Laboratory and Ground Testing Results from ATOMMS: the Active Temperature, Ozone and Moisture Microwave Spectrometer

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Abstract— **ATOMMS represents a new class of active, airborne, limb-viewing spectrometer that is a cross between Global Positioning System (GPS) occultations and NASA's Microwave Limb Sounder. ATOMMS will characterize atmospheric water vapour and ozone by actively probing the absorption lines at 22.2 GHz, 183.3 GHz and 195 GHz, respectively. Two instrument packages are being constructed for NASA's WB-57F high altitude research aircraft, now equipped with precise WAVES gimballed pointing systems. One aircraft will generate multiple tones near the 22 GHz water line and 183 GHz to 204 GHz absorption lines and transmit them across the Earth's limb through the atmosphere to receivers on a second aircraft. Flight paths of the two aircraft begin over the horizon, with the two aircraft flying at 65 kft altitude. This creates a rising occultation geometry as the aircrafts fly towards each other. ATOMMS provides the sensitivity, vertical spatial resolution and accuracy 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. Predicted 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 flight altitude of ~20 km. 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. The ATOMMS experiment is a pathfinder experiment for eventual implementation on a constellation of satellites. Space observations from multiple satellites in precessing orbits will allow for global spatial coverage and increased altitude coverage. 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.**

The ATOMMS instruments have been completed and are now undergoing extensive laboratory and ground testing. We report on the laboratory testing results including the differential amplitude and phase stability of the instrument and systems integration testing. We will also report on ground testing experiments, where the ATOMMS instruments, located on two building tops, were used to measure atmospheric water vapour content. Comparison measurements were made using in-situ hygrometers. Further ground-based tests are planned to exercise the full ATOMMS system, including the GPS-based positioning and time correction system, accelerometer system and dual-one-way phase correction system. We will also discuss planned instrument upgrades to be implemented in preparation for air-to-ground and air-to-air flights on the WB-57F aircraft.

INTRODUCTION

For more than ten years, our group has been developing an atmospheric remote sensing system called the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS). ATOMMS combines the best features of the GPS radio occultation (RO) [1], [2] and the Microwave Limb Sounder (MLS) [3] techniques by actively probing via radio occultation the 22 GHz and 183 GHz water vapour lines; the latter observe via passive emission by the MLS, and the Ozone emission line near 195 GHz. Our analysis shows that ATOMMS will profile tropospheric and middle atmosphere water vapour and middle atmosphere ozone to 1-5%, temperature to 0.5K, and geopotential heights to 10-20 m, all with ~200 m vertical resolution, in both clear and cloudy air. This unprecedented performance will improve significantly with averaging. Because the occultation signal source is observed immediately before or after each occultation, ATOMMS is self-calibrating, which eliminates long-term drift. These capabilities will fulfil crucial needs for climate change monitoring, research and policymaking.

ATOMMS OVERVIEW

ATOMMS limb-viewing occultation system, promising unprecedented performance, will likely become a key observing system in the Global Climate Observing System (GCOS). We have nearly completed a pair of ATOMMS instrument for the WB-57F high altitude aircraft to aircraft demonstration of its performance.

The ATOMMS instrumental configuration is depicted in Fig. 1. The ATOMMS system consists of 5 elements:

1. The ATOMMS microwave instruments with 13 GHz, 22 GHz and 183 GHz transmitters and receivers,
2. ATOMMS precise positioning system which is a combination of hardware consisting of a GPS receiver and a 3 axis precision accelerometer on each aircraft combined with precise positioning system software from JPL,
3. The two WB57F aircraft,
4. The WAVE gimbal built by SRI for NASA that points the ATOMMS microwave instrument and
5. The ATOMMS retrieval software system under development at the University of Arizona.

During an occultation, each ATOMMS microwave transmitter radiates several monochromatic signal tones that pass through the atmosphere to the receiver on the opposite side of the atmosphere which digitizes and records the signals. We have designed the ATOMMS transmitters and receivers to simultaneously sample water vapor at both the 22 and 183 GHz lines to create the dynamic range needed to profile water vapor from the surface into the mesosphere as well as measure ozone at 195 GHz in the upper troposphere and middle atmosphere. The ATOMMS signal processing system later derives the phase and amplitude of the signals and combines them with the precise knowledge of the transmitter and receiver positions (from the ATOMMS precise positioning subsystem) and physical constrains such as the hydrostatic equation to derive profiles of atmospheric moisture, ozone, temperature and pressure.

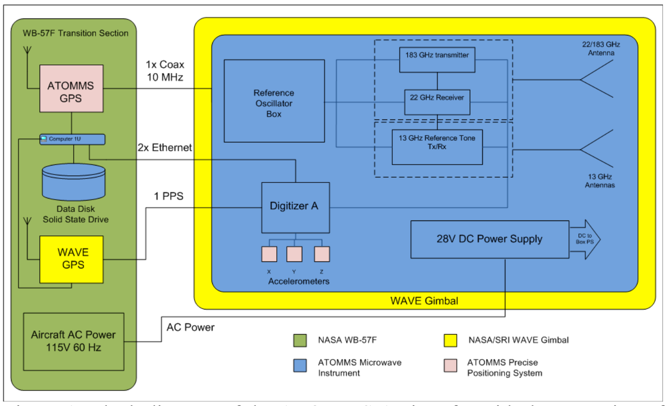


Figure 1: Block diagram of the ATOMMS A aircraft. With the exception of the 22 & 183 GHz transmitter and receiver pairs, ATOMMS B is identical.

Accuracy and Vertical Resolution of Temperature and Water Vapour Profiles

ATOMMS unique observations & parameter retrievals are very well suited for monitoring climate change and will provide a new window into the atmosphere strongly constraining thermodynamic & dynamic processes needed to assess and improve the realism of climate models. The unprecedented combination of performance includes

- High *precision* profiles of temperature to 0.4 K, water vapor to 1-10% and geopotential height to ~10-20 m extending through the free troposphere to the mesopause and ozone to 1-10% through the middle atmosphere, whose *accuracy* should be better by an order of magnitude or more when many profiles are averaged.
- ~200 m vertical resolution, as demonstrated by GPS occultation missions, that exceeds the vertical resolution of passive systems (e.g., AIRS, IASI, AMSU and MLS) by approximately an order of magnitude or more,
- Self calibration because ATOMMS measures differential absorption and the signal sources are measured immediately before or after each occultation which eliminates drift and should provide absolute accuracy,
- Retrievals in both clear and cloudy conditions with performance in clouds expected to be within a factor of 2 of clear sky performance, thus eliminating clear sky biases that plague other remote sensing systems.
- Full sampling of the diurnal cycle every orbit with a satellite constellation like the COSMIC GPS RO mission,
- Refinement of the spectroscopy from orbit [4],
- ATOMMS ability to estimate the climate state independent of atmospheric models, an achievement that is simply not possible with passive radiometric sensors (e.g. [5]), and yet is fundamental to both determining the true climate state and quantifying climate and weather model performance and realism.

A more complete description of ATOMMS and its improvements on the state of the art can be found in [6].

ATOMMS provides the combined vertical resolution and precision critical to resolving the 1.5 km scale height of water vapor and fundamental vertical structure such as ubiquitous layering in the troposphere with vertical scales of a few hundred meters [7]. Only RO can globally determine temperature and lapse rates at the sharp vertical scales at which they vary and can do so in both clear and cloudy conditions. While accurate GPS-RO temperatures are limited to the upper troposphere (by moisture) through the mid-stratosphere (by the ionosphere), ATOMMS will accurately determine temperature and vertical stability from the free troposphere through the mesosphere. Another key point is that GPS-RO measures temperature *or* water vapor, not both. GPS-RO has shown some of the potential for RO observations to measure water vapor in the warmer regions of the lower and middle troposphere with accuracies of 0.2 – 0.5 g/kg [8]. ATOMMS will extend this dynamic range by orders of magnitude to precisely profile water vapor over mixing ratios ranging from several percent in the lower troposphere to a few ppm at the mesopause while simultaneously profiling temperature to sub-Kelvin precision over the same altitude interval. With averaging, we anticipate the absolute accuracies will be better by an order of magnitude or more (depending on spectroscopy which we will refine with ATOMMS).

Upper Troposphere / Lower Stratosphere Retrievals

ATOMMS offers a means to significantly improve our ability to globally measure temperature, water vapor and ozone behavior in the climatically critical upper troposphere and lower stratosphere (UTLS). Despite the crucial roles this region plays in determining how our climate will change in the future, its behavior has been and continues to be poorly observed, particularly on a global scale. To place ATOMMS in context, a basic conundrum for understanding and predicting climate change has been that our ability to measure water vapor and temperature in the upper troposphere (UT) under all sky conditions has been close to nil. The existing observational techniques all have very different types of uncertainties, errors and resolutions. When comparisons have been made, they have not agreed very well. This region is critical for climate because changes in temperature as well as changes in the water and ozone concentrations here will produce large changes in the outgoing long wave radiation that cools the Earth. UT temperature changes are also indicative of how realistic models are in transporting added heat from additional greenhouse gases from the surface up to the upper troposphere. There has been an issue for quite some time as to whether model simulations at the surface in relation to the free troposphere are realistic. For instance, a primary feedback is water vapor above 500 mb. It appears climate models have a tendency to produce more water vapor in the upper troposphere in response to increased greenhouse gas concentrations and surface warming than may be occurring in the real world. Unfortunately we really don't know whether or not this is true because the water vapor and temperature observations in the upper troposphere are simply not good enough.

Retrievals can be made in the presence of most clouds

Earth is at least two-thirds cloud covered [9] such that data sets from remote sensing systems with limited ability to penetrate clouds such as IR probing systems like AIRS [10] & IASI [11] and even MLS will be incomplete and dry-biased. This limits the ability to measure and understand processes that control climate and aid in weather prediction as well as detect and attribute the cause of climate change. GPS experiments have demonstrated the ability of radio occultations to make observations and retrievals in both clear and cloudy conditions (see for instance [12] and references therein). Coincident cloud observations and ATOMMS-derived relative humidity in and around clouds will establish the relation between cloud properties and relative humidity at scales typically resolved by models. Other important issues include the frequency and amount of supersaturation and supercooled mixed phase clouds, all important but poorly observed and understood phenomena sorely waiting for new critical, globally distributed, observational constraints. One can see from these discussions that once deployed in orbit, ATOMMS will provide something approaching a global field campaign for studying convection at the scales of GCMs.

ATOMMS Development Status

A. *ATOMMS Microwave Instrument*

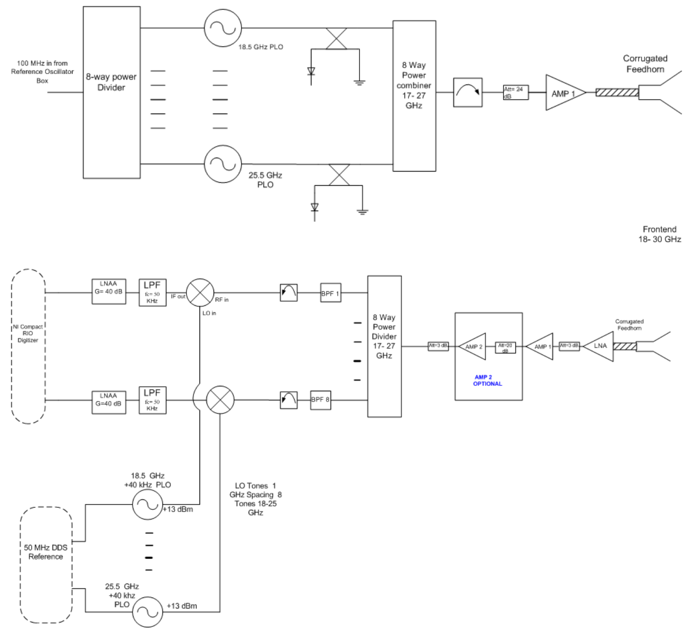


Figure 2: The ATOMMS 22 GHz transmitter (top) and receiver (bottom) subsystems. Two of the eight channels are shown in each block diagram for clarity.

The ATOMMS microwave instrument has been designed to take advantage of off-the-shelf telecommunications technology whenever possible, particularly for the 22 GHz channel. The basic instrument design uses very similar circuits for all channels. Figure 2 shows the block diagram of the 22 GHz transmitter and receiver. The transmitter uses eight separate phase locked YIG oscillators to generate the tones. These tones are individually power-monitored before they are power combined. A single amplifier then amplifies these eight tones to a level of ~100 mW per tone. Since ATOMMS measurements are effected by differential amplitude noise, a common power amplifier is used for all tones to attenuate differential amplitude fluctuations. The receiver amplifies all eight received tones simultaneously for the same reason. The amplified signal is then power divided into eight channels. Bandpass filters in each channel isolate a single received tone. These tones are then mixed with LO signals generated by YIG phase locked oscillators fed with a reference from a DDS synthesizer. This synthesizer is used to offset the frequency of the LO, generating a ~ 40 kHz IF frequency. The low frequency IF is then low pass filtered and amplified with a low noise audio frequency amplifier. The IF is then fed into a National Instruments Compact RIO real-time data acquisition system, where the time domain waveform is digitized and recorded. This data acquisition system has been shown to operate at ambient pressure in the WB-57F in previous experiments. The 13 GHz reference tone transmitter and receiver are identical to the 22 GHz system, but with a single transmitted and received tone rather than eight.

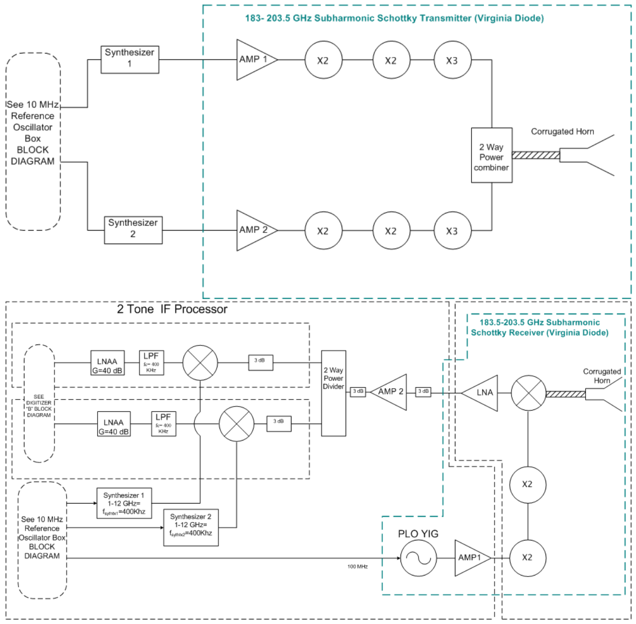


Figure 3: The ATOMMS 183 GHz transmitter (top) and receiver (bottom) system block diagrams.

The 183 GHz subsystem is based on a two tone transmitter and subharmonically pumped Schottky mixer receiver front end from Virginia Diodes. The transmitters each provide 40 mW of power from 180-203.5 GHz, and are power combined using a waveguide magic tee. Power monitoring diodes before the magic tee record the transmitted power level of each channel, for later removal of differential amplitude effects. After power combining, the transmitted power is ~20 mW per tone. The subharmonically pumped Schottky receiver has a measured noise temperature of ~1100K, and is flat across the band. A low noise amplifier with a 1-12 GHz bandwidth relays the IF signal to a downconverter module. The receiver IF downconverter is identical in architecture to the 22 GHz receiver system with the exception that tunable synthesizers are used to generate the LO signals rather than fixed tuned oscillators. Block diagrams of the 183 GHz subsystem are shown in figure 3. Figure 4 shows the 183 GHz transmitter system mounted to the ATOMMS-A rear plate.

The ATOMMS antenna system uses a pair of coaxially mounted feedhorns to illuminate a single 30 cm diameter high density polyethylene lens, anti-reflection grooved for operation at 183 GHz. [13].

A detailed link budget simulated the performance of the instrument using realistic antenna parameters and estimated losses. This link budget was used to specify all the components of the ATOMMS transmitter and receiver systems. Transmitter and receiver pairs are mounted in opposite aircraft, with each aircraft containing a transmitter for one band and the receiver for the other band. This balances both the data acquisition and power needs for each instrument.

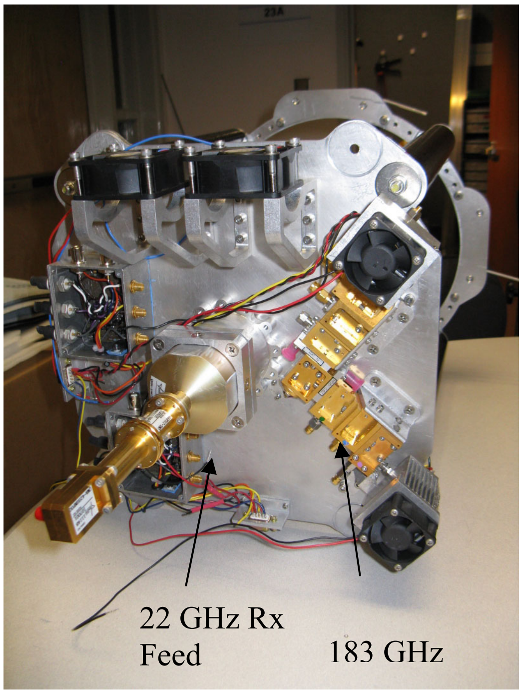


Figure 4: The ATOMMS 183 GHz transmitter system and 22 GHz receiver feed.

The ATOMMS instrument package mechanical aspects are as highly engineered as the electronics. Past experience in flying complex research instruments in the WB-57F aircraft have shown that a fairly sophisticated minimum level of integration of structure, power, thermal, vibration, low pressure and various other design factors are required to build a successful instrument. The ATOMMS instrument design, shown in figure 5, was engineered down to the level of fasteners, connectors and wiring using 3D Computer Aided Drafting (CAD) software before any manufacturing. Figure 6 shows the ATOMMS-A instrument, completely assembled and awaiting system testing.

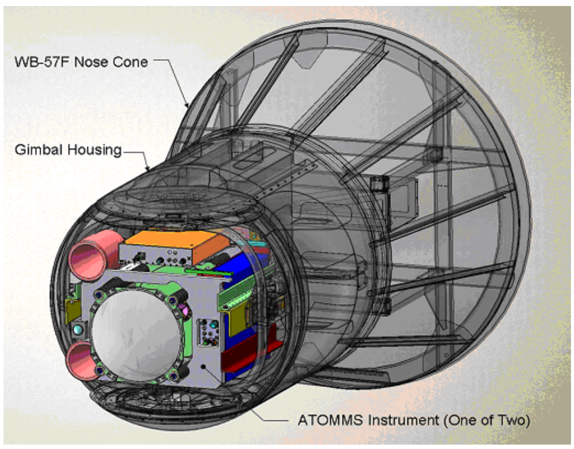


Figure 5: A 3D CAD model of one of the ATOMMS instruments in the SRI WAVE gimbal. The ATOMMS instrument was completely built in CAD before any fabrication took place.

Data acquisition duties are handled by National Instruments Compact RIO systems. These small chassis can be loaded with up to eight multifunction interface modules to handle science signal and housekeeping digitization, digital I/O and accelerometers readout. Each Compact RIO system communicates with a PC over two dedicated Ethernet cables. These PCs are mounted in a partially pressurized part of each aircraft, just behind the moving portion of the gimbal. Each PC is equipped with large capacity solid state hard drives, and runs Labview Realtime OS. These computers receive the data collected by the Compact RIO system mounted directly on the ATOMMS instruments and record the data to disk. They also are responsible for collecting the GPS observables from the JPL provided GPS receiver used as part of the Precise Positioning System.

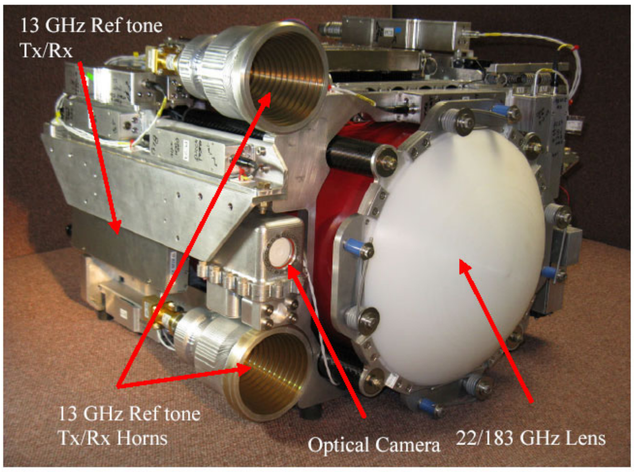


Figure 6: The fully assembled ATOMMS A instrument. Visible components are labeled. The 183 GHz Tx and 22 GHz Rx modules are not visible.

B. Precise Positioning System

The ATOMMS system will profile atmospheric temperature, humidity and pressure. Air temperature and barometric pressure, in a dry atmosphere, are derived from a profile of refractivity that is derived from a profile of bending angle derived in turn from a profile of Doppler shift versus time (see for instance [14]). The determination of the atmospheric absolute humidity profile requires the analysis of the vertical profile of atmospheric water vapour [15], and this is the most important contribution of ATOMMS when compared to the GPS-RO technique that probes only the real part of the atmospheric index of refraction.

In the aircraft to aircraft occultations, the atmospheric Doppler shift is much smaller than for the spacecraft occultation case because the aircraft move much slower (~200 m/sec) than the spacecraft (several km per second). At the uppermost altitudes, just below the altitude of the aircraft, the atmospheric bending angle is quite small. Therefore the atmospheric Doppler shift is quite small. In order to precisely determine atmospheric temperature and pressure, the ATOMMS system must measure very small bending angles at high altitudes. The system goal is to estimate the motion of the aircraft to an accuracy of 0.1 mm/sec.

Over the course of the experiment design, we refined our understanding of the necessity of this goal and how to achieve this small error. The ATOMMS Precise Positioning System consists of accelerometers and GPS receiver on each aircraft. Positions can be estimated very accurately from the GPS receiver data about every 100 seconds. In profiling the atmosphere via the ATOMMS occultations, we determined that we will use integration times of ~10 seconds or less. To achieve the high vertical resolution and performance over these short intervals, we determined that low-noise and very accurate accelerometers must be used. Essentially the precise reconstruction of the time-varying aircraft positions and velocities will integrate the acceleration measured by the accelerometers to obtain the velocities of the two ends of the ATOMMS instrument. The GPS receiver data will essentially be used to estimate the bias and scale factor of the accelerometers. Extremely low-noise accelerometers (Endevco Model 86), developed for seismic research, were selected for the ATOMMS experiment after extensive analysis by the ATOMMS team at the University of Arizona and JPL.

High performance GPS receivers have been selected that could satisfy the ATOMMS requirements that were also familiar to JPL. The receivers already in the WB-57F aircraft were deemed insufficient to deliver the quality of phase data needed. JPL suggested a high performance Ashtech receiver that they use for other applications.

Figure 7: The WAVE system mounted on the nose of a WB-57F. ATOMMS will replace the optical telescope in this system. A microwave transparent radome will replace the front skin and optical window.

C. NASA/Southern Research Institute (SRI) WAVE Gimbal Pointing System

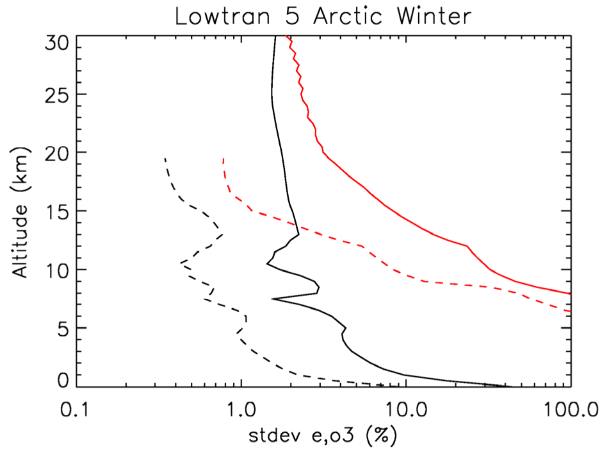
The ATOMMS experiment takes advantage of NASA's WB-57F Ascent Video Experiment (WAVE) system, designed to optically image the space shuttle during launch. This system is a complete replacement nose for the WB-57F, containing a 2-axis gimbaled pointing system capable of 0.25 degree pointing accuracy (see figure 7). The system also contains an optical telescope with a high definition video camera and recorder. The ATOMMS microwave sensors replace this optical imaging package, but still use the replacement nose and gimbal. The optical window will be replaced with a microwave-transparent radome manufactured by Nurad corporation.

ATOMMS does present several challenges for pointing and integration with the WAVE system. The ATOMMS instrument must be adequately balanced, and within weight limits for the gimbal. More importantly, ATOMMS is not an imaging detector, so pointing cannot be done with image recognition. In addition, the atmospheric attenuation effects we wish to measure will not allow pointing based on feedback from the microwave signal strength. Any atmospheric fluctuations would be interpreted as a pointing error, and would cause the pointing loop to become unstable. We have therefore developed, jointly with Southern Research Institute (SRI) a pointing system based on GPS coordinates. As a development effort with NASA, SRI has already proven the capability to point and track a known GPS coordinate to far better than 0.25 degree accuracy in level flight. This accuracy has been demonstrated by SRI on several WB-57 test flights with the WAVE optical sensor. Using an optical camera co-mounted with the ATOMMS instrument, we can calibrate this GPS pointing system using SRI's existing algorithm to allow ATOMMS to also point to within 0.25 degrees of a known GPS coordinate. The ATOMMS microwave beam will be measured in the lab relative to the center of this optical camera to compensate for any fixed pointing offset.

The next challenge was to predict the GPS coordinate for each aircraft, and provide that information to the other aircraft to allow them to point at each other. This will be done with a combination of a pre-computed flight plan based on GPS waypoints and times, and pseudo-real time updates of position provided by an Iridium phone data link between aircraft. Because of the slow speed and unreliability of the Iridium link, the primary location information will be the flight plan, which the pilots will attempt to fly as accurately as possible. Meeting the waypoint locations accurately is not a large challenge for the pilots, but timing arrival at those waypoints is a significant challenge. Therefore, the Iridium link will be used to provide time shifts along the flight path rather than for full position and time information. The code for this implementation has been written by SRI and is now undergoing testing.

D. ATOMMS Retrieval System

Retrieval Software



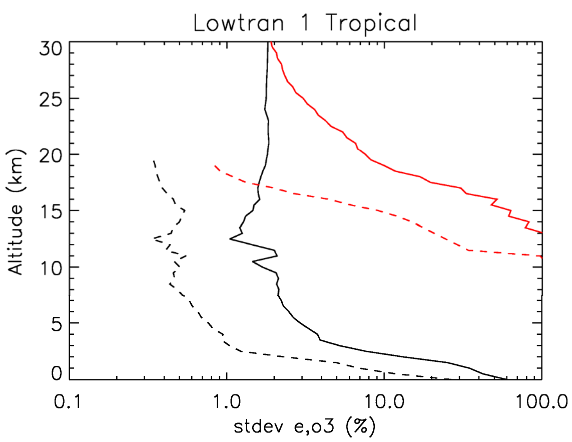


Figure 8. Standard deviation of simulated errors of H2O vapor (black) and O3 (red) from satellite (solid) and aircraft occultations (dashed). top: arctic winter conditions. bottom: tropical conditions.

Prior to this project, we developed simulations to investigate the accuracy of retrievals for an ATOMMS-type instrument in a satellite-to-satellite geometry. We have been adapting this code to perform retrievals in the MRI aircraft to aircraft geometry. We have used this code to understand how instrumental parameters, such as SNR and antenna gain pattern, will affect retrieval accuracy. We have also developed an improved method to deal with liquid water clouds distributed inhomogeneously along the occultation signal path. We developed a two relaxation dielectric model of liquid water for simulating ATOMMS retrievals when liquid clouds are present [16].

ATOMMS will retrieve the atmospheric profile of index of refraction using the method proven to work for GPS occultations, modified for the aircraft geometry. JPL has agreed to provide the JPL GPS occultation processing software to the UA that we will modify for the ATOMMS processing. Simulated errors based on this retrieval technique for water and ozone are shown in figure 8.

Atmospheric Turbulence

Amplitude scintillations ("twinkling of a star") are an unwanted source of amplitude variation that reduces the accuracy of how well we can isolate the absorption on the ATOMMS signals. To better understand this error, Angel Otarola's recently defended dissertation research [17] focused on atmospheric turbulence and its impact on the ATOMMS observations. We have coupled this effort to the retrieval system development to understand the impact these variations will have on the accuracy of the ATOMMS retrievals.

We have developed a relation between the scintillations due to the real part of the wet refractivity variations that allows us to estimate the magnitude of the scintillations due to water vapor knowing the average of the wet-component of atmospheric air refractivity [17]. Using high resolution radiosonde data, we have developed an understanding of the spectrum of turbulent variations in the vertical coordinate in particular the spectral transition from homogeneous turbulence at smaller scales to a different spectral dependence of turbulence at larger scales.

Prior to this work, the impact of turbulent variations in the imaginary component of refractivity has thus far been ignored by the radio occultation community. We are working towards generalizing the equations that describe the impact of turbulence variations in the real part of the index of refraction to include the contributions of the imaginary variations. This work is important because we now realize that the simple two tone amplitude ratioing method described by [4] will not work as well for the imaginary contributions. The two tone method cancels the real contributions well because of their weak frequency dependence, but does not perfectly cancel the contributions due to the imaginary component. Based on this new understanding, we feel that it is essential that we simultaneously measure more than two tones at our high band frequencies (180 – 203 GHz) to diagnose and minimize the effects of turbulence on our retrievals.

Figure 9: View of the Gould Simpson building from AME building. ATOMMS transmitter is shown in right side of the figure on the AME roof. The insert in the lower left shows the ATOMMS receiver on the 11th floor roof of Gould Simpson.

ATOMMS GROUND TESTING

ATOMMS has been undergoing ground testing experiments at 183 GHz for several months. The ATOMMS data is clearly tracking the water vapour variations observed by the rooftop hygrometer of the University of Arizona Department of Atmospheric Sciences.

A. Introduction

ATOMMS is a differential absorption measurement system that will profile water vapour, temperature, pressure and ozone from orbit. The water vapour content is derived from the frequency dependence of the absorption and knowledge of the spectroscopy.

Figure 10: ATOMMS receiver on Gould-Simpson looking back at the transmitter on AME located in the white circle. Photograph taken on the morning of March 12, 2010. The cement beam above the ATOMMS receiver is in front of and above the ATOMMS receiver and is part of a façade that encircles the entire building..

Presently we are testing the “high band” portion of the ATOMMS instrument prototype that probes the 183 GHz water line. In these tests, signals are transmitted from the 8th floor rooftop of the Aeronautics and Mechanical Engineering (AME) building along an 820 m path to the 11th floor rooftop of the Gould-Simpson (GS) building on the University of Arizona campus. The view from the AME building of the transmitter looking toward the receiver on the Gould-Simpson building is shown in figure 9. The view from the receiver to the transmitter is also shown in figure 10. The map of the geometry is shown in figure 11.

B. Phase stability testing

Measurements of the 13 GHz transceiver systems set the phase noise floor for the ATOMMS instrument. The bidirectional 13 GHz system is used for the dual-one-way phase correction system, allowing the data from each aircraft to be phase locked after the fact. Since ATOMMS IF data is recorded as a time series with Nyquist sampling, timing errors between the two aircraft can be corrected after flight. The data from the 13 GHz system is the reference for this process. Figure 13 shows the Allan variance of the phase for the 13 GHz system. With integration times of 0.5s or longer, the phase noise introduced by the 13 GHz electronics is well below the 0.1mm/s velocity specification for ATOMMS.

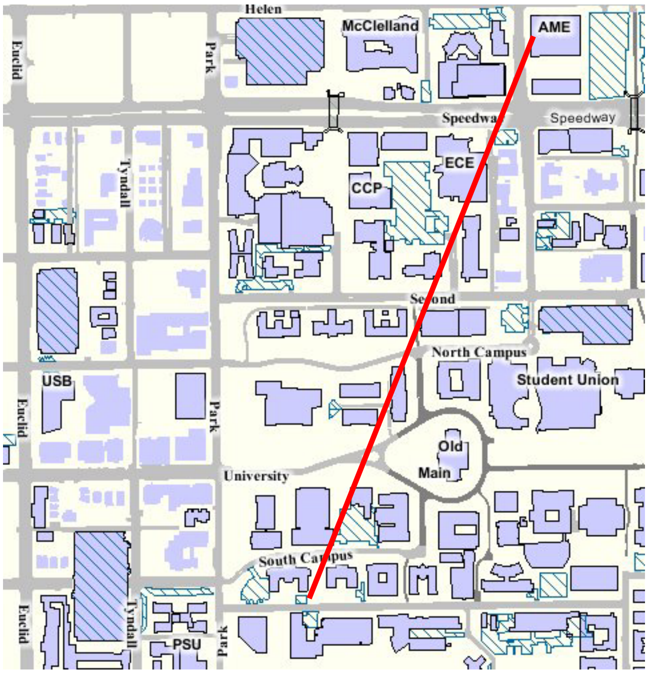


Figure 11: Map of University of Arizona showing the ATOMMS rooftop geometry. Path length is 820 m.

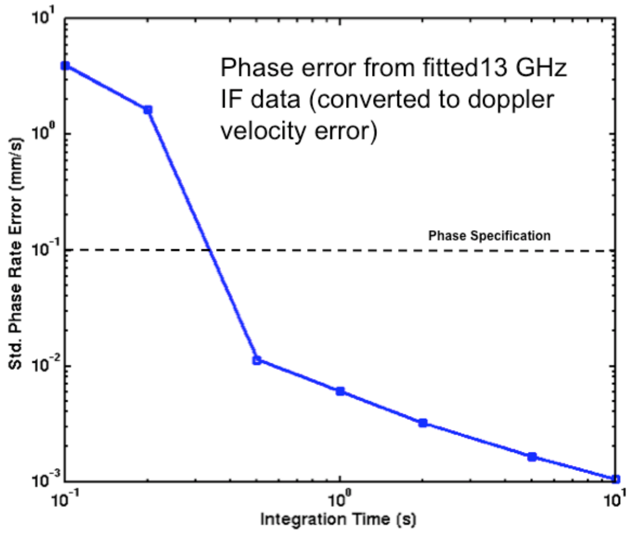


Figure 12: Allen variance plot of ATOMMS phase noise converted to velocity error. The total phase error budget is shown by the dotted line. For integration times of less than 1s, the 13 GHz system is an order of magnitude below the phase error specification.

C. *ATOMMS Atmospheric Measurements*

The ATOMMS ground based testing described above has allowed us to estimate the water vapour content integrated along the 820m line of sight though fitting of the measured 183 GHz absorption line profile. These data have then been compared to a fast capacitive hygrometer located near one of the ATOMMS instrument packages. These first results are shown in figure 14. Given an expected ~10% error in the water vapour content as measured with the hygrometer, the correlation between the two sets of data is encouraging.

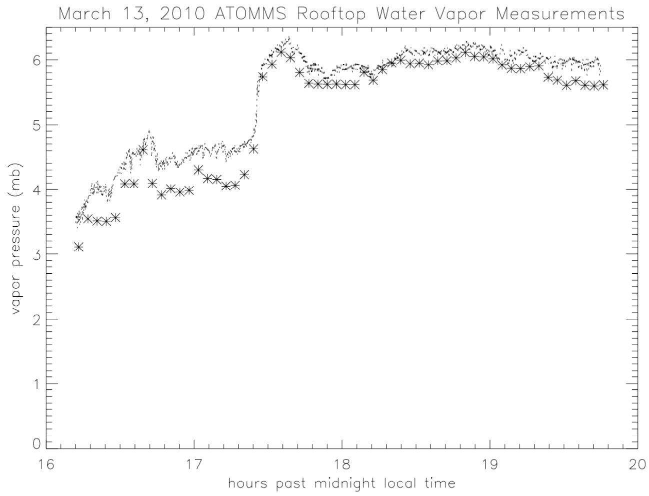


Figure 13: Water vapour data from March 13, 2010 on the University of Arizona campus. Asterisks are water vapour derived from ATOMMS measurements. The fine dots are 5 second partial pressure derived from the capacitive hygrometer on the roof of Physics and Atmospheric Sciences (PAS) building just east of the Gould-Simpson building (see map above).

CONCLUSION

ATOMMS offers a unique and unprecedented capability for measuring key atmospheric variables fundamental to climate independently from models and other climatological assumptions. The ATOMMS aircraft to aircraft occultations offer the best way to demonstrate and assess the ATOMMS concept and its performance without the very costly step of placing at least one if not both of the instruments in orbit. Assuming the aircraft demonstrations prove successful, they will pave the way for support from the larger science community for the ATOMMS concept and a NSF/NASA/NOAA spacecraft mission and a major new global research instrument for atmospheric science. Recent ground based testing shows ATOMMS is capable of measuring amplitudes and frequencies to the required accuracy, a crucial step in the evolution of this instrument.

ACKNOWLEDGEMENTS

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