ATOMMS Status Report
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Rationale: Observational Needs for Climate

Climate models are wrong in ways that we don’t yet know.

*When you don’t understand something, you measure it*

Need observations as complete as possible to determine the atmospheric state and what is actually happening, independent of models.

Can we achieve this via satellite to satellite occultations?
Figure 1. Plots of the trends in specific humidity in the different reanalyses, over the time periods discussed in the text (1979 onward, except for the ECMWF-interim, which begins in 1989). The plots are divided into three geographical regions: tropics (20°S–20°N), NH (20°N–50°N), and SH (20°S–50°S). Trends are divided by the average specific humidity over the entire time period, so they are expressed in percent per year. The 95% confidence interval for trends in the ERA-interim reanalysis are shown for illustration purposes.
Atmospheric Spectrum below 200 GHz
ATOMMS vs. GPS

Profiles
- \( \text{H}_2\text{O} \) vapor, temperature & pressure \textit{simultaneously}
- \( \text{O}_3 \) and \( \text{H}_2\text{O} \) isotopes
- LoS winds > mid strat
- Sees thru clouds
- Very little sensitivity to ionosphere
- Profiles extend to ~ mesopause
- Requires new transmitters in orbit

![Diagram showing comparison between ATOMMS and GPS profiles. ATOMMS has measurements extending to the mesopause and requiring new transmitters in orbit, while GPS has measurements limited to lower altitudes and does not require new transmitters.](image)
Precision of Individual ATOMMS Profiles

Water vapor

Temperature

90km

0km

1% 1%

Fractional RMS water vapor error 10%

0.1K 1K

RMS temperature error (K)

With turbulence
Field Measurement Summary

• Water vapor measurements & Spectroscopy
• Turbulence measurements
• Cloud & rain water measurements
• August 18, 2011 measurements
  – Movie
  – Droplet & Rainfall inferences
  – Turbulence
  – Water vapor estimates
• Conclusions
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
View from Mt Hopkins to Mt. Lemmon
Spectroscopy & Water Vapor Retrievals

- 840 m Rooftop measurements

Sensitivity to pressure error
Amplitude noise: 0.3%

Spectroscopic model comparisons

Comparison with hygrometer
Water Vapor
June 28-29, 2011

• 22 & 183 GHz systems
• Mt. Bigelow to Mt. Lemmon
• Arrows indicate times of max and min water vapor
• Used to generate water vapor ratio spectrum
• Evaluate spectroscopy farther from line center & at lower pressure
• First ATOMMS measurement of $\text{H}_2^{18}\text{O}$ isotope
84 km 18-24 GHz Measurements

View from Mt. Hopkins to Mt. Lemmon July 2, 2011
• **Blue line**: change in water vapor derived from the 8 channels of ATOMMS 22 GHz system and comparisons with AM model spectra using average pressure & temperature measured at Mt. Hopkins & Mt Lemmon.

• **Red line**: water vapor measured at Mt. Lemmon.

• **Green line**: water vapor measured at Mt. Hopkins.
Atmospheric turbulence causes amplitude and phase scintillations in occultation signals.

- Scintillations are a source of noise when trying to isolate the water vapor absorption signature.
- We need to know how the scintillations will limit the accuracy of observations from orbit.
- The best way to estimate this prior to orbit is via aircraft occultation measurements.
- Scintillation measurements between rooftops and mountaintops are shown here.
Turbulence Measurements

- PSD of 150 sec of log amplitude fluctuations at 23.5 GHz.
  - PSD 6 mHz frequency resolution
- 10-ms amplitude estimates (50 Hz Nyquist rate).
Time evolution of turbulence intensity

- $C_{nr}^2$ maximum around noon, then decrease
- Relative maximum as thunderstorm came near in late afternoon
August 2010 & 2011
Mt. Bigelow & Lemmon Field Experiments
Attenuation due to Cloud & Rain Drops

Extinction coefficient

\[ k(D, \lambda) = \int \sigma(D)n(D)dr = \int Q(D, \lambda) \frac{\pi}{4} D^2 n(D)dD \]

Use Mie scattering theory to interpret ATOMMS, radar and visible measurements
Simultaneous 197 GHz, weather radar & visible obs.
Separate cloud & rain
$\tau (197 \text{ GHz}) \sim \tau (\text{visible})$
$\Rightarrow$ Rain at onset
Consistent with radar
Bigelow-Lemmon
August 18, 2011

• Weather radar
14:25:00 MST

Change in optical depth

24.4 GHz
198.611 GHz
rain

24.4 GHz
198.611 GHz
2 minute images
rain
15:22:00 MST

24.4 GHz
198.611 GHz
Onset of heavy rain
VERY heavy rain
15:50:00 MST

24.4 GHz

198.611 GHz
15:52:00 MST

24.4 GHz

198.611 GHz

time (hours MST)

change in optical depth
• Extremely windy
16:08:00 MST

24.4 GHz
198.611 GHz
30 second images
Cloud
16:34:00 MST

24.4 GHz
198.611 GHz
2 minute images
change in optical depth

17:22:00 MST

24.4 GHz

198.611 GHz
24.4 GHz
198.611 GHz

17:40:00 MST
17:42:00 MST

24.4 GHz
198.611 GHz
17:58:00 MST

- 24.4 GHz
- 198.611 GHz
Summary of August 18, 2011 large opacity variations

Humans opening tents
Humans closing Lemmon tent

2:1 2.6mm
3:1 2mm
2mm

<0.4mm cloud
7:1 1.5mm
9:1 1.4mm

clear
rain
heavy rain

7:1 1.4mm
Crude estimate of maximum rainfall

- At 15:50: $\tau_{24.4\, \text{GHz}} = 10.5$
- Assume $\tau_{198.6\, \text{GHz}} / \tau_{24.4\, \text{GHz}} = 2:1$ (3:1) based on measured ratio at onset of heavy rainfall
- Implies droplet radius of $\sim 1.3$ (1.0 mm)
- Fall speed: 7.6 m/s (6.5 m/s)
- Mass density: 2.7 g/m$^3$ (3.2 g/m$^3$)

$\Rightarrow$ Rainfall: 53 mm/hr (55 mm/hr)

- Reasonable agreement with our local, precise rainfall measurements
- Rainfall rate measured at nearby Scout Camp was 46.4 mm per hour.
Turbulence in Clear Air

- Amplitude variations \( \sim 6\% \)
- FFT spectra shows 3 intervals
- Middle interval is Kolmogorov
- Equivalent \( C_n^2 \): \( 3 \times 10^{-13} \, \text{m}^{-2/3} \) (LARGE!)
Cal-Tone Attenuation of Scintillations

- Ratio of 16:54 vs. 14:20 spectra
- Without & with normalization by caltone
Thermodynamic Conditions

- Surface pressure is representative of pressure along signal path.
- Surface air temperature is NOT representative of air temperature over the mountain valley.
- Estimate average air temperature along signal path from the pressure scale height.
• Sensitive to water vapor variations of ~0.1 mb which is < 1% absolute
Summary

• Instrument is working well in the field
  – High dynamic range: Max $\tau$ measured so far $\sim 11$
    • Can push this further with longer integration time
  – Water vapor retrievals working
    • 183 GHz results equivalent to better than 1%
  – Scintillations due to turbulence are generally in expected range
    • Ratioing reduced scintillations

• Powerful ground tool for atmospheric research
  – $\text{H}_2\text{O}$, T, P, spectroscopy, droplet size distribution, radar interpretation, hydrology, turbulence
  – Looking to deploy instrument in mountains for extended periods
    • Issues: clear line of sight, power, internet, security, lightning protection
Aircraft to Aircraft Demonstration

- Instrument presently too heavy for WB-57 nose
  - Identified mechanical changes to lighten instrument

- Problem with compact optics design
  - Modifying optics design to separate 22 & 183 GHz optics

- Conducted review for NSF
  => Need more funds

- Transferring NSF grant to U. Colorado next month
  - Work with LASP, NSF & NASA to obtain funds needed to perform the air-to-air demo