ATOMMS: Active Temperature, Ozone, Moisture Microwave Spectrometer
A LEO-LEO Occultation Observing System

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Abstract
Understanding our evolving climate and reducing uncertainties about its future state depend critically on our knowledge of the 3D distributions of atmospheric water, and temperature and their variations and trends, trends to determine how climate is actually changing and to construct the processes that must be accurately represented in predictive models.

ATOMMS is a new radio occultation (RO) observing system that essentially combines GPSRO and the Microwave Limb Sounder (MLS) by actively measuring absorption as well as bending. The ATOMMS occultation system will transmit a set of tones at selected frequencies near the 22 and 183 GHz water absorption lines from one LEO satellite to another across the limb of the atmosphere. 195 GHz will be used to profile ozone. Water isotopes can be determined with additional frequencies. Profiles of delay and attenuation accumulated during signal passage through the atmosphere are inversely related to profiles of atmospheric water, temperature and the geometrical height of pressure surfaces from the near-surface through the mesosphere. ATOMMS obtains the strengths of GPSRO such as 200 m or better vertical resolution, high precision, and accuracy via self-calibration in both clear and cloudy air while overcoming the weaknesses of existing systems, such as tropospheric ozone profiling. ATOMMS is entirely self-contained with no reliance on external models, analysis or other remote sensing information and should be limited ultimately by our spectroscopic knowledge. The power of ATOMMS for climate monitoring, process studies and ionospheric sensitivity, avoiding subtle residual solar or diurnal cycle signatures that likely exist in the GPSRO results. ATOMMS is entirely self-contained with no reliance on external models, analysis or other remote sensing information and should be limited ultimately by our spectroscopic knowledge. The power of ATOMMS for climate monitoring, process studies and ionospheric sensitivity, avoiding subtle residual solar or diurnal cycle signatures that likely exist in the GPSRO results. ATOMMS is entirely self-contained with no reliance on external models, analysis or other remote sensing information and should be limited ultimately by our spectroscopic knowledge.

Combined Occultation Bending Angle and Absorption Retrieval

The measurements
• Each transmitter transmits multiple signals across the Earth’s limb to a receiver that downconverts, filters, digitizes and records the complex signal spectrum.
• The time varying amplitude and frequency of each occulted tone are extracted in subsequent processing.

Profiling Index of Refraction, n:
• This occultation geometry is precisely reconstructed using GPS
• Measured signal frequencies + geometry => Atmospheric Doppler profiles => bending angle profiles => refractivity profiles via Abel integral transform (e.g., Kursinski et al., 1997)

Determining water vapor, temperature, ...
• (1) and (2) are combined with spectroscopy and hydrostatic equilibrium to directly and uniquely determine atmospheric density, temperature, pressure, water vapor and ozone vs height.

Bending Angle Forward and Inverse Abel Integral Transform Pair

\[ \beta(a) = 2a \int_0^a \frac{d \ln(n)}{d r} \frac{d r}{a^2} \]

Opticy and Absorption Coefficient Abel Integral Transform Pair

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Standard deviation of ATOMMS geometrical height error vs. height

Estimated Accuracy

Standard deviation of water vapor and temperature errors from 0 to 90 km altitude: a water vapor errors for tropical clear sky conditions.

Errors in individual water vapor and temperature profiles (250 m in vertical resolution) 0 to 20 km altitude for 4 km of conditions:
(1) Arctic Winter (AW) clear conditions
(2) AFW with a 1 km thick, supercooled fog layer with LWC = 0.15 g/m³
(3) Mid-latitude Summer (MLS) clear conditions
(4) MLS with a broken deck of altocumulus (Ac) clouds between 4.5 and 5.5 km altitude with LWC = 0.3 g/m³

Errors include estimated effects of turbulence.

Larger near-surface errors for warmer conditions are due to reduced orthogonality between refractivity and extinction coefficients under very wet conditions (Kursinski et al., 2002). Accuracy improves with averaging, limited altitude by spectroscopy.

Importance of combined vertical resolution and precision:

Comparison of vertical resolution vs. precision of individual MLS and ATOMMS (AMS) water vapor profiles near the tropical cold point tropopause.

ATOMMS provides the combined vertical resolution and precision needed to determine variability in concentric processes and resolve behavior invisible to passive sensors such as absorption line scale-laying observed by in-situ observations (e.g., Neuville et al., 1999). With ATOMMS we will be able to globally determine how stability is evolving throughout the free troposphere as our climate changes.

Summary

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Summary of ATOMMS Features
ATOMMS will determine the 4D thermodynamic state and constituents of the atmosphere well beyond present capabilities.

• Wide dynamic range yields temperature, moisture and pressure profiles from near surface to mesopause
• Self-calibrating, relative measurements normalized to signal properties measured at the atmosphere immediately before or after each occultation eliminate long term drift
• Use of cal tones dramatically reduces unwanted amplitude variations during each occultation
• Stand-alone retrievals (no apriori estimate required to produce a unique profile solution)
• Provides at least 20 m vertical resolution, well beyond that of passive sensors
• Limits volume vertical averaging yields more representative profiles than point measurements
• Provides very high precision of individual profiles to capture variability
• Provides still better absolute accuracy with averaging limited ultimately by spectroscopy
• Similar performance in clear and cloudy air
• Additional frequencies will determine additional constituents including water isotopes
• High frequencies are 4 orders of magnitude less sensitive to ionosphere than GPSRO eliminating subtle solar and diurnal cycle leakage into GPSRO refractivity profiles and extending middle atmosphere RO profiling to ~mesopause
• Particularly well suited to difficult and important upper troposphere/lower stratosphere regime
• Can accurately profile middle atmosphere winds above 30 km as well

References