Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS)

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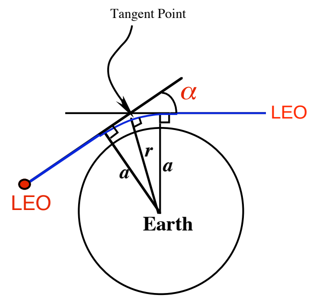
Summary: Over 3 years beginning in August 2007, supported by the NSF Major Research Instrumentation (MRI) program, we will build a prototype instrument and use it to demonstrate a powerful new satellite-borne atmospheric remote sensing concept called the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS). With previous funding from NSF, we have been developing the ATOMMS concept and our analysis shows that such an instrument will improve upon the vertical resolution, precision and absolute accuracy of present satellite observations of atmospheric water vapor, temperature and pressure by an order of magnitude or more in both clear and cloudy weather, capabilities that will fulfill crucial needs for climate change research and policy making. NSF has further indicated that ~$300M could be available to support an ATOMMS satellite mission once we demonstrate broad support in the geoscience research community for the mission.

A crucial step in enlisting such support is demonstrating that our predicted performance levels are achievable with real instrumentation. The NSF MRI is providing the funding needed to develop the first ATOMMS instrument at the University of Arizona, where we have been working on the instrument design for Earth and Mars for many years, and then use it to make the critical first demonstrations. Specifically following completion of the prototype instrument, we will use it to make measurements initially in a static geometry at the surface and then, with NASA support, make observations in an aircraft-to-aircraft occultation geometry that approximates the final orbiting satellite-to-satellite occultation geometry. We are developing plans for several aircraft-to-aircraft measurement demonstrations with NASA. Successful aircraft demonstrations will pave the way for support from the larger science community for the ATOMMS concept and a NSF/NASA/NOAA sponsored spacecraft mission.

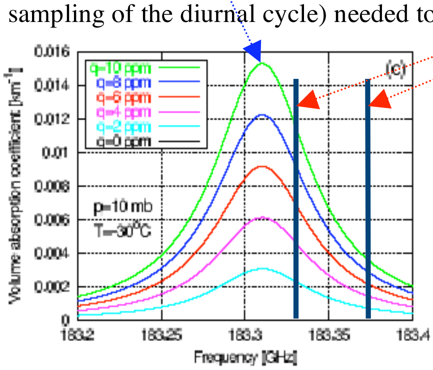


Climate Observational Needs

The global observing system is a crucial component in solving the climate change problem but, as the *Cicerone et al.* (2001) National Academy Report indicates, the present observing system is simply inadequate for the task, providing neither the information nor the continuity in the data needed to support measurements of climate variables. They indicate that it is essential to ensure the existence of a long-term observing system that provides a more definitive observational foundation to evaluate decadal- to century-scale variability and change. This observing system must include observations of key state variables such as temperature, precipitation, humidity, pressure, and clouds.

ATOMMS Concept

ATOMMS represents a new class of active, orbiting, limb-viewing spectrometer that is a cross between Global Positioning System (GPS) occultations (e.g. *Kursinski et al.,* 1997) and NASA's Microwave Limb Sounder. ATOMMS will characterize atmospheric constituents by actively probing their cm and mm wavelength absorption lines. One satellite will generate multiple tones near an absorption line such as the 183 GHz water line and transmit them across the Earth's limb through the atmosphere to a receiver on a second satellite in the occultation geometry shown at the top of the page and in the first figure (*Kursinski et al*., 2002). ATOMMS provides the sensitivity, resolution, accuracy and unbiased global coverage (clear and cloudy conditions and full sampling of the diurnal cycle) needed to satisfy key monitoring needs for temperature, pressure, moisture and ozone.



The 100 to 200 m ATOMMS vertical resolution will far surpass the 1 to 4 km vertical resolution of present state-of-the-art satellite radiometers opening a window into atmospheric scales previously inaccessible from space. Typical precisions of individual ATOMMS temperature, pressure and moisture profiles are unprecedented at ~0.4 K, 0.1% and 1-3% respectively, extending from near the surface to the mesopause (~90 km altitude). ATOMMS ozone profiles precise to 1-3% will extend from the upper troposphere well into the mesosphere. Other trace constituents such as water isotopes can be measured with performance similar to that of ozone. ATOMMS observations are self-calibrating and drift-free because signal levels during each occultation are normalized to the signal level observed above the atmosphere just prior to or following each occultation. This eliminates drift that can plague radiometric measurements and means that averaging ATOMMS profiles will yield accuracies one to two orders of magnitude better than the high precision of the individual profiles. Our long term goal is a constellation of approximately a dozen small spacecraft making ATOMMS measurements that will provide dense, global coverage and complete cloud-penetration and diurnal sampling every orbit. Given its unique and powerful combination of qualities critical to characterizing climate, ATOMMS will be a key element in the global climate observing system (GCOS) ***IF*** we can demonstrate its capabilities. A white paper submitted to the NRC Earth satellite climate mission decadal study summarizing ATOMMS (Kursinski et al., 2005). Radio occultations have been given very strong endorsement in the recent NRC report in February, 2007 and climate benchmark observations from space (Anderson et al., 2007).

Accuracy of ATOMMS profiles Figure 3 shows our estimated accuracies of *individual* temperature and water vapor profiles derived from ATOMMS occultation measurements up to 20 km altitude. These represent the accuracies of ~300 km horizontal averages associated with the occultation limb viewing geometry. The conditions shown span very dry, arctic winter to very warm and moist mid-latitude summer conditions, both with and without liquid water clouds present. Performance is generally better under colder, drier conditions. The presence of liquid water clouds degrades performance relative to clear air conditions by less than a factor of 2. Water vapor accuracies are better than 5% above 2 km reaching minimum errors of 1% or better in the upper troposphere. Sub-kelvin temperature errors extend down to the surface in arctic winter conditions and to 3 km altitude for mid-latitude summer conditions. With averaging, the accuracy should improve substantially, limited ultimately by our knowledge of the absorption line spectroscopy.

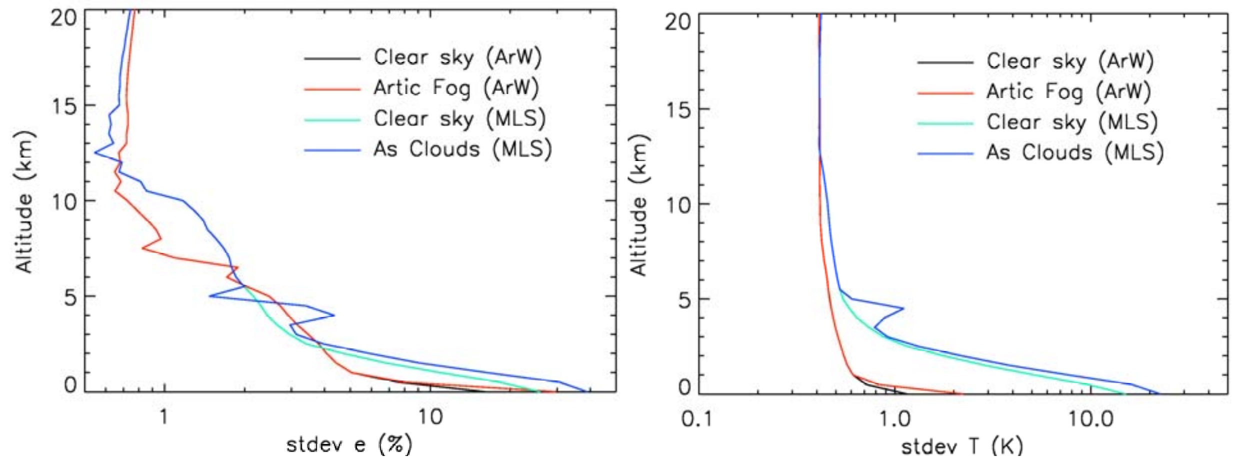
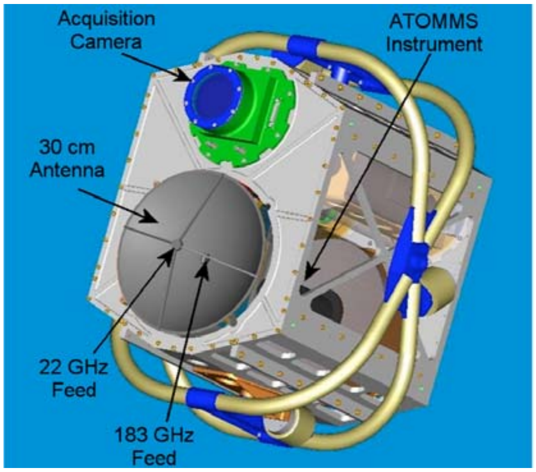


Figure 3. Computed standard deviation of the errors in the retrievals of water vapor pressure and temperature using simulated ATOMMS satellite to satellite observations. MLS here refers to the Lowtran 2 mid-latitude summer profile and ArW is the Lowtran 5 arctic winter profile. The MLS cloud is a broken deck of altostratus clouds placed between 4.5 and 5.5 km altitude. The cloud field is highly non-symmetric about the local tangent point. Cloud elements have liquid water contents of 0.3 gm^{-3}. For the Arctic fog case, a cloud with liquid water content of 0.15 gm^{-3} extends from ground level to 1.0 km altitude. The near-surface errors for the Arctic case may be overestimated because the turbulence may be an overestimate for Artic winter conditions.

ATOMMS at Mars (MACO) ATOMMS is also the basis of our Mars Atmospheric Climate Observatory (MACO) concept we developed with NASA seed funding and internal funding at the University of Arizona and JPL. With 2 satellites orbiting Mars, MACO will make ATOMMS-type satellite-to-satellite microwave occultation observations focused on understanding the Martian hydrological and dust cycles and climate in general. Based on the MACO effort, we have developed the design and know how to build ATOMMS instrument and, with NSF funding, we are proceeding with the Earth demonstration.

MRI Instrument Description The ATOMMS prototype instrument consists of 2 active, microwave spectrometers: an 8 channel lo-band 10-32 GHz spectrometer and a 2 channel hi-band (180-195 GHz) spectrometer. Probing both the weaker 22 and stronger 183 GHz water absorption lines will characterize water vapor over the more than 6 orders of magnitude range of concentrations across the troposphere and stratosphere. Simultaneous overlapping measurements at both 22 and 183 GHz will provide critical information for evaluating performance, consistency and spectroscopy. The hi-band spectrometer will also characterize ozone via its 195 GHz absorption line. If the instrument can deliver sufficient bandwidth, we will also demonstrate the ability to profile tropospheric $H_2^{18}O$ via its 203 GHz line. The two spectrometers share a common 30 cm diameter antenna and consist of separate heterodyne transmitters and receivers located on opposite sides of the atmosphere as shown in the 1st figure and at the top of the page.

In brainstorming about how to achieve this ATOMMS demonstration relatively inexpensively, Dr. Donald Anderson, at NASA Headquarters, suggested that we perform the ATOMMS occultation demonstration using two WB57 high altitude jets, the responsibility of Co-I Dr. Marty Ross, funded by NASA. The ATOMMS instrument will be mounted in the gimbled “X frame” (Figure 4) in the nose cone of the high altitude NASA WB57 aircraft (Figure 5) to take advantage of the precise pointing system used to photograph damage to Space Shuttle tiles. Our instruments in two WB57 aircraft flying toward one another at ~19 km altitude from positions over the horizon will create the first set of occultation observations at cm and mm wavelengths to profile atmospheric temperature, water vapor and ozone below 19 km altitude. Students will participate in designing and building the prototype ATOMMS instrumentation at the Steward SORAL facility under the direction of Professor Kursinski and Co-Is Professor Walker and Dr. Groppi in Steward Observatory as well as in developing the retrieval software and interpreting the first profiles working with Prof. Kursinski and Dr. Ward.



References

Anderson J., et al., 2007, The climate benchmark constellation: A critical category of small satellite observations, http://map.nasa.gov/clarreo_materials.html.

Cicerone, R. J., et al., *Climate Change Science: An Analysis of Some Key Questions*, NRC, 2001, National Academy Press.

Kursinski, E. R., et al., *J. Geophys. Res.*, **102**, 23429-23465, 1997.

Kursinski, E. R., et al., *J. Atmos. Oceanic Technol.*, **19**, 1897-1914, 2002.

Kursinski et al., 2005: See ‘NRC White paper’ on http://www.atmo.arizona.edu/personalpages/kursinsk/NextGenOccEarth.htm