FIRST Observations of Downwelling Infrared Radiation from 200 to 800 cm^{-1}

Table Mountain California and Cerro Toco Chile

M. Mlynczak, NASA Langley

R. Cageao, D. Kratz, J. Mast, D. Johnson (NASA Langley)

H. Latvakoski, K. Johnson, E. Syrstad, J. Swasey (USU/SDL)

CLARREO SDT Meeting

January 2014

GSFC, Greenbelt, MD

FIRST wins Best Article Award in 2013 IEEE Earth Science Technology Showcase!

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Energy, Climate Change Entry Tops 2013 Earth Science Technology Showcase

By Earthzine staff , posted on December 16th, 2013 in ESTO Showcase 2013

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Earthzine and the NASA Earth Science Technology Office (ESTO) are pleased to announce the Best Article Award for the inaugural 2013 Earth Science Technology Showcase.

The showcase, launched Dec. 2, features 10 articles on current Earth-observing technology development projects, authored by ESTO principal investigators. Each paper was reviewed by subject matter experts before publishing, and judged by a panel of graduate students afterward.

By the thinnest of margins, the judges chose the entry by Martin Mlynczak, of the NASA Langley Research Center in Hampton, Virginia, for the Award.

Mlynczak's article, titled, "The Far-Infrared Spectroscopy of the Troposphere (FIRST) Instrument: New Technology for Measuring Earth's Energy Balance and Climate Change" was co-authored by Langley colleagues R.P. Cageao, D. Kratz and D. Johnson. Other co-authors included H. Latvakoski of Space Dynamics Laboratory in Logan, Utah; and J. Mast of Science Systems and Applications Inc. in Hampton, Virginia.

The winning team will take home the ESTO trophy, pictured at the top right of this page. Other entries in the Showcase can be found below.

ESTO funds and manages advanced technology projects – through regular peer-reviewed

The ESTO Pyramid award for the Showcase. Image Credit: Phil Larkin.

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Outline

- Background
- Current status of FIRST ground based data
- Update on measurement/model radiance comparisons from Table Mountain campaign
- Improvements in radiance modeling and calibration
- Refinement of uncertainties in radiance modeling
- Overall assessment of measurement/model agreement
- Summary and future plans

Background

- In late 2011, FIRST won a small ESTO intramural competition and used to funding to calibrate FIRST using the SDL LWIRCS blackbody which had recently been calibrated at NIST LBIR
- FIRST calibrated in 2012, in "ground based" mode, with 2 blackbodies, ambient and "warm" (about 325 K)
  - ***Results published in Applied Optics, Latvakoski et al., 2013***
- FIRST deployed to Table Mountain for 2 months Aug-Oct 2012
- Operated in ground based mode recording downwelling IR
- Data analysis has been ongoing in 2013***: update reported today***
- Late 2013 FIRST recalibrated in "space/balloon mode" with one ambient blackbody and a space view simulator
- Non-linearity in FIRST Si bolometers also discovered and characterized
  - ***These results were reported today by Harri Latvakoski***

FIRST Calibration Results

Absolute Calibration and Noise Performance

Scene Temp (K)	Absolute Cal (K, 1-sigma)	NEDT (K, 1-sigma)
310.35	0.20 K	0.13 K
270.55	0.30 K	0.13 K
247.42	0.70 K	0.32 K
225.18	1.50 K	0.61 K
209.41	1.50 K	0.71 K
189.33	4 K – 7 K	3.60 K
169.05	4 K – 7 K	3.80 K

FIRST calibration measured across range of geophysical scene temperatures

***Latvakoski et al.*, 2012, in Applied Optics**

On-Site at Table Mountain

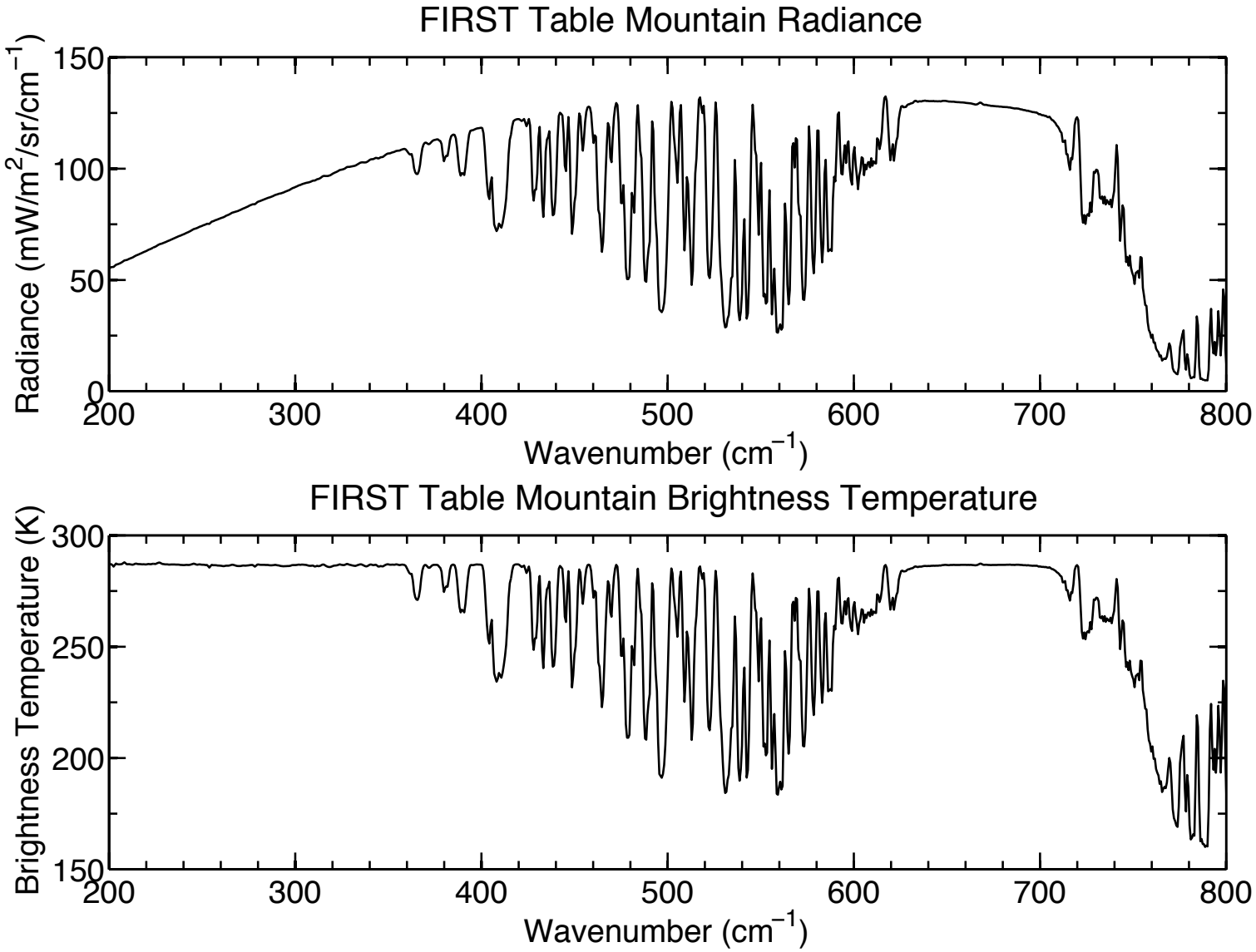
FIRST Trailer at TMF

FIRST Instrument inside trailer at TMF

Current Status

- Data analysis
  - Substantially improved radiative transfer modeling with fine (~ 10 m "thin") layering of atmosphere in first km above instrument
  - Removal of "hot path" absorption and emission within the instrument
  - Updated uncertainty analysis to include specific HITRAN uncertainties
- Calibration
  - Non-linearity in Si bolometers identified and corrected in all data
  - Entire data sets from Table Mountain and Cerro Toco reprocessed with new calibration and non-linearity correction
- Results/ Status
  - Both updated datasets (TMF, Cerro Toco) available for study
  - Radiosonde data from Cerro Toco recently reprocessed by D. Turner
  - TMF "golden day" analysis essentially complete – journal article in preparation

FIRST Spectrum from Table Mountain 10/19/12



FIRST Spectrum From Cerro Toco, Chile (17,500 feet)

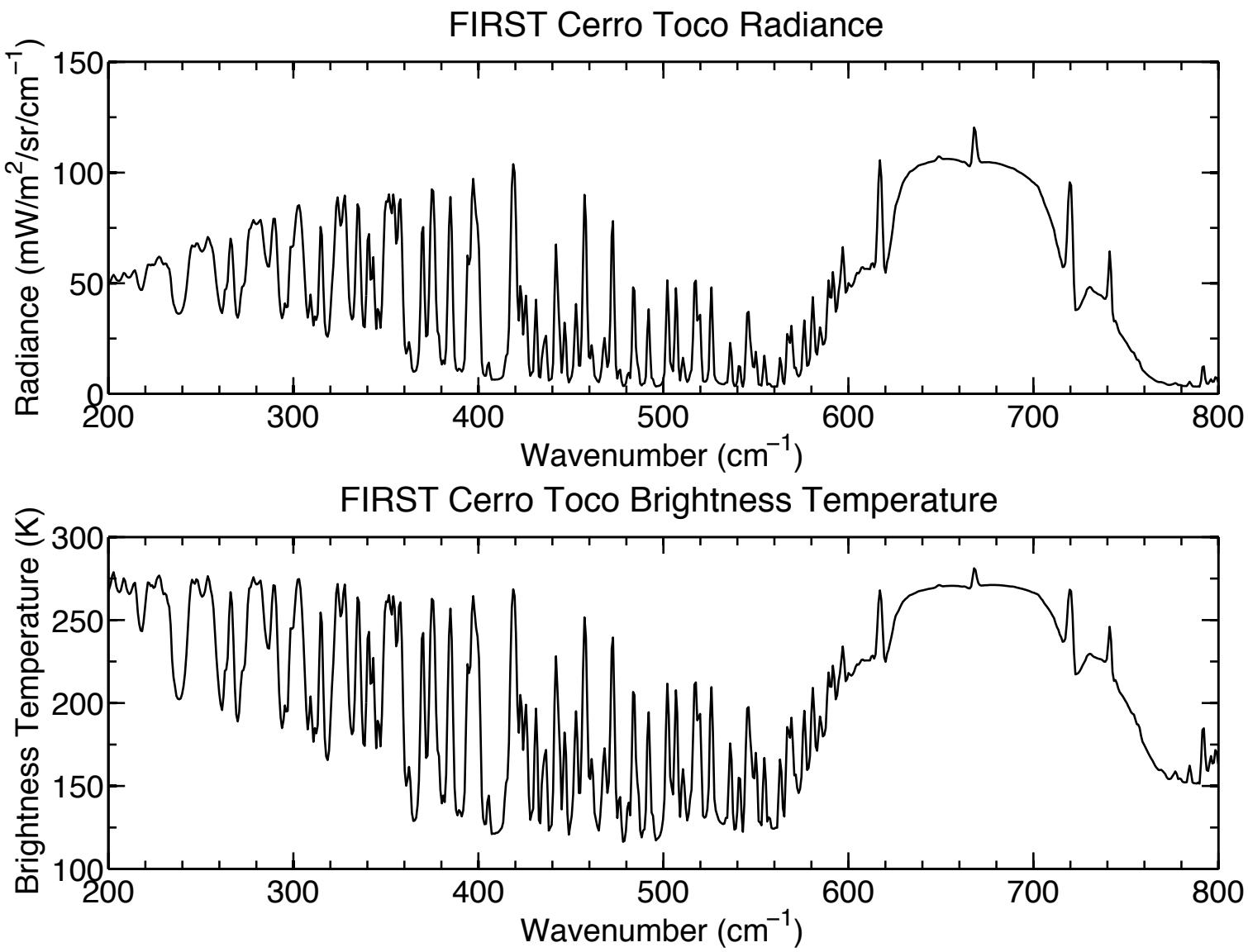
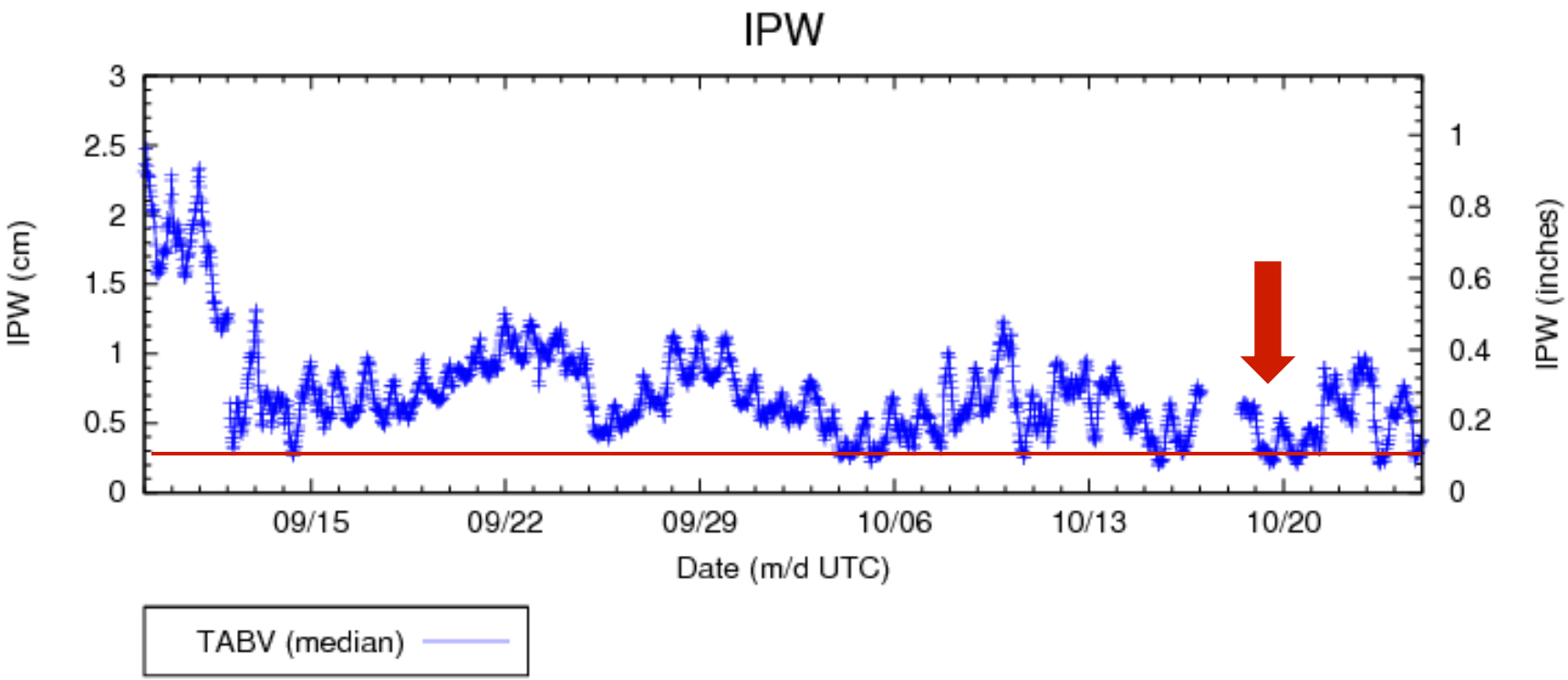


Table Mountain Update

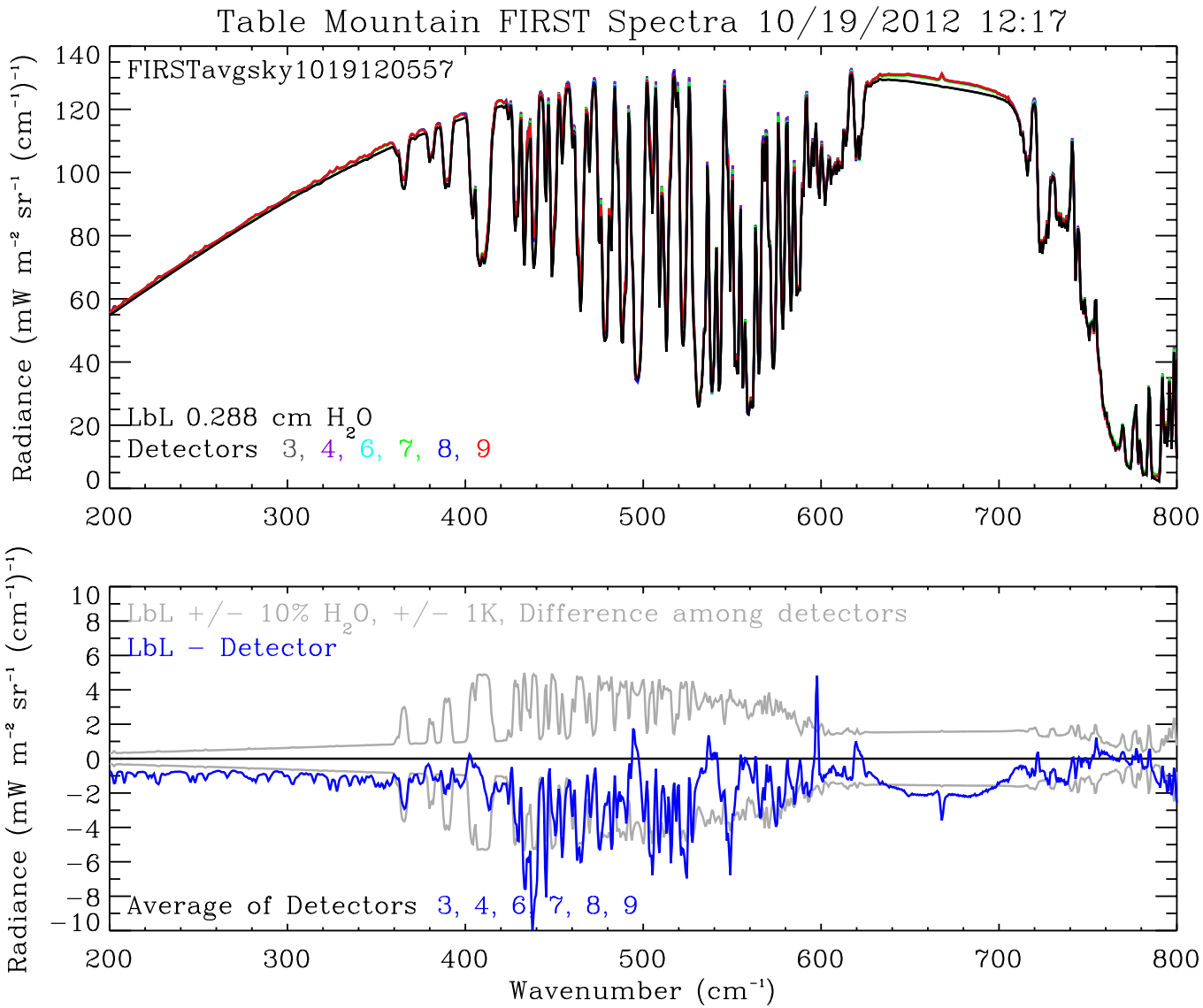
- Compare FIRST, calculated line-by-line radiances
  - LBL code is MRTA code of Dave Kratz
- Use concurrent radiosonde data as inputs for T, H_2O
  - 390 ppm CO2 is used
- Voigt lineshape to ~ 20 cm^{-1} from line center
- No line mixing (see distinct feature in spectrum)
- MT-CKD 2.5 H_2O continuum model
- 2012 HITRAN line parameters
- Will show where we were last April, and then today

GPS-Met Time Series of Precipitable Water at Table Mountain 9/2012 – 10/2012



Driest day was 10/19, approximately 0.3 cm (or 3 mm) of IPW

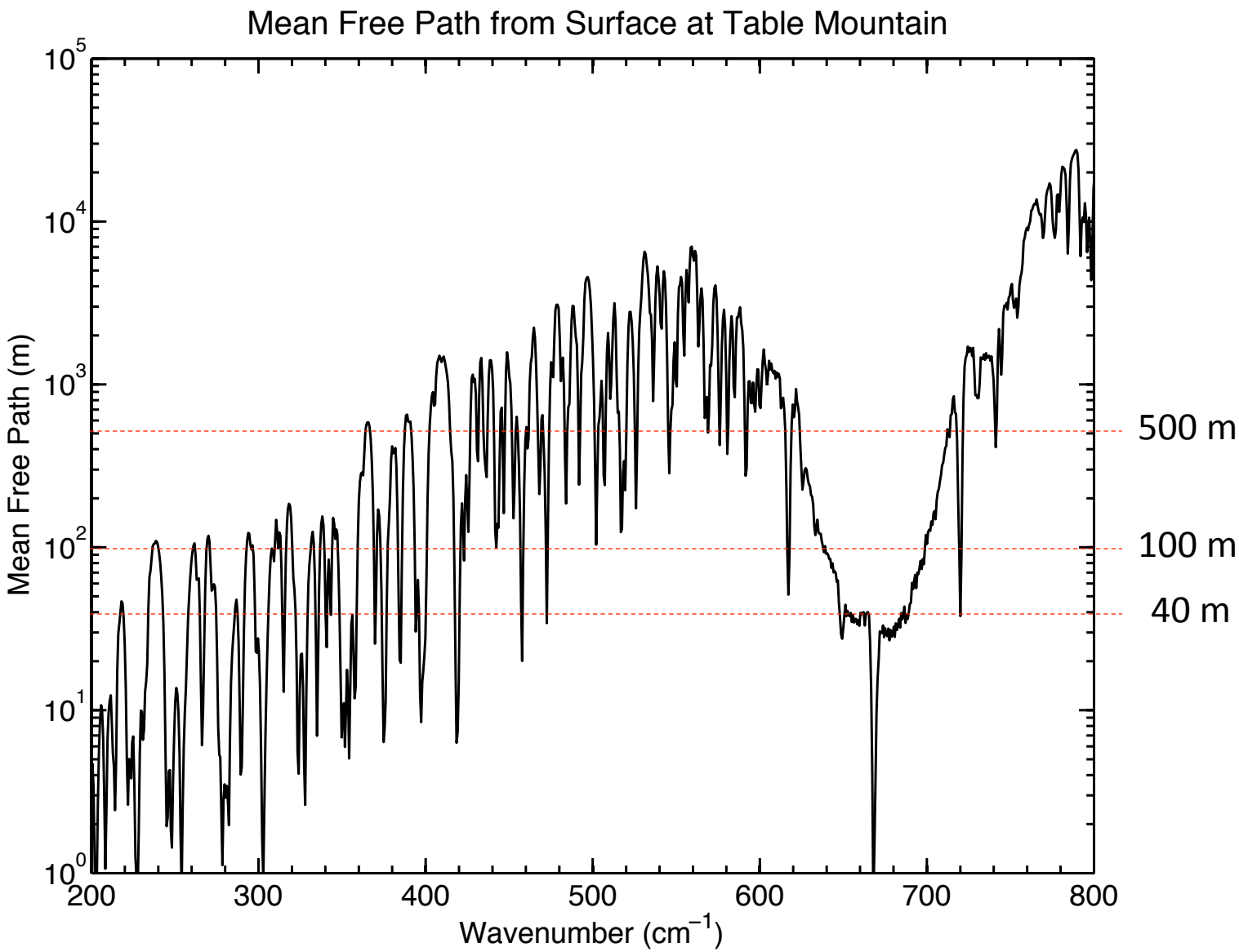
Differences in Radiance compared with H_2O, T uncertainties – **As of April 2013 SDT**



Improvements since April 2013 SDT Meeting

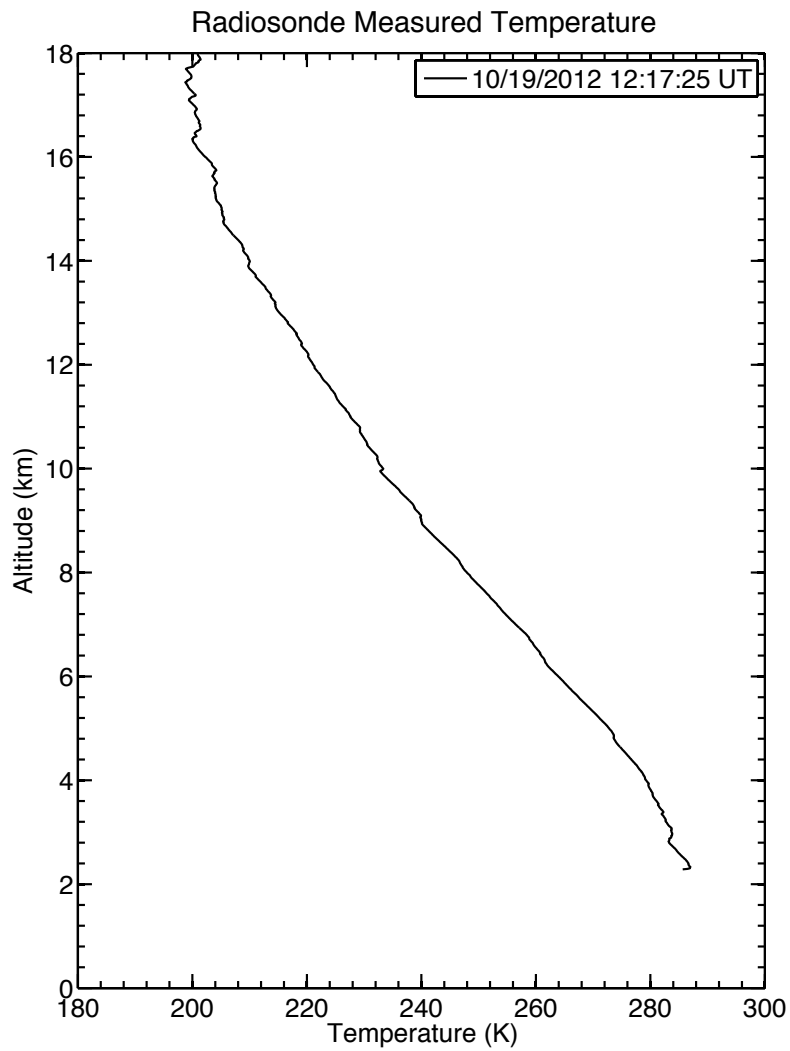
- Fine layering of the atmosphere in radiance modeling
- Detector non-linearity correction
- Instrument "hot path" correction
- Included HITRAN specified uncertainties in S and α_L in overall calculation uncertainties
  - In addition to T, H_2O, calib, and sky variability

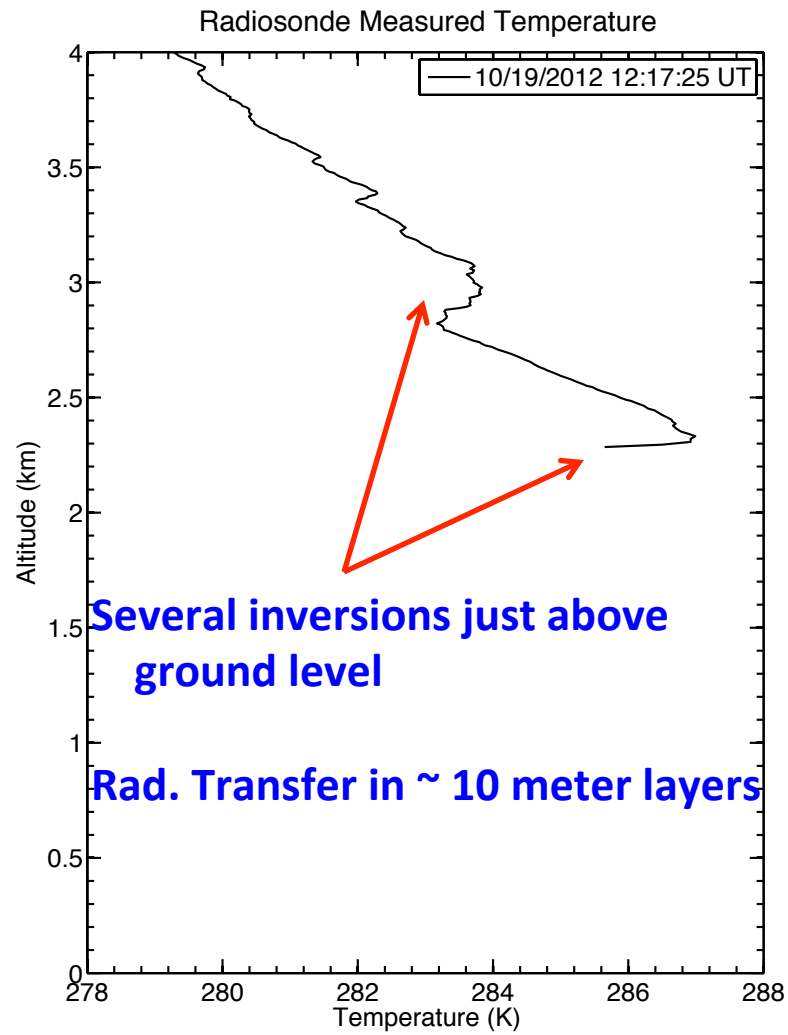
Where does measured FIRST radiance originate?



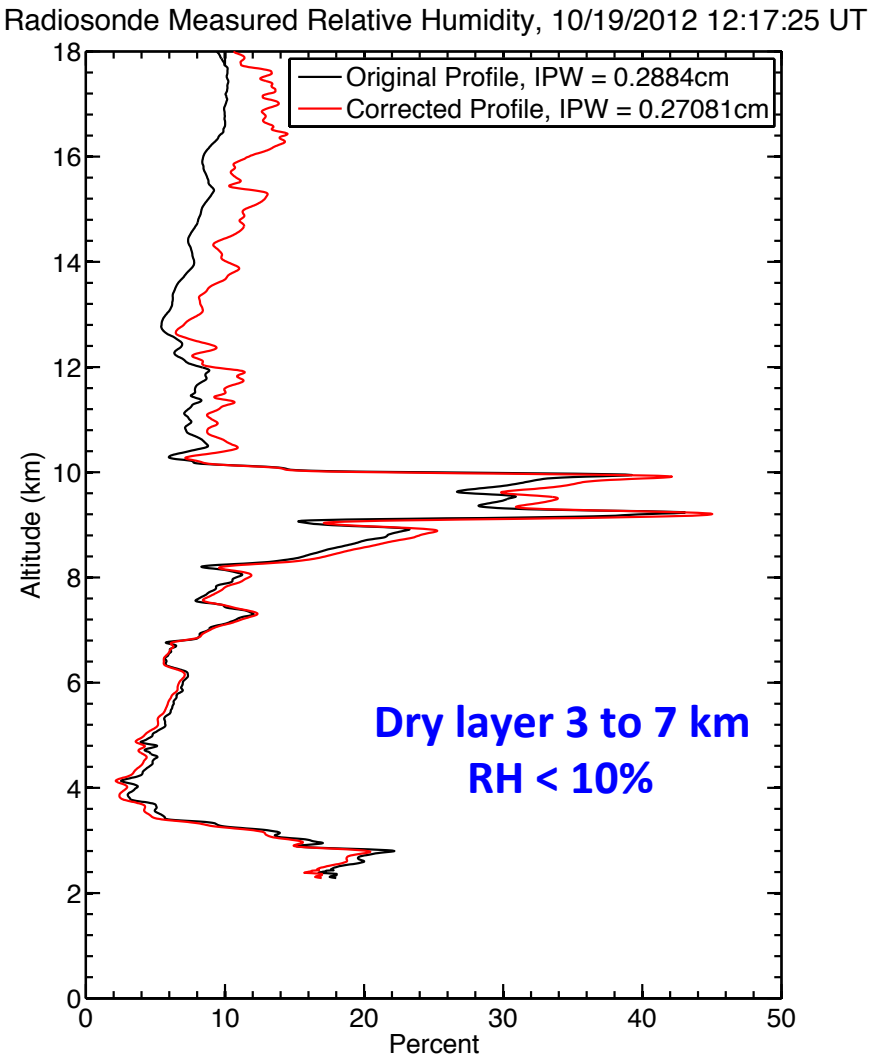
<u>Most of measured radiance originates within a few hundred meters above ground</u>

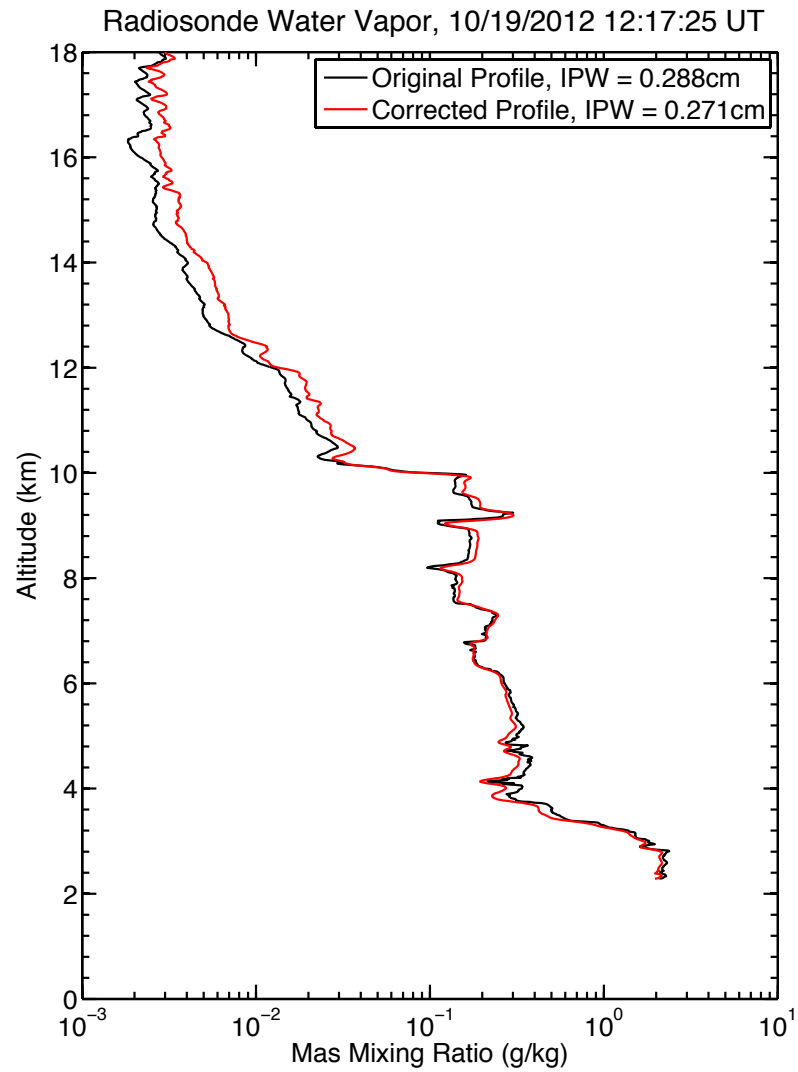
Thermal Structure above TMF 10/19/12



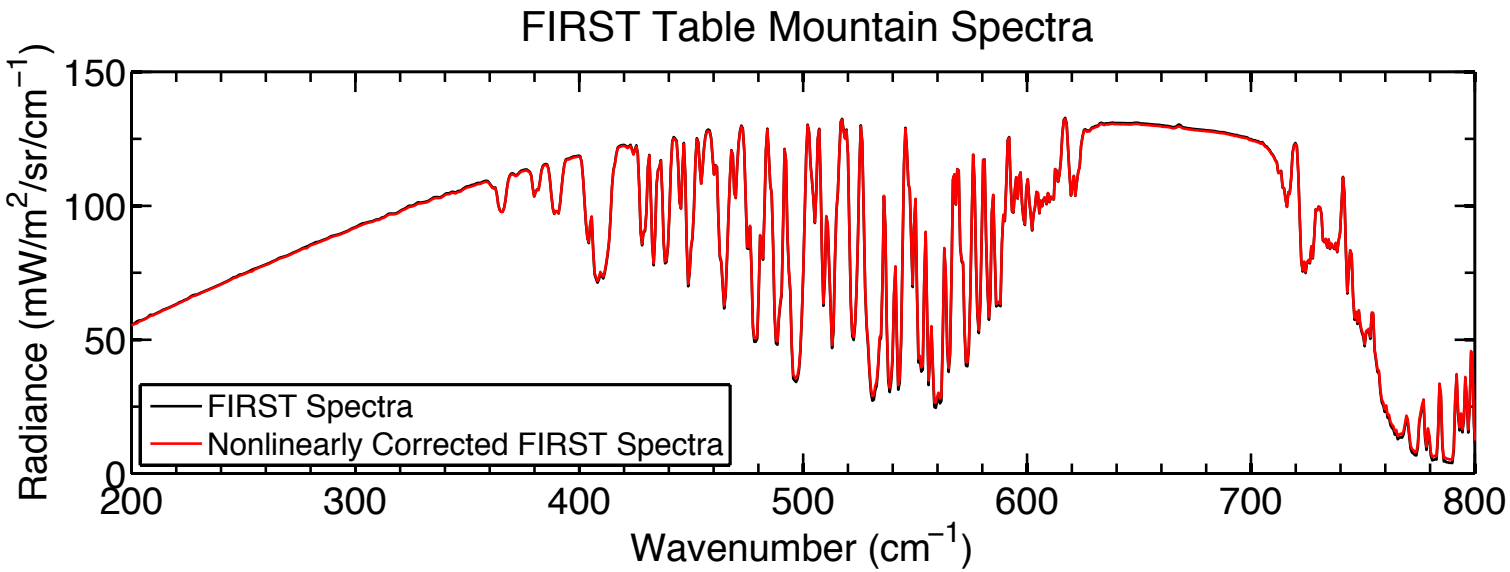


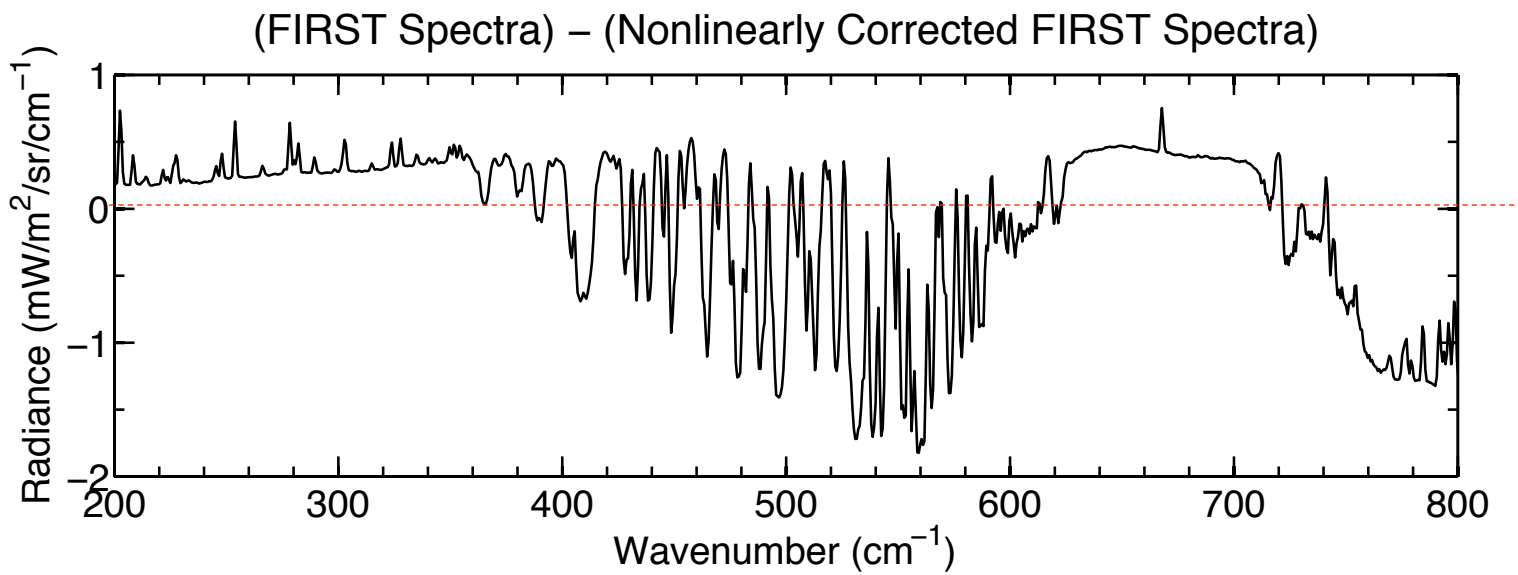
Water Vapor Sounding at TMF 10/19/12





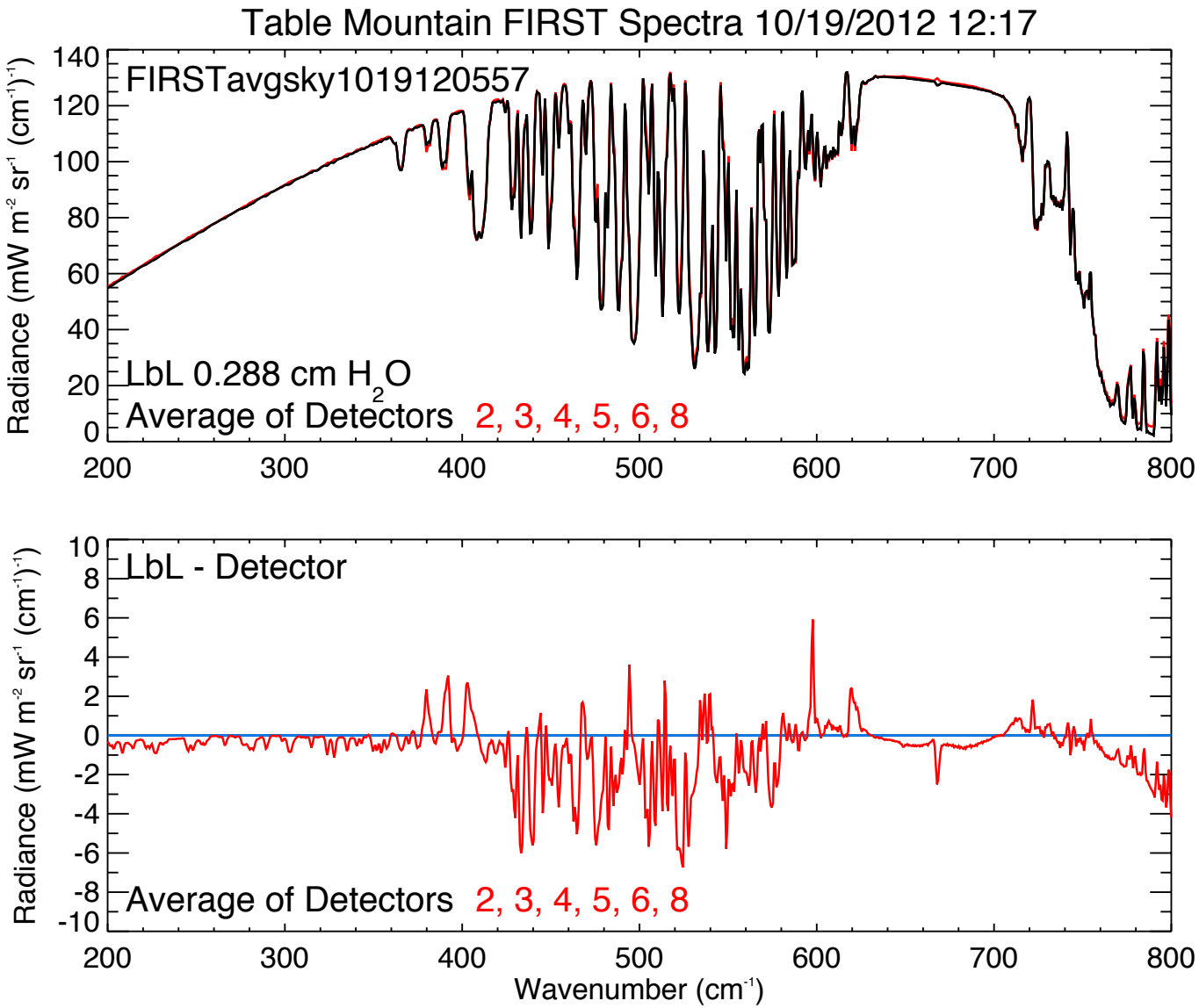
FIRST Non-Linearity Correction in Radiance



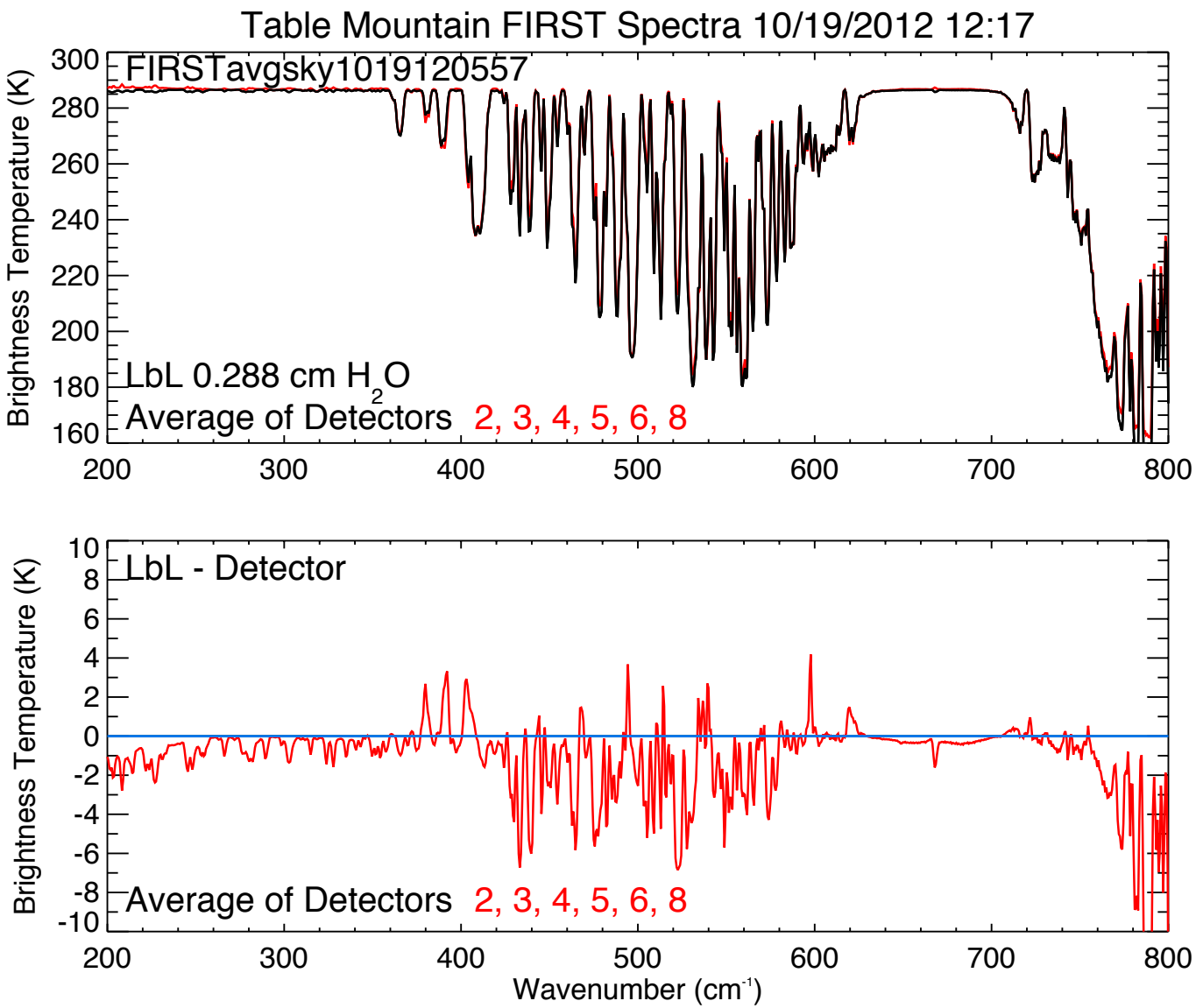


Positive differences above IMPROVE comparisons with LBL

Comparisons with finer layering and non-linearity corrections



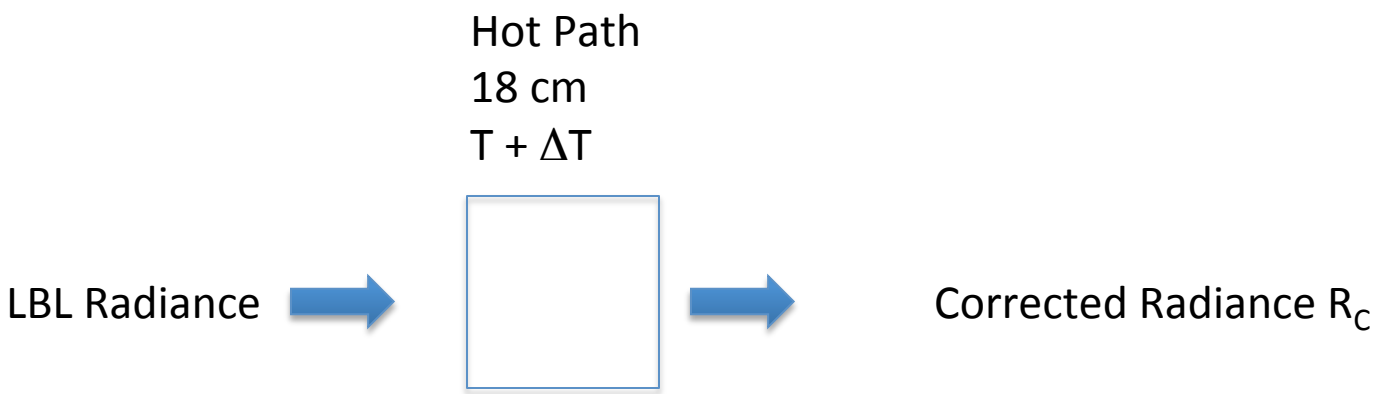
Comparisons with finer layering and non-linearity corrections



Instrument Hot Path Correction

- Warm BB is at 46 C, ~ 30 C above ambient
- Warmer than ambient air definitely in path above scene select mirror (~ 7 in)
- Temp sensors on scan mirror indicate up to 7 K warmer than ambient air
- Correct for this in both CO_2 and H_2O

Hot Path Correction
For monochromatic radiation



$$R_C = \tau_{Hot} * LBL + \varepsilon_{Hot} * B(T+\Delta T)$$

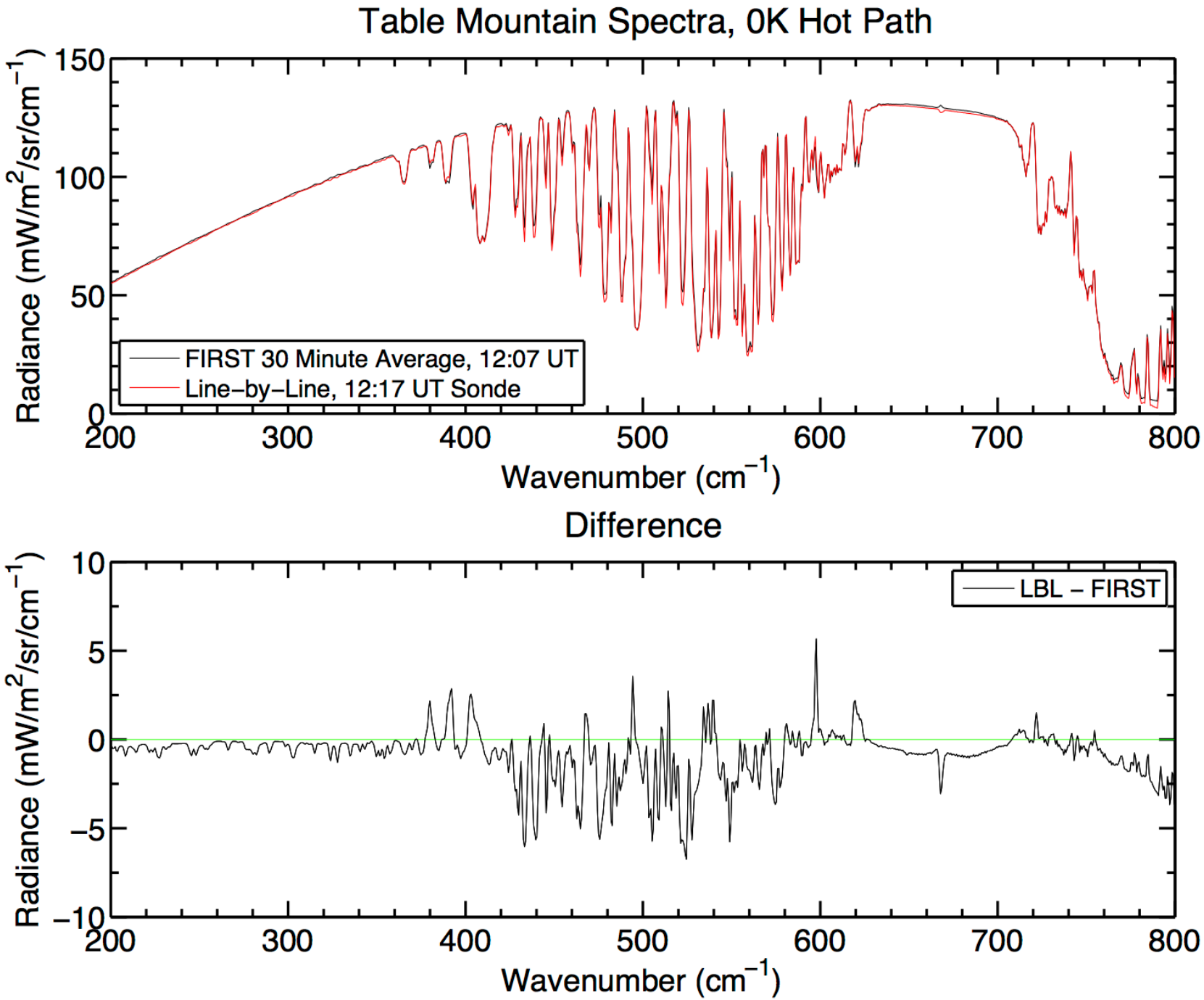


Table Mountain Spectra, 0K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST

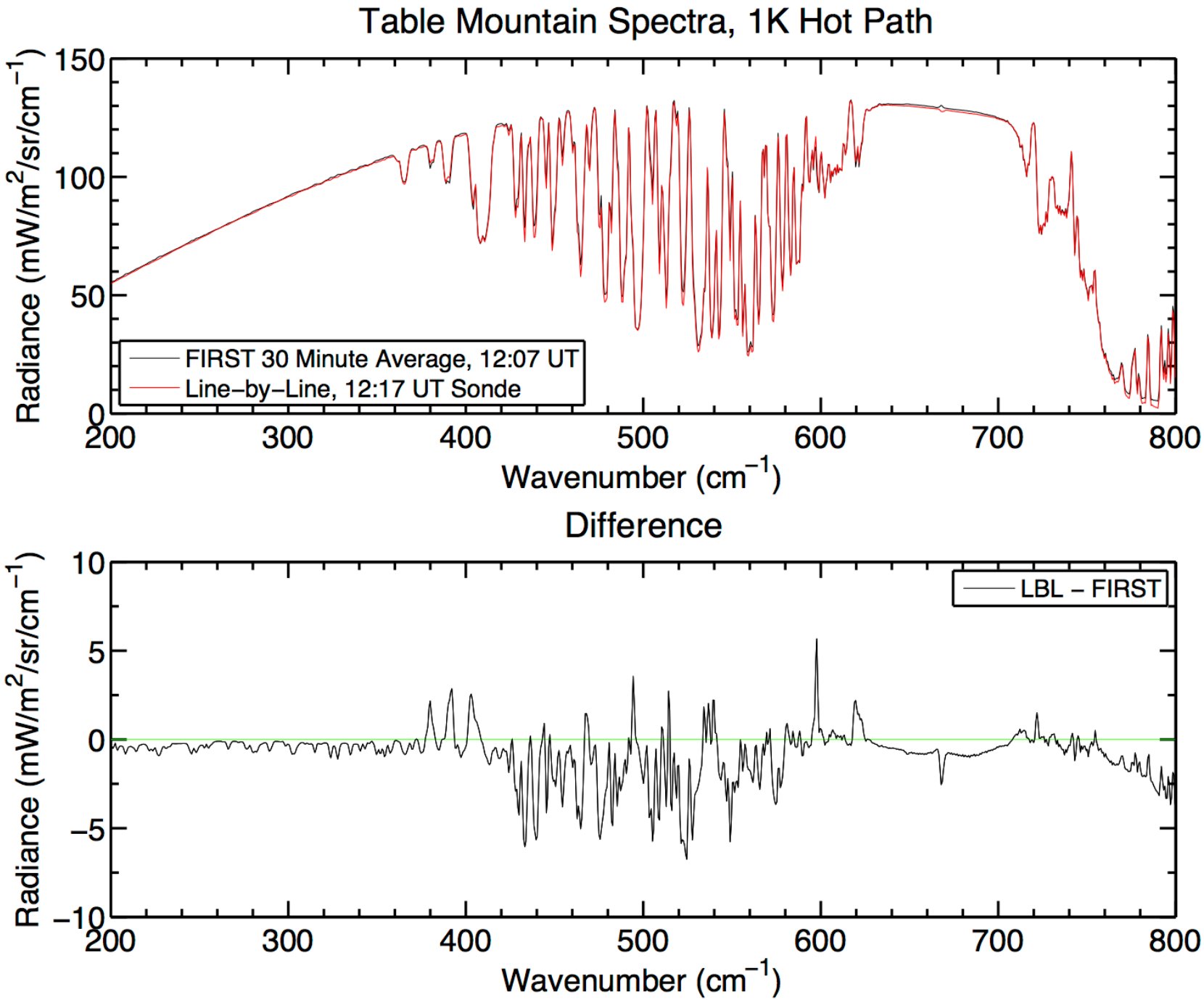


Table Mountain Spectra, 1K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST

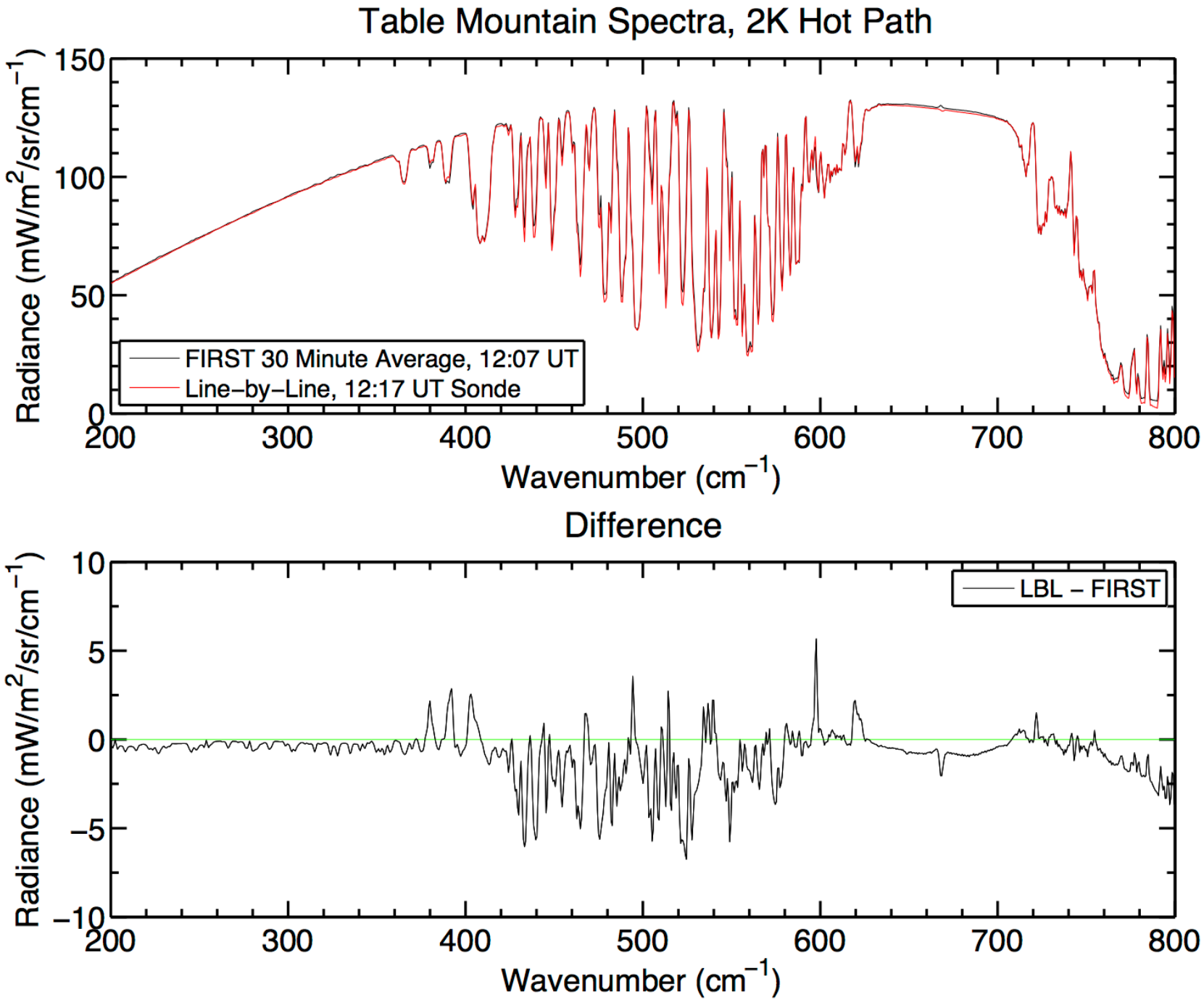


Table Mountain Spectra, 2K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST

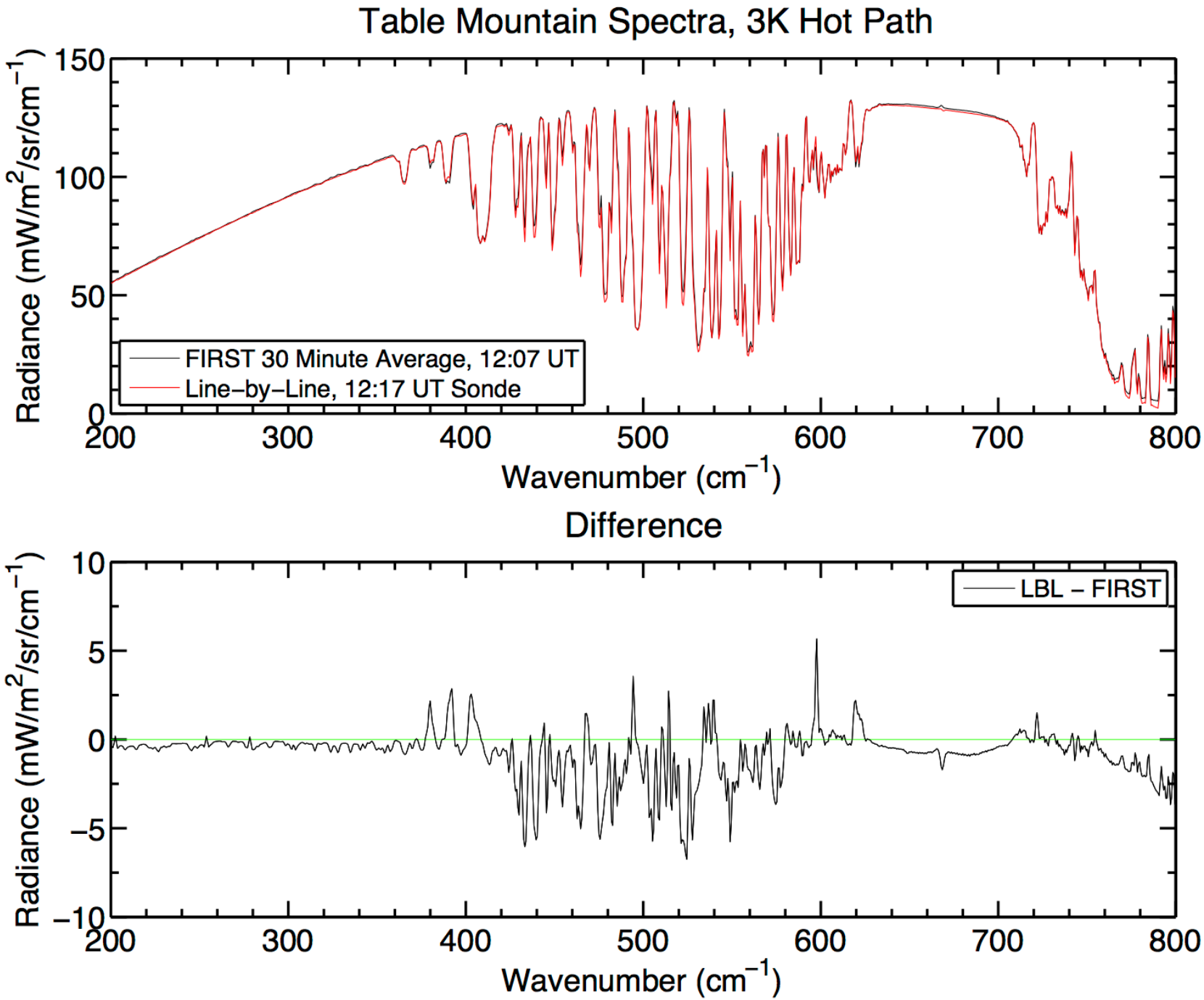


Table Mountain Spectra, 3K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST

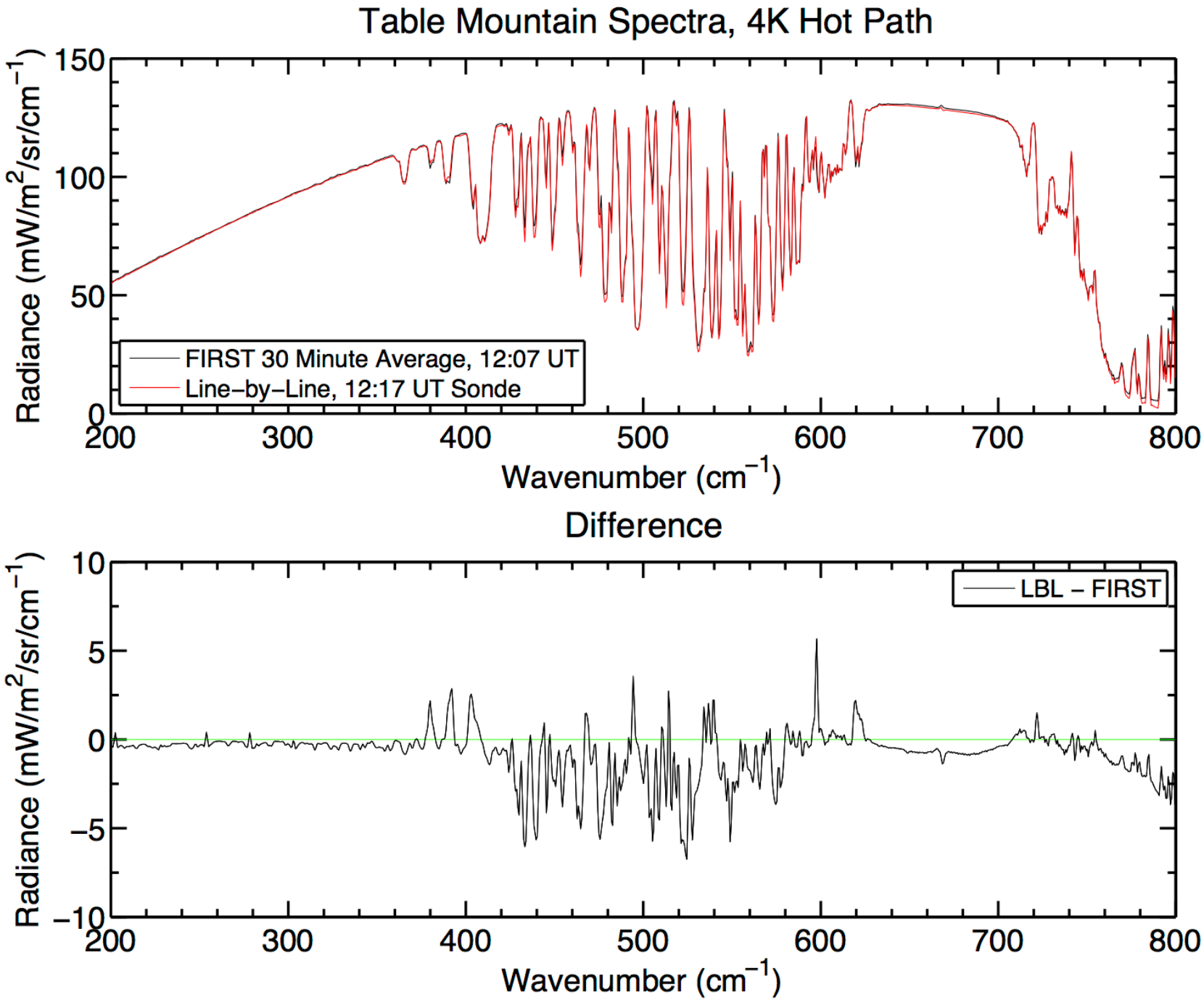


Table Mountain Spectra, 4K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST
150
100
50
0
10
5
−5
−10
200
300
400
500
600
700
800

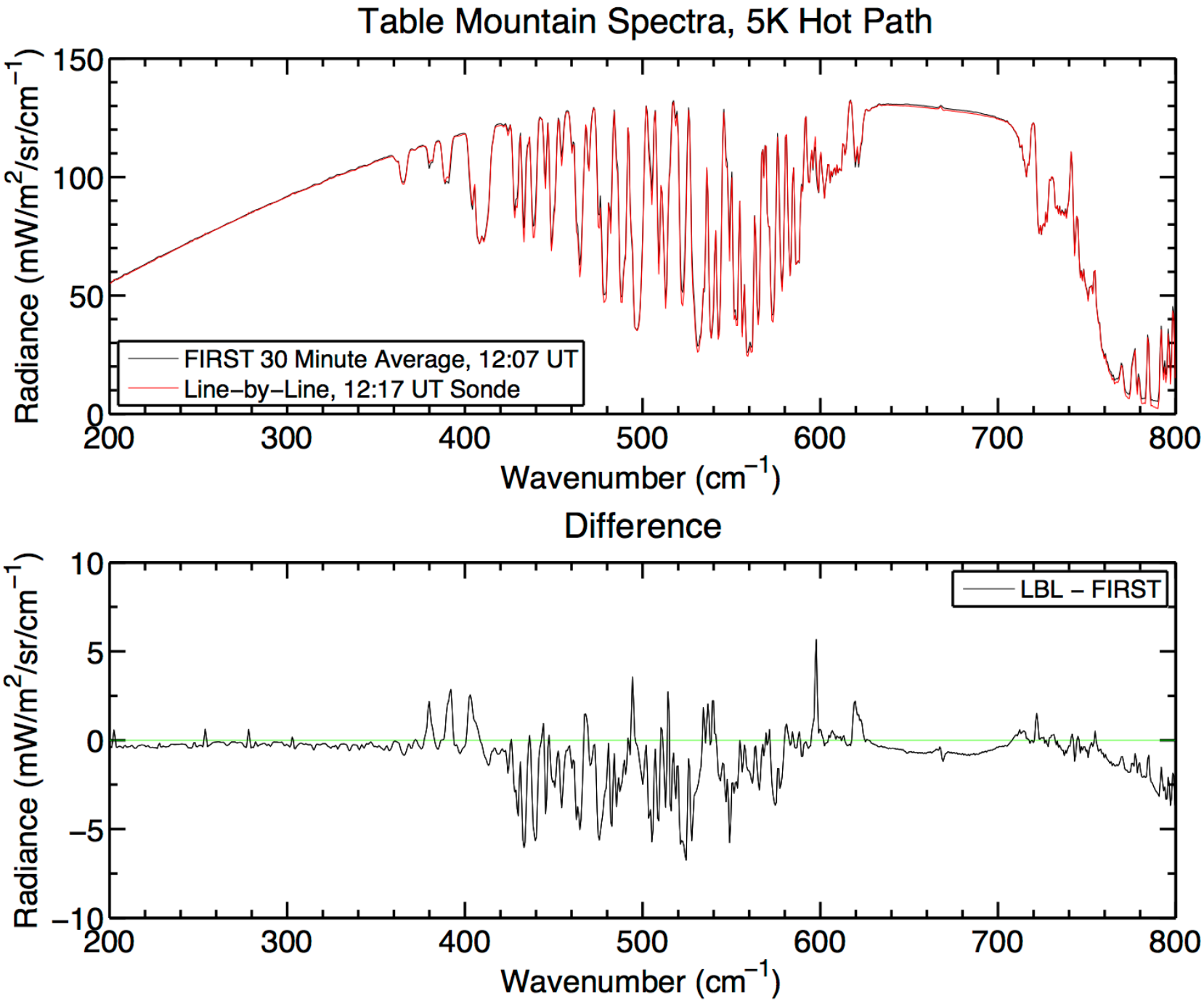


Table Mountain Spectra, 5K Hot Path
Radiance (mW/m^2/sr/cm^{-1})
Wavenumber (cm^{-1})
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
LBL − FIRST

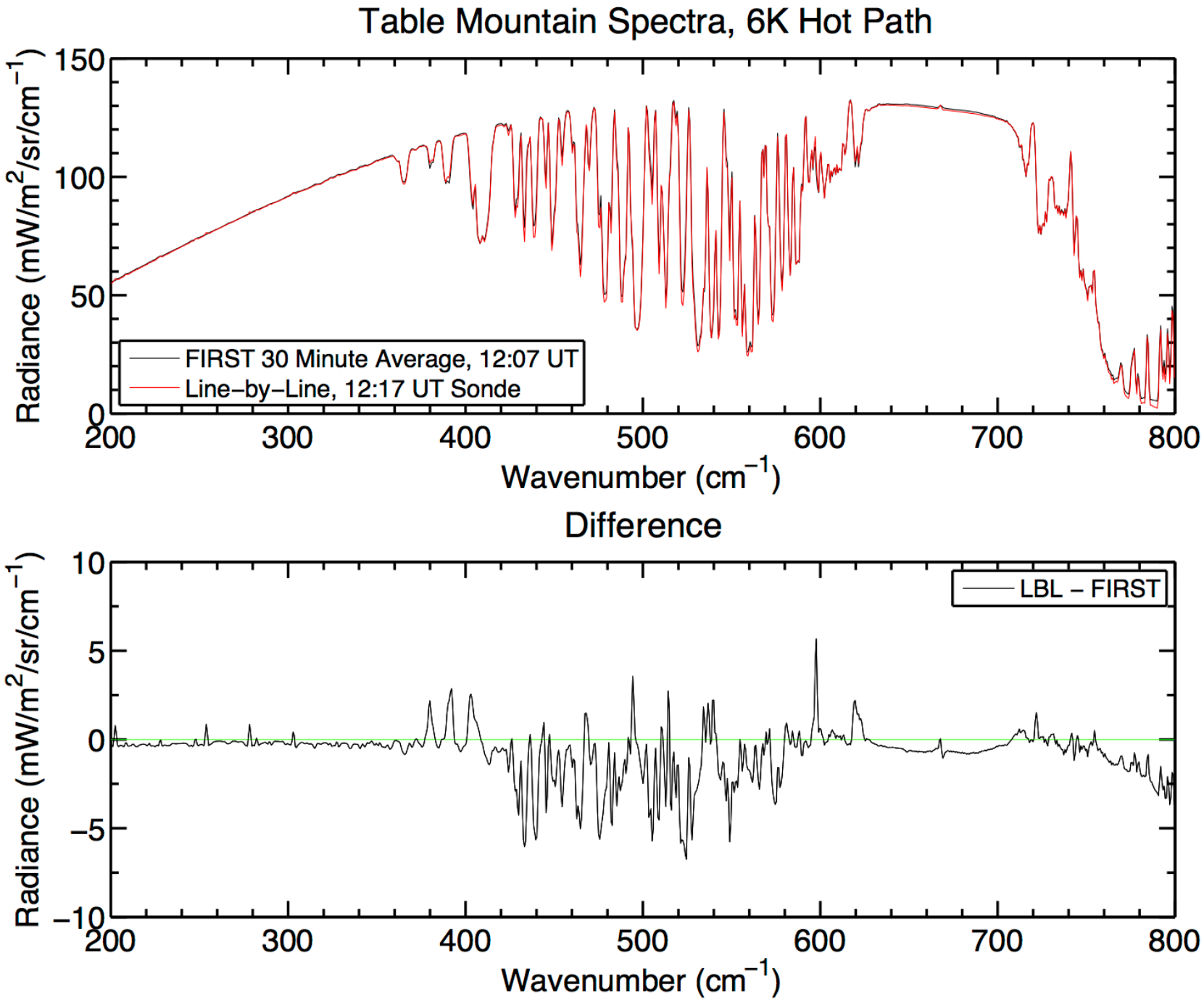


Table Mountain Spectra, 6K Hot Path
Radiance (mW/m2/sr/cm−1)
150
100
50
0
200
300
400
500
600
700
800
Wavenumber (cm−1)
FIRST 30 Minute Average, 12:07 UT
Line−by−Line, 12:17 UT Sonde
Difference
Radiance (mW/m2/sr/cm−1)
10
5
0
−5
−10
200
300
400
500
600
700
800
Wavenumber (cm−1)
LBL − FIRST

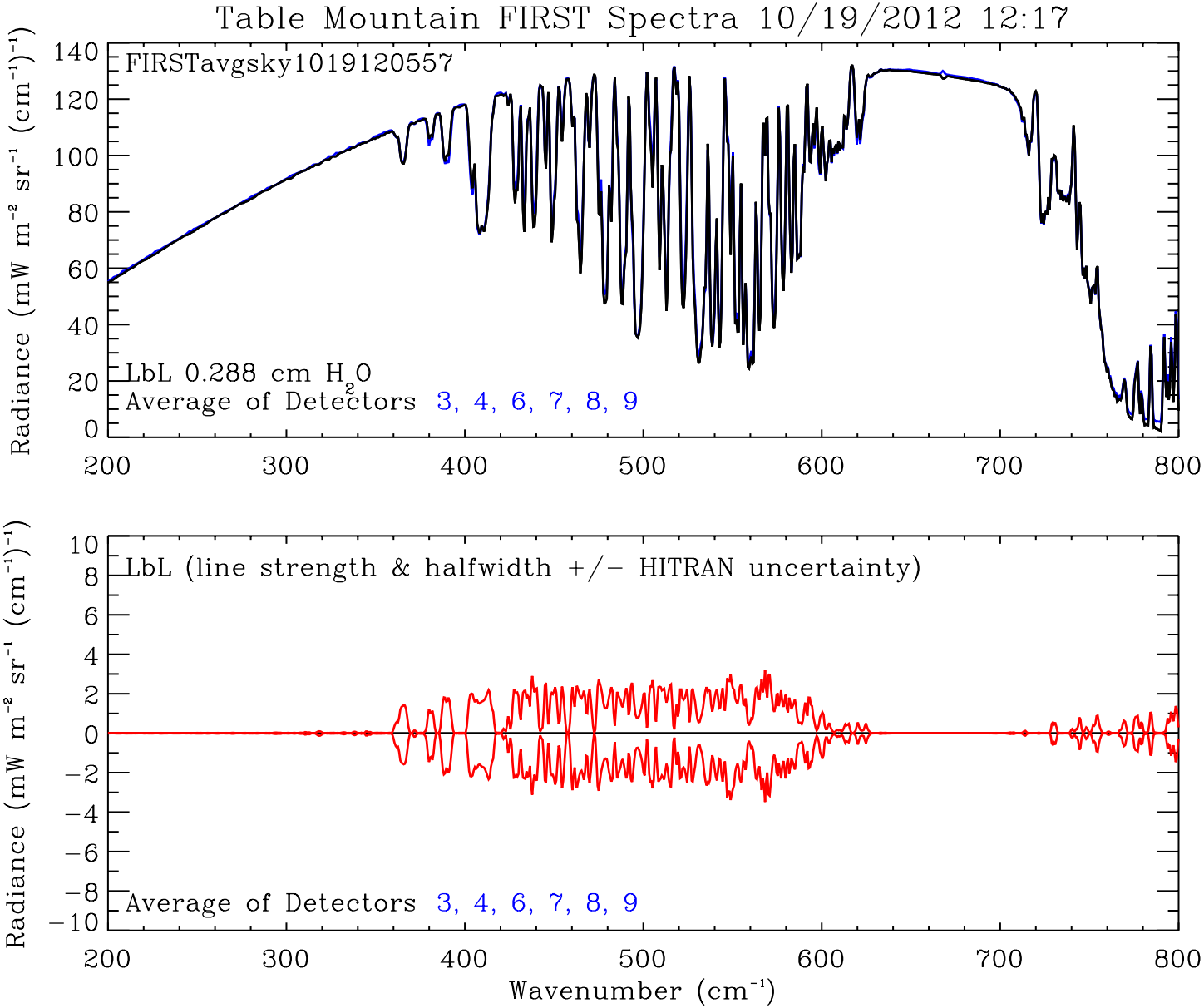
Uncertainties in HITRAN Line Parameters

- Still have to resolve differences between measured radiance and modeled radiance between 400 and 600 cm-1, or assess if differences are within uncertainties
- HITRAN line parameters (S, α_L) are assigned uncertainties
- Assess uncertainty in LBL calculations due to these
- Also examine effect of 2012, 2008 HITRAN line parameters on the LBL comparisons with FIRST measurements

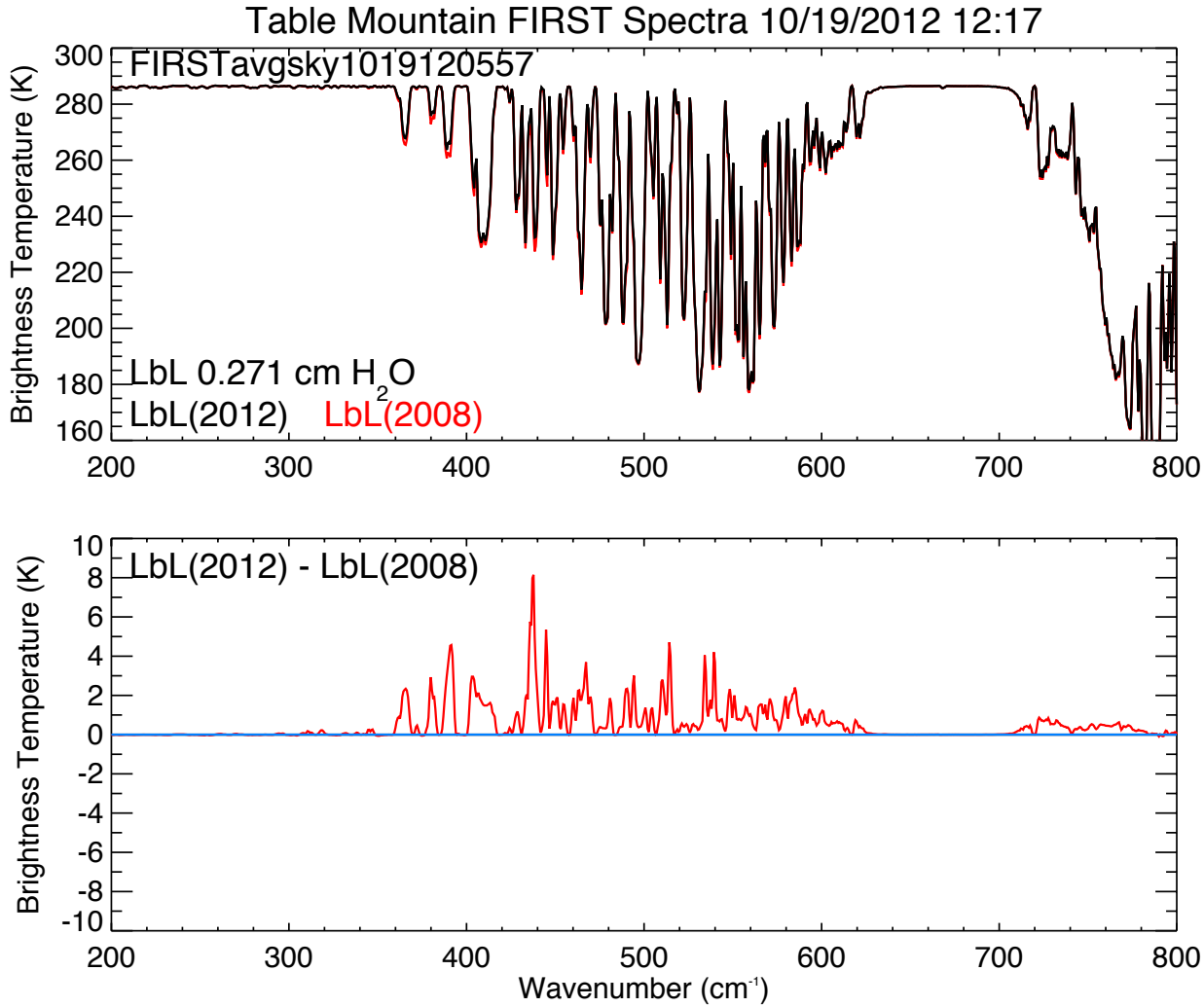
- We find uncertainties are relatively small, but the change from 2008 to 2012 HITRAN is significant

- Also, there was no change in the H_2O continuum from 2008 to 2012 HITRAN despite apparent large change in line params.

Additional uncertainties – line parameters

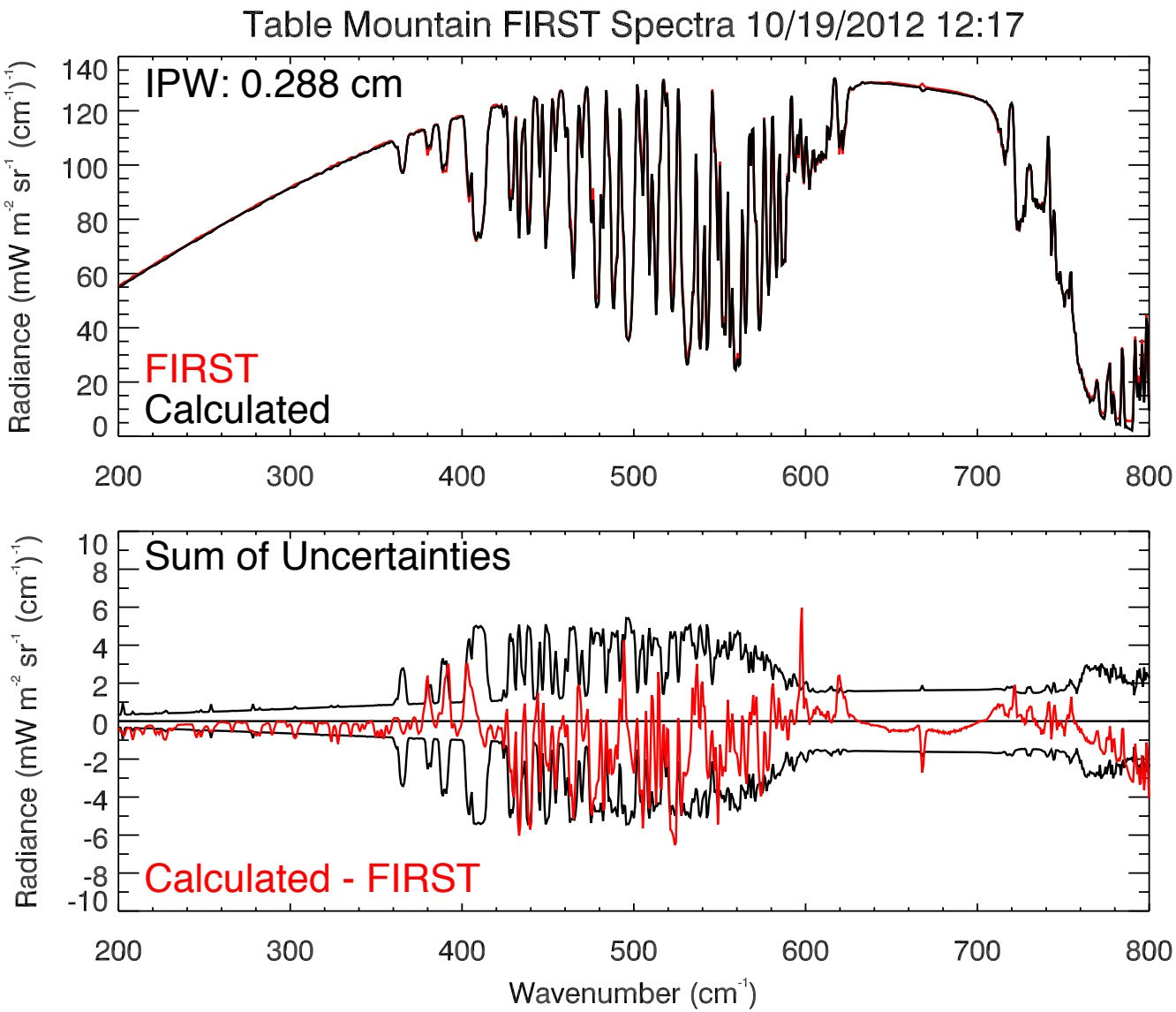


Radiance Difference using 2012, 2008 HITRAN



Radiance difference due to HITRAN versions sometimes larger than stated uncertainties in S, α_L

Summary Comparison



Residual differences due to combination of water vapor and spectroscopy

Summary (1 of 2)

- Comparison between LBL and FIRST improved in optically thick regions with finer atmospheric layering
- Non-linearity correction improves comparison in optically thick regions (far-IR; CO_2 15 um)
- Hot path corrections improve comparisons in optically thick regions (modestly, but definitely there)
- Still have significant difference in radiances between 400 and 600 cm^{-1}

Summary (2 of 2)

- Comparison between LBL and FIRST are within measurement and computation uncertainties:
  - 10% in H2O
  - HITRAN-specified uncertainties on S, α_L
  - Temperature (1 K)
  - Calibration
  - Sky variability (30 minutes)
- Cannot definitively distinguish between uncertainty in water vapor and line parameters to resolve differences 400-600 cm^{-1}
- There is no one change that will yield agreement in magnitude and spectral content
- Likely combination of both H_2O and line parameters

Future Prospects

Far-infrared Atmosphere and Cirrus Exploration Technology (FACET)
Validating Uncooled Detectors for Measurement of Far-Infrared Earth Radiance

A proposal submitted to NASA Instrument Incubator Program
July, 2013

Proposal Team
NASA Langley, SSAI
Space Dynamics Laboratory
U. Michigan
Texas A & M
Imperial College
IFAC-CNR

Proposal to place a pyroelectric focal plane into FIRST, and validate the technology by flying on a long-duration balloon flight at 30 km in Antarctica for 2+ weeks

Advantage is correlative satellite overpasses approximately every 20 minutes
AIRS, CrIS, IASI, CERES, MODIS, VIIRS – over 800 correlative opportunities in 2 weeks

Goal to to validate the operational CLARREO technology in a flight environment with comprehensive correlative measurements
Potential flight on ULDB super pressure balloons (2 months aloft) after this flight