Updates on RO Water Vapor & Implications

E. Robert Kursinski[1]

D. Ward[2], A. Otarola[2], J. McGhee[1], A. Kursinski[1]

[1]Space Sciences & Engineering,

[2]University of Arizona

GRUAN Workshop June 14, 2017 Helsinki

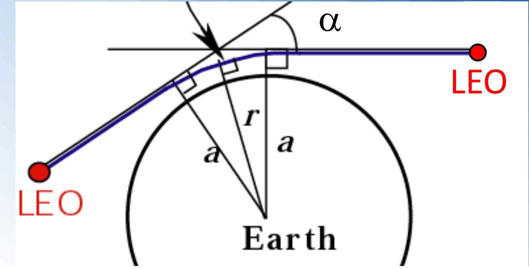
Outline

- ATOMMS 22 & 183 GHz RO overview & polar concept
- Spectroscopy of 183 GHz H_2O absorption line
- Low latitude water vapor structural uncertainty & implications

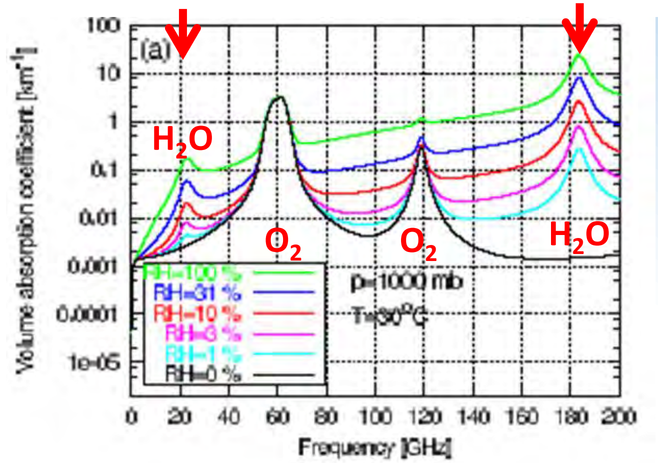
Active Temperature Ozone and Moisture Microwave Spectrometer

- Satellite to satellite occultations concept
- Operating near 22 & 183 GHz water vapor absorption lines
- Fly low power transmitters and receivers on each ATOMMS satellite
  - ~$5M per satellite including launch

22 & 183 GHz RO ACTIVE Spectrometer



RO geometry: Transmit & Receive
22 GHz & 183 GHz



- Profiles speed of light (like GPS RO) & attenuation of light (unlike GPS RO)

⇒ Profiles H_2O vapor, temperature & pressure versus height ***simultaneously***, unlike GPS RO

in clear & cloudy air, over land & water

⇒ Also O_3, NO_2, water isotopes, cloud LWC, LoS winds above 10 mb

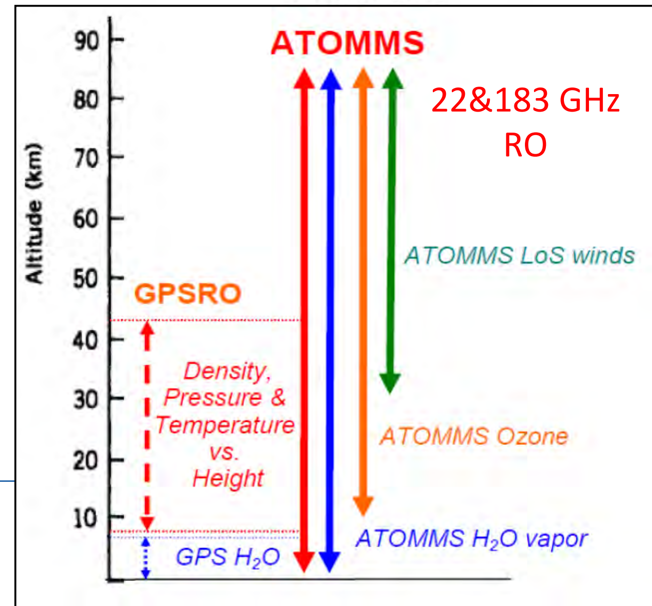
RO: Self calibrating, **no drift**

Resolution: ~100 m vertical, ~50 km horiz.

H_2O vapor: < 3% precision, < 1% accuracy

Temperature: 0.4K precision, < 0.05 K accuracy

- Profiles of **turbulence** from orbit

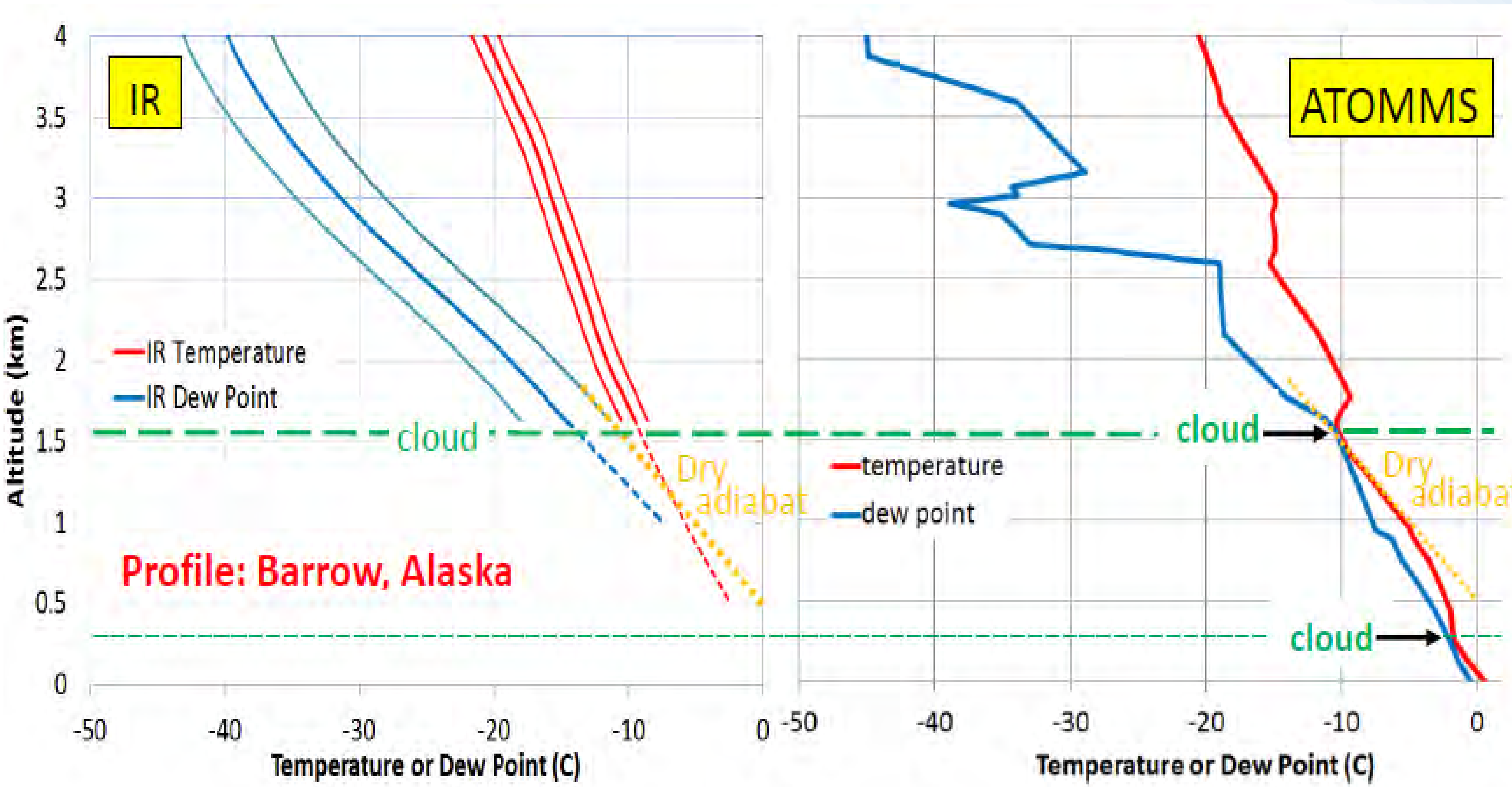


Kursinski et al.

Profiling: ATOMMS vs. IR

IR: Smoothed temperature to 1 km and water vapor to 2 km

ATOMMS: Resolves vertical structure of temperature, stability, water vapor, clouds



Kursinski et al.

Build Up ATOMMS Constellation Gradually

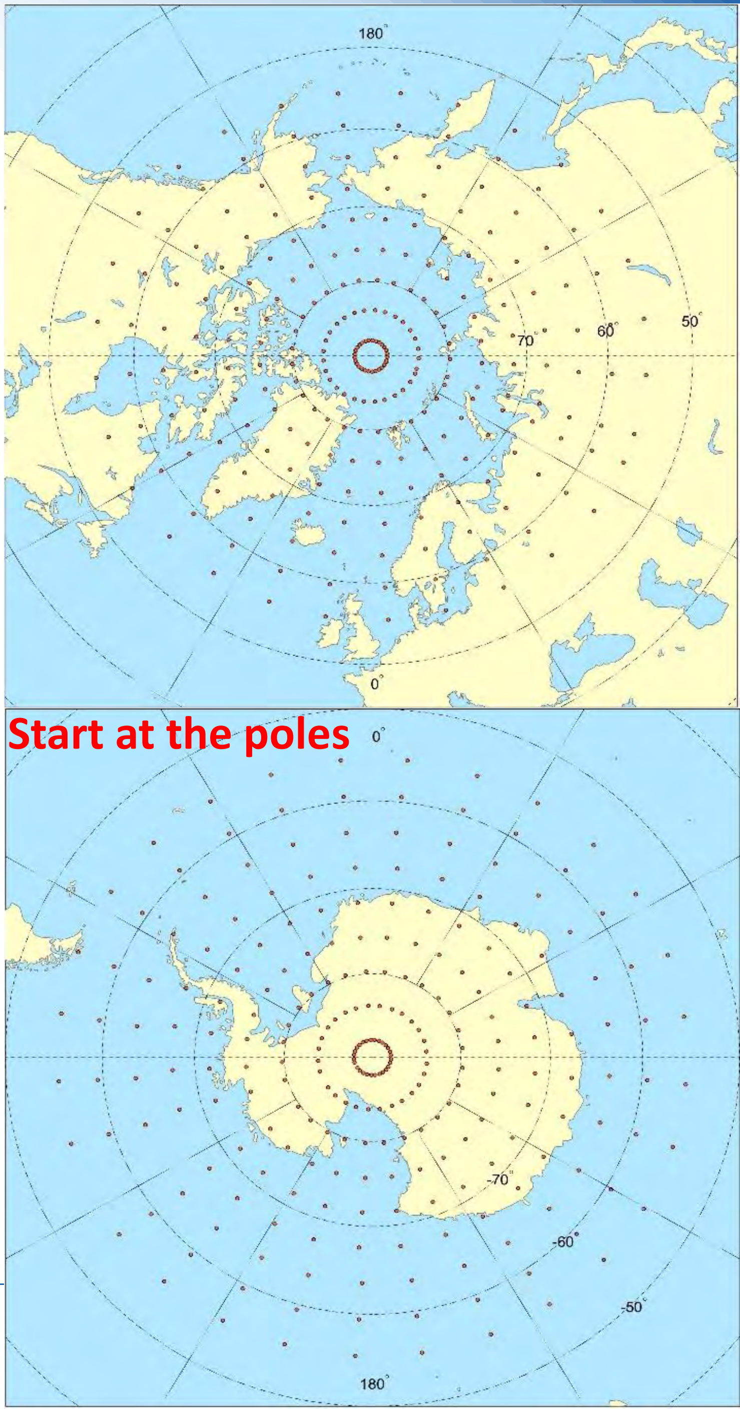
Begin with ATOMMS 4-6 satellite constellation focused on the **poles**:

- ⇒ 250-500 ATOMMS occ/day over the poles
- ⇒ + GNSS RO: 10K-15Kocc/day
- $25M-$35M including launch

Then build up much larger ATOMMS constellation over time

- # of ATOMMS occultations increases as square of # of satellites

Could have initial constellation up in 2 years

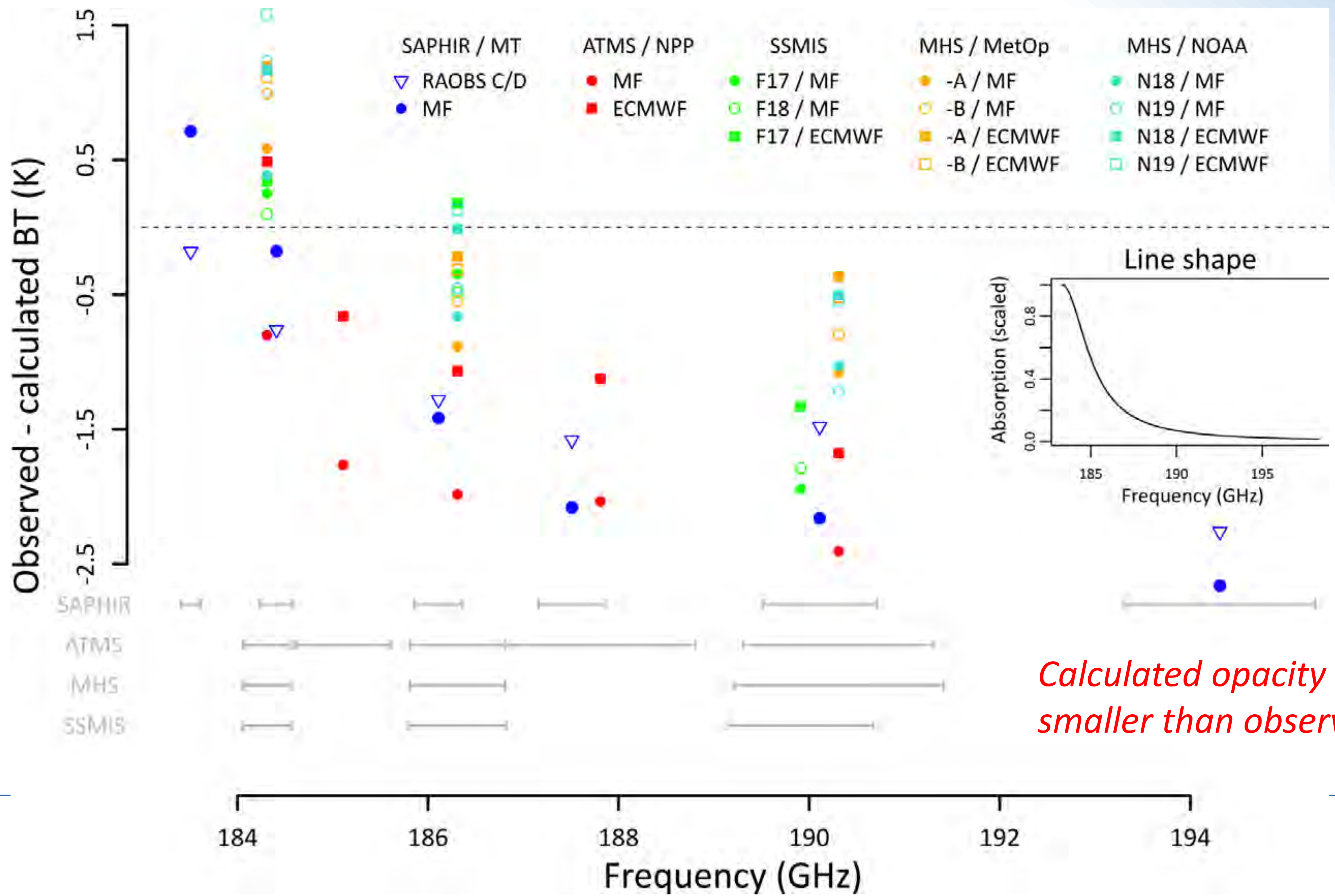


ATOMMS Spectroscopy

- Spectroscopy issue: why we care
- ATOMMS ground data set
- New ATOMMS processing
- Comparison of new ATOMMS results with spectroscopic models

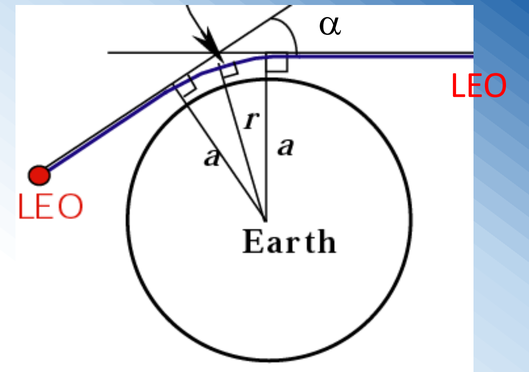
183 GHz Problem: Brogniez et al. (2016)

- Inconsistencies between Observations & RT calculations



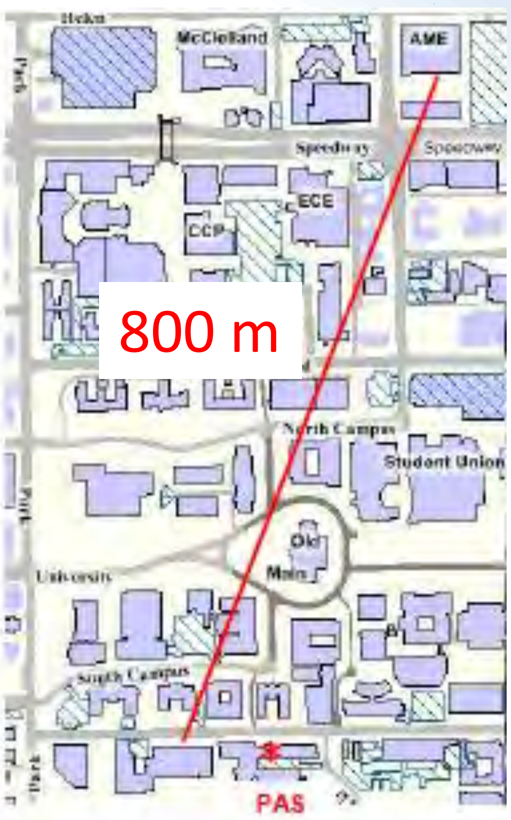
Calculated opacity is smaller than observed

ATOMMS Near-Surface Water Vapor Measurements



In orbital occultation geometry,

- Normalizing signal amplitudes are measured in vacuum above the atmosphere immediately before (or after) each occultation



In fixed geometry on Earth,

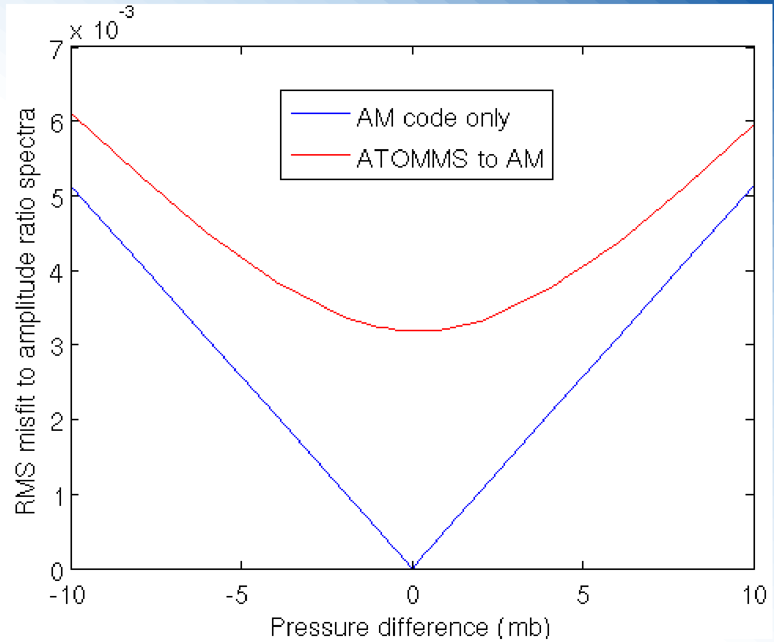
- No vacuum normalization period like in an occultation

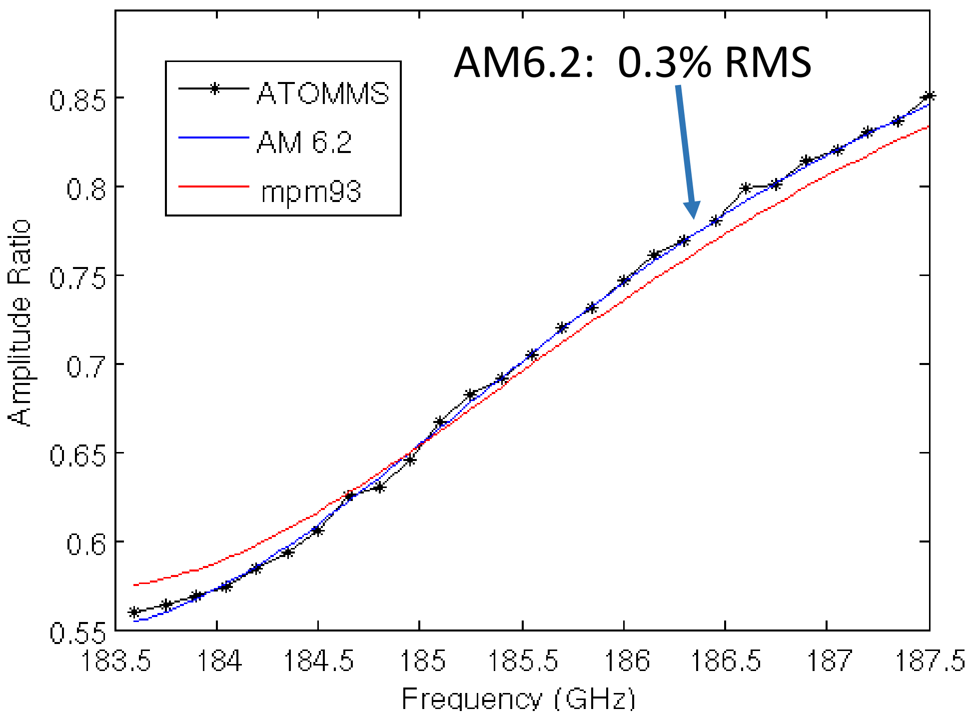
  $\Rightarrow$ Normalize to selected reference period that includes atmospheric absorption

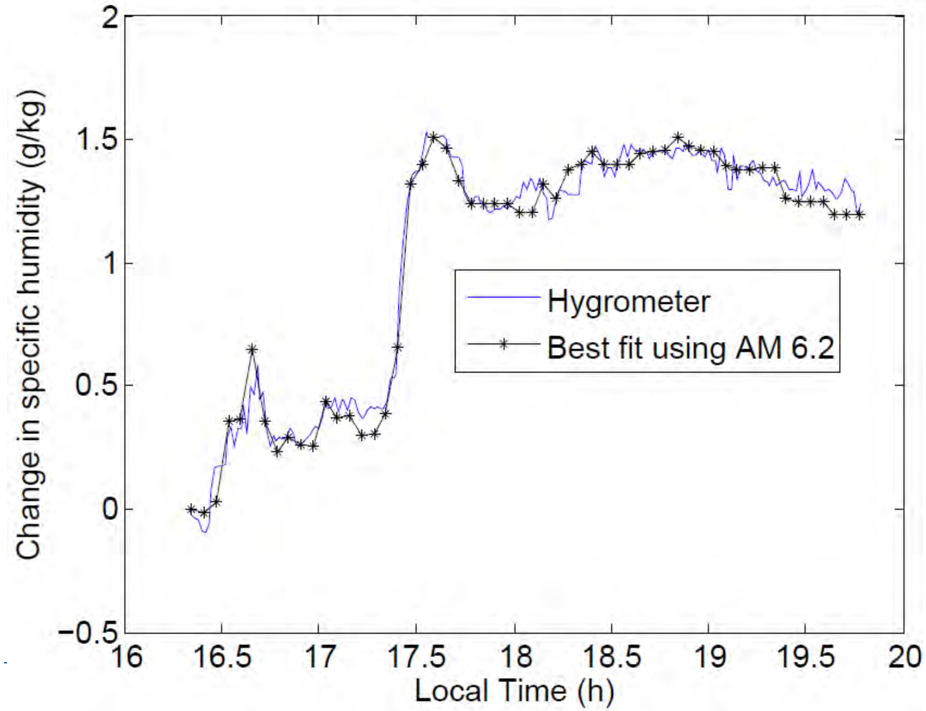
  $\Rightarrow$ Desire rapid, large step changes in water vapor advected across the beam path.

First ATOMMS Measurements

- Fixed geometry measurements across 800 m path
- Disagreement with Liebe et al. 1993 model line shape
- Agreement with AM 6.2 model to **0.3%** RMS (prev. uncertainty was 2%)



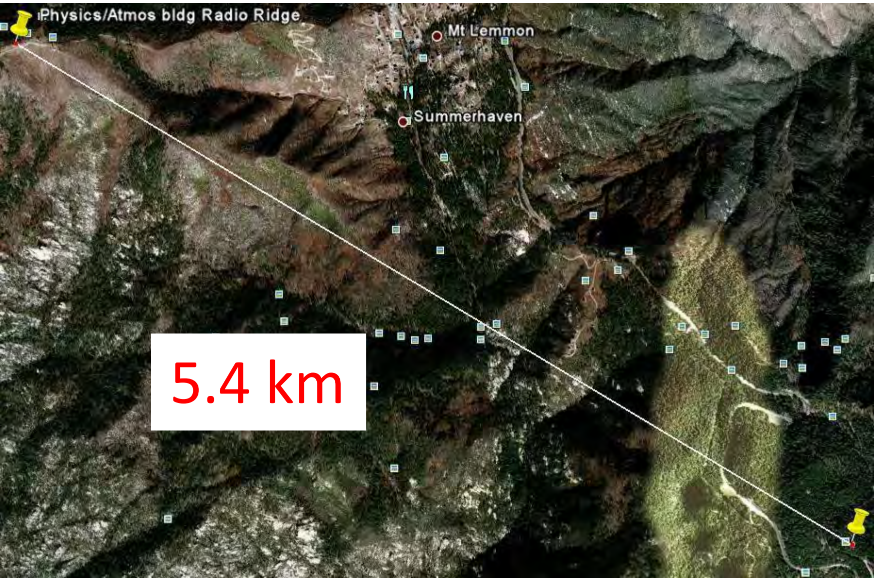


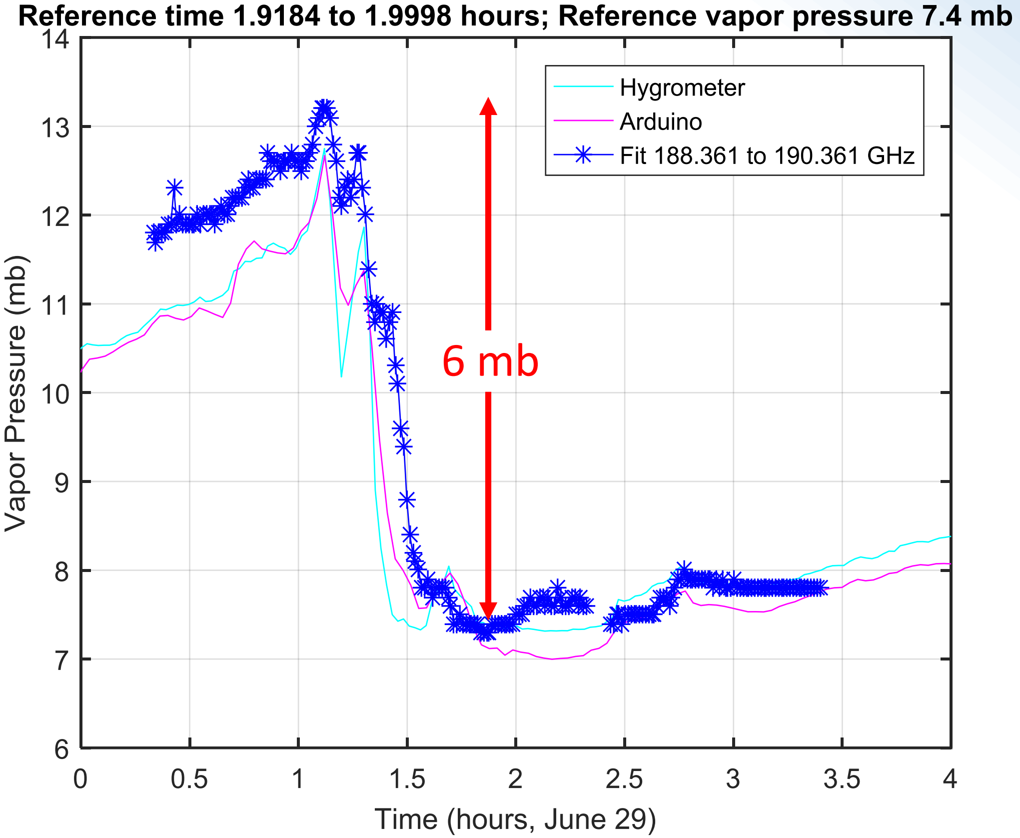


Kursinski et al. 2012 AMT

More ATOMMS Water Vapor Near-Surface Measurements

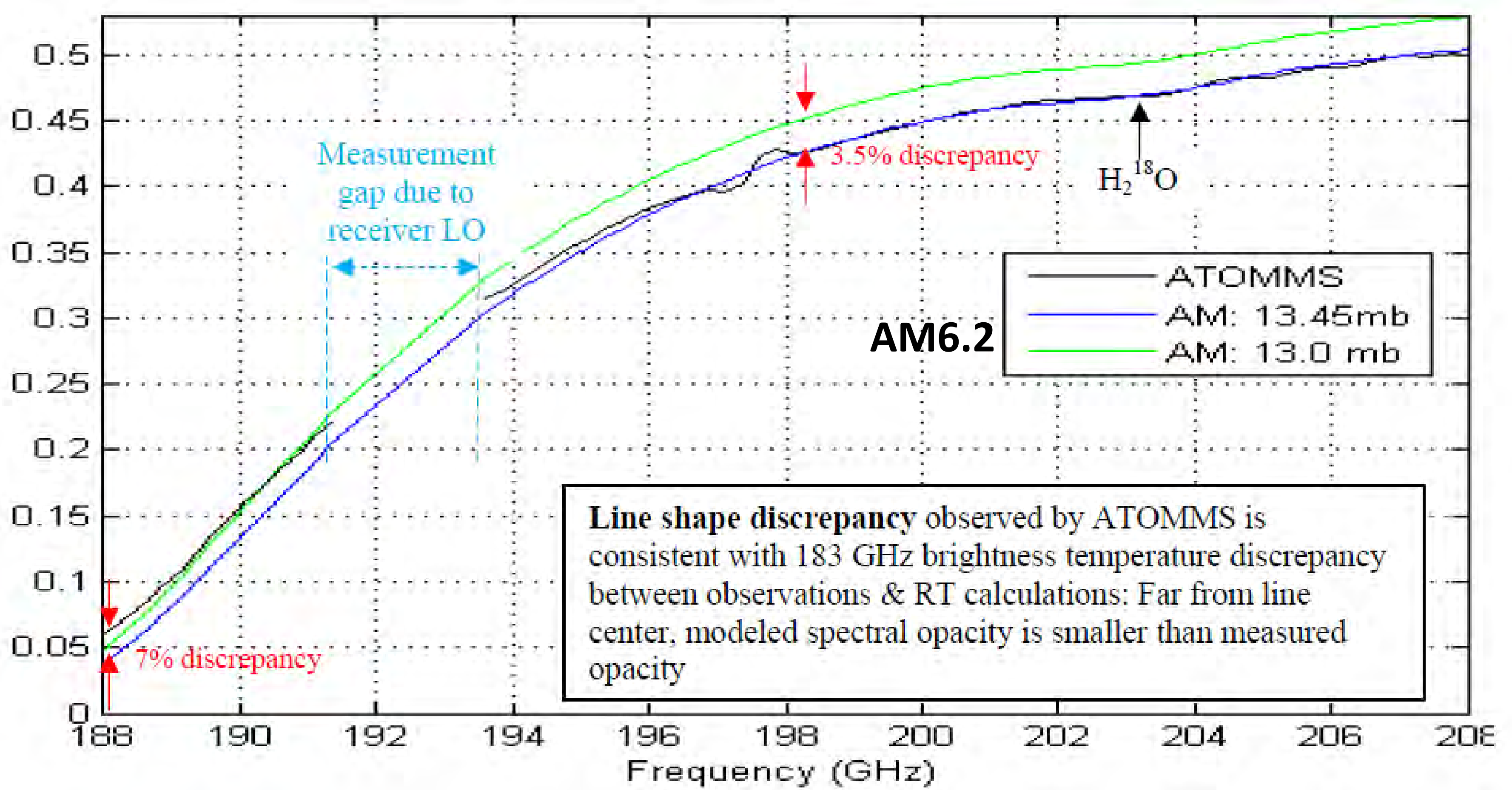
- 5.4 km Mountaintop to Mountaintop Measurements



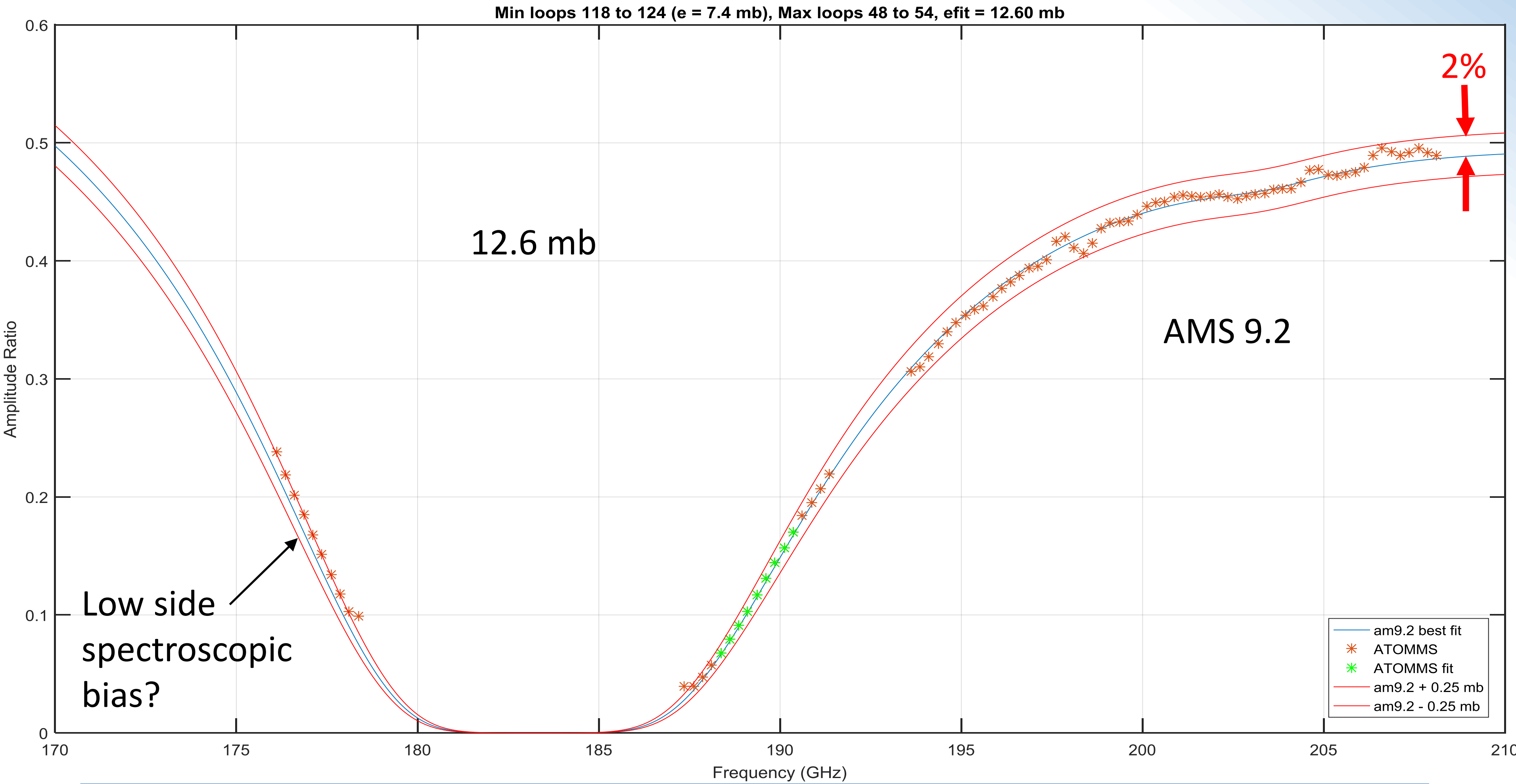


Spectroscopic problem farther from line center?

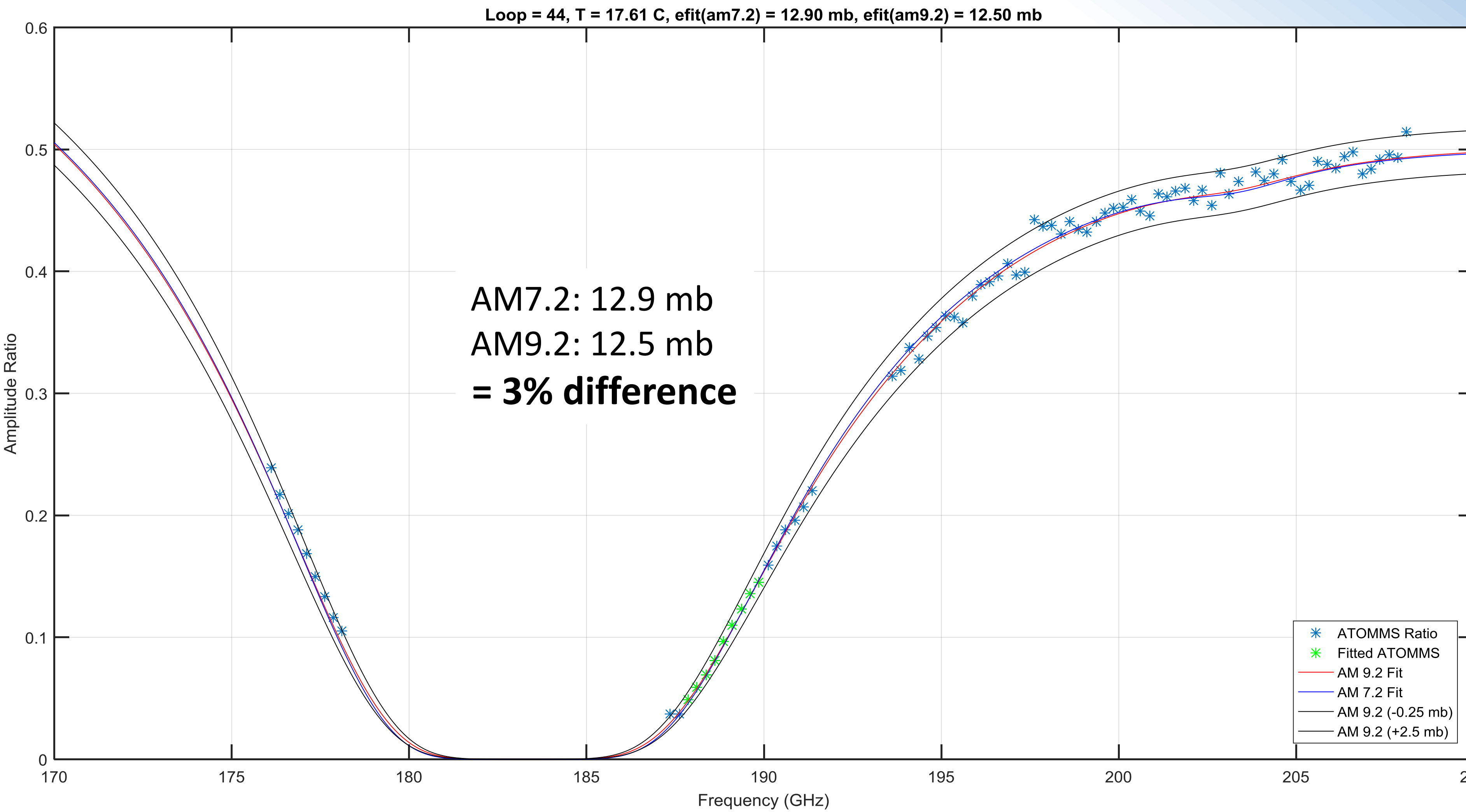
- Kursinski et al., 2016 (SPIE)



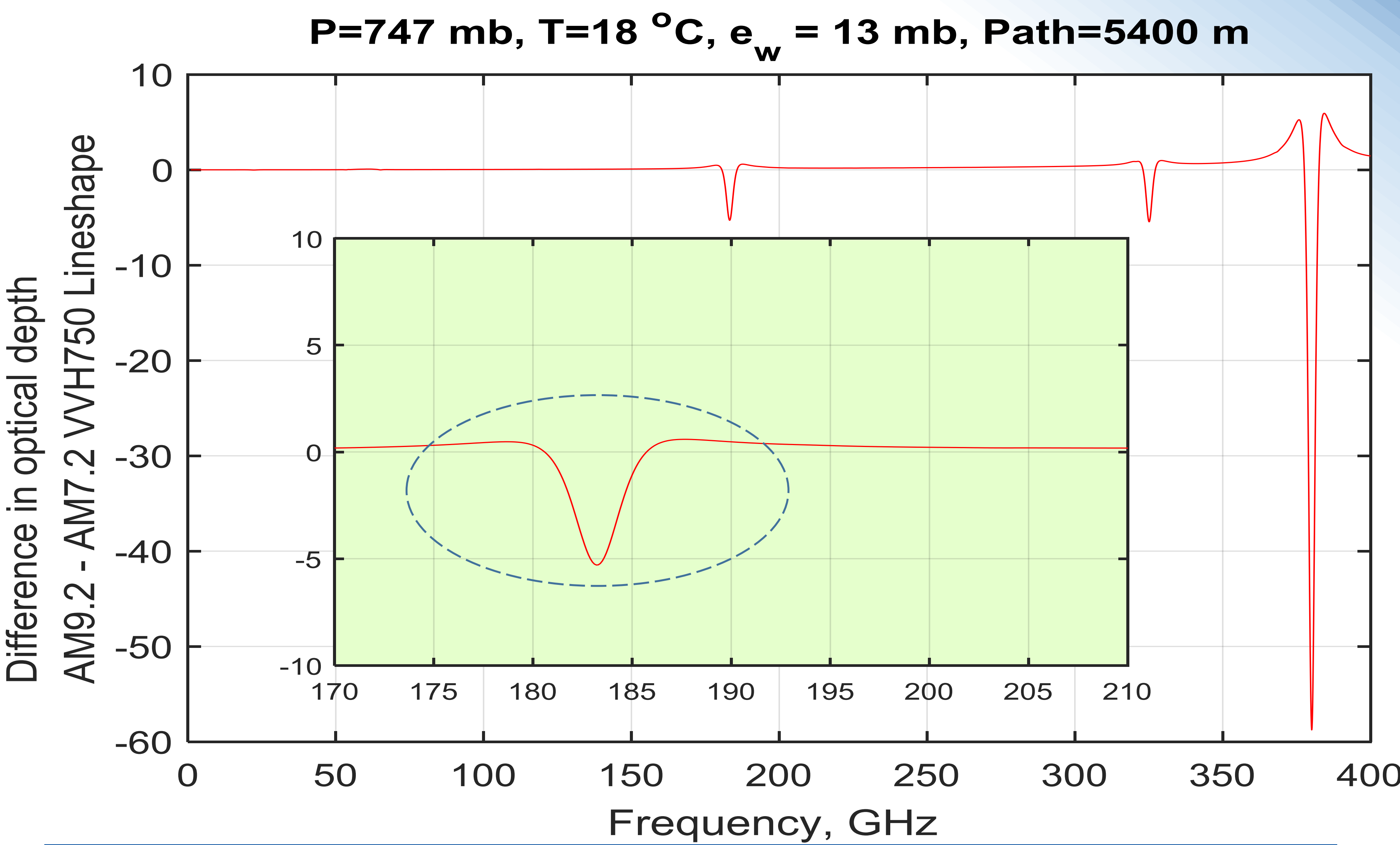
Preliminary re-processed ATOMMS results



Spectroscopic bias in water vapor amount



Measurements to Distinguish Between Models

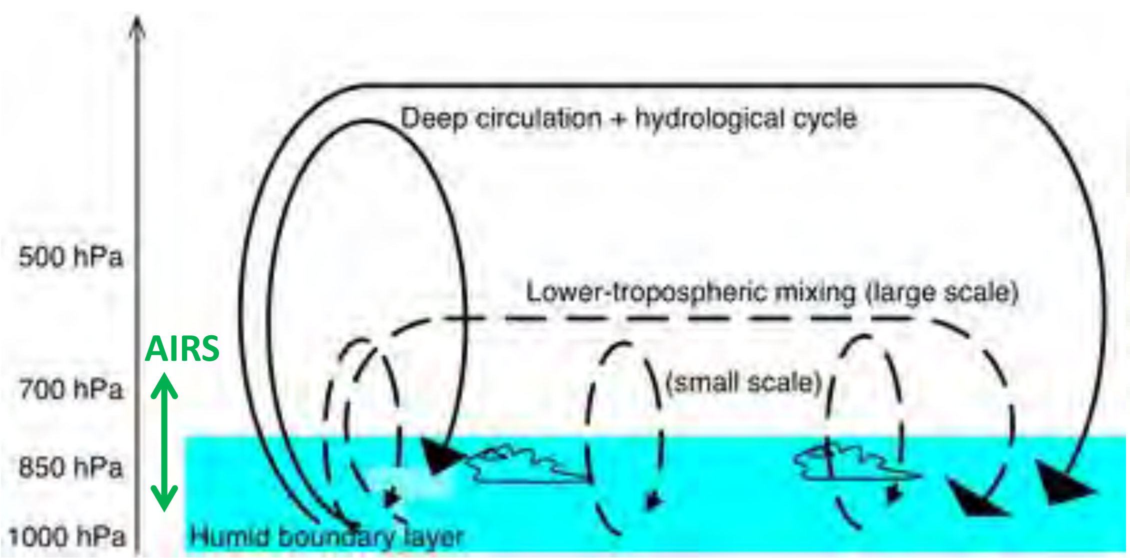


Do observations provide the information needed to answer key climate questions?

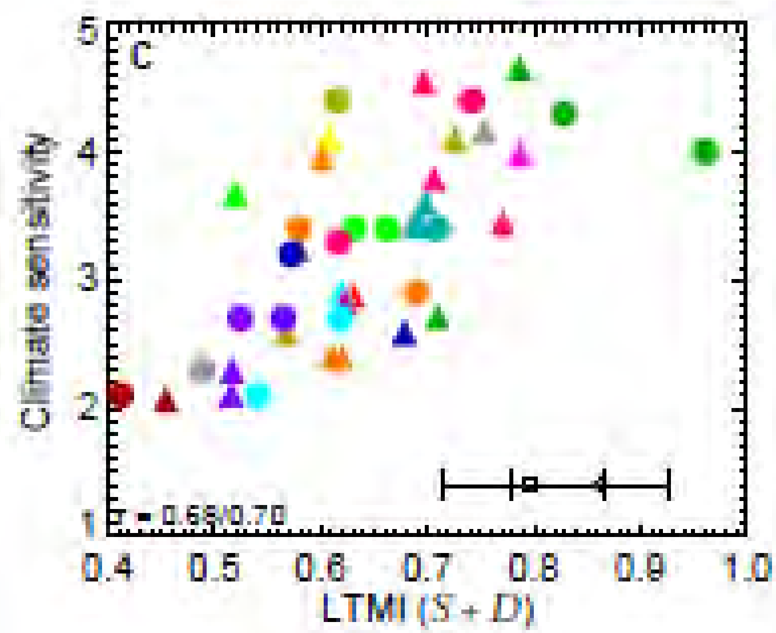
Structural Uncertainty of Radiance-Derived Low Latitude Water Vapor

Sherwood et al. (2014) Reduction in Climate Uncertainty?

- As climate warms, models indicate stronger mixing => dehydrates BL
  $\Rightarrow$ Reduces low cloud cover => lowers albedo => more SW absorption
- Increase in mixing & dehydration of low-cloud layer in warmer climate proportional to mixing strength in present climate
- Evaluated model mixing against "observations" (MERRA+ERAI analyses)
  $\Rightarrow$ High climate sensitivity **> 3°C** for CO_2 doubling.

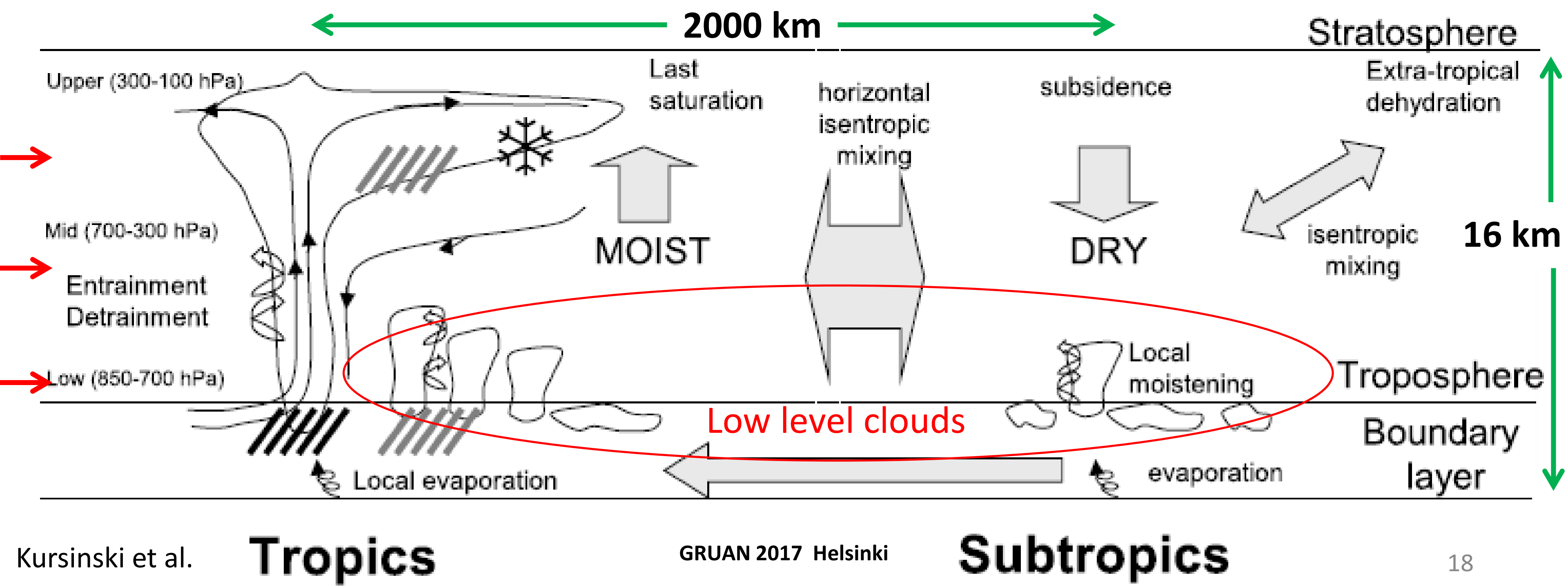


Kursinski et al.



Low Latitude Moisture

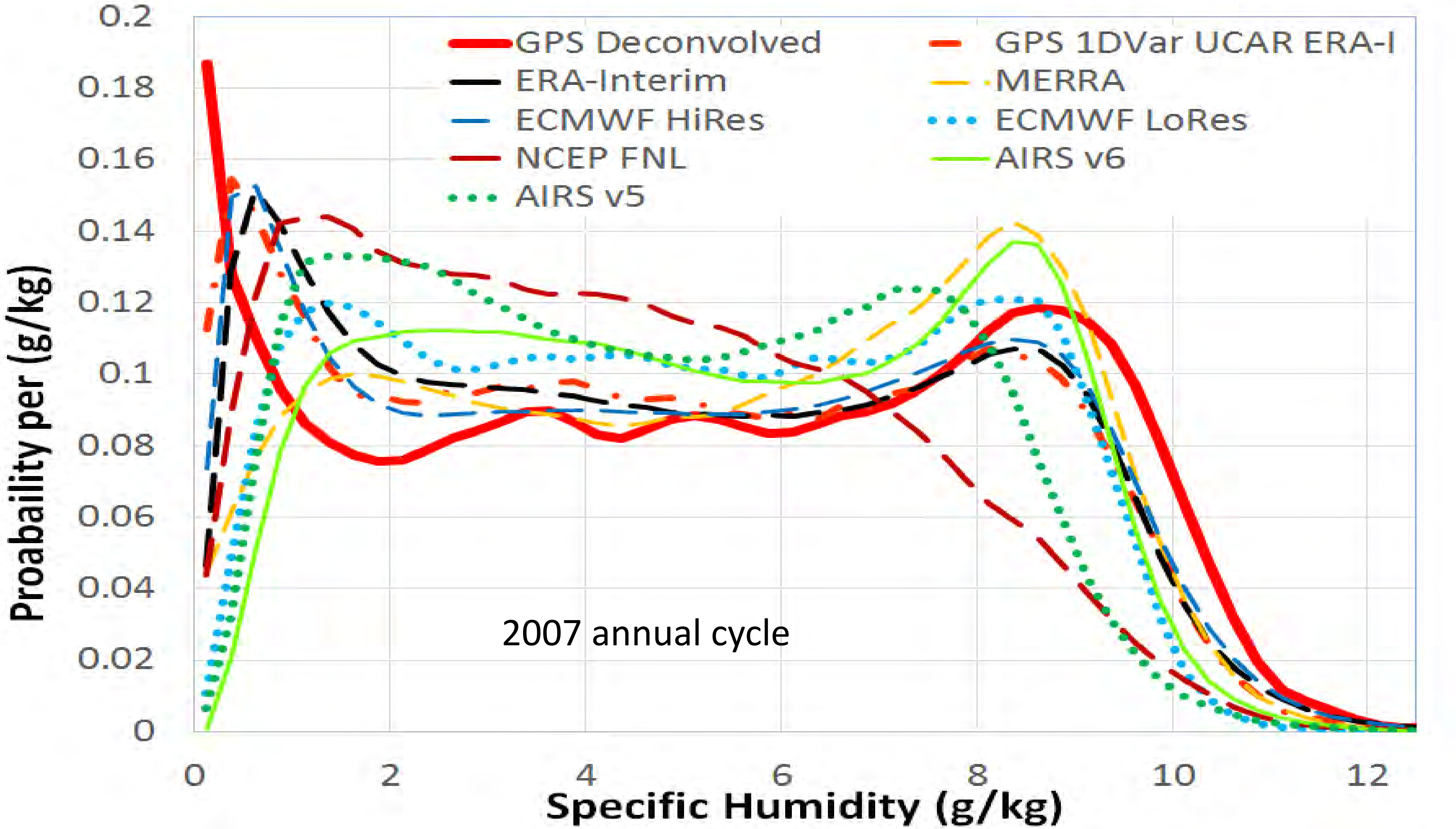
- Convection creates extremes, stretching the H_2O vapor distribution
- Mixing & diffusion compress distribution toward its center
- Specific humidity is conserved in the absence of sources & sinks => ***tracer***
- Relative humidity important for conversion between vapor & condensed phases => ***clouds & precipitation***



Kursinski et al.

Water Vapor Histograms

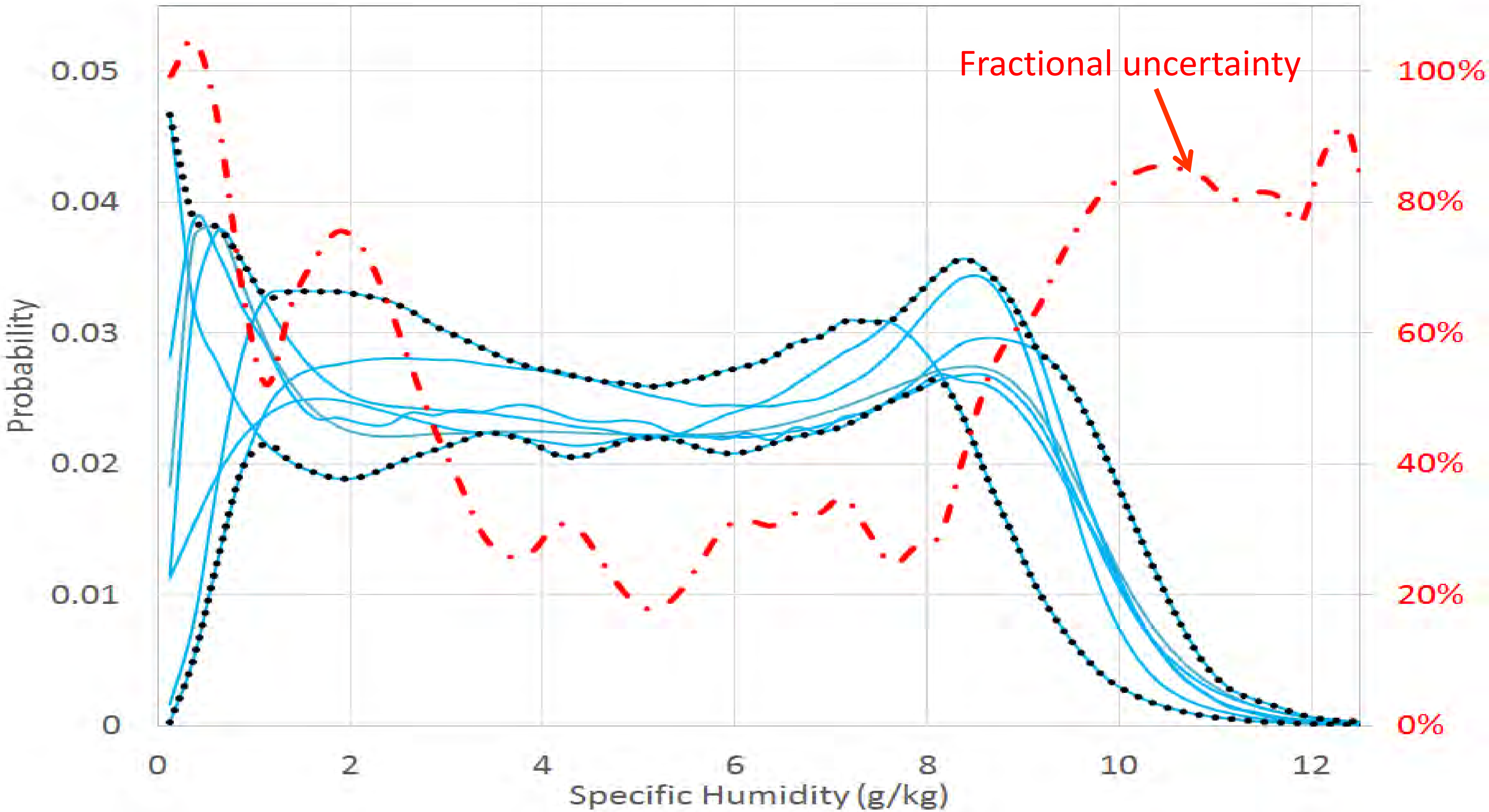
- Assess NWP & climate models via GPS-derived H_2O vapor



Kursinski et al.

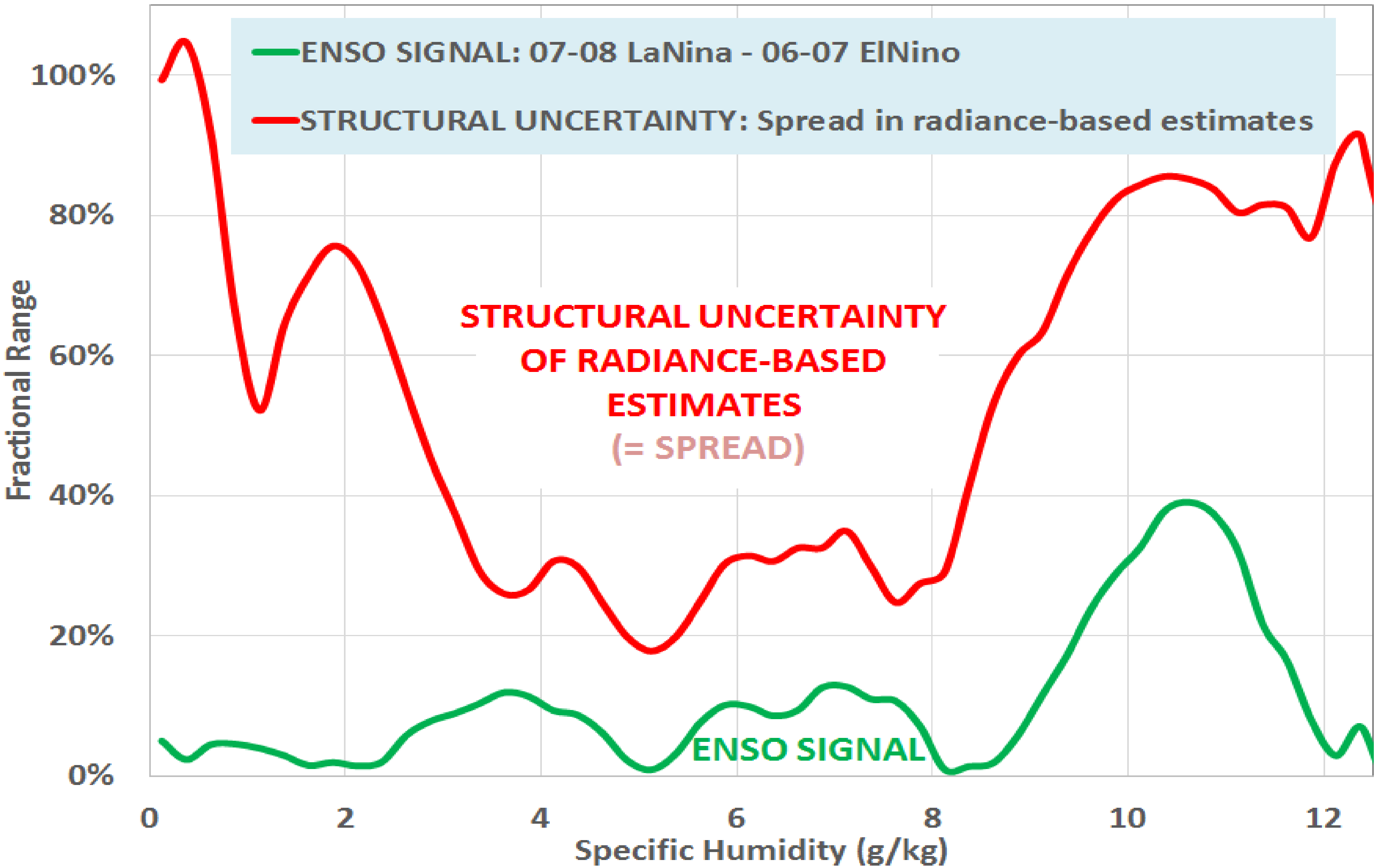
Uncertainty of state-of-the-art estimates

- 725 hPa specific humidity estimates
  - 30N-30S 2007 annual cycle



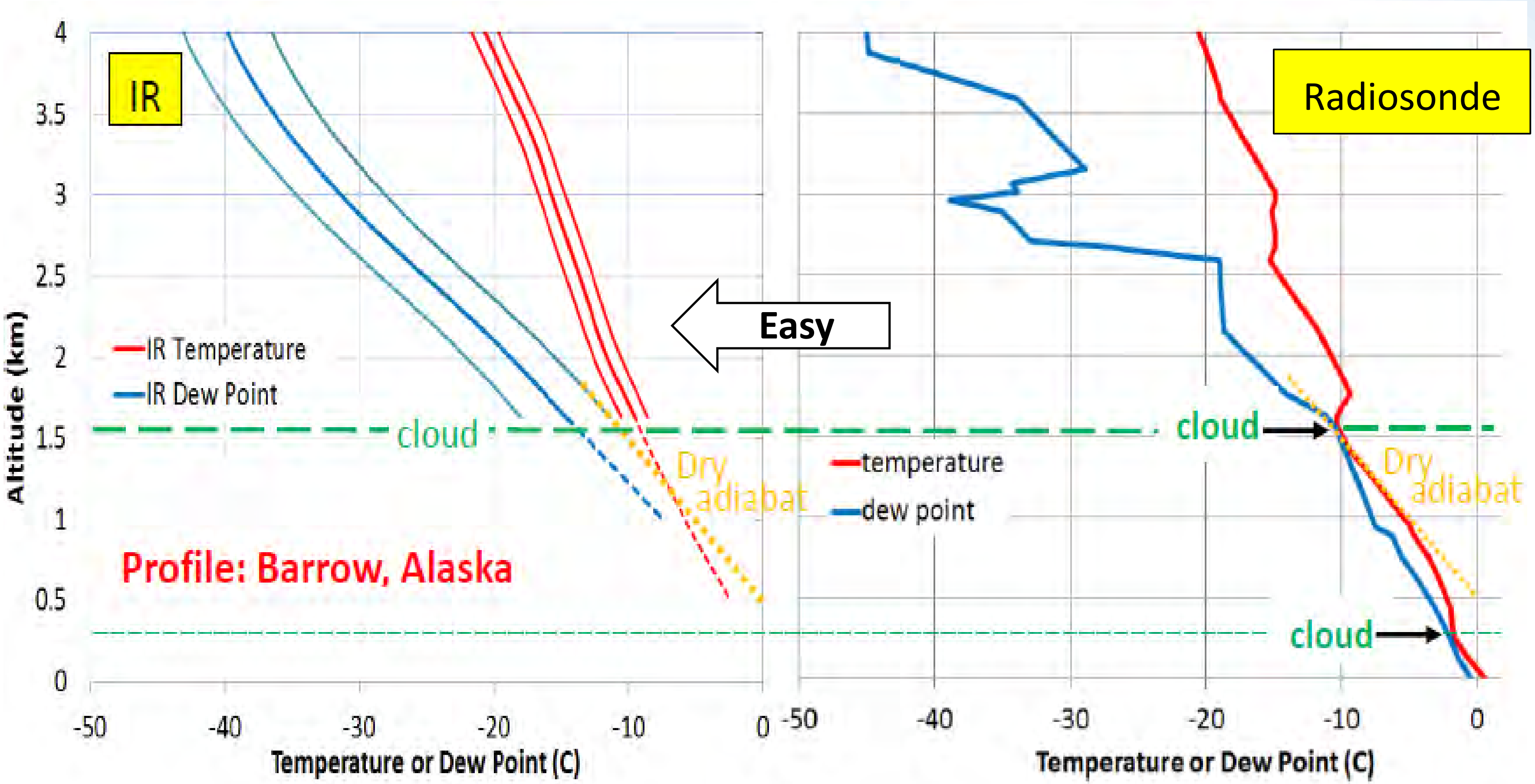
Kursinski et al.

Structural Uncertainty vs ENSO Variation



Profiling: Sonde vs. IR

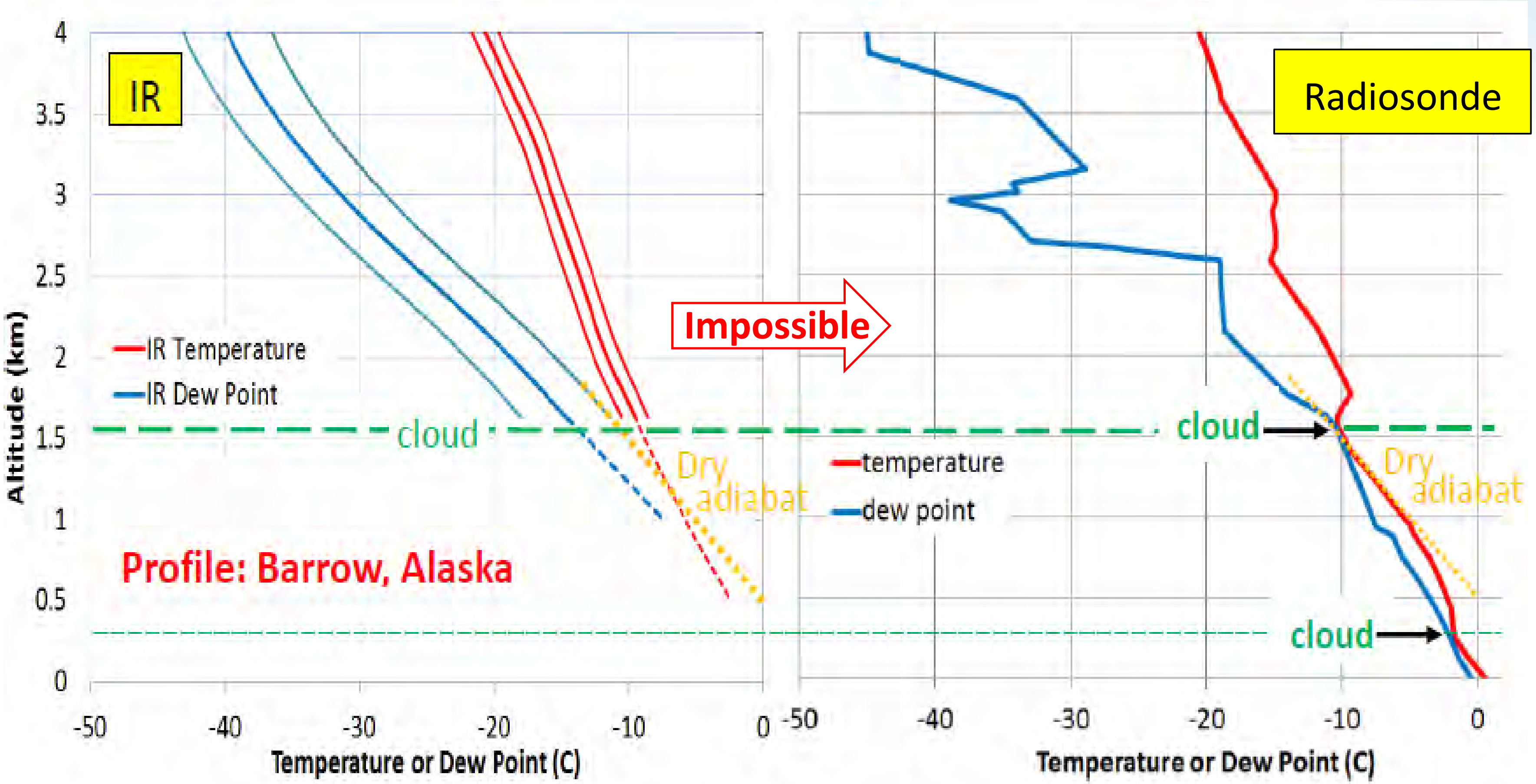
Sonde: Resolves vertical structure of temperature, stability, water vapor & cloud
IR: Smoothed temperature to 1 km and water vapor to 2 km
Data assimilation: In remote regions, the hope is the NWP system will take the smoothed IR information and somehow recreate the fine scale of the sonde.



Kursinski et al.

Profiling: Sonde vs. IR

Sonde: Resolves vertical structure of temperature, stability, water vapor & cloud
IR: Smoothed temperature to 1 km and water vapor to 2 km
Data assimilation: In remote regions, the hope is the NWP system will take the smoothed IR information and somehow recreate the fine scale of the sonde.



Kursinski et al.

Reducing Climate Model Uncertainty?

$\Rightarrow$ Reducing climate model uncertainty requires observations with

- Much smaller structural uncertainty,
  - much higher vertical resolution,
  - direct mapping to geophysical variables
  - in all weather conditions.
- Coverage: Global, remote regions

RO has big potential to help here but much denser data is needed if it is to strongly “constrain” NWP analyses.

Summary

ATOMMS

- Next gen. RO system to profile temperature & water vapor simultaneously (<0.1K, <1%)
- 4-6 satellite ATOMMS RO constellation great polar profiling system (250-500 profiles/day + 10K-15K/day GNSS RO)
  - 2 year development, ~$30M

- ATOMMS is very high resolution open-air spectrometer

$\Rightarrow$ Evaluating 183 GHz line spectroscopic models

Do observational systems provide the information needed to answer key science questions?

- Structural uncertainty of water vapor derived from radiance observations is too large to answer critical climate sensitivity questions about low level clouds.
- Dense RO should help a lot here

Backup slides

Doubly Differential Absorption Measurements

1. **Self Calibration:**

- Derive optical depth via

  change in signal level during occultation

  relative to

  signal level measured above the atmosphere, before or after each occultation

- Maintain stable signal amplitude over ~100 second (duration of an occultation) achieves climate quality stability

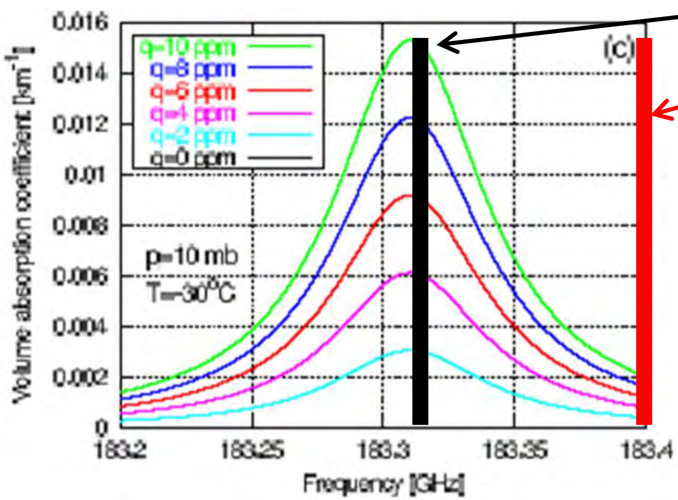
$\Rightarrow$ No long term drift

Kursinski et al.

Doubly Differential Absorption Measurements

2. **Use two or more simultaneous tones**

Differential Absorption: 2 tones



- 1^{st} tone on absorption line
- 2^{nd} calibration tone off the line

2 tone amplitude ratio eliminates common mode noise

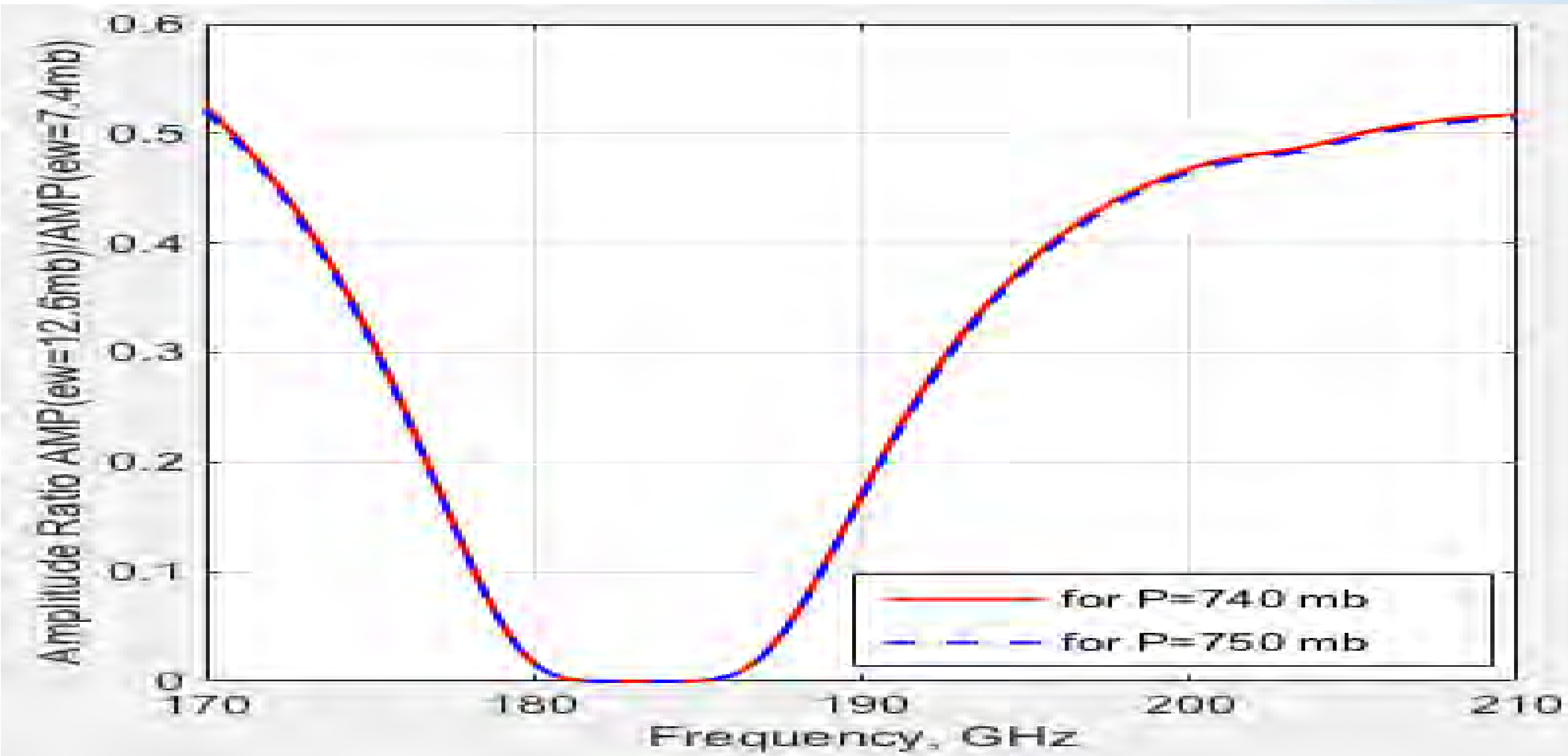
$\Rightarrow$ Enables profiling in clouds & rain

$\Rightarrow$ Enables profiling of cloud LWC

- Enables profiling in & of clouds
- Isolate and reduce or remove turbulent scintillations

Kursinski et al.

Pressure cannot explain the wing variations



Spectroscopy Summary

Spectroscopic results in Kursinski et al. (2016) were 2011 processed ATOMMS results vs. AM 6.2 model.

Comparison of re-processed ATOMMS results with updated AM (7.2 & 9.2) spectroscopy models yields better line shape agreement.

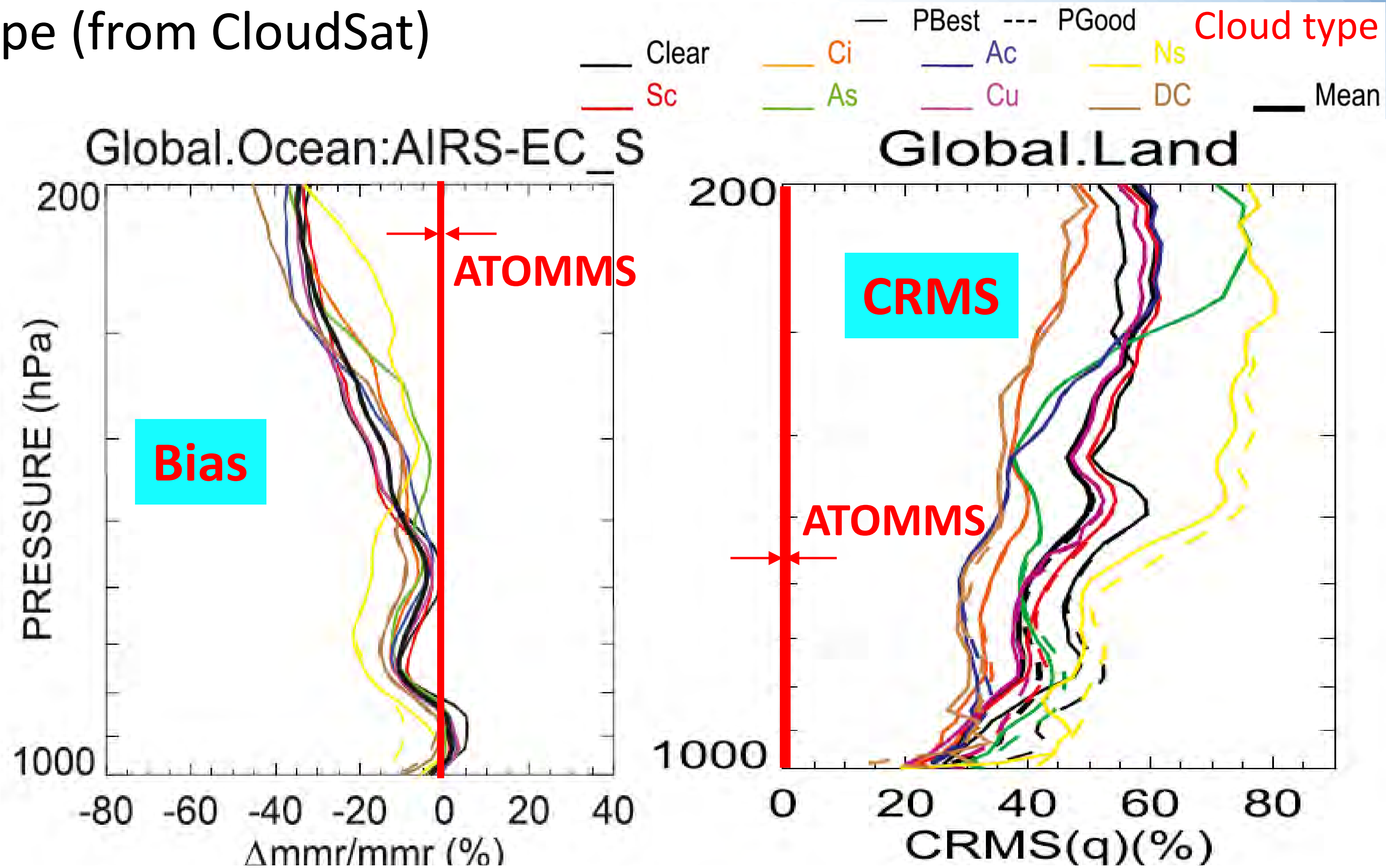
- Suggestion of systematic error on low side of the line.
- Some correlated variation in wings

Fitting ATOMMS' water vapor amount using the AM7.2 & AM9.2 models yielded 3% difference in water vapor.

$\Rightarrow$ Accuracy of ATOMMS retrieved geophysical variables limited by spectroscopy

ATOMMS vs. Hyperspectral IR

- Yue et al. (2013) compared AIRS water vapor retrievals with ECWMF by cloud type (from CloudSat)



ATOMMS 1% uncertainty ~the 2x linewidths

=> Quantum improvement in information about the atmospheric state