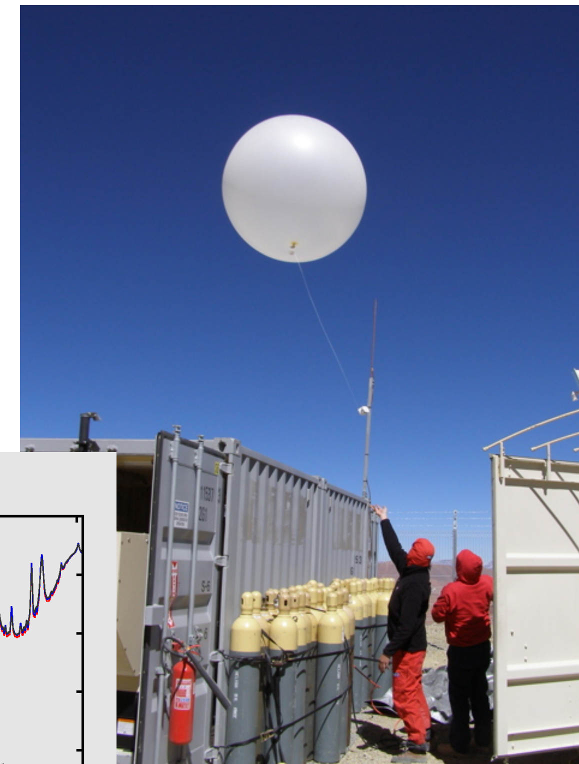
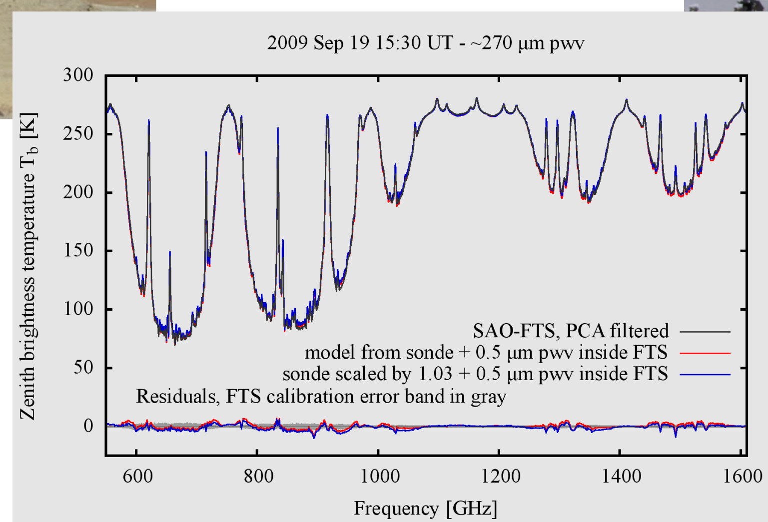
Atmospheric Modeling at Submillimeter Wavelengths





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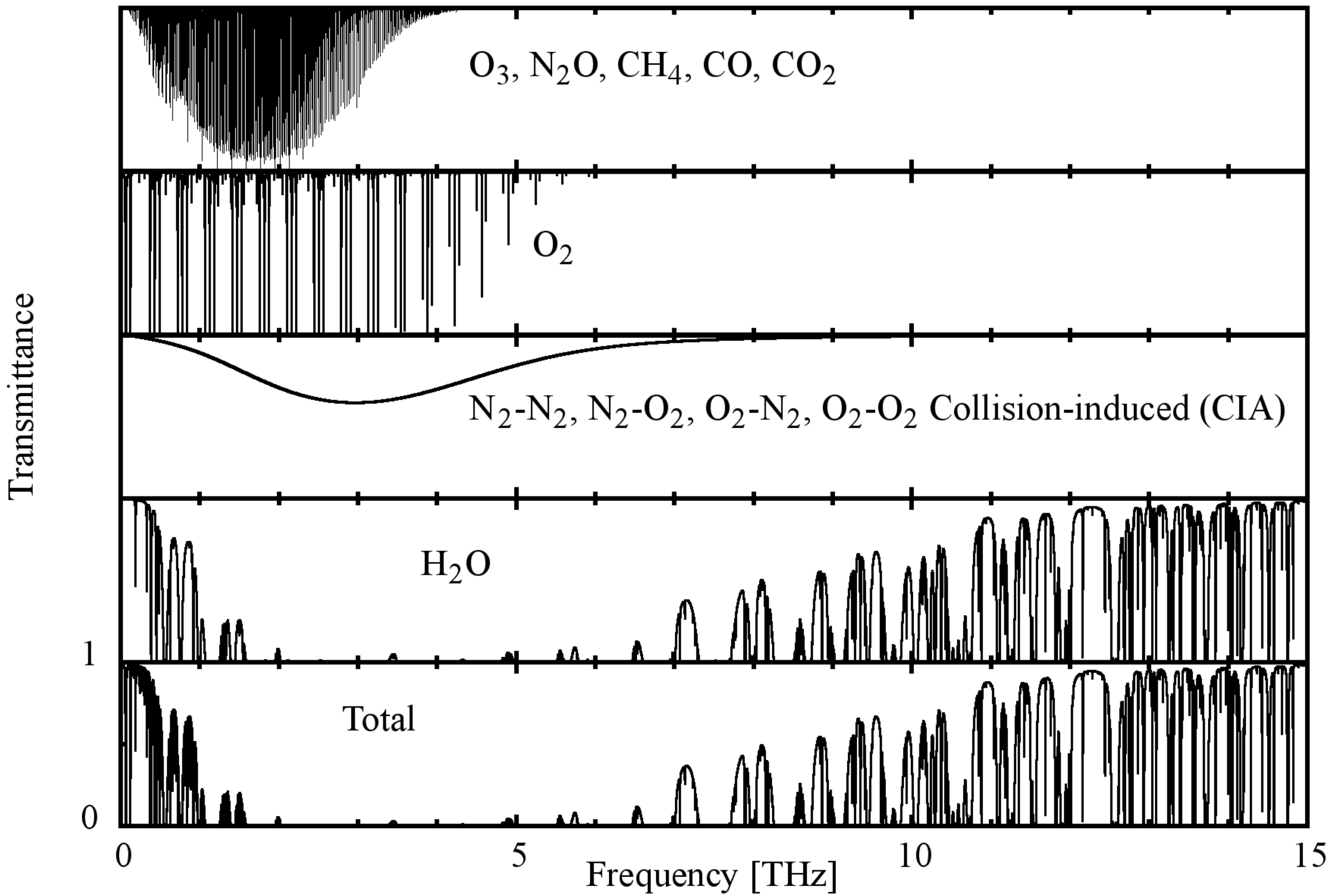
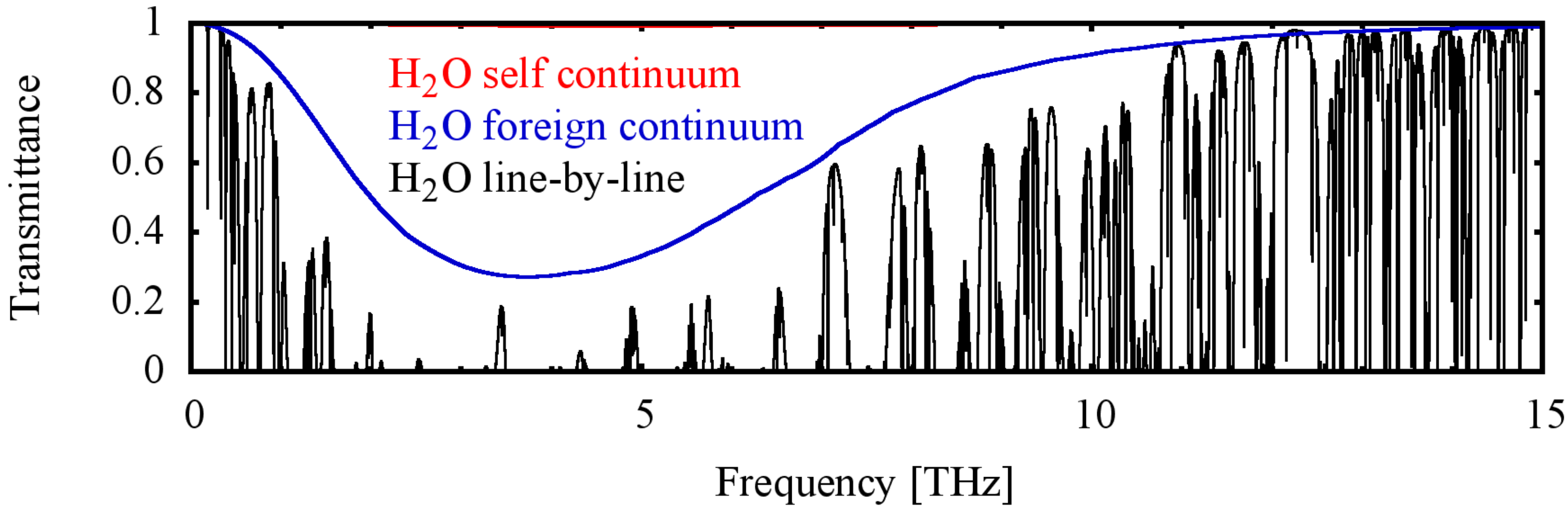
Outline

- Submillimeter absorption in the terrestrial atmosphere
- Improving models for water vapor absorption
  - Importance for models of the Earth's climate
  - The RHUBC-II campaign from Cerro Toco
- Models of transmittance and delay for ALMA under dry conditions

Submillimeter absorption from ALMA site (290 μm pwv)

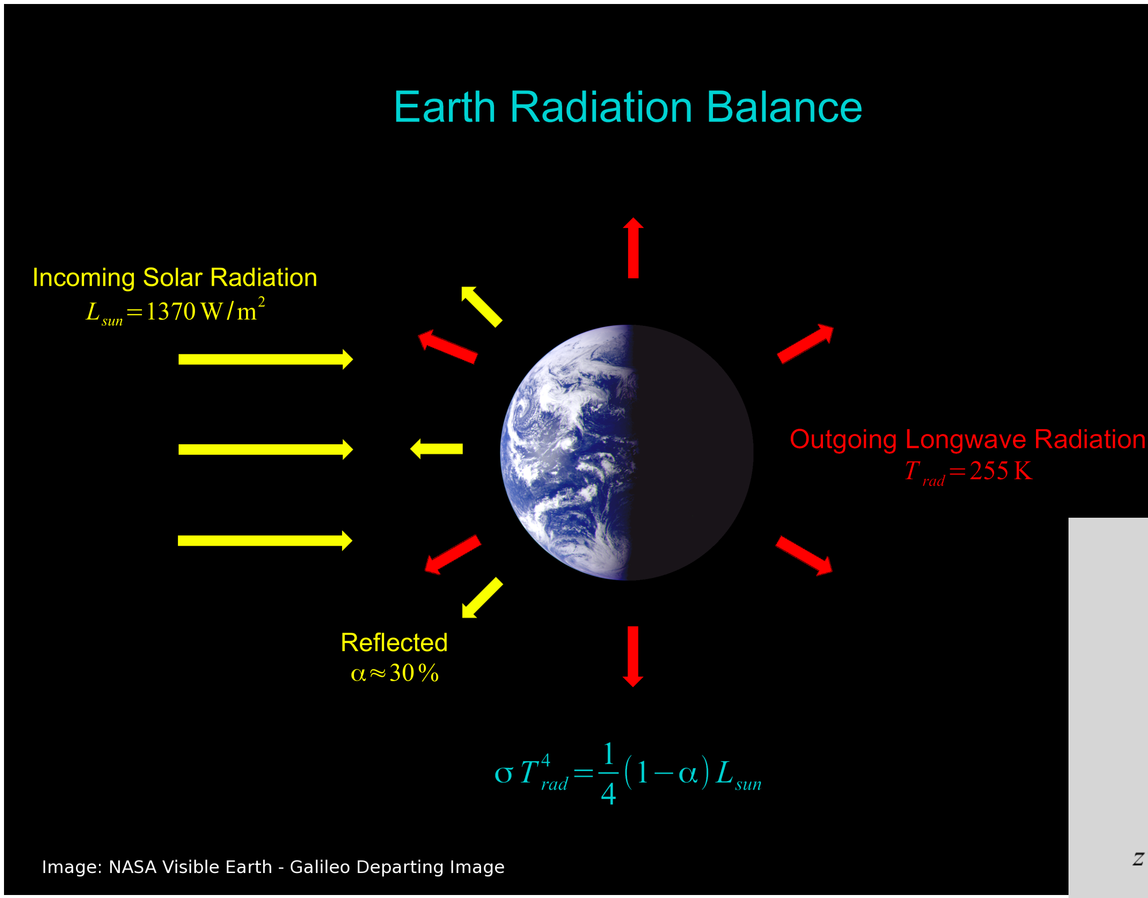


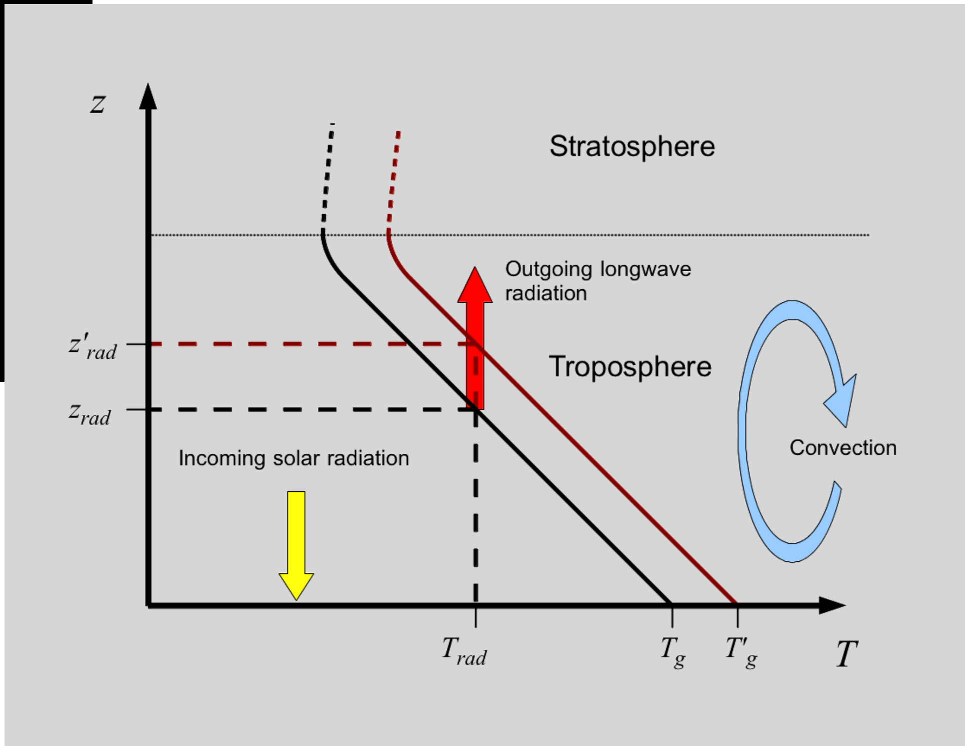
Water vapor absorption



- H_2O modeled as lines + continuum
  - Laboratory measurements of continuum are difficult
  - Physics is not well understood
  - For this dry site, self continuum is small – not so in lower troposphere!
  - Best regularly-updated model is MT-CKD (Mlawer, et al.)
- Key component of climate models...

Gray gas greenhouse effect





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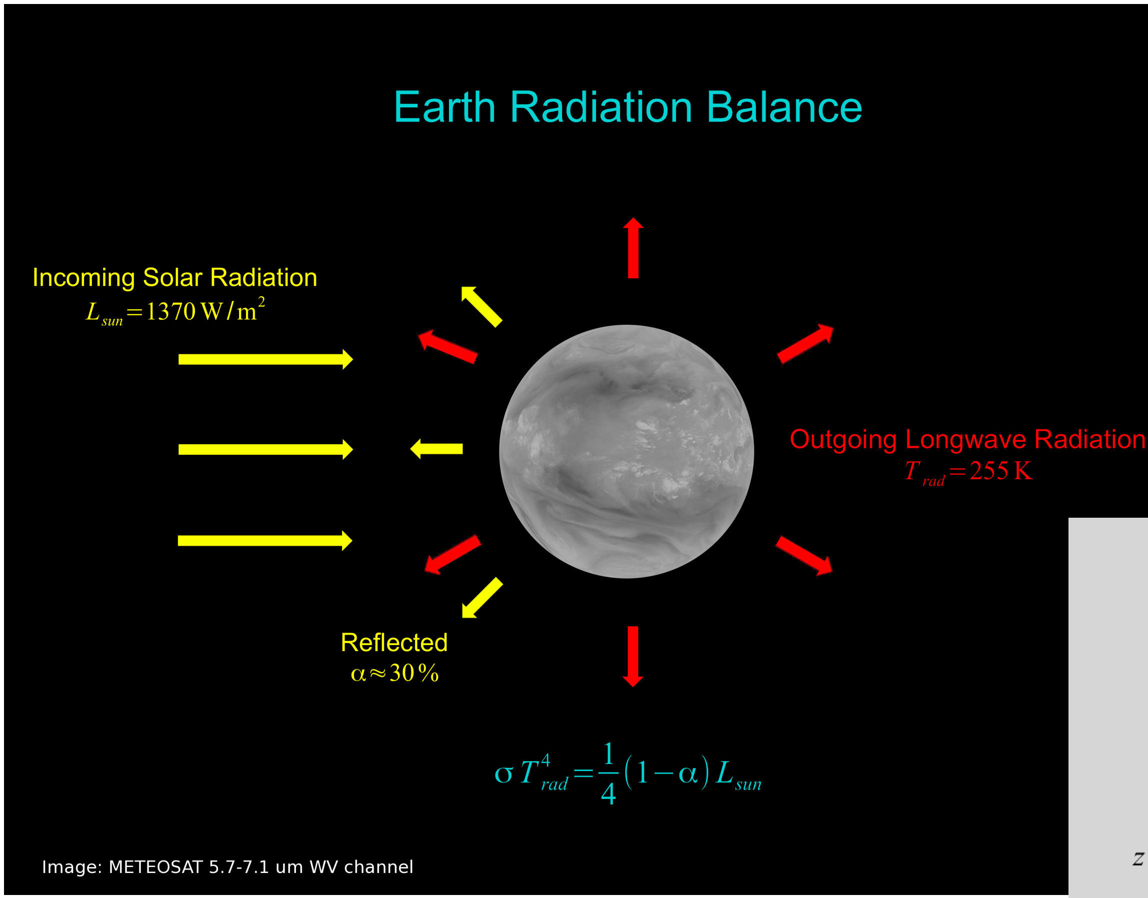
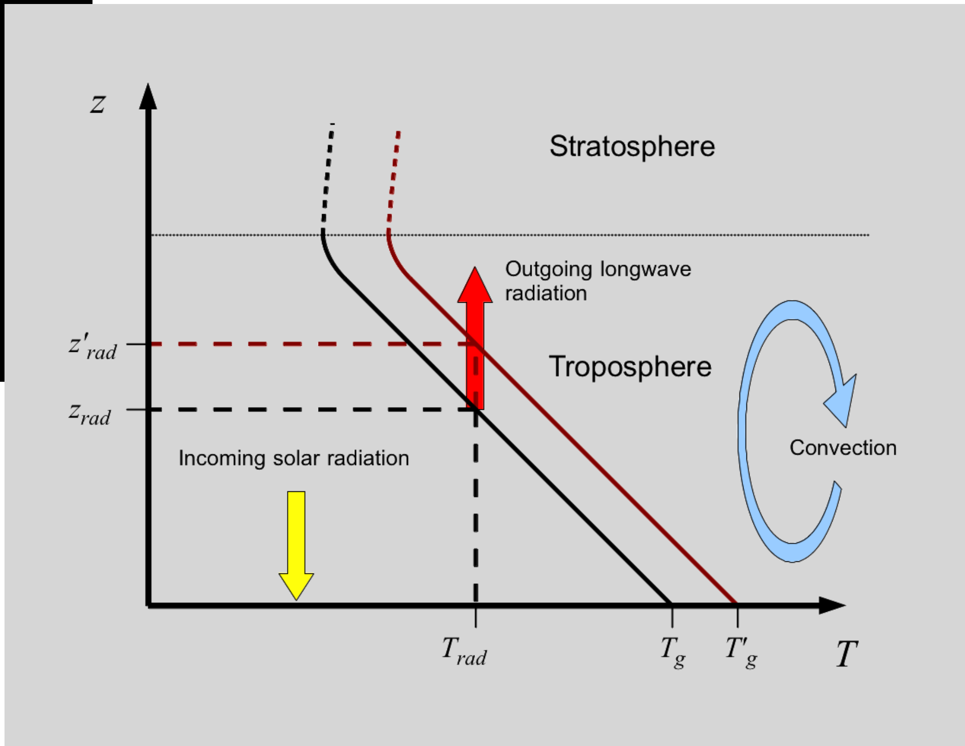
Gray gas greenhouse effect





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Radiative cooling rate – Clough diagram

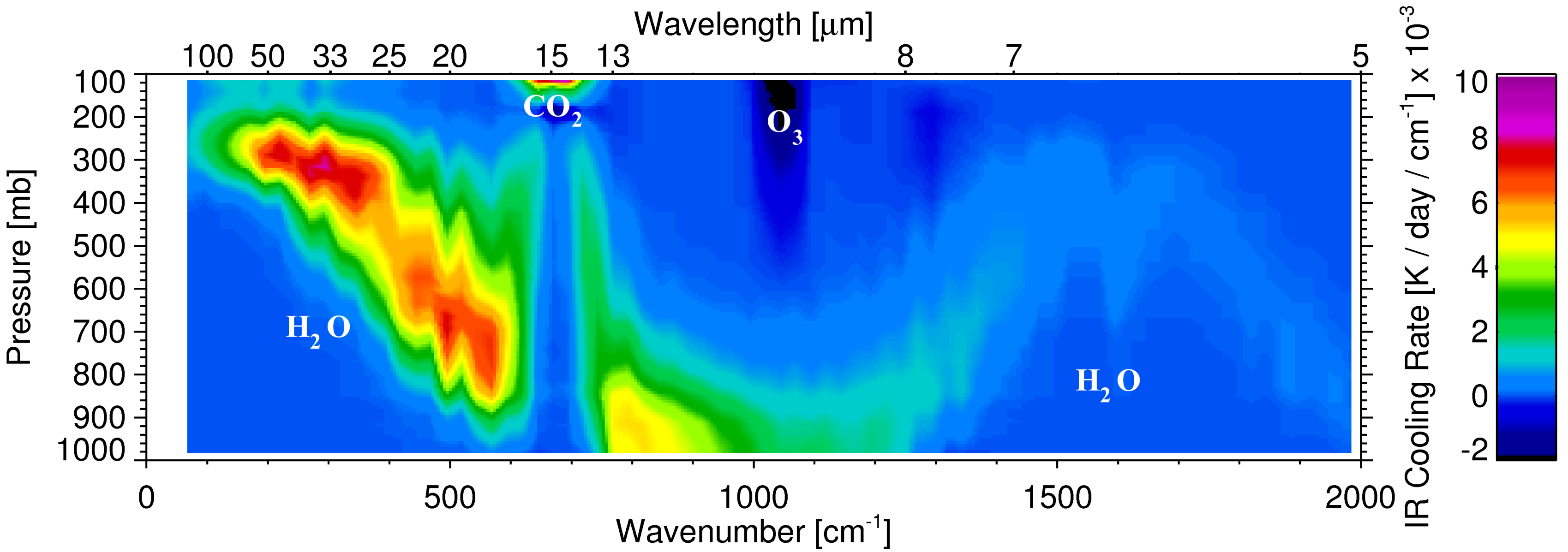
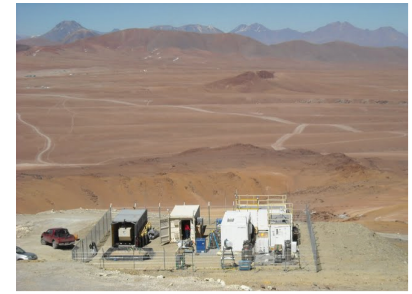


Figure: Turner and Mlawer (2010) BAMS 91:911

- Shows radiative flux divergence / heat capacity.
- Water vapor dominates radiative heat transfer in the mid- to upper troposphere.
- The need for improved H_2O spectroscopy in climate models has motivated field campaigns that use the atmosphere as a natural laboratory.

The RHUBC-II campaign



- Radiative Heating in Underexplored Bands campaign – II
- Carried out in 2009 on Cerro Toco, to north of ALMA
- Designed to address deficiencies in water vapor spectroscopy for the mid- to upper troposphere
- Multiple radiometers covering entire thermal IR, with radiosonde measurements of atmospheric state
- US DOE-sponsored campaign organized by D. Turner (NOAA) and E. Mlawer (AER).
- Participation by groups and instruments from multiple institutions, including SAO.

RHUBC-II instruments

- Radiosondes and surface meteorology
- Millimeter-wave temperature and RH profiling radiometers
- Four Fourier transform spectrometers covering entire thermal IR

RHUBC-II – spectral coverage over entire thermal IR

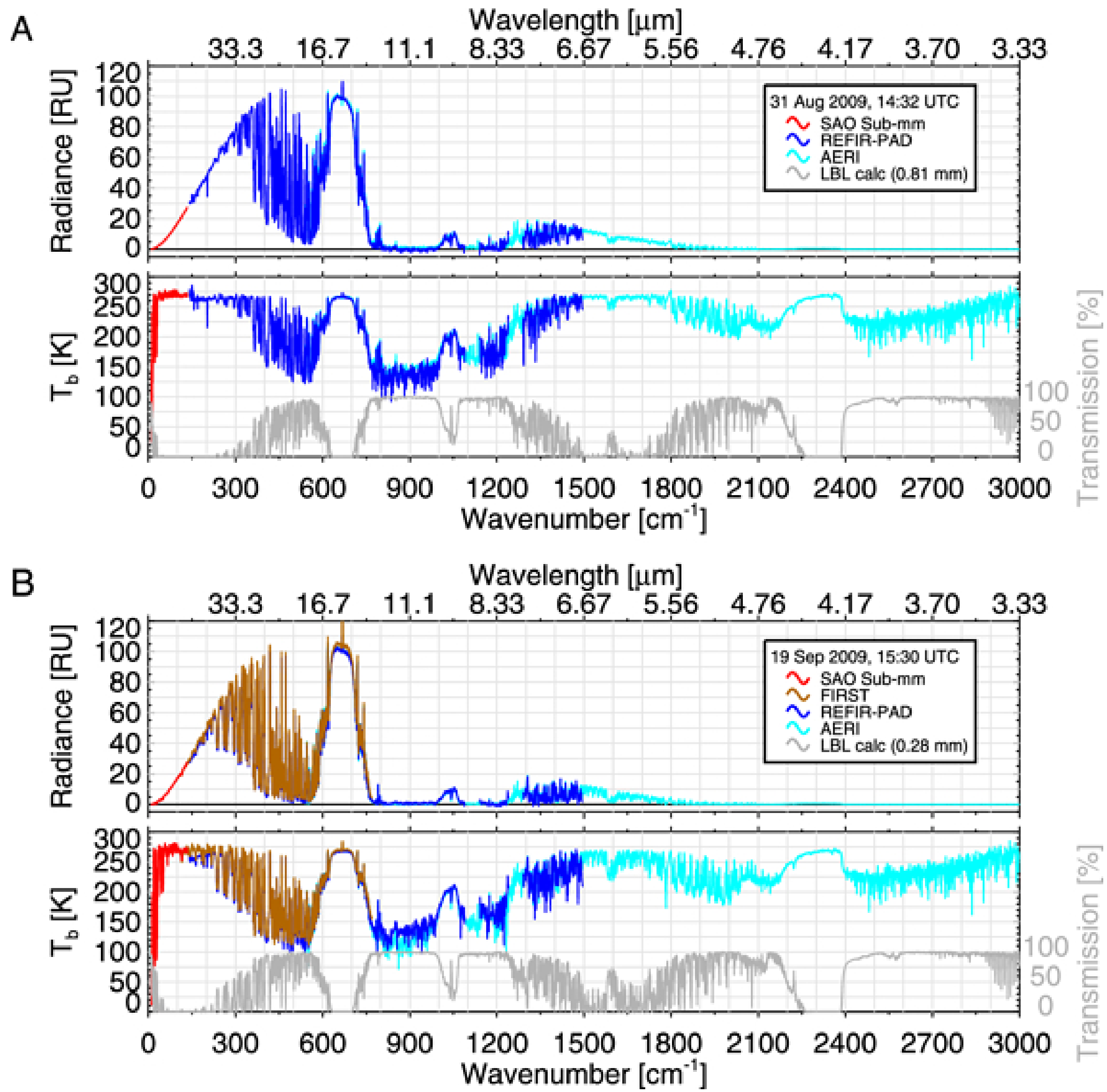


Figure: Turner, et al. GRL 39:L10801

RHUBC-II – $H2O$ pure rotation band

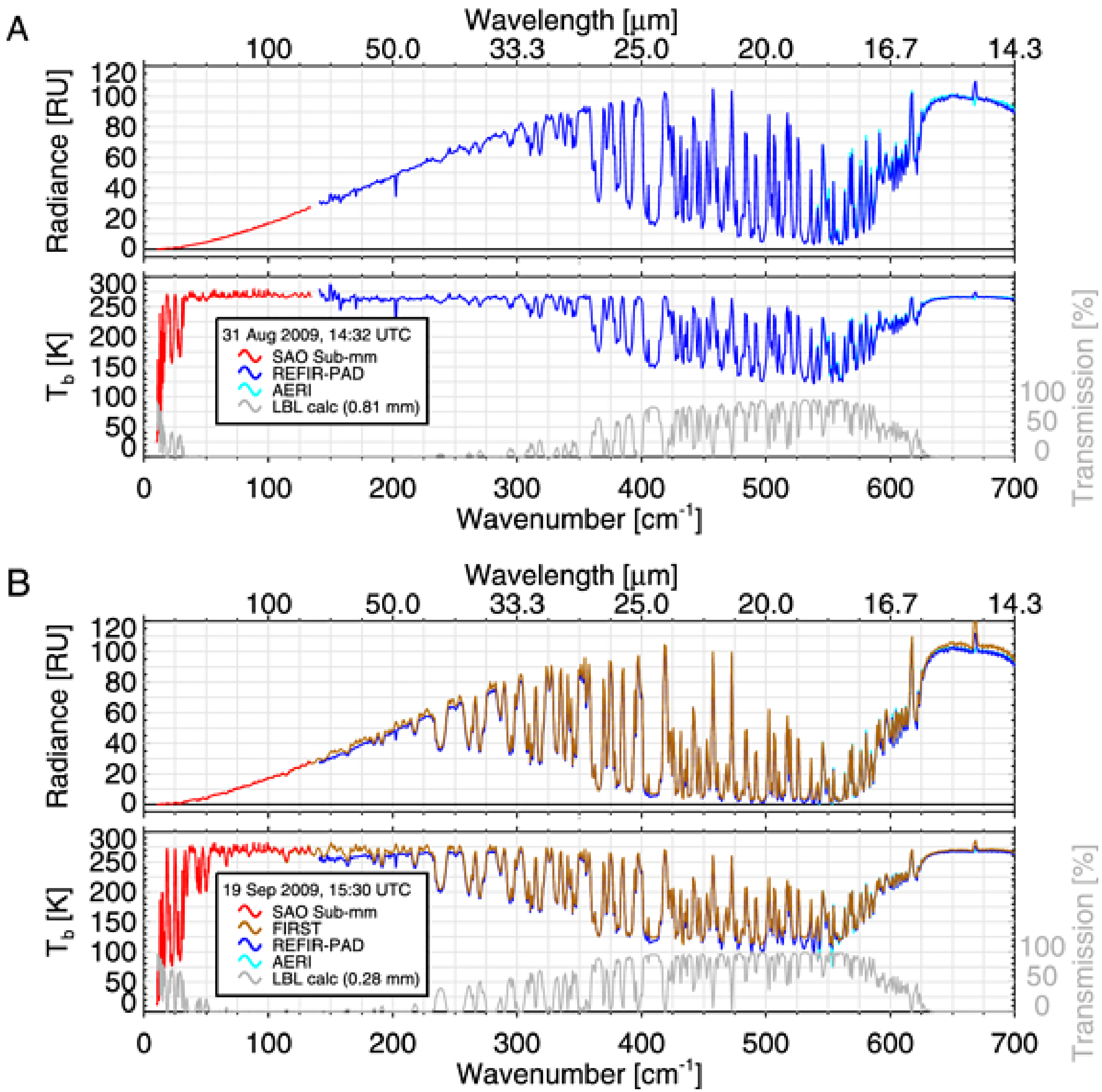


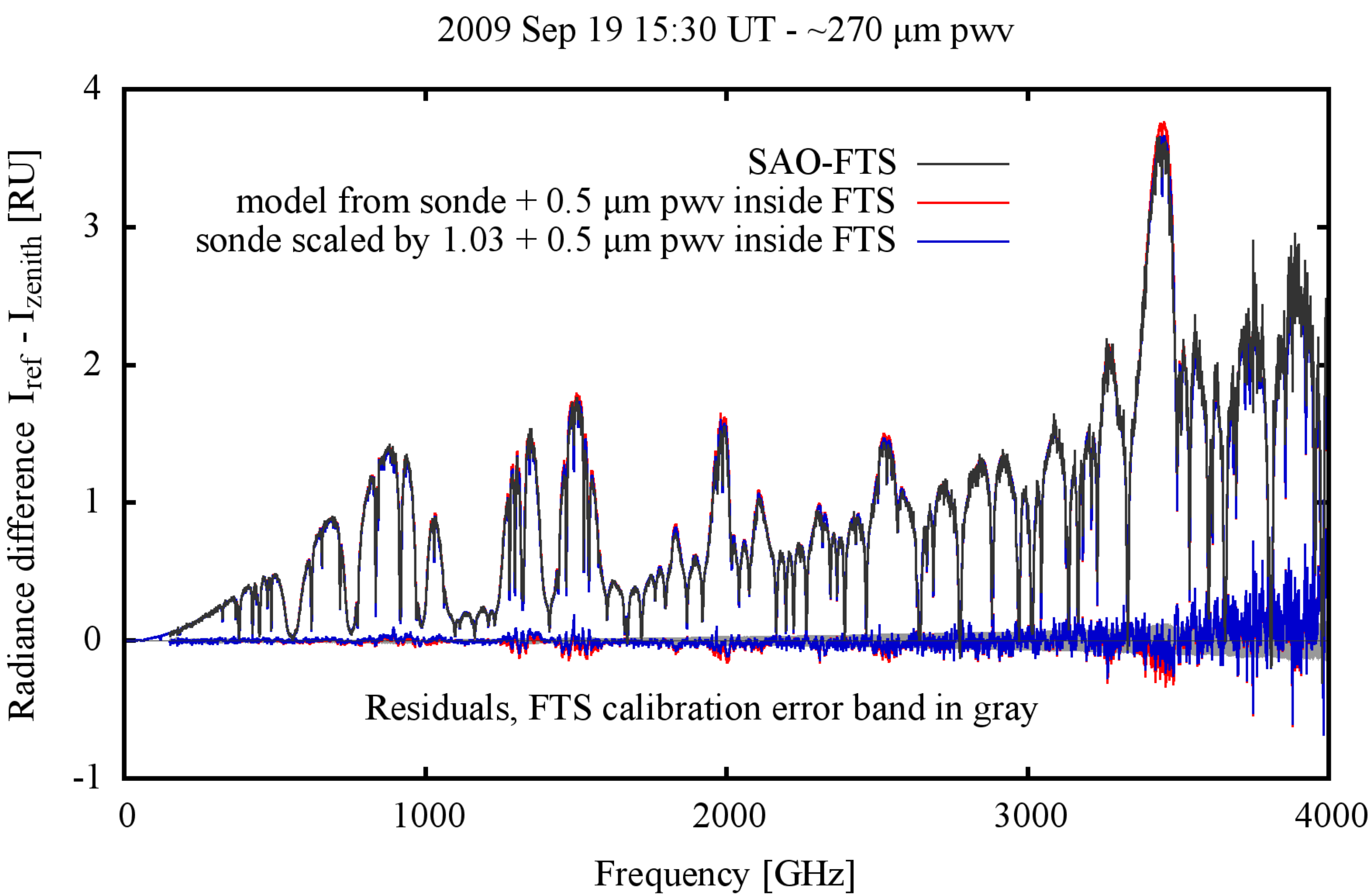
Figure: Turner, et al. GRL 39:L10801

RHUBC-II analysis example – submillimeter band

- Compare measured and model spectra
  - Measured spectrum from SAO FTS, 300 GHz – 4 THz
  - Model spectrum based on radiosonde T, RH profiles, am-7.3 code
- Adjustments
  - Radiosonde RH profile corrected with 8-level retrieval from 15-channel 183 GHz radiometer (Turner, Cadeddu)
  - "Instrument layer" added to model to account for H_2O in FTS enclosure
  - Also try additional global scale factor on RH profile




RHUBC-II analysis example – measured vs. modeled differential radiance between reference load and zenith sky



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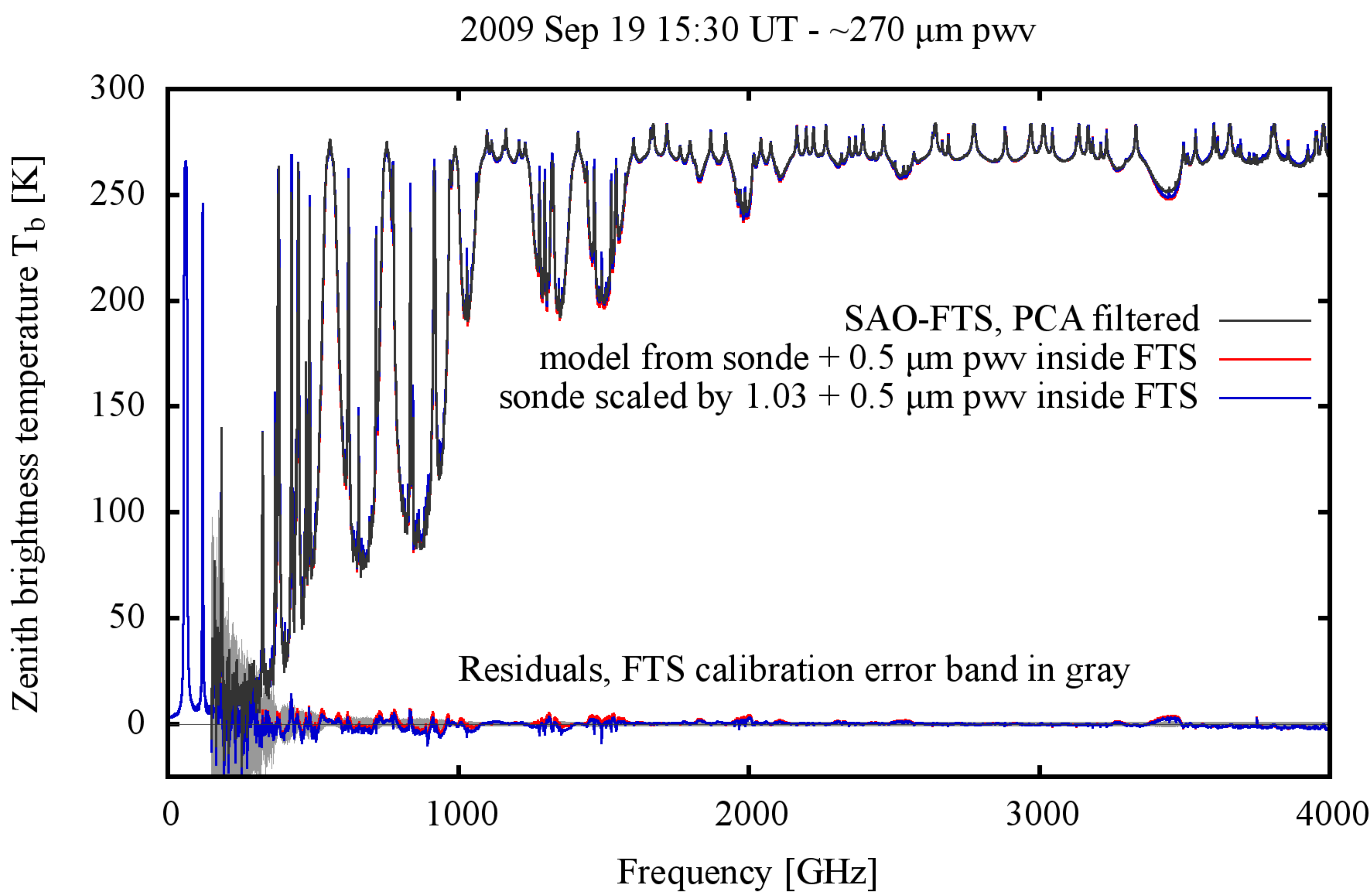
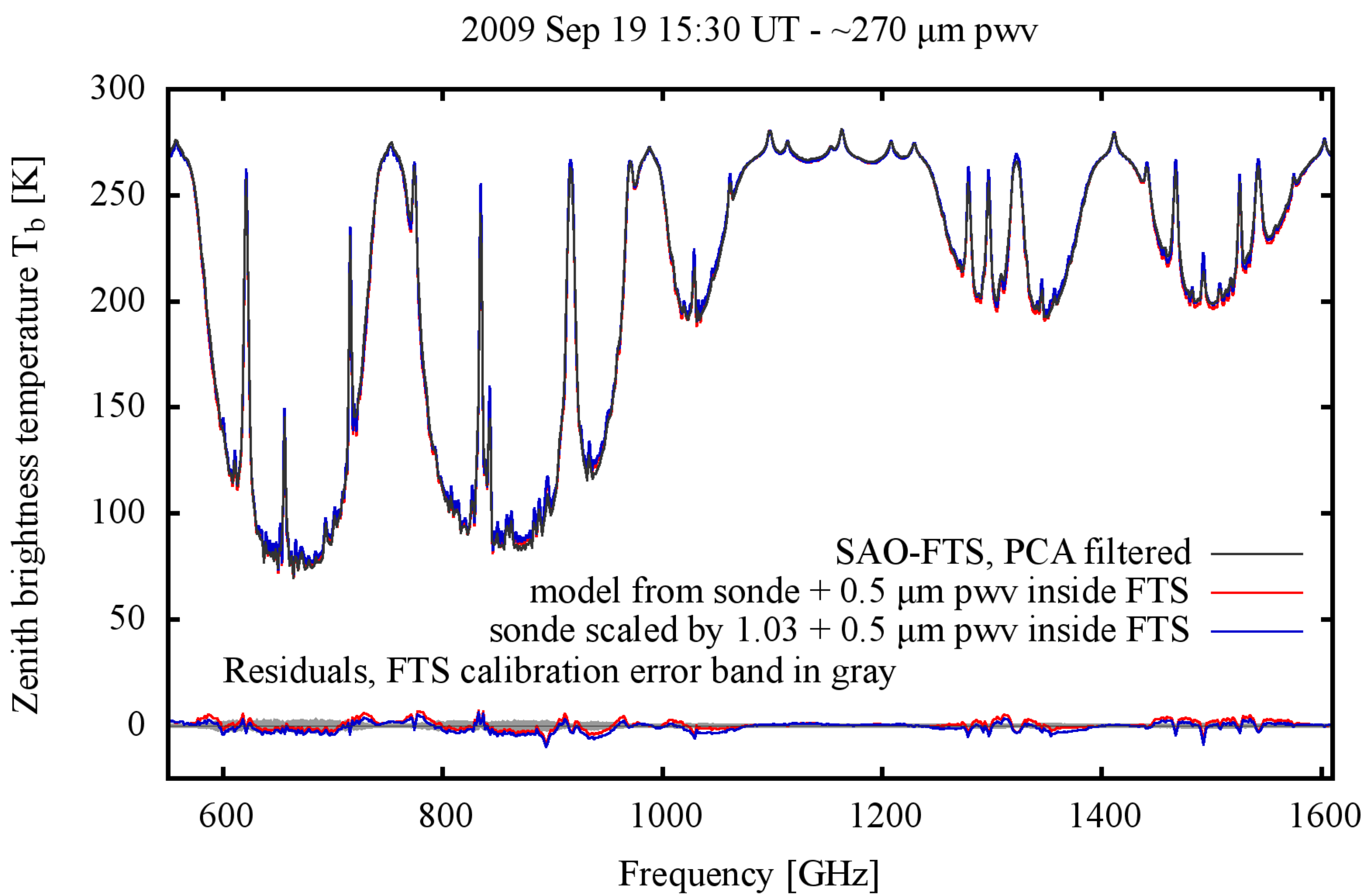
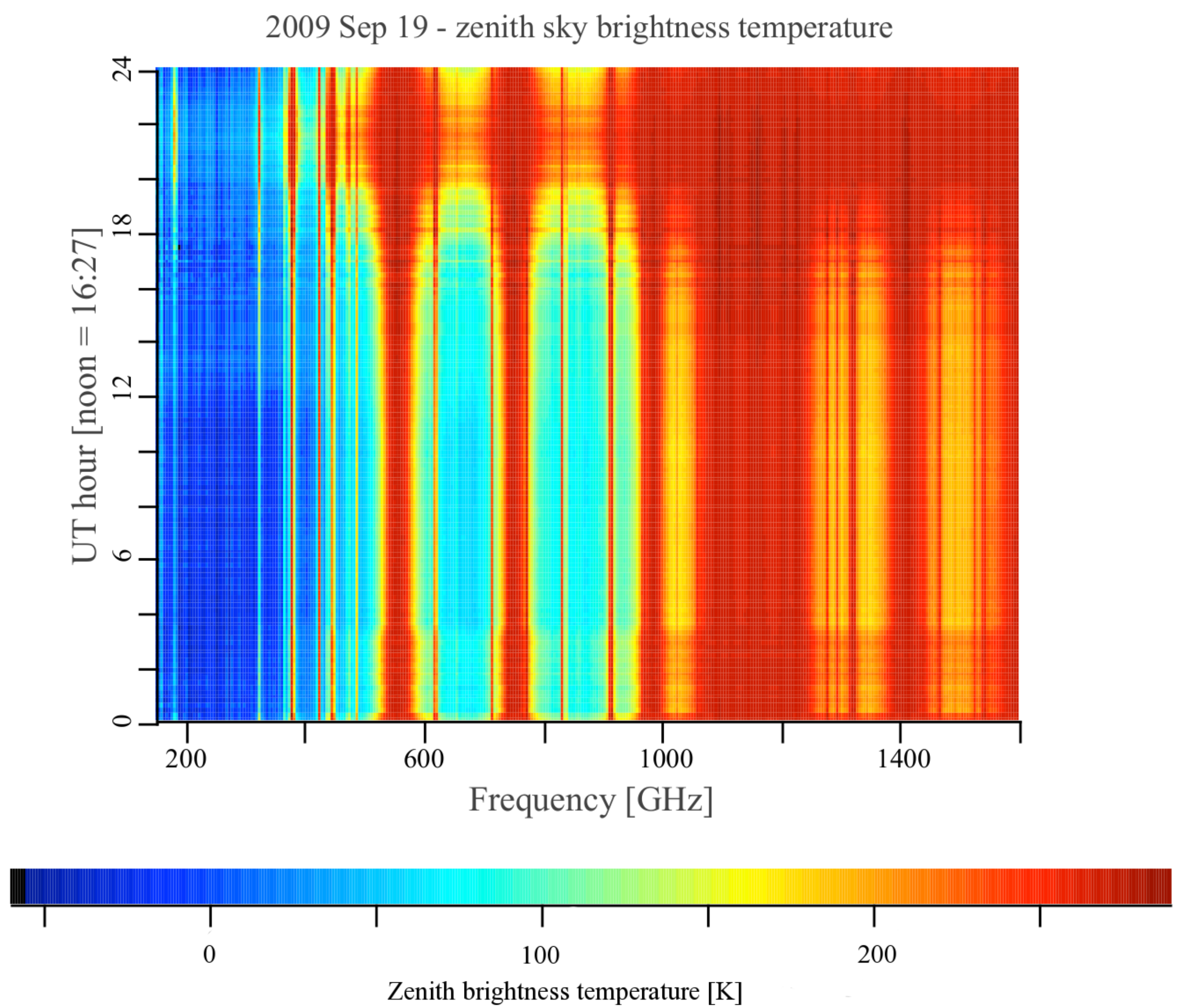
RHUBC-II analysis example – measured vs. modeled T_b



RHUBC-II analysis example – measured vs. modeled T_b



Typical dry weather diurnal variation of submillimeter T_b



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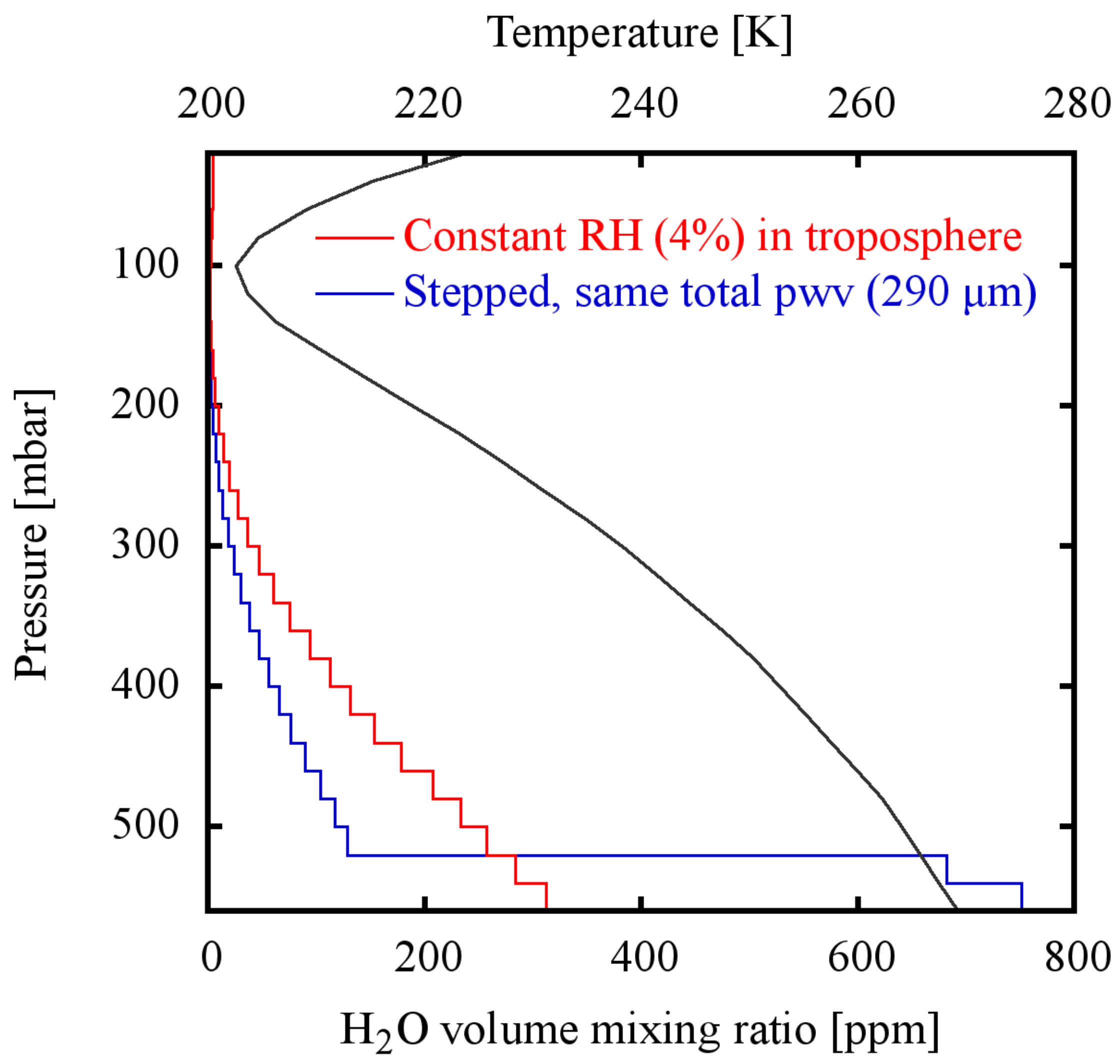
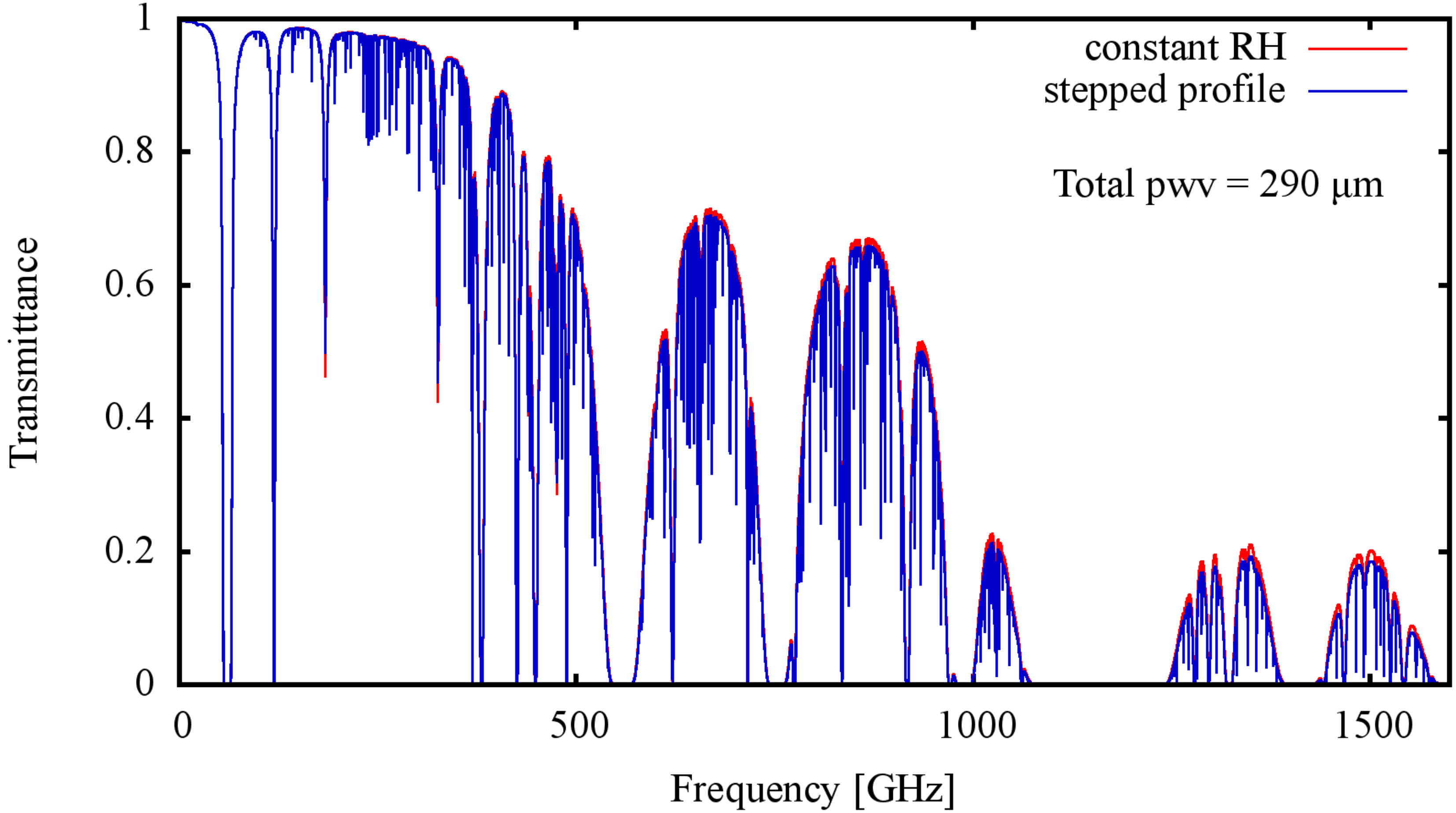
Models for ALMA – two dry weather examples

- We've shown that models are accurate for known profiles.
- But, profiles not always available for:
  - Prediction of THz site conditions from mm-wave data
  - Phase correction
- Consider two dry weather models with the same PWV, but different RH profiles, and examine the differences.

Two realistic dry-weather profiles for ALMA

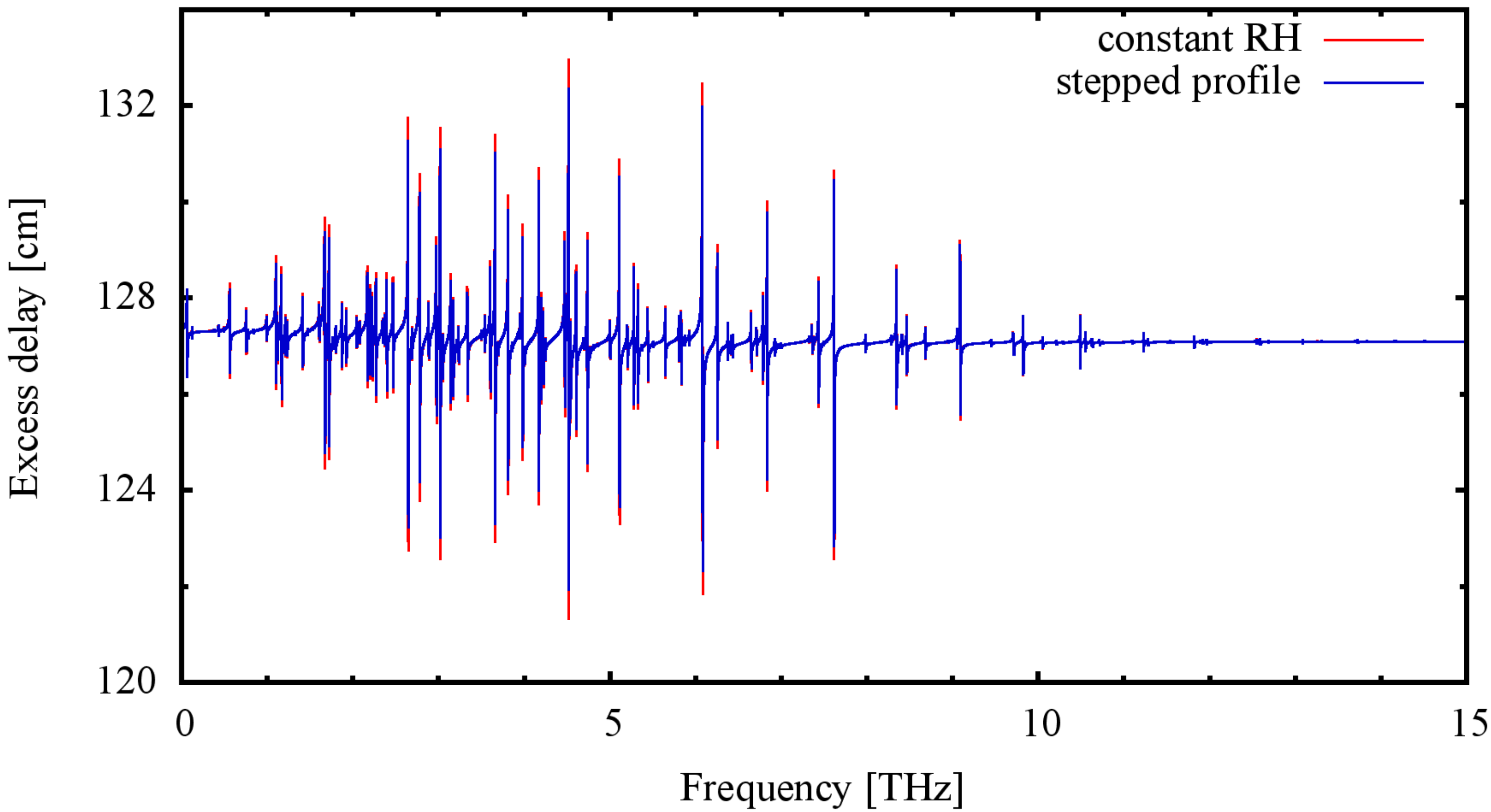


ALMA dry examples – transmittance



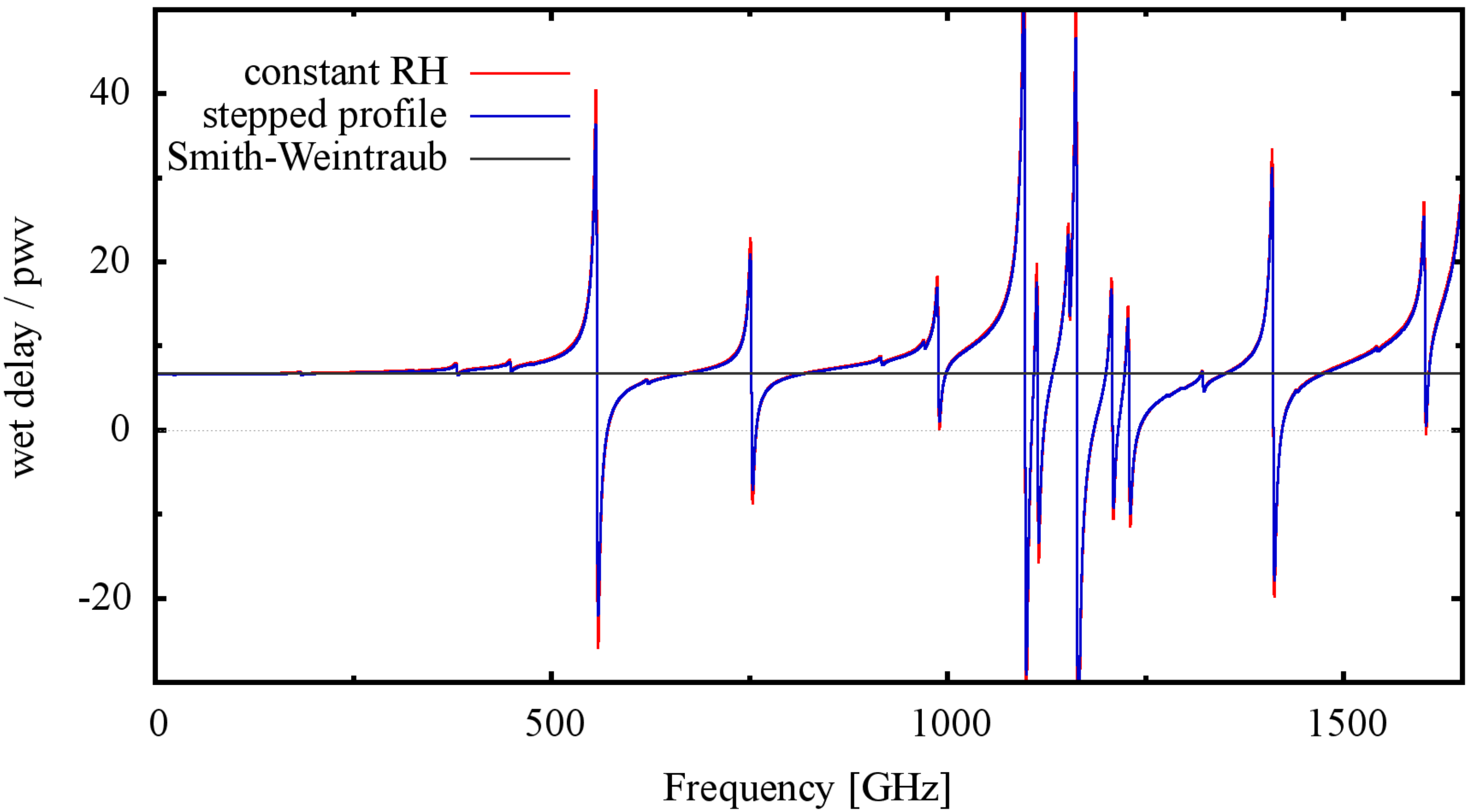
- Small difference from more H_2O at higher pressure in stepped profile
- Good enough for accurate prediction of THz transmittance statistics

ALMA dry examples – total delay



- Main effect of different profiles is on line widths (not important)
- Dynamical effects on dry delay could be significant for ALMA band 11.

ALMA dry case examples – normalized wet delay



- Wet delay becomes significantly dispersive in bands 9, 10, 11

Summary

- RHUBC-II substantially validated current models of submillimeter atmospheric propagation for ALMA bands, under ALMA site conditions.
- With up-to-date models, prediction of band 11 conditions based on millimeter-wave data and scaled climatological profiles is secure.
- Phase correction will be especially important for band 11. Dry delay may be important, and significant wet delay dispersion needs to be taken into account

Resources

- RHUBC-II campaign data

  http://www.archive.arm.gov/

  (create account, then look under IOP data > 2009 > cjc > rhubc-ii)

- *am* code and documentation

  Atmospheric propagation tool for microwave – submillimeter band.

  http://www.cfa.harvard.edu/~spaine/am/

- LBLRTM

  Comprehensive atmospheric radiative transfer code maintained by AER, widely used by the atmospheric science and remote sensing community.

  http://rtweb.aer.com/