The Active Temperature, Ozone and Moisture Microwave Spectrometer, A New Global Climate Sensor

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1. INTRODUCTION

In order to determine how our climate is changing and assess and improve climate models and their predictions, we are developing a new global remote sensing system to precisely and accurately measure key variables in the climate state, independent from models. The new remote sensing technique called the Active Temperature Ozone and Moisture Microwave Spectrometer (ATOMMS) combines many key features of GPS Radio Occultations (RO) and the Microwave Limb Sounder (MLS) by actively probing via satellite-to-satellite occultations absorption lines that MLS probes passively. Radio occultation is a powerful technique for remotely sensing Earth's atmosphere for weather prediction and climate (e.g., [1]). ATOMMS overcomes several limitations of GPSRO by simultaneously profiling both bending angle and absorption (GPSRO profiles only bending angle) in order to provide the information necessary to profile water and temperature independent of other observations and model and climatological constraints. ATOMMS measures differential absorption by probing the atmosphere simultaneously at multiple frequencies. Conceptually, two occultation tones are sent through the atmosphere with one tuned on the absorption line and the other is tuned off the line such that when the ratio of the amplitudes of the two signals is formed, it largely eliminates common noise like antenna gain variations while retaining most of the desired absorption signature.

Probing via occultation offers several key advantages over passive emission including an order of magnitude better vertical resolution, simple and unique retrievals, very high SNR and precision to capture variability critical to revealing signatures of processes, all-weather sampling eliminating clear sky-only biases and S. I. traceable self-calibration eliminating long term drift. ATOMMS profiles of temperature, geopotential height and moisture will extend from the lower troposphere to the mesopause with typical precisions over much of this altitude range of ~0.4 K, 10 m and 1-3%. With additional signal frequencies, other trace constituents such as water isotopes can be measured in the upper troposphere and above with similar performance. ATOMMS will profile line of sight winds above the 10 mb level and will also profile turbulence.

With funding from NSF and aircraft time from NASA, we are building a prototype instrument to demonstrate the ATOMMS concept and performance using two NASA high altitude WB-57F aircraft in 2010. The long term goal is a constellation of microsatellites that will provide full global and diurnal cycle coverage to function as a backbone of the global climate observing system (GCOS).

2. WATER VAPOR AND TEMPERATURE PERFORMANCE

The first systematic error analysis of the ATOMMS concept revealed the potential of the technique for clear sky conditions [2]. More recent error analysis includes scintillations ("twinkling of a star") caused by atmospheric turbulence and the effect of clouds [3]. Simple 2-tone amplitude ratioing dramatically reduces the impact of turbulent variations in the real part of the index of refraction [3]. Fig. 1 shows the estimated clear sky accuracy of the ATOMMS temperature and water vapor profiles includes the effects of scintillations due to turbulent fluctuations of temperature and water vapor.

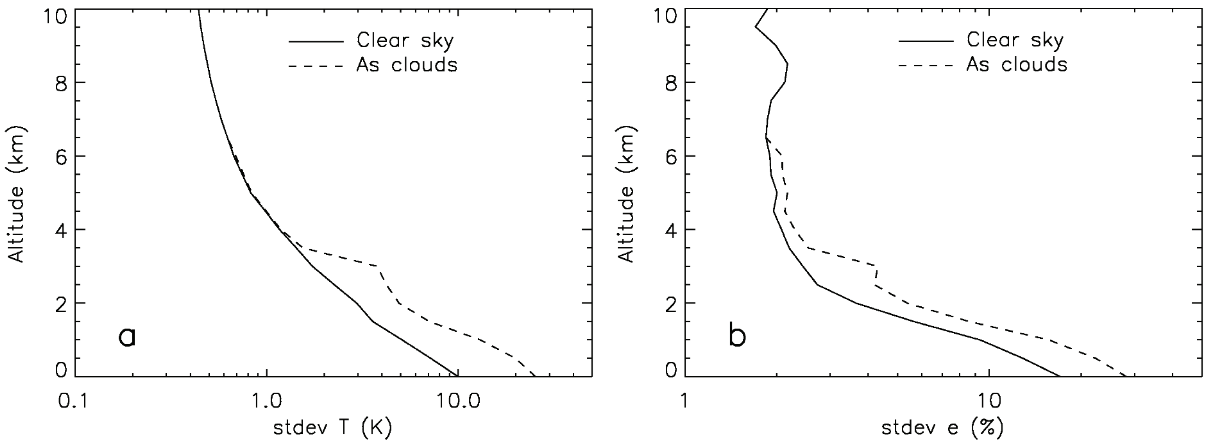

Figure 1. *Computed standard deviation of the errors in the retrievals of (a) temperature and (b) water vapor pressure using simulated ATOMMS observations. The background atmosphere is the Lowtran 2 mid-latitude summer profile. Solid lines are for clear sky conditions. The dashed lines include the effects of two broken decks of altostratus clouds between 3 - 3.5 and 6 - 6.5 km altitude with liquid water contents of 0.3 and 0.2 gm*$^{-3}$ *respectively. The cloud fields are highly non-symmetric about the local tangent point.*

ATOMMS will probe the 22 and 183 GHz water lines. Because absorption by *liquid* water in clouds is very large at frequencies near 200 GHz, the occultation signals near 22 GHz will probe through liquid water clouds. Under these conditions, observations near 200 GHz will be limited to altitudes above the freezing level (~ 5 km and above in the tropics and lower altitudes at higher latitudes).

We have developed a method for isolating the effects of ice and liquid water clouds that allows the ATOMMS retrievals in cloudy conditions to be within a factor of 2 of clear sky conditions as summarized in [4]. For climate, it is critical that the ATOMMS observations provide sufficient information to ensure this is an over-determined rather than underdetermined problem. Fig. 2 provides an example of the estimated performance for 2 inhomogeneously distributed cloud decks.

3. OZONE PROFILES

The changes in stratospheric ozone concentrations due to human activity are very difficult to predict because ozone depends on a number of factors that are also being modified anthropogenically. ATOMMS will profile ozone using the 184 and 195 GHz lines of ozone. Fig. 2 indicates predicted precisions for individual profiles will be 3% or better above the altitude of maximum mixing ratios in the lower portion of the middle atmosphere. Performance decreases at altitudes below the altitude of maximum ozone mixing ratios remaining quite useful in the upper troposphere. Fig. 2 shows that the aircraft to aircraft occultations will provide significantly better performance in the upper troposphere/lower stratosphere than the satellite observations because the air-air occultations are thus not affected by the overlying O_3 layer in the stratosphere. Aircraft to aircraft occultation capability will have utility for supporting scientific field campaigns. A peer-reviewed manuscript on the ozone performance is near submission [5].

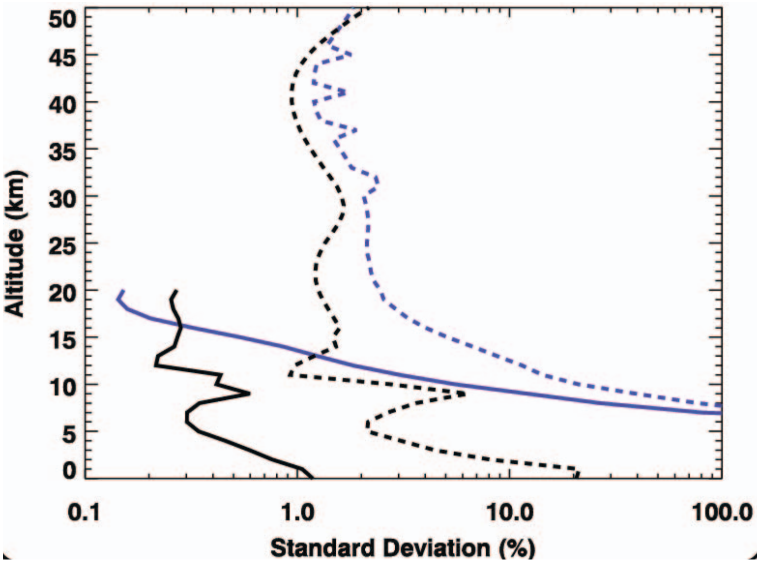

Figure 2. *Standard deviation of simulated errors of water vapor (black) and ozone (blue) from satellite (dashed) and aircraft occultations (solid) for US standard atmospheric (LOWTRAN 6) conditions.*

4. ATOMMS AT MARS

The ATOMMS concept actually works better at Mars because the low surface pressure there allows a number of trace species as well as line of sight winds via the Doppler shift to be accurately profiled right to the surface. A white paper on the Mars concept is available at the planetary decadal survey web site: http://www8.nationalacademies.org/ssbsurvey/publicview.aspx.

5. ATOMMS AIRCRAFT DEMONSTRATION

With funding from NSF, our group is building a prototype of the ATOMMS instrument at the University of Arizona to perform an aircraft to aircraft occultation demonstration in 2010. The temperature, water vapor and pressure profiles will extend from the surface to the 19 km altitude of the aircraft. The prototype instrument has 8 channels between 18 and 26 GHz and 2 tunable channels in the 180 to 203 GHz range that will be upgraded to 4 channels. This capability will profile water vapor and ozone as well as $H_2^{18}O$ and N_2O in the upper troposphere and lower stratosphere. The instrument also uses 13 GHz to precisely measure the phase shift associated with atmospheric bending of the signal path from which profiles of refractivity are derived. Instrument tests and initial demonstrations are presently underway at the University of Arizona.

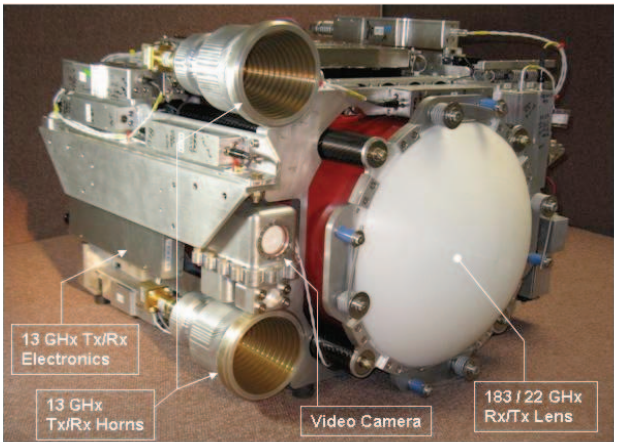

Figure 3. One of the two ATOMMS prototype instruments. Visible components are labeled. The 183 GHz Transmitter and 22 GHz Receiver modules are not visible.

6. REFERENCES

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