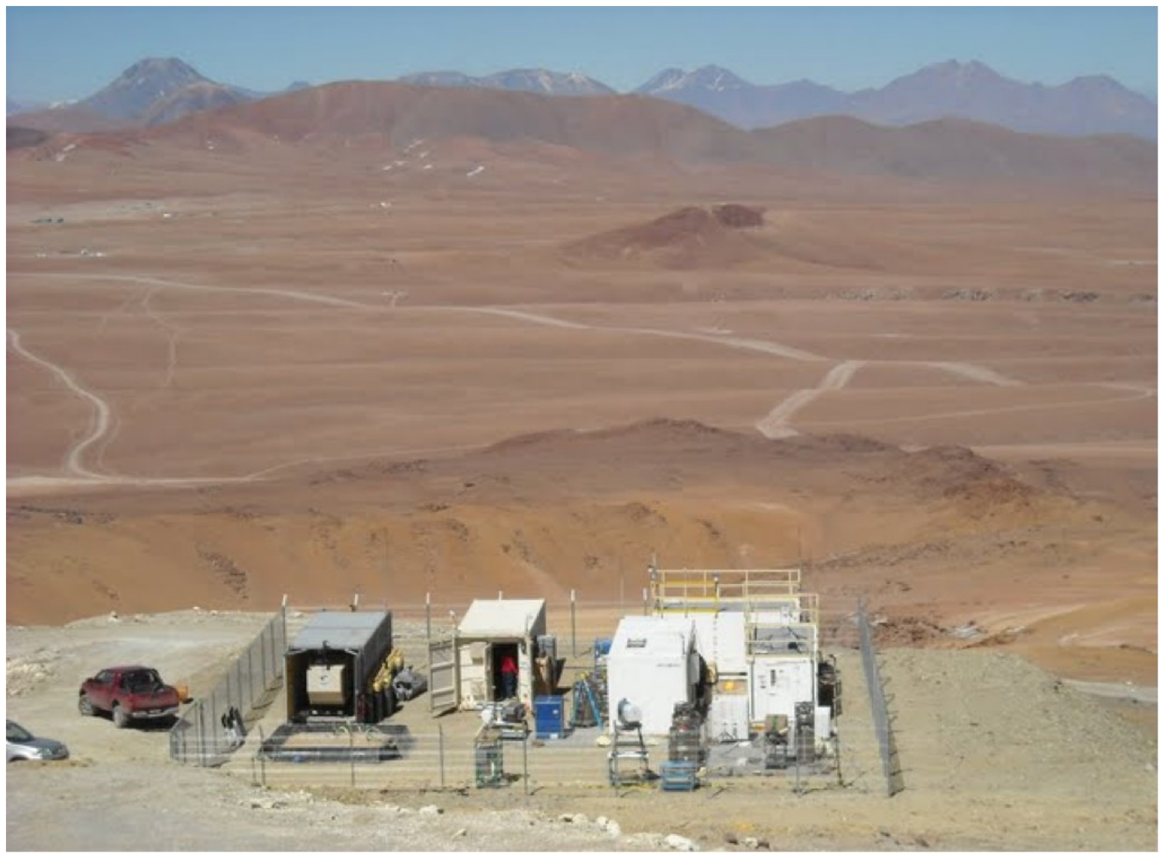
Advancing the Understanding of Radiative Properties in the Upper Troposphere: The RHUBC Campaign on Cerro Toco



Scott Paine, SAO, on behalf of the RHUBC-II team

Astronomical Site Testing Data – Valparaiso – 2010 December 1

RHUBC-II People

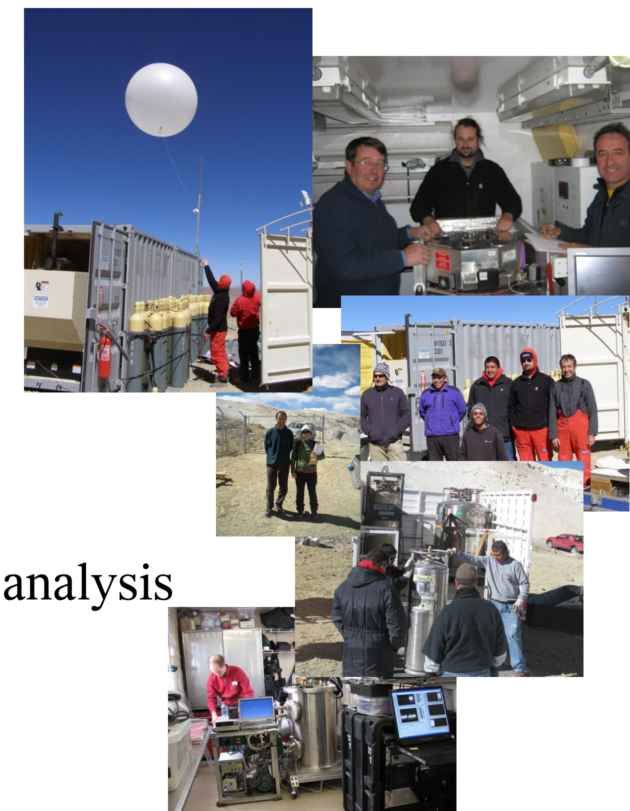
Principal Investigators

Eli Mlawer, Atmospheric and Environmental Research, Inc.
Dave Turner, NOAA

Campaign Logistics

Jim Mather, Pacific Northwest National Laboratory
Kim Nitschke, Los Alamos National Laboratory

Collaborating Institutions / Instrument PI's



NASA Langley Research Center, USA / Marty Mlynczak

Instituto de Fisica Applicata, Italy / Luca Palchetti

University of Denver, USA / Tom Hawat

University of Cologne, Germany / Susanne Crewell

Smithsonian Astrophysical Observatory / Scott Paine

Argonne National Laboratory / Maria Cadeddu, Rich Coulter

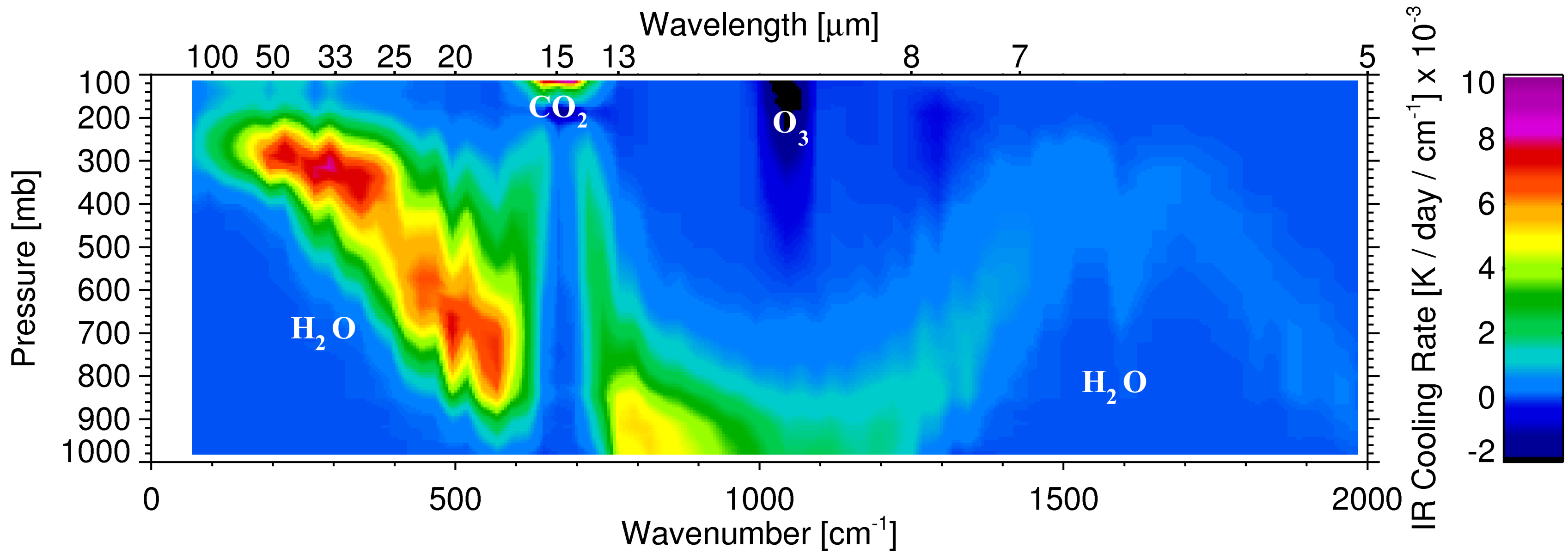
Many others involved in planning, field campaign, and data analysis

Outline

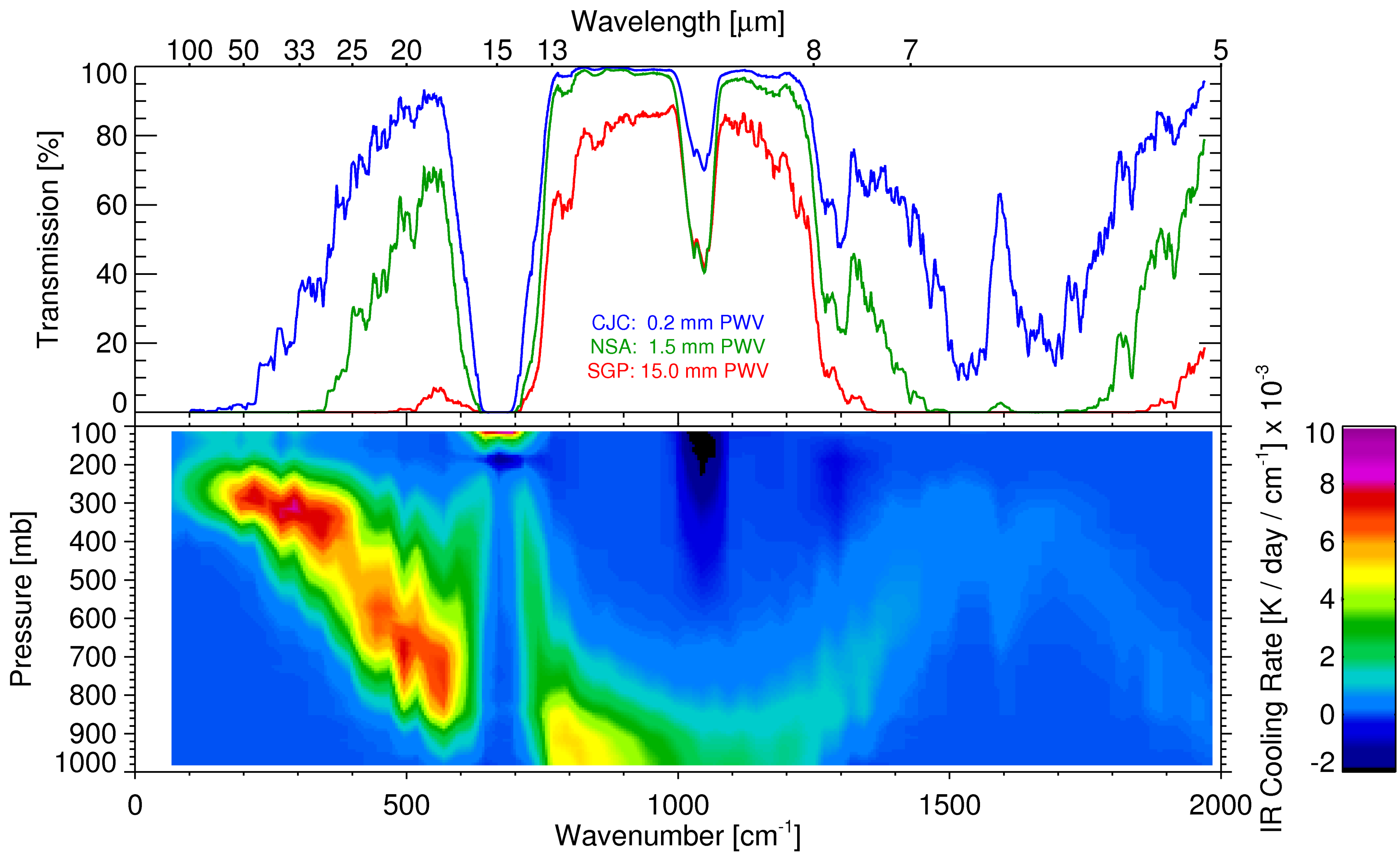
- Background: Atmospheric radiation, water vapor, and climate
- The Radiative Heating in Underexplored Bands Campaigns (RHUBC)
- A case study from RHUBC-II: Radiative closure using submillimeter FTS spectra and radiosonde profiles

Infrared spectral cooling rate

(Midlatitude summer, after Clough and Iacono, 1995)



- Radiation, convection, and circulation govern climate.
- Far-IR radiation from mid- to upper troposphere accounts for about half of longwave cooling. ($T_{eff} \sim 255$ K)
- Accurate radiation modeling is essential for accurate climate modeling.
- Water vapor line and continuum radiation play a central role.



Validation of radiation models for the mid- to upper troposphere is hard:

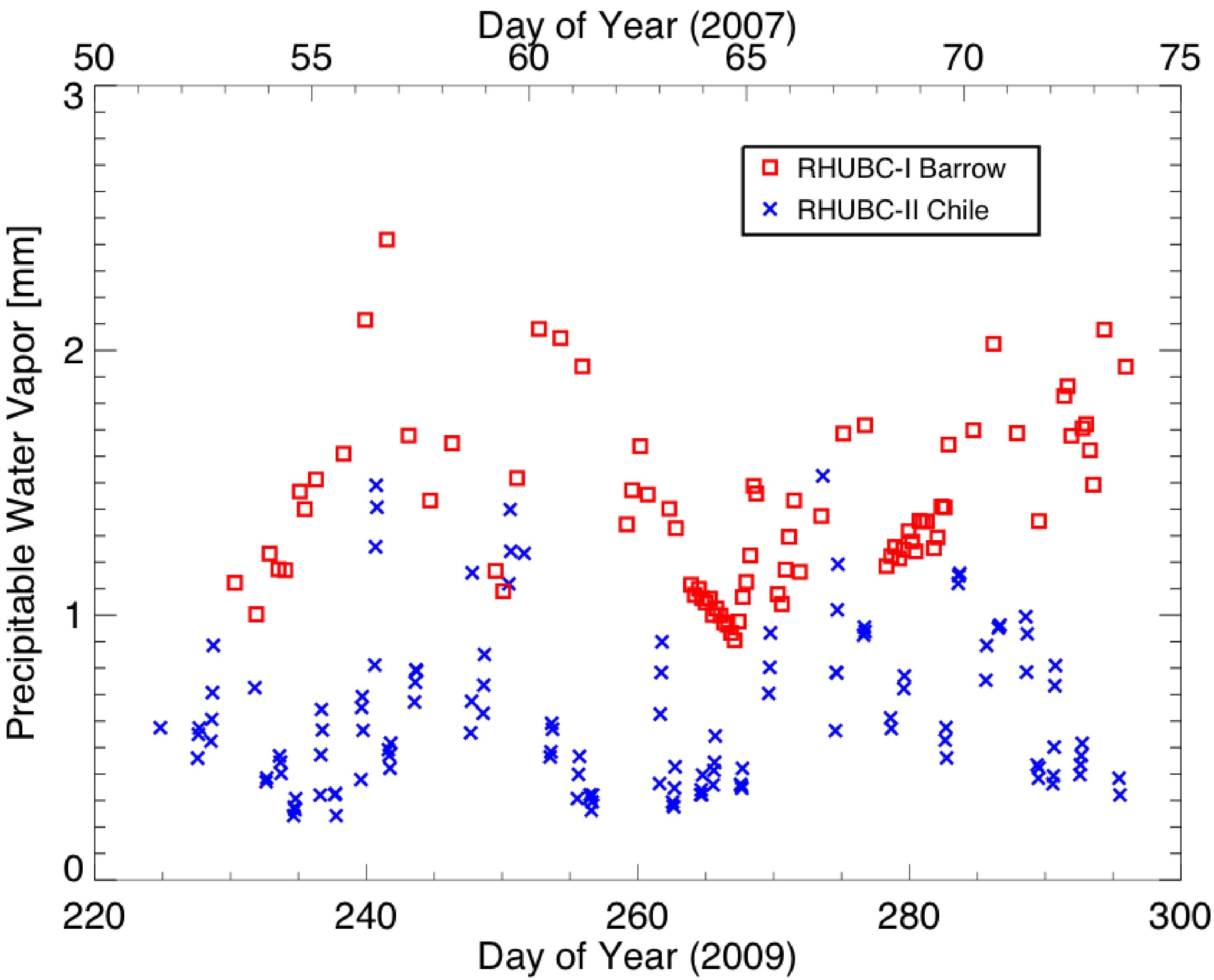
- Opacity of the lower troposphere hinders measurements.
- Laboratory measurements under appropriate P, T are very difficult.

Solution: go to very dry, high site

The Radiative Heating in Underexplored Bands Campaigns (RHUBC)

- Proposed in 2006 by Turner and Mlawer to the Atmospheric Radiation Measurement (ARM) program of the US Department of Energy
- Motivated by:
  - Importance of FIR contribution to outgoing longwave radiance
  - Few spectrally-resolved measurements with coincident H_2O profile data
  - Newly-available FIR spectrometers and 183 GHz radiometers
  - Availability of ARM infrastructure
  - Existence of supported high, dry sites in Chile at tropical latitude
- Campaigns:
  - RHUBC-I: ARM North Slope Alaska (NSA) site, Feb-Mar 2007
  - RHUBC-II: Cerro Toco in CONICYT science preserve, Aug-Oct 2009

How dry? RHUBC-I and RHUBC-II radiosonde PWV:

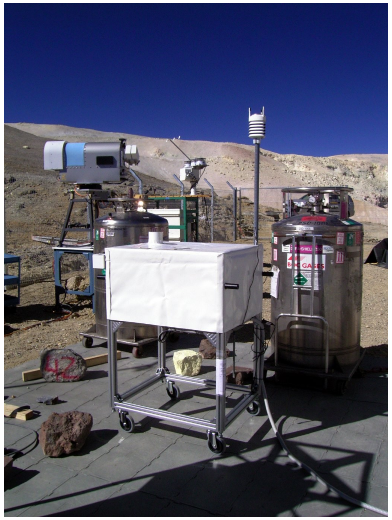


RHUBC-II Instruments (1)

- Fourier transform spectrometers spanning entire thermal infrared:
  - AERI (ARM / Turner) 3.3 μm – 25 μm
  - FIRST (NASA / Mlynczak) 6.3 μm – 100 μm
  - REFIR-PAD (IFAC – CNR / Palchetti) 7 μm – 100 μm
  - SAO-FTS (SAO / Paine) 85 μm – 1000 μm

AERI

FIRST



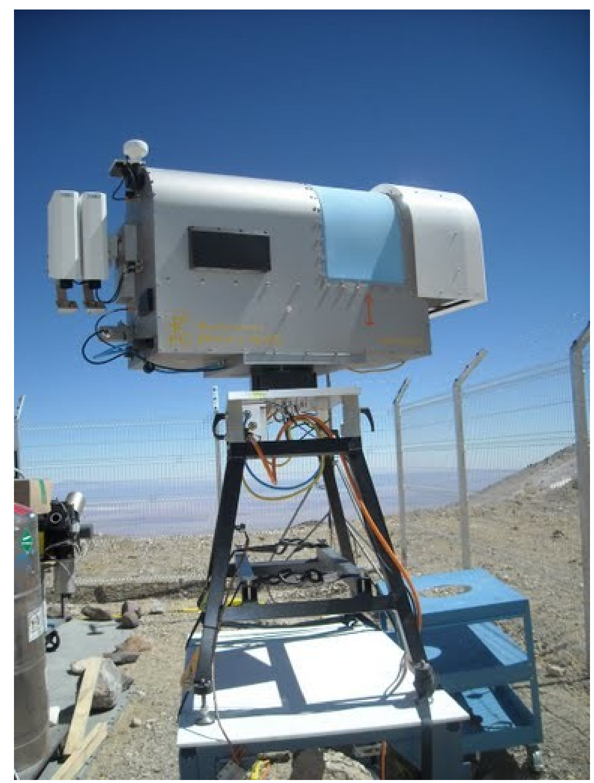
REFIR

SAO-FTS

RHUBC-II Instruments (2)

- Multi-channel radiometers:
    - GVRP 15-channel 183 GHz radiometer (ARM / Cadeddu)
    - HATPRO 22 GHz / 60 GHz radiometer (Cologne / Crewell)

GVRP



HATPRO

RHUBC-II Instruments (3)

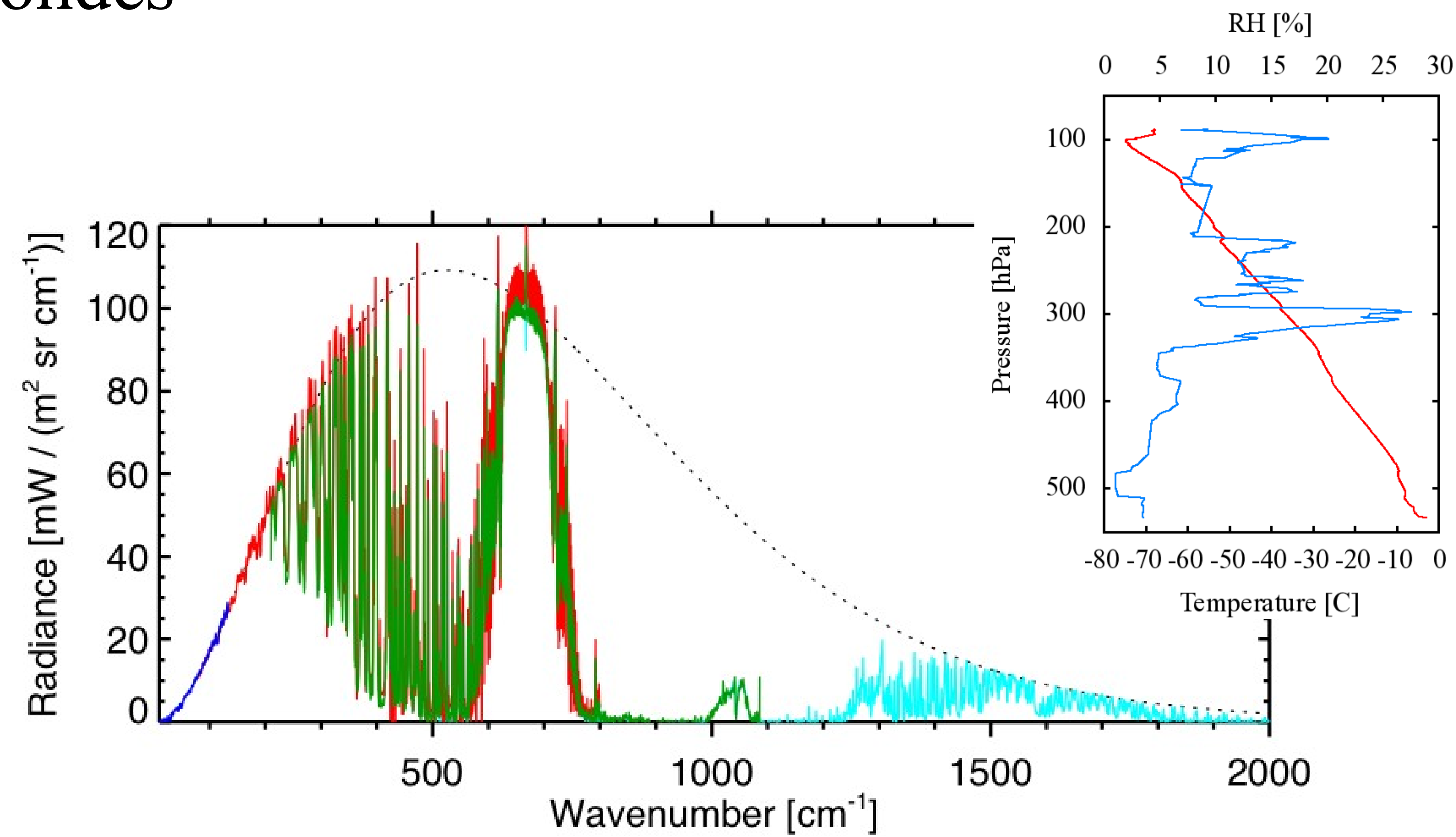
- Atmospheric state:
  - Vaisala RS-92 radiosondes
  - Met tower

- Sun / Scattered light
  - ASTI solar tracking FTS (U. Denver / Hawat) 1 μm – 5 μm
  - ARM MFRSR shadow band radiometers

MFRSR

ASTI

Spectral coverage of entire thermal infrared – with coincident atmospheric state data from sondes



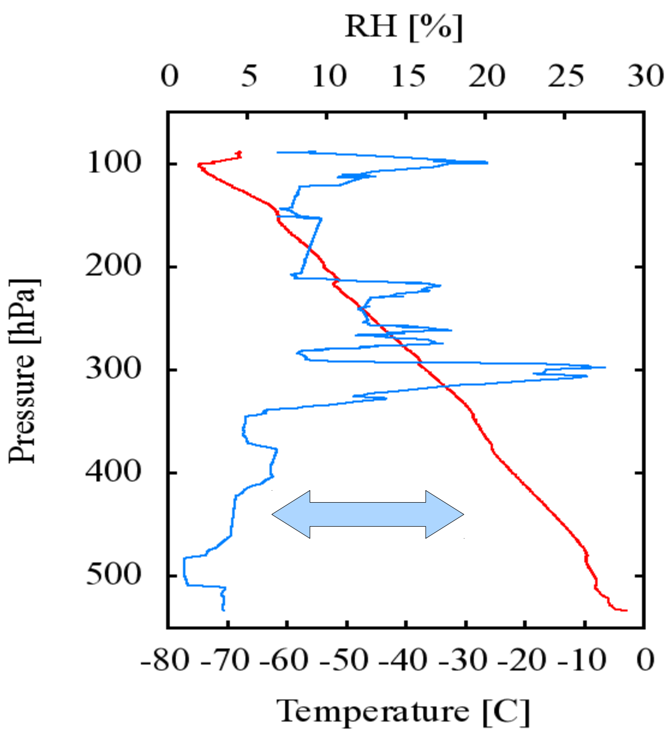
(Preliminary data from 2010 Sep 19, 15:30 UT)

Problem: Sondes aren’t perfect

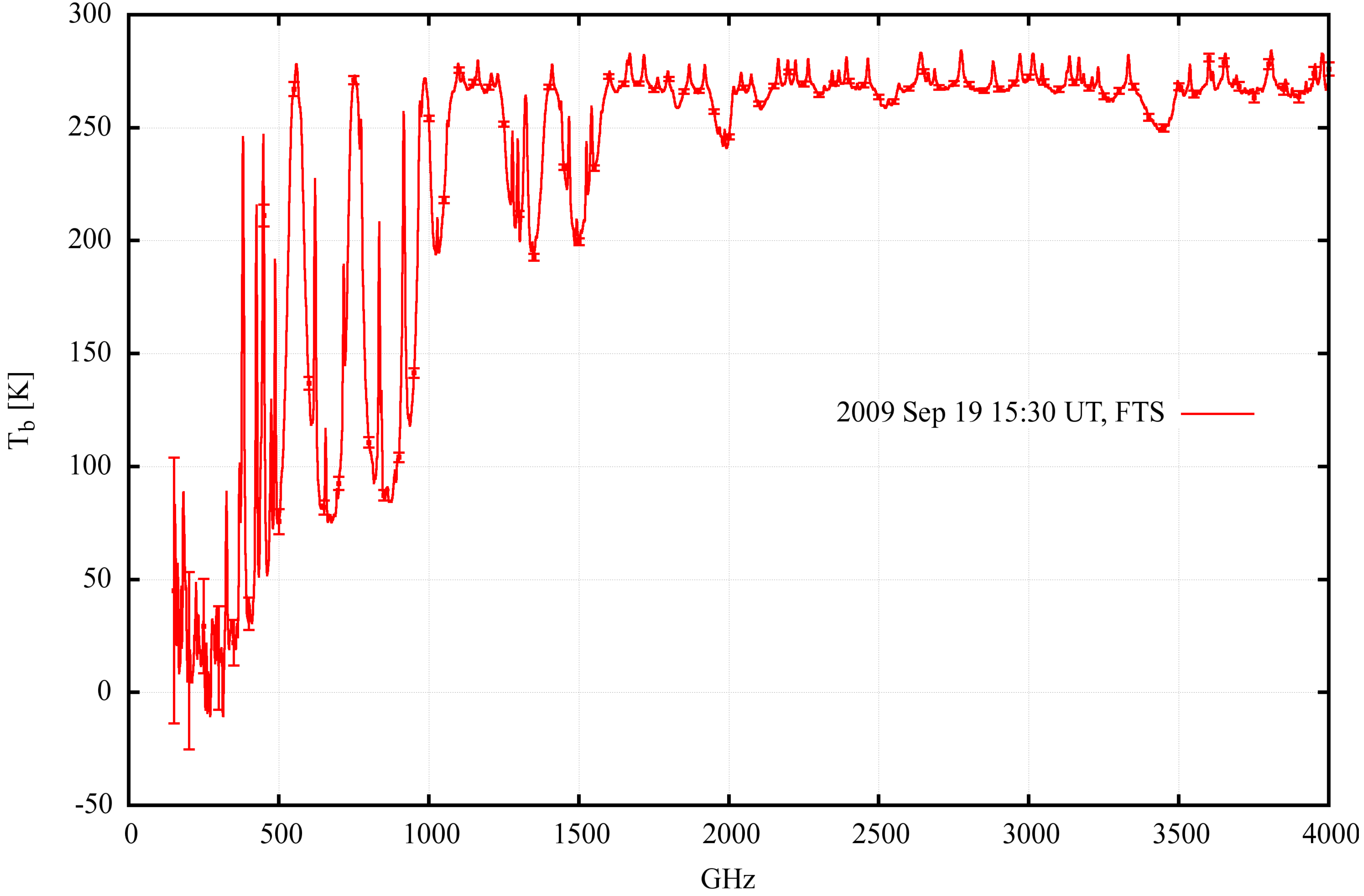
- Sondes give high-resolution profiles for temperature and humidity, but humidity accuracy under dry conditions can be poor.
- Various problems:
  - Dry calibration
  - Response lag
  - Solar heating
  - Data processing
  - Manufacturing variations
- Miloshevich, et al. 2009 formulated a correction for RS92 sondes based on comparison with chilled-mirror sensor data. Validity for very dry conditions is not clear.

A case study from RHUBC-II – radiative closure between sonde profiles and submillimeter FTS spectra

- Fit forward model to measured spectrum, using just two adjustable parameters:
  - Scaling factor on sonde humidity profile
  - Water vapor column in instrument enclosure (~ 1 μm PWV)

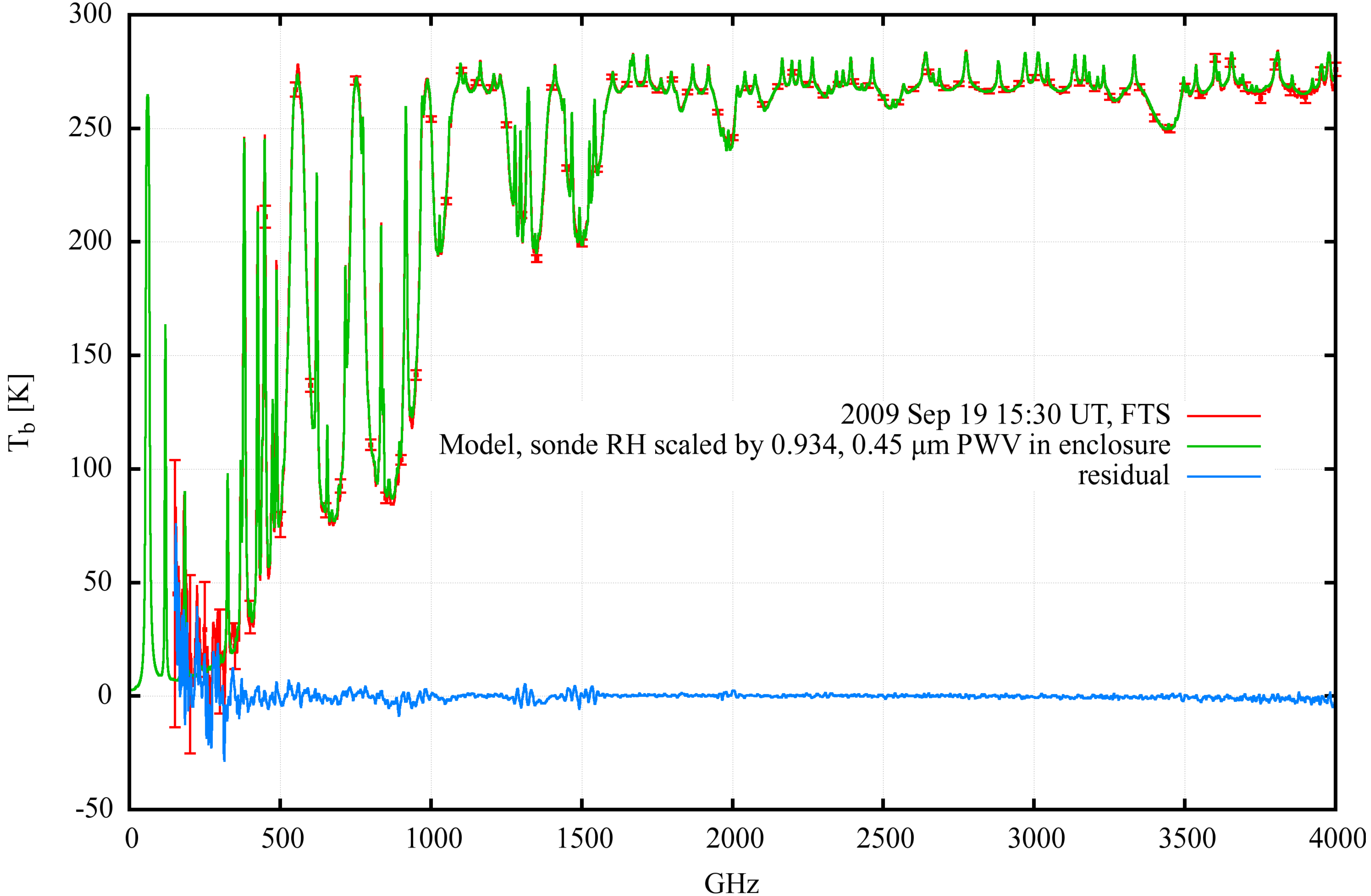


Zenith Planck T_b from SAO FTS



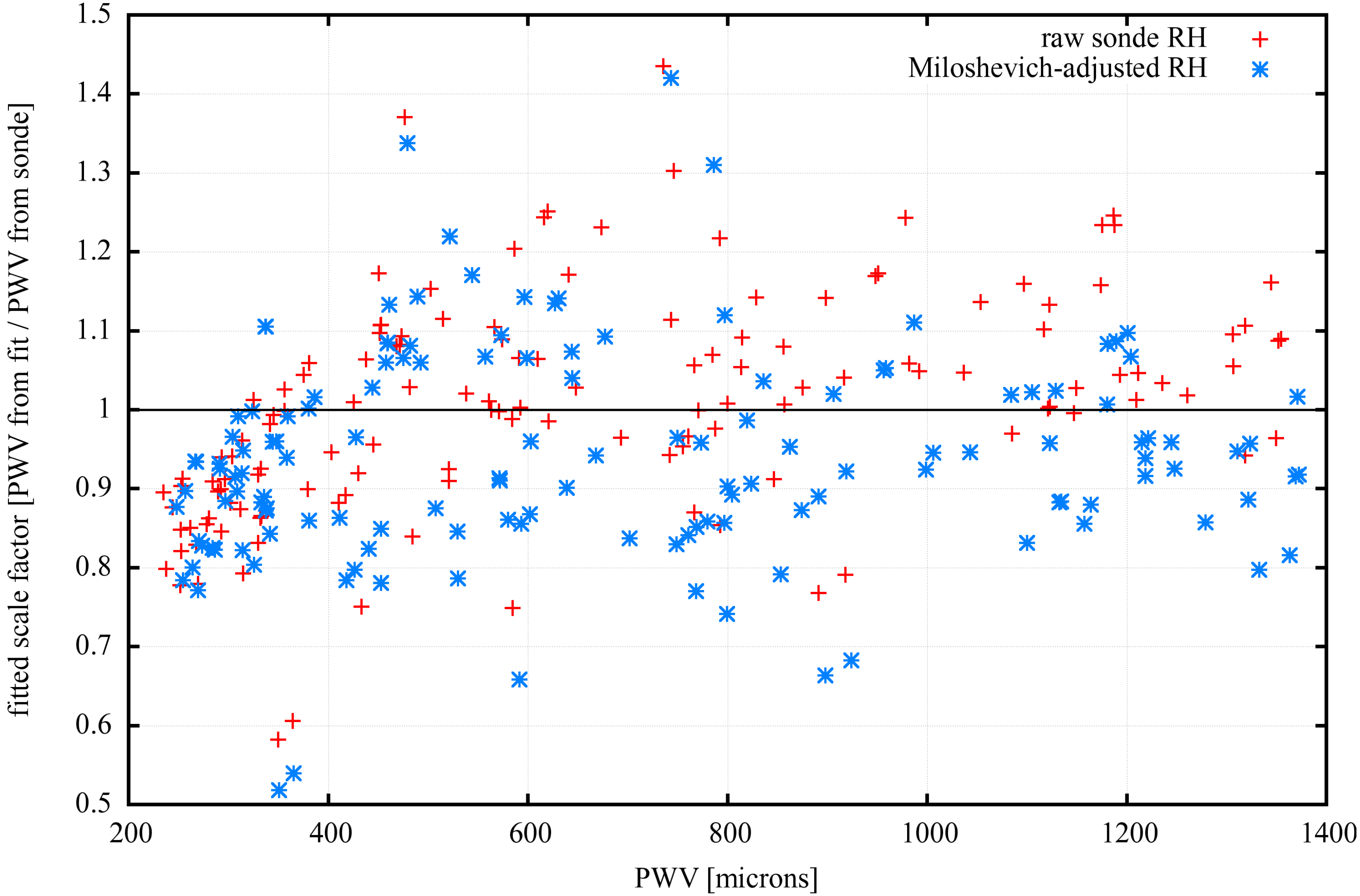
- Error bars (every 50th point) reflect cal error and quadrature noise spectrum

Two parameter model fit



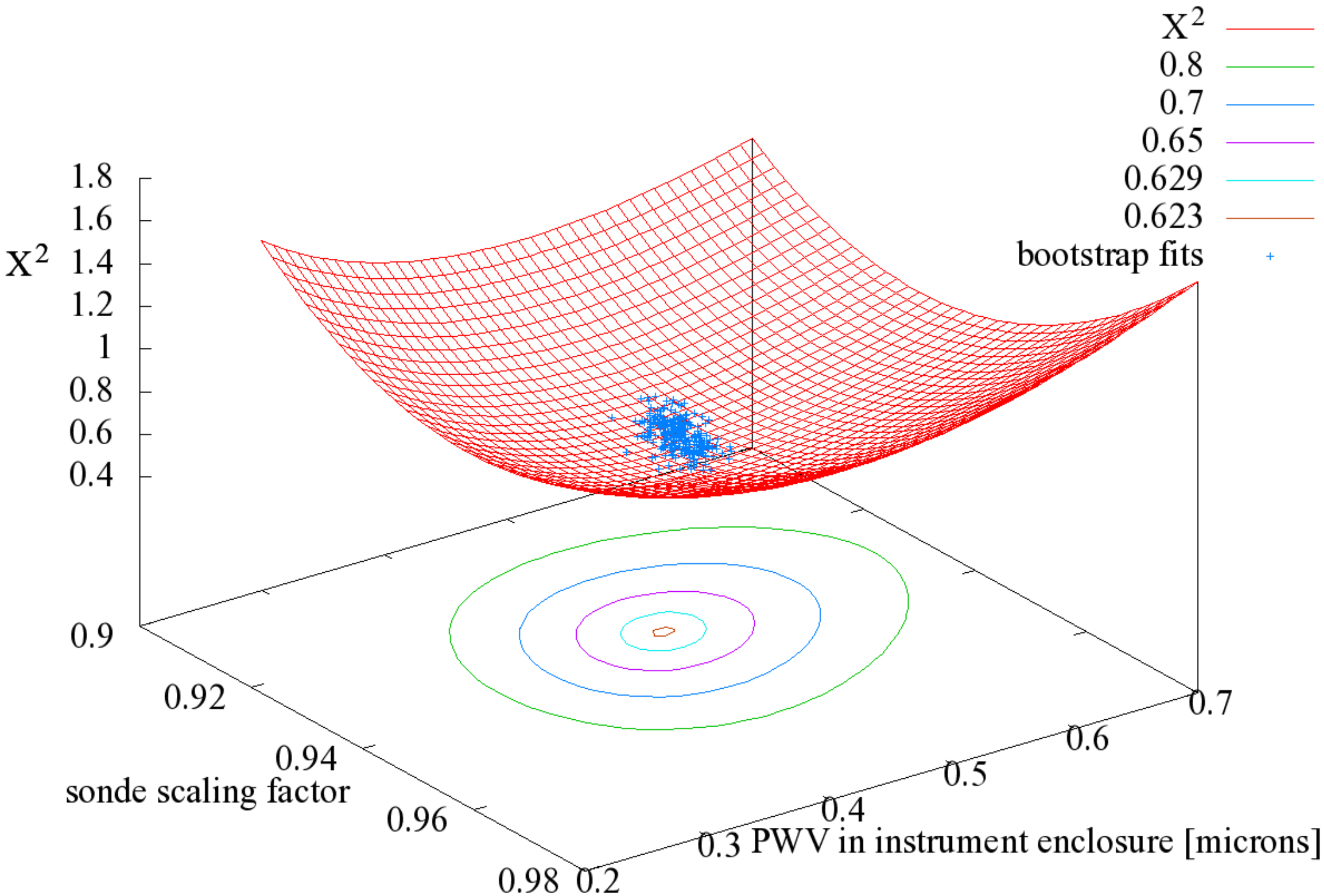
- Fit scale factor on sonde RH, small H_2O layer inside instrument.

Fit all spectra with clear sky sonde profiles



- Little systematic trend vs. total PWV, except at low end.
- Statistical error on fitted scale factor is about 0.5%, based on bootstrap analysis

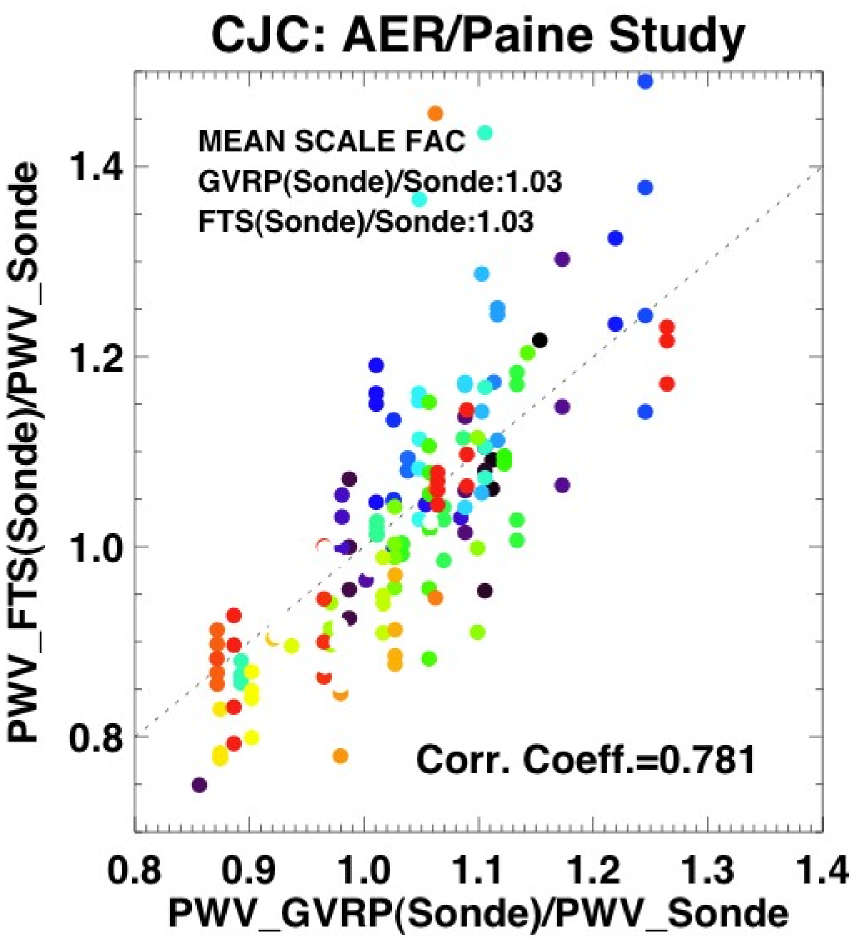
How much information is in the spectrum?

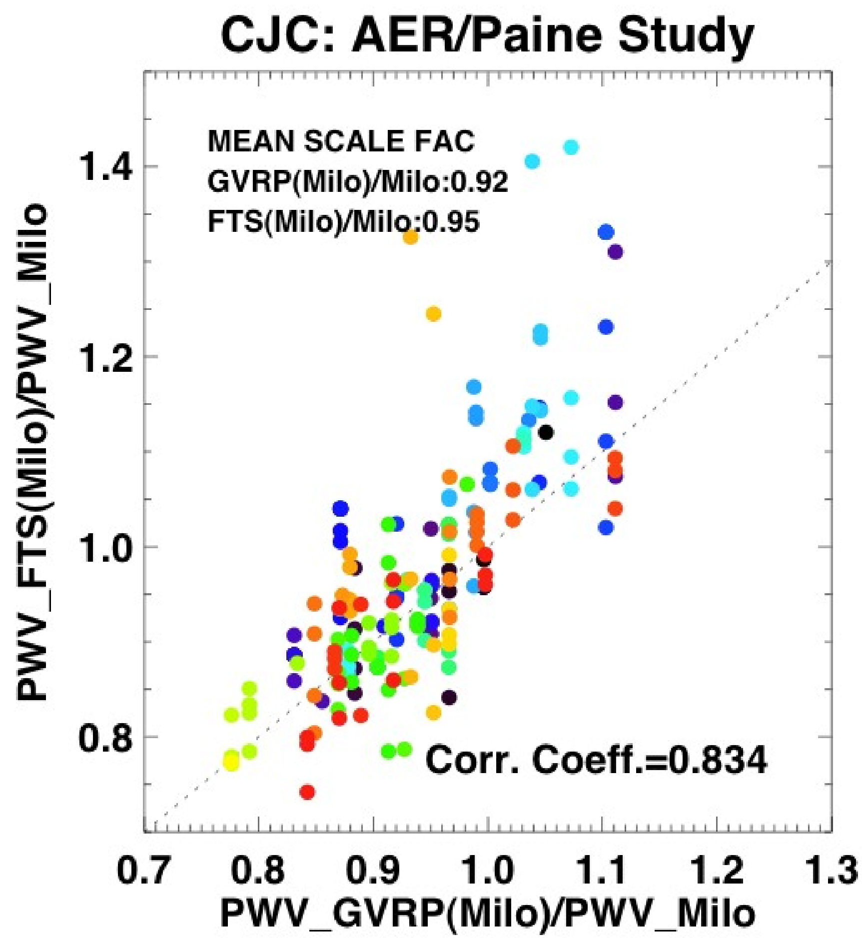


- Comparison between bootstrap analysis and chi-squared suggests ~100 degrees of freedom constrain sonde scaling.

Preliminary comparison of sonde scalings: submillimeter FTS vs. GVRP 183 GHz radiometer

(with Mlawer et al., AER)





- Miloshevich correction helps, but effect is slight.
- More sophisticated sonde RH calibration analysis underway (Turner, Caddedu)

Conclusion

- RHUBC-II has provided an unprecedented data set for understanding radiative properties of the upper troposphere.
- Multiple analyses are currently ongoing – showed one example
- Data are available from the ARM archive at www.archive.arm.gov