Future cm & mm Wavelength Occultation System:

Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS)

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What could you do if you were to design an RO system from scratch?

Answer:

- Build an RO system that probes the 22 & 183 GHz water vapor absorption lines

⇒ ***Open air spectrometer***

⇒Profiles water vapor, temperature & pressure *simultaneously*, unlike GNSS RO, to much higher altitudes

⇒ Cross between GPS RO & MLS

⇒ Approaching sonde profiling from orbit in may ways (but generally more accurate, in theory)

⇒Eventually LEO Constellation of ATOMMS

22 & 183 GHz RO Active Spectrometer

- 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 cloud LWC, O_3, NO_2, water isotopes, LoS winds above 10 mb & turbulence

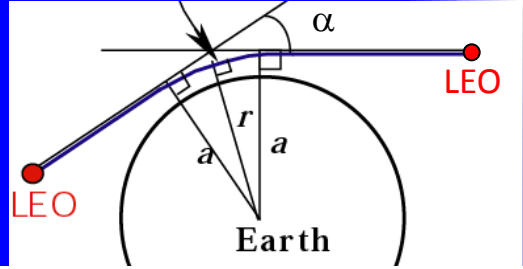
RO: Self calibrating, **no drift**

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

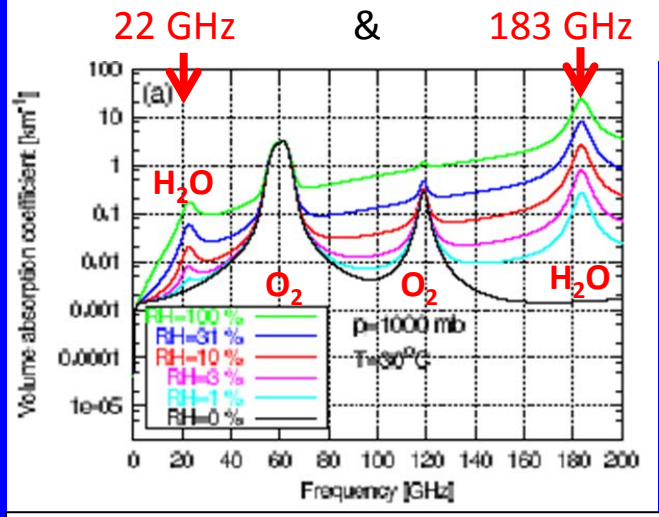
H_2O vapor: < 3% precision, < 1% accuracy

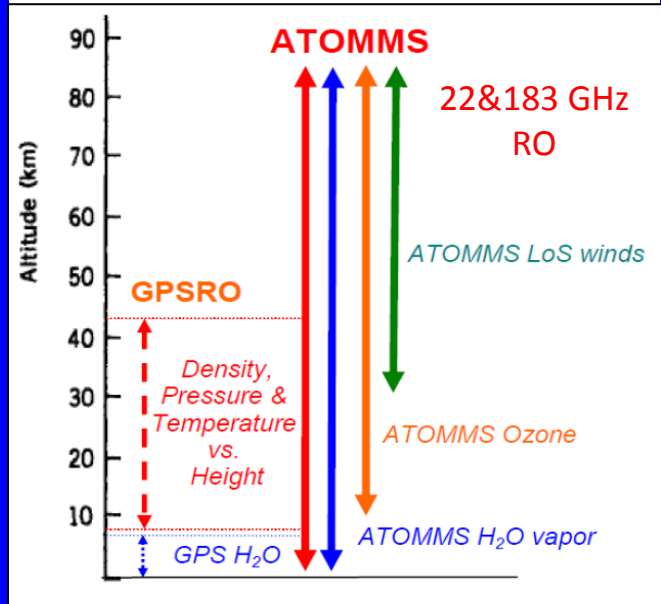
Temperature: 0.4K precision, < 0.05 K accuracy

- Will provide unique profiles of **turbulence** from orbit



RO geometry: Transmit & Receive





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

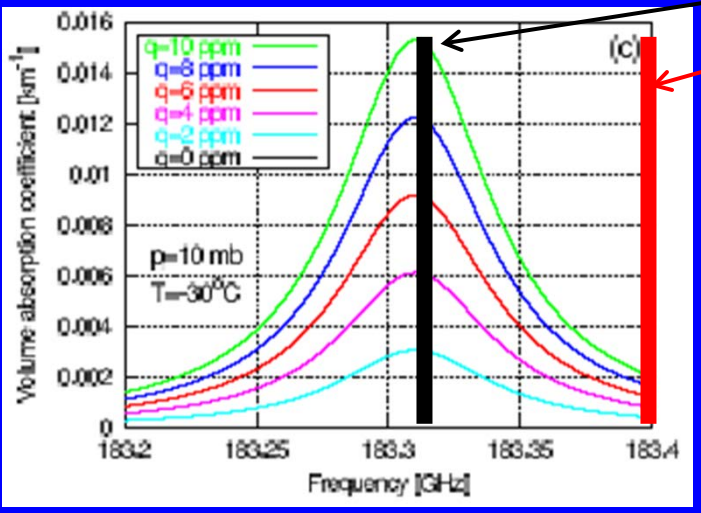
- Signal amplitude only has to be stable over ~100 second duration of an occultation to achieve climate quality stability

$\Rightarrow$ No long term drift

Doubly Differential Absorption Measurements

2. Use two or more simultaneous tones

Differential Absorption: 2 tones



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

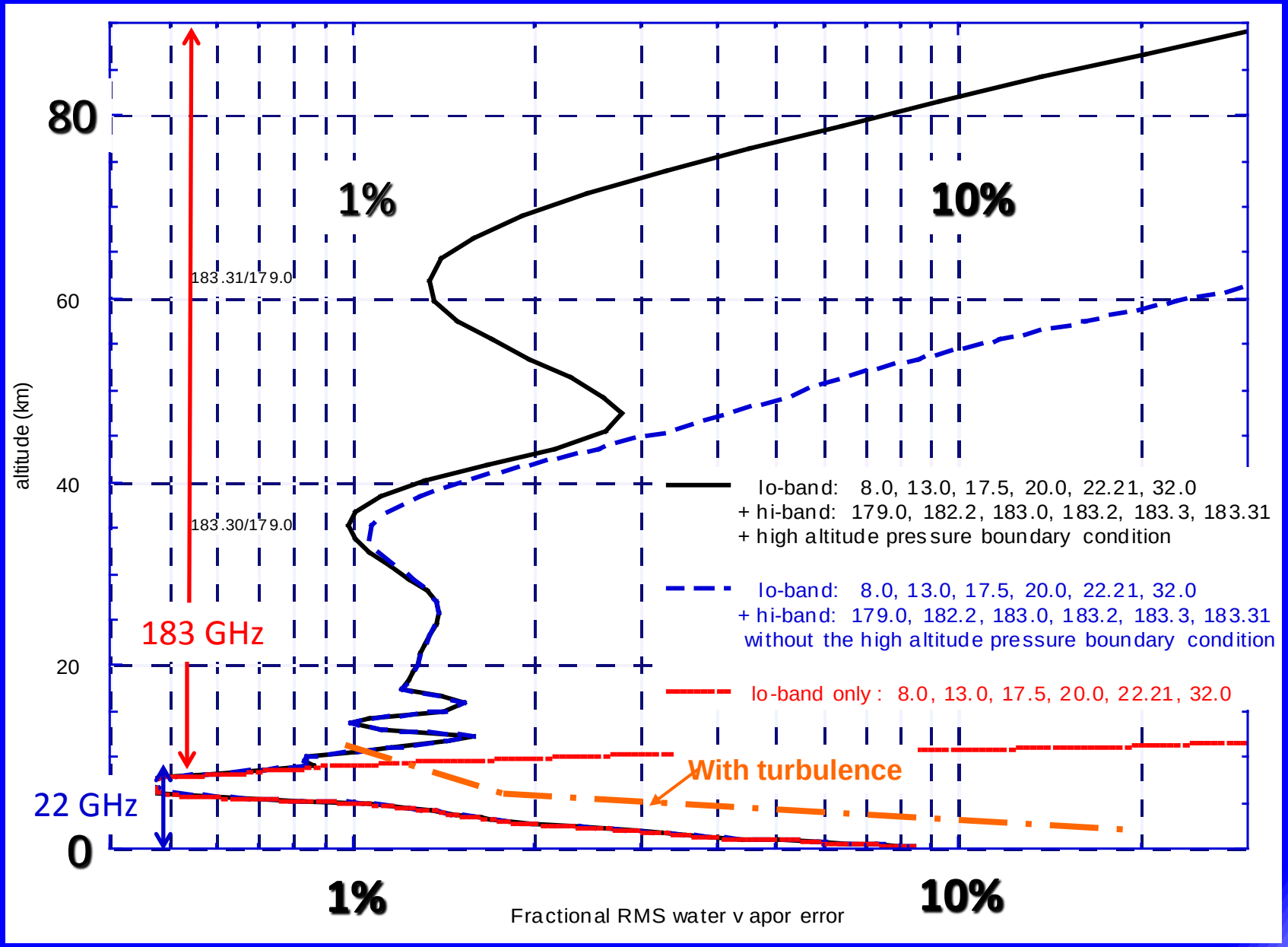
2 tone amplitude ratio eliminates common mode noise

⇒ Enables profiling in clouds & rain

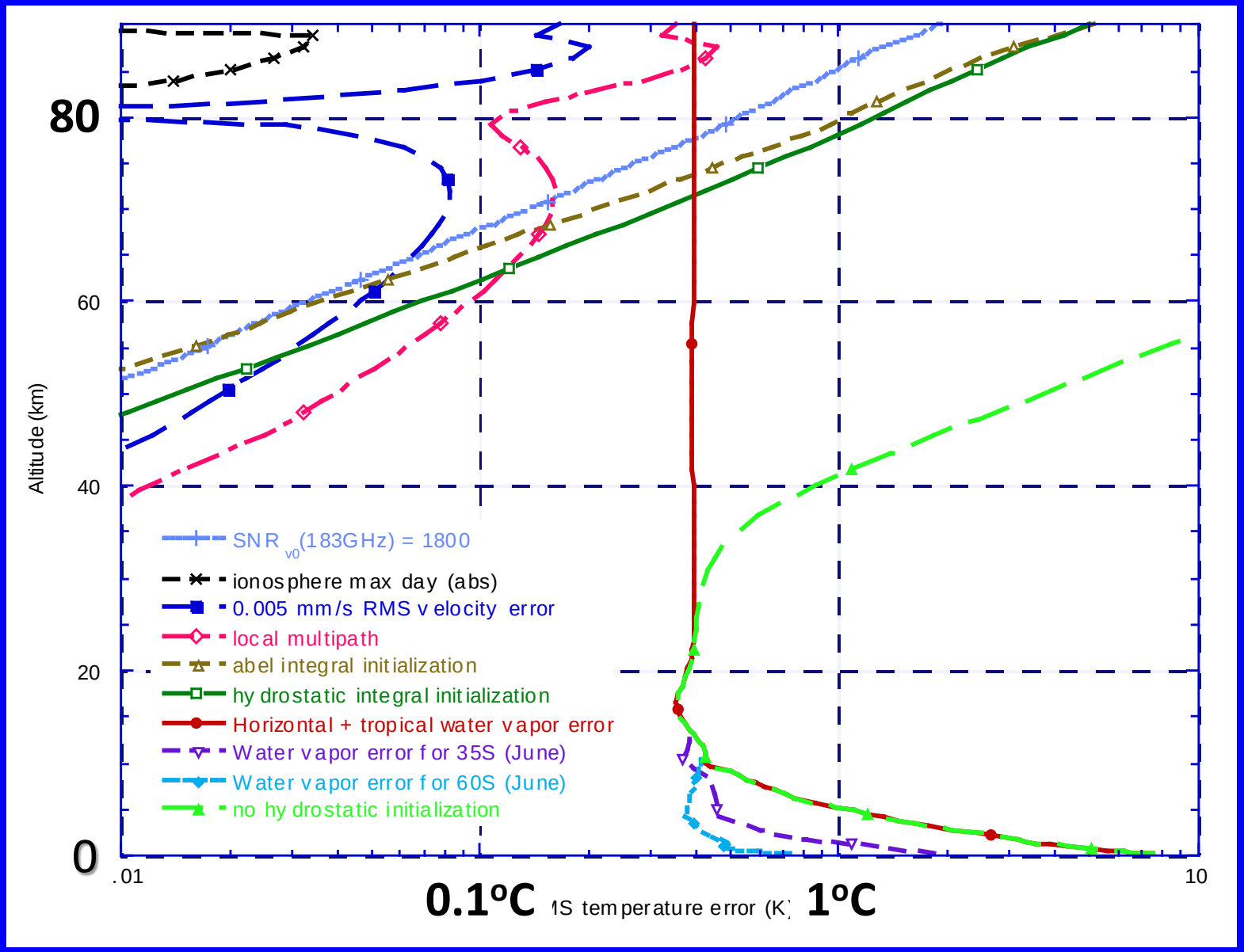
⇒ Enables profiling of cloud LWC

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

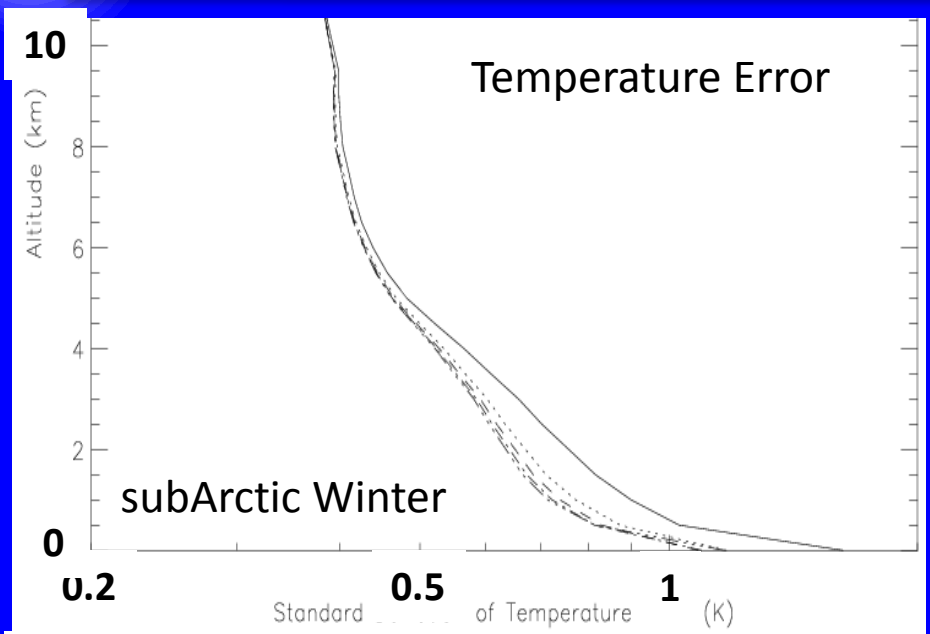
Precision of Individual Water Vapor Profiles

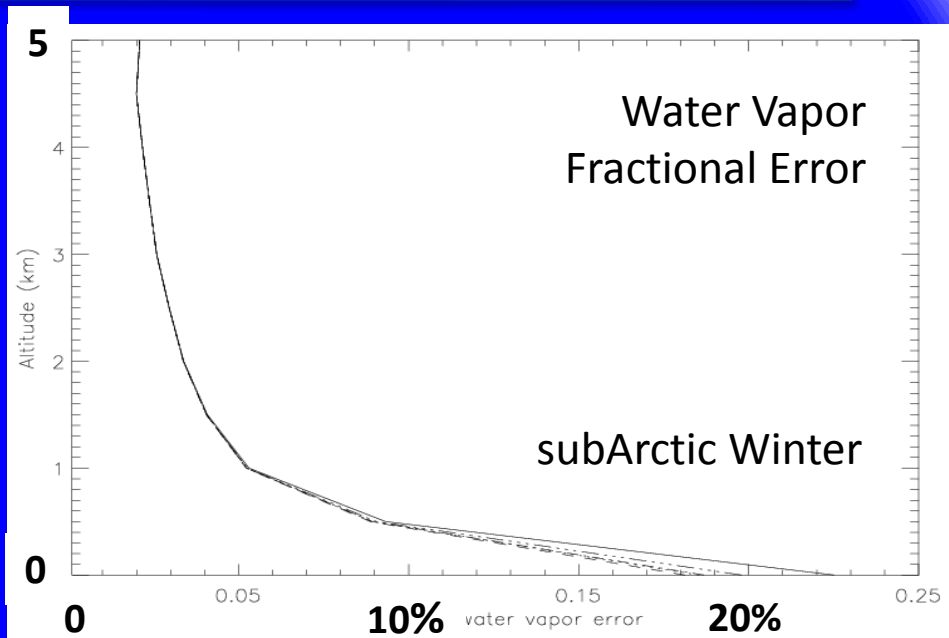


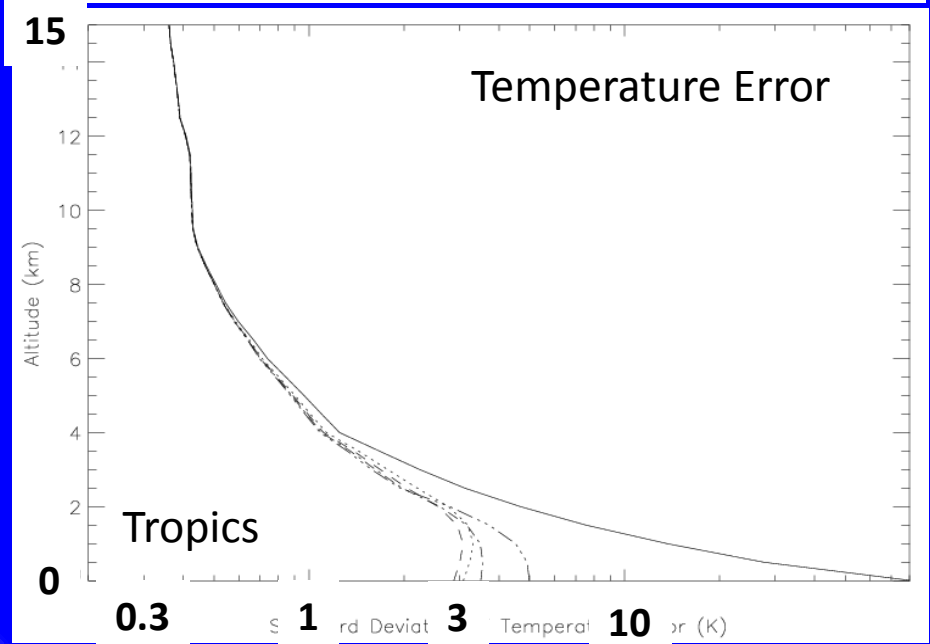
Precision of Individual Temperature Profiles

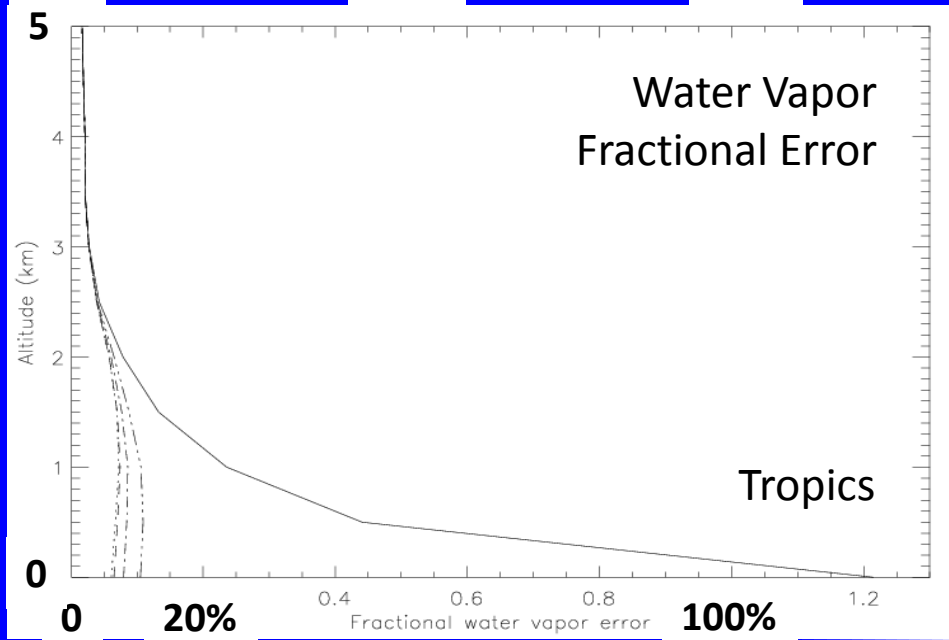


Near-Surface Precision with **3**, 22 & 183 GHz tones

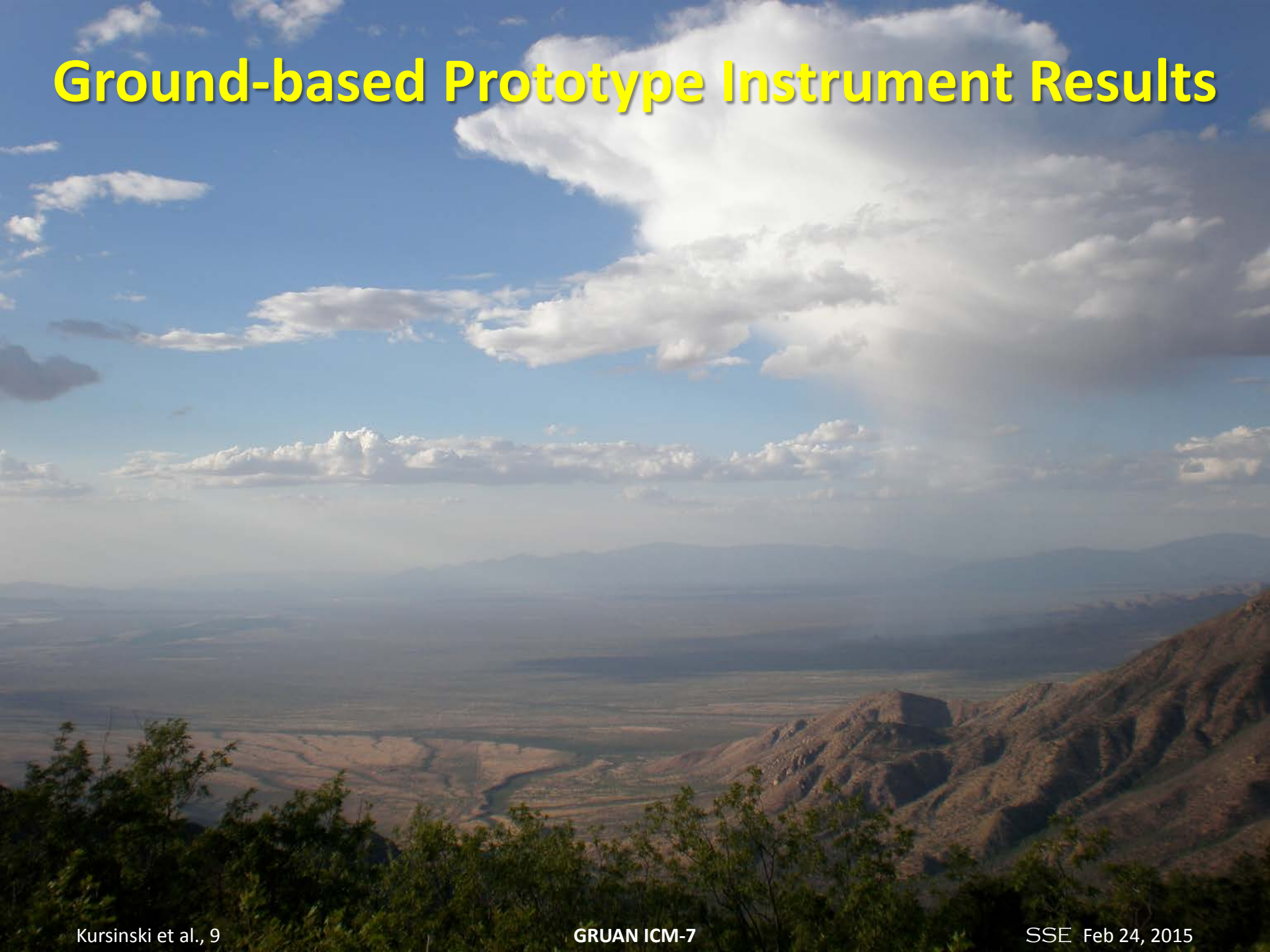






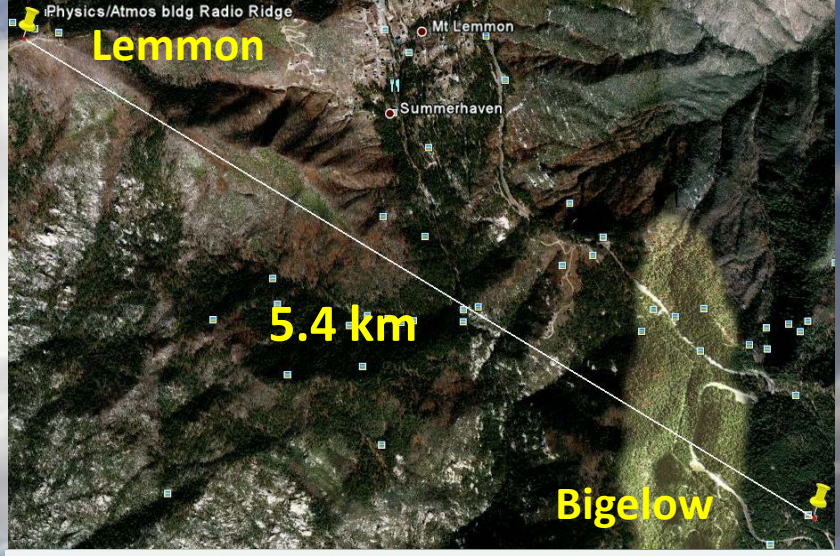


Ground-based Prototype Instrument Results



3 Field Test Geometries

- Rooftop: 840 m
- Lemmon to Bigelow: 5.4 km
- Hopkins to Lemmon: 84 km

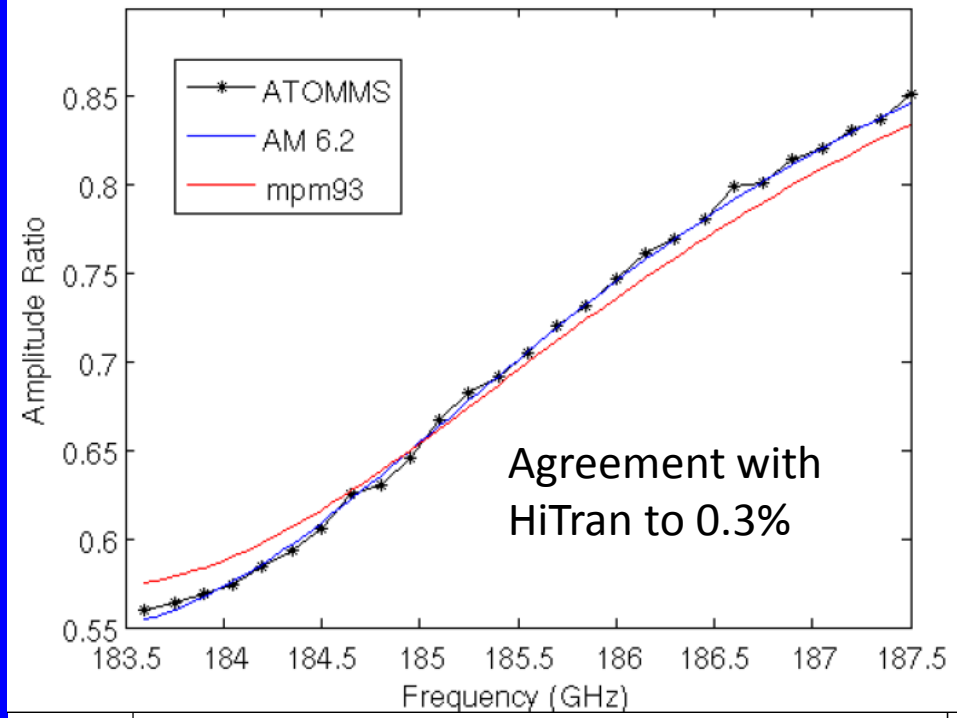


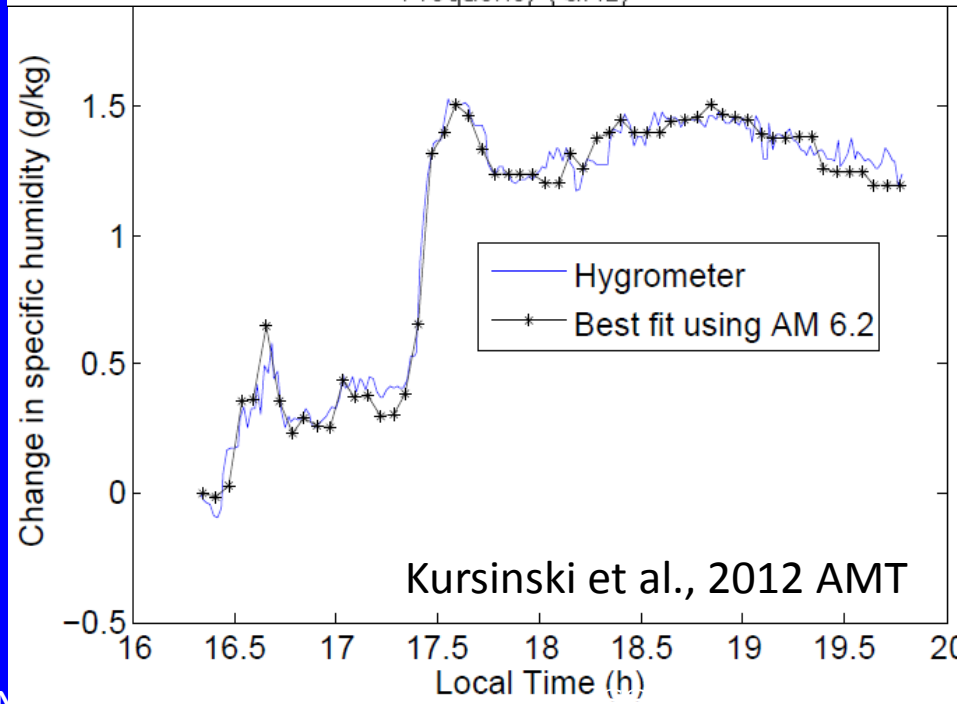
View of Mt. Lemmon from Mt. Bigelow

Deployed Instrument Photos

Water Vapor Spectroscopy & Retrievals

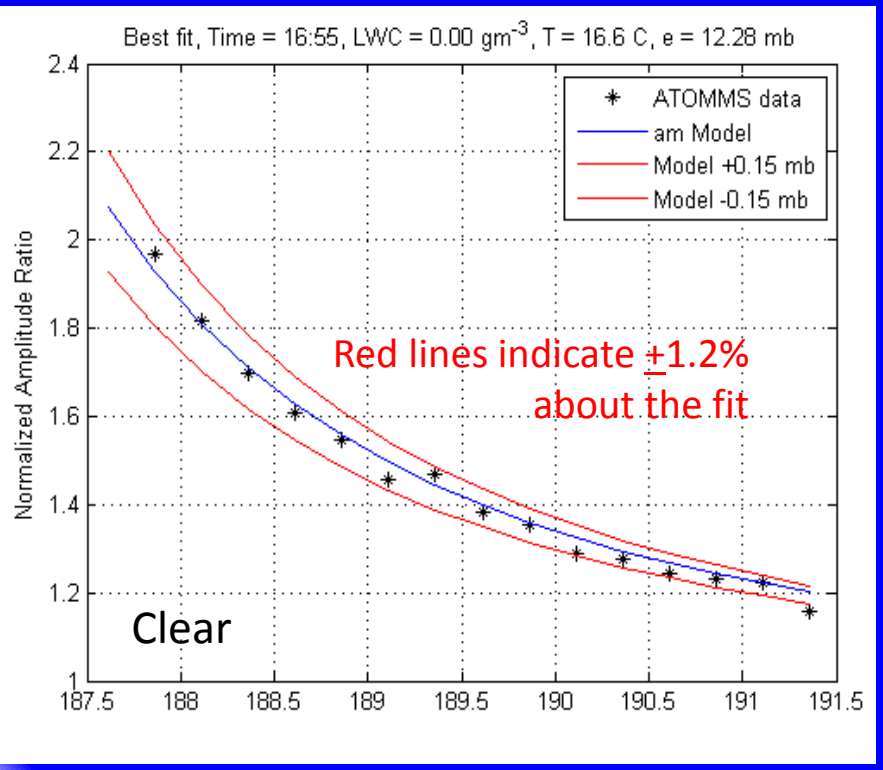
- 183 GHz line shape spectroscopy agreement to 0.3% (10x better than previous best spectroscopy)
- ATOMMS water vapor estimates agreement with capacitive hygrometer to 1%

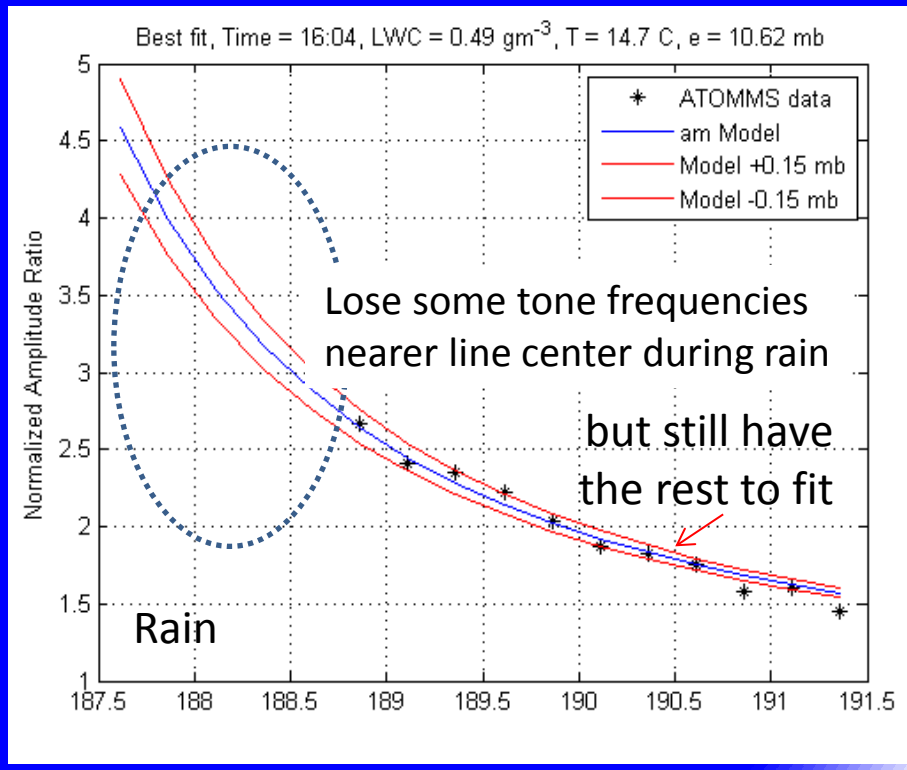




Water Vapor Retrievals: Clear, Cloudy & Rain

- Using mountaintop observations to demonstrate ability to retrieve water vapor spectra in clouds and rain
  - Enabled by calibration tone at 198.6 GHz
  - Figures show spectrum of amplitude ratios relative to calibration tone





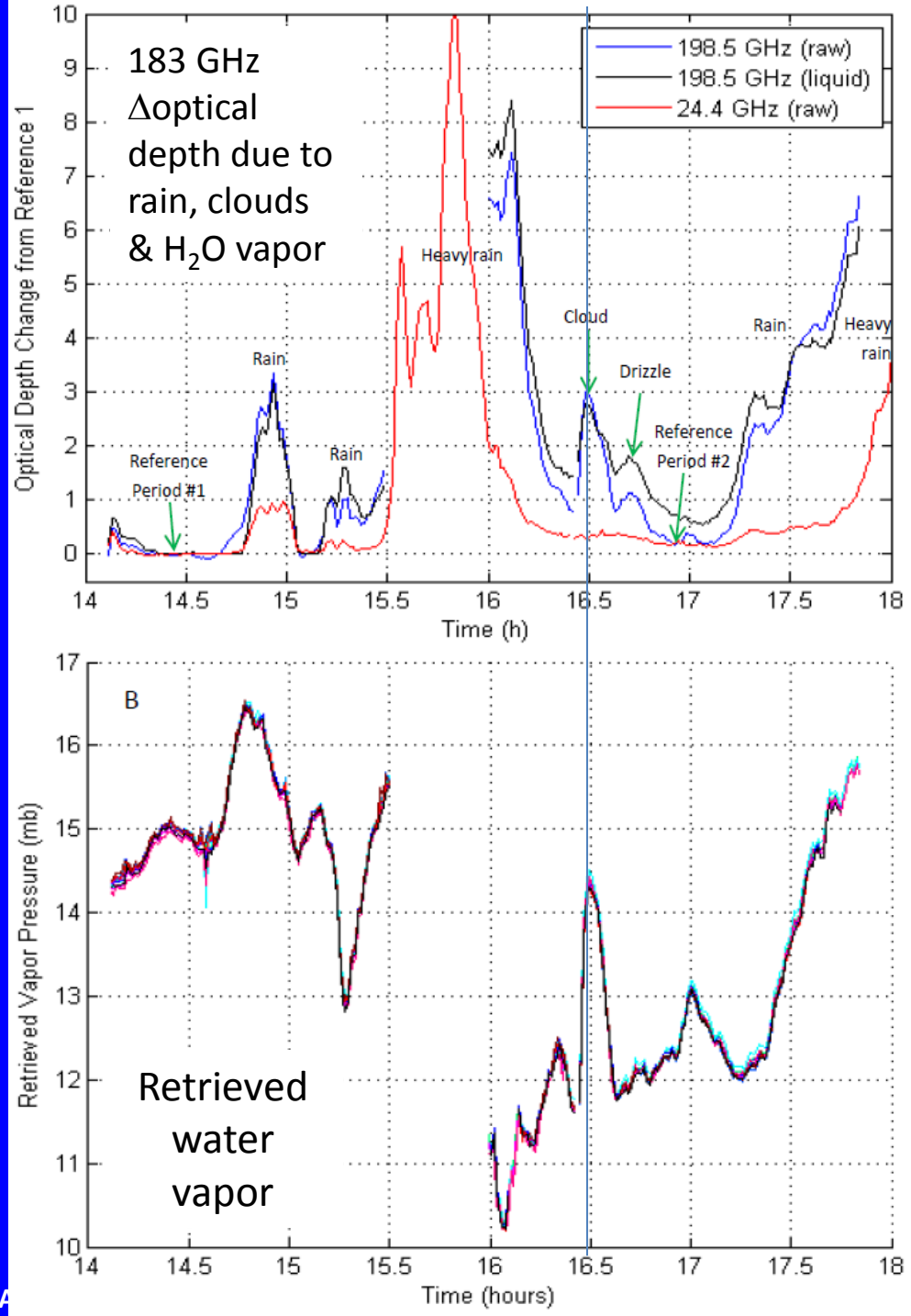
ATOMMS Mountaintop Results

Mtn-top retrievals

- In clear, cloud & rain
- optical depth up to 17

Water vapor retrievals

- Extremely little ambiguity even in rain
- Stdev < 1%
- Ward et al. (2015) to submit to GRL



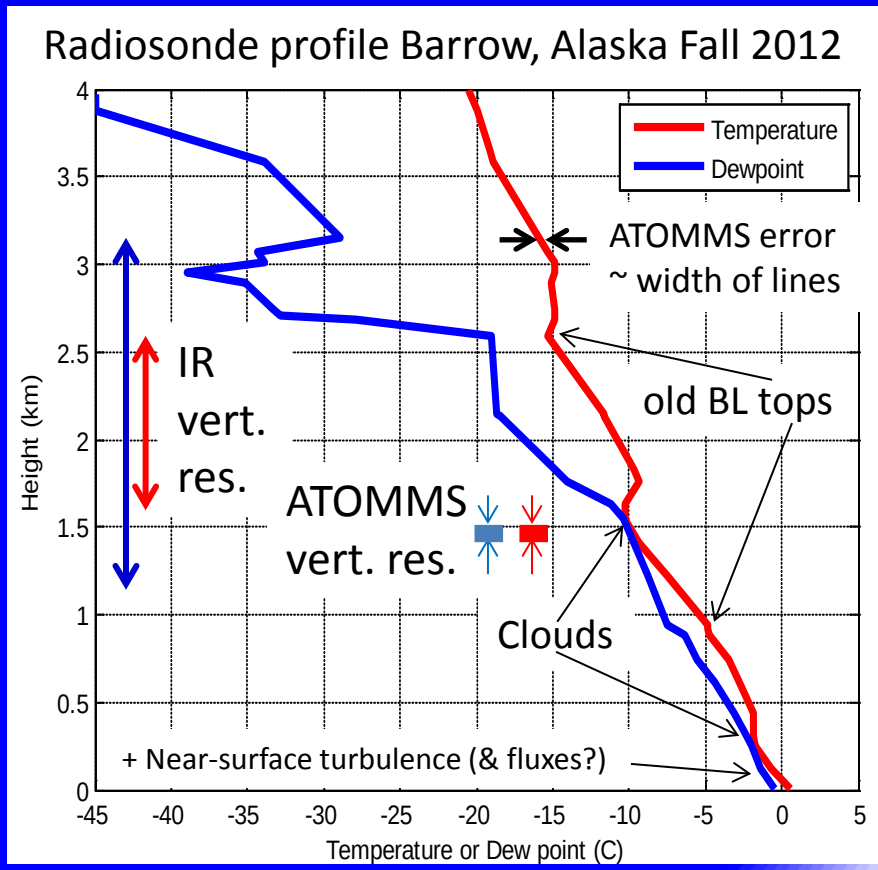
Example: High Latitude Profiling

Relevance: Large spread among sea ice melting predictions

- Uncertainties in modeled clouds & energy fluxes
- Need observations to tie down uncertainties
- Passive observations limited by vertical resolution & sensitivity to surface emissivity

ATOMMS would routinely profile atmospheric structure to the surface

- Insensitive to surface emissivity
- T, q, z(P) resolved to 100 m, 50 km horiz somewhat like a sonde but better accuracy
- Resolve near surface temperature & stability & moisture structure
- Liquid water cloud presence, LWC & temperature

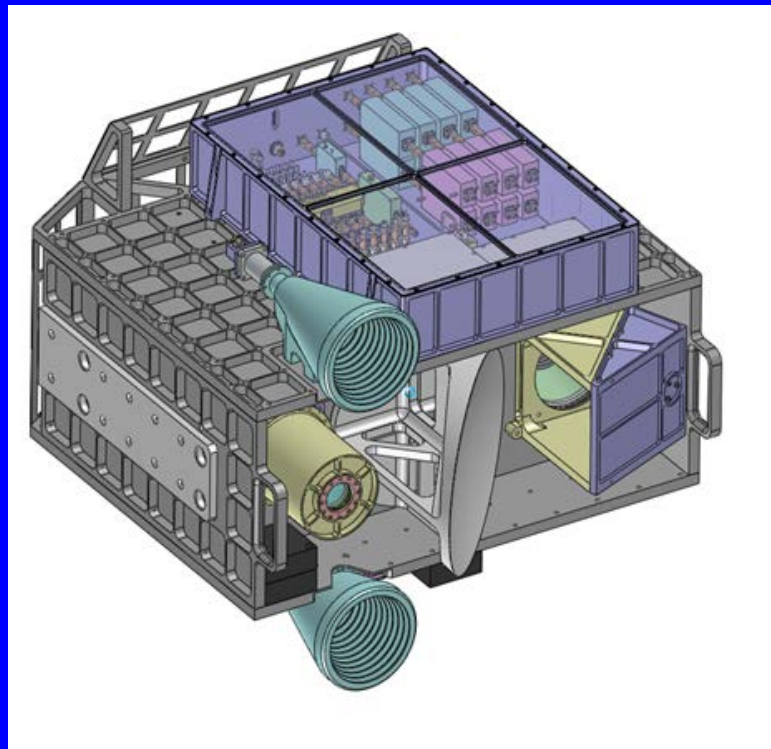


- ATOMMS would fill a data sparse region with precise vertical observations particularly near surface to tightly constrain and quantitatively understand convection, sensible & latent heat fluxes, clouds & radiative transfer
- Complement CloudSat & Calipso measurements

New Compact Instrument Design

Planned demonstration:

- Rising occultations between two WB57 high altitude aircraft
- Reduce instrument volume and mass for WB57 noses
- Reflective design



Still simpler design for LEO

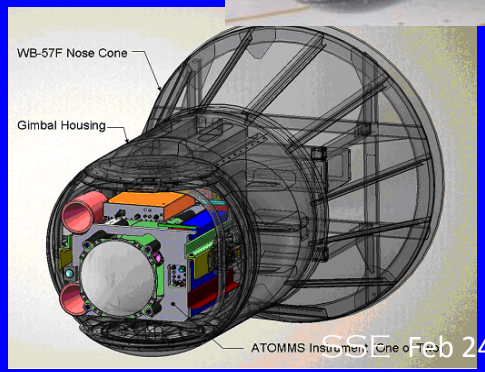
Global Field Campaign?

New window into atmosphere from orbit

- Measure atmospheric stability, weather fronts, profile pressure surface
- High precision to measure variability to constrain processes & guide models, e.g….
  - New constraints to help understand cloud formation; complement Cloudsat/Calipso
  - Strat-trop exchange (co-located temperature, H_2O vapor & O_3 as tracers)
  - Help constrain surface energy fluxes at high northern latitudes
- Trends: UT humidity & temperature, Stratospheric humidity, Stability (e.g. PDFs vs means)
- Accuracy & precision => Improve reanalyses
- Build up statistical database for processes and climatology

Development Status

- Prototype instrument done & used for testing
- Next: aircraft-aircraft occultations demonstration
- Next next: LEO-LEO constellation of small satellites



Challenges: funding, funding, funding