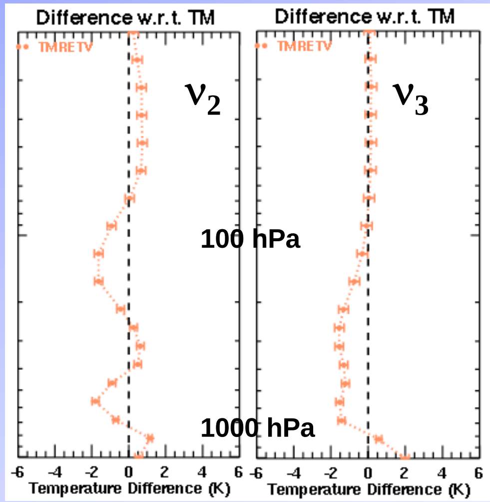


Figure 1: Temperature retrievals using LBLRTM v9.4

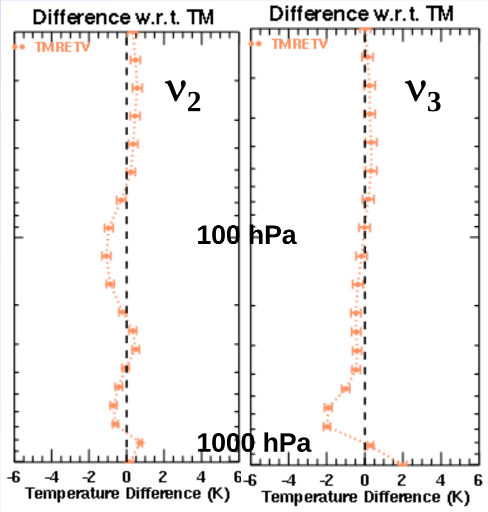


Figure 2: Temperature retrievals using LBLRTM v10.3