ATOMMS: A cm and mm Wavelength Satellite to Satellite Occultation System for Weather & Climate

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***Abstract*—We describe a new satellite to satellite occultation system for profiling the atmosphere for weather and climate. It will extend the GPS occultation capability by profiling the atmosphere via at cm and mm wavelengths near water vapor and ozone absorption lines to profile water vapor and temperature simultaneously which GPS cannot do. We summarize both its expected performance and a subset of its performance demonstrated via ground based measurements. A constellation of tiny satellites carrying these sensors promises to open a new window into the atmosphere globally extending weather forecasting accuracy and duration and reducing climate uncertainty.**

I. Introduction

Remote sensing from satellites provides a global perspective required for weather prediction and climate monitoring and research. Significantly better understanding of the water and energy cycles and associated feedbacks is required to reduce uncertainty about future climate globally and regionally and to extend the duration of accurate weather forecasts. Reducing weather and climate prediction uncertainty requires global observations with substantially higher information content than present satellite observations provide. Here we discuss a constellation of cubesats making radio occultation (RO) measurements that will provide dense, active, very high vertical resolution, precision and accuracy water and temperature profiling. These will complement existing observations of clouds, precipitation, energy fluxes and winds that will tie the entire weather and climate system together as well as dramatically improve the realism and utility of global analyses for climate and forecasting (increasingly extreme) weather.

II. ATOMMS vs. GNSS RO

GPS occultations have provided a major advance in satellite remote sensing of the atmosphere via their very high vertical resolution, precision, accuracy and all-weather profiling from orbit. However, GPS occultations are limited by wavelengths which were chosen specifically to minimize their interaction with the atmosphere. Significantly more information about the atmosphere can be obtained via satellite to satellite occultations made at wavelengths chosen specifically to sense the atmosphere. Here we describe a satellite to satellite occultation system that probes the 22 and 183 GHz water vapor absorption lines and several mm wavelength ozone absorption lines. This system is called the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS). ATOMMS was conceived because GNSS RO cannot simultaneously profile temperature and water vapor and has little sensitivity to water vapor in the UT, the winter hemisphere and stratosphere. Profiling both the speed and absorption of light enables ATOMMS to profile temperature, pressure and humidity *simultaneously*, which GPS occultations cannot do.

III. ATOMMS Performance

ATOMMS profiles extend from the surface to the mesospause with random uncertainties better than 1 kelvin, 10 meters and 3% for temperature, geopotential height and water vapor respectively [1]. It also profiles ozone from the upper troposphere into the mesosphere with better than 3% random uncertainty. Like GPS, ATOMMS will profile the atmosphere with 100 meter vertical resolution in both clear and cloudy conditions. Unlike GPS, ATOMMS both sees and sees through clouds via a differential absorption approach. It will also profile turbulence as well as line of sight winds in the mid-stratosphere and above. ATOMMS will profile rain and constrain the facets of ice clouds via polarization .It is inherently self-calibrating, eliminating drift. Its systematic uncertainties are approximately an order of magnitude better than the random uncertainties.

We also note that while the utility of RO has been questioned due to its horizontal resolution, in the tropical free troposphere, GNSS RO actually observes higher percentages of both extremely high and extremely low humidity than climate models, AIRS and all but one of the global analyses[7]. Clearly, very high vertical resolution, precision and all-weather sampling are important to observing water. The result is that ATOMMS vertical profiling from space with qualities approaching those of sondes but with better accuracy.

IV. ATOMMS Applications

ATOMMS has a myriad of applications including monitoring climate change in terms of temperature, atmospheric stability, water vapor, cloud liquid water, ozone and turbulence. By profiling near surface temperature, water vapor and turbulence, ATOMMS provides unique constraints on surface sensible and latent heat fluxes, a critical and highly uncertain aspect of climate. ATOMMS will provide bias correction for other observations in numerical weather prediction systems. ATOMMS will refine the spectroscopy as required both to interpret the ATOMMS observations and to improve the utilization of other remote sensing instruments using these same lines.

ATOMMS will complement CERES measurements of short and long wave TOA fluxes and Cloudsat and Calipso profiling of clouds and aerosols and Aeolus measurements of winds by providing the key missing global observational element of comparable very high vertical resolution water vapor and temperature profiling for understanding the hydrological and energy cycles. Through its unique combination of features, ATOMMS will act as a global field campaign from orbit for process studies.

V. ATOMMS Ground Based Demonstrations

We have developed a prototype ATOMMS instrument and used it for ground based field measurements [2]. With these measurements, we have demonstrated several important capabilities including retrieving temporal variations in path-averaged water vapor to 1%, in clear, cloudy and rainy conditions, up to optical depths of 17 [3], as well as remotely sensing turbulence and determining rain rates [4].

VI. Orbiting ATOMMS Constellation

In order to have high impact on both weather and climate analyses and forecasts, the number of daily ATOMMS occultations must number in the thousands. Key to placing many ATOMMS sensors in orbit at a reasonable cost are miniaturization of the ATOMMS transmitters and receivers to fly on very small spacecraft, together with a mission design concept that maximizes the number of ATOMMS occultations per day. An ATOMMS constellation must provide both its own transmitters and receivers, in contrast to GNSS RO which requires only receivers. With the proper design, 12 ATOMMS satellites would produce approximately 2,000 daily occultations and 60 satellites could produce approximately 50,000 daily occultations. These satellites would carry GNSS RO receivers as well generating approximately 2,500 daily GNSS occultations per satellite as well.

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