# P2.7 CHARACTERIZATION OF AIRS TEMPERATURE AND WATER VAPOR MEASUREMENT CAPABILITY USING CORRELATIVE OBSERVATIONS

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AMS 85th Annual Meeting, San Diego, CA, January 2005

## 1. INTRODUCTION

The Atmospheric Infrared Sounder (AIRS) system on NASA's Aqua spacecraft is an important new source of information about weather and climate processes. We use correlative observations to show that AIRS total water vapor estimates have no cloud-dependent biases. We also demonstrate that AIRS is meeting its fundamental measurement requirements of 20% absolute humidity uncertainty in 2 km layers, and 1 K temperature uncertainty in 1 km layers for infrared cloud fraction up to 70%. AIRS has provided over 300,000 globally distributed retrievals per day since September 2002, and has a five-year planned lifetime. Each retrieval includes profiles of temperature and water vapor, plus characteristics of clouds, the surface and minor gases. Higher information content retrievals –at infrared cloud fractions up to about 70%-- result from a combination of infrared and microwave measurements; lower information content retrievals are obtained from the microwave for higher cloud fractions. In this presentation we address several fundamental issues in the measurement of temperature and water vapor by AIRS: accuracy, precision, vertical resolution and biases as a function of cloud amount. We use two correlative data sources. First we compare AIRS total water vapor with that from the Advanced Microwave Sounding Radiometer for EOS (AMSR-E) instrument, also onboard the Aqua spacecraft. AMSR-E uses a mature methodology with a heritage including the operational Special Sensor Microwave Imager (SSM/I) instruments. AIRS and AMSR-E observations are collocated and simultaneous, providing a very large data set for comparison: about 200,000 over-ocean matches daily. We show small cloud-dependent biases between AIRS and AMSR-E total water vapor for several oceanic regions. Our second correlative data source is several hundred dedicated radiosondes launched during AIRS overpasses. Closely matched in space and time with AIRS retrievals, these sondes provide information about the vertical structure of temperature and water vapor. We present height-dependent AIRS-sonde differences at several locations around the globe, and show that AIRS is meeting its fundamental measurement requirements for temperature and water vapor profiles. We also show where AIRS exceeds it vertical resolution requirements. These results demonstrate that AIRS temperature and water vapor retrievals are suitable for the study of a wide variety of weather and climate phenomena.

## 2. OVERVIEW OF THE AIRS EXPERIMENT

The AIRS experiment orbits on the NASA Aqua spacecraft, launched in May 2002. The experiment includes AIRS [Aumann et al. 2003] and companion microwave instruments Advanced Microwave Sounding Unit (AMSU) [Lambrigtsen 2003] and Humidity Sounder for Brazil (HSB) [Lambrigtsen and Calheiros, 2003]. HSB ceased operating in February 2003. The AIRS instrument is a 2378 channel grating spectrometer observing within ±45 degrees of nadir; earth curvature means the satellite zenith angle is within about ±60 degrees of nadir. AIRS samples 33.75 spectra per second, with a nadir field of view diameter of 14.5 km. Each AIRS spectrum is spatially collocated with a 4-channel microwave spectrum from HSB. AMSU has 15 channels, its fields of view are about 45 km in diameter at nadir, and it samples at one-ninth the rate of AIRS and HSB. The AIRS retrieval algorithm is applied to a collocated combination of a single AMSU spectrum and nine spectra each from AIRS and HSB [Susskind et al. 2003]. The AIRS retrieval generates estimates of surface temperature, cloud properties and profiles of temperature and water vapor. The validation of geophysical fields in ongoing [Fetzer et al. 2003; Fetzer et al. 2003a].

## 3. COMPARISONS WITH AMSR-E

The companion Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on the Aqua spacecraft sounds over-water total atmospheric water vapor for all conditions except precipitating clouds (REFERENCE). AMSR-E offers a very large correlative data set (~50,000 points per day) for comparison with AIRS retrieved total water vapor. The total water vapor observations from AIRS and AMSR-E are sampled with fundamentally different methodologies. Consistency between these two datasets –as shown here-- strongly supports the argument that both AIRS and AMSR-E are making reliable measurements of total water vapor.

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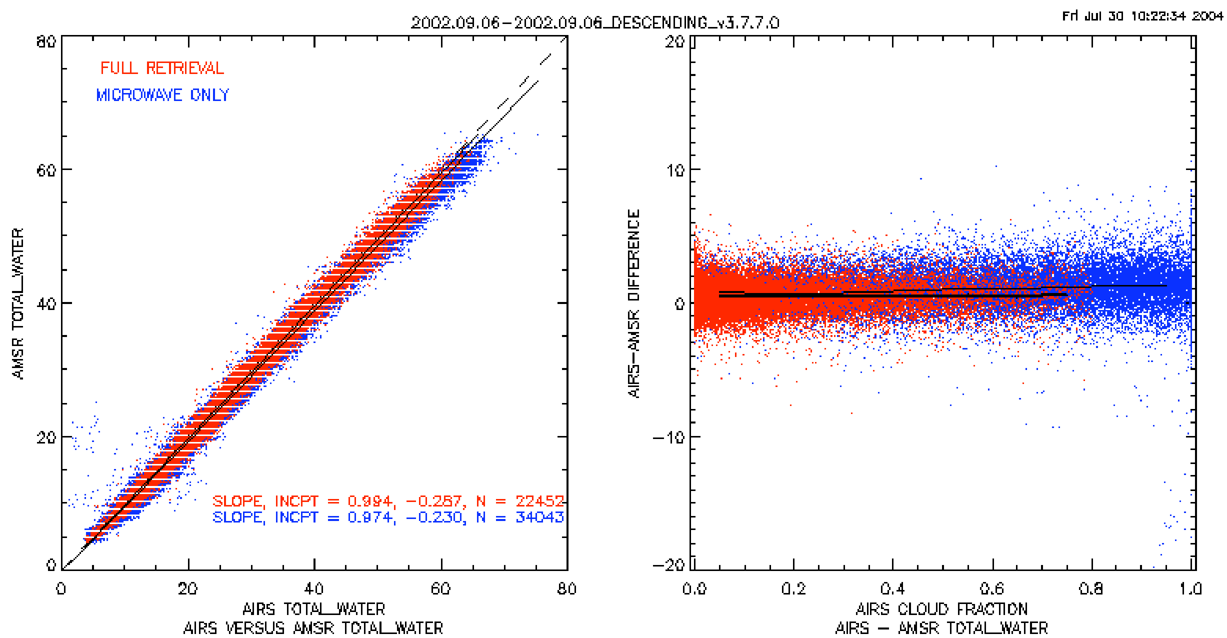


Figure 1. AIRS-AMSR-E comparison for descending (nighttime orbits on 6 September 2002. Left: Total water from AIRS and AMSR-E for full infrared AIRS retrievals (red) and microwave-only AIRS retrievals (blue). Right: The difference between the measurements as a function of AIRS cloud amount.

Figure 1 shows total water from AIRS versus that from AMSR-E for complete and microwave-only AIRS retrievals. (Microwave-only retrievals rely exclusively on radiances from AMSU and HSB beneath heavy clouds, while full retrievals utilize infrared and microwave radiances from the full AIRS/AMSU/HSB suite. Full retrievals occur under clearer conditions; the AIRS retrieval algorithm defaults to microwave-only retrievals under cloudier conditions. No retrievals are generated for precipitating conditions [Susskind et al. 2003].) The correlation for full retrievals in Figure 1 of 0.994, suggests that both AIRS and AMSR-E are correctly capturing the variability in total water vapor. The slightly degraded correlation of 0.974 for microwave-only retrievals is likely due to slight miscalibration of HSB and AMSU.

Figures 2 and 3 further summarize the observations in Figure 1 as a function of AIRS retrieved cloud amount. Several features of Figure 2a are of importance, including the slight decrease in total water vapor with cloud fraction. The explanation for this may be the two generally cloudy phenomena included in Figure 1a: midlatitude storms systems and the Intertropical Convergence Zone (ITCZ). The decrease in mean total water vapor with cloudiness in Figure 1a suggests that the drier midlatitude storms dominate the statistics over the more moist ITCZ. Also apparent in Figure 1a is a rapid decrease in full retrieval yield with increasing cloud amount, a well-known effect.

Figures 2b and 3b show the absolute difference between AIRS and AMSR-E total water. Note the bias of about 0.5 mm of precipitable water for descending (nighttime) orbits in Figure 2b for full retrievals, but almost no bias during daytime in Figure 3b. This may be due to increased stratus cloud at night; stratus has known deleterious effects on AIRS retrievals.

Also apparent in Figures 2b and 3b is a slight increase in root mean squared (RMS) differences for increasing cloud amount. This demonstrates the contribution of clouds to retrieval random error. The slight cloud dependent bias for microwave only retrievals in Figures 2b and 3b may be due to a correlation between surface wind and cloud amount, very light precipitation, or, the slight contribution of cloud to the microwave signal.

Figures 2c and 3c shows the relative errors in percent. Note that all errors are roughly 5 percent or less, the AIRS measurement specification (we are ignoring uncertainties in AMSR-E water vapor). Note also how small biases in Figures 2c and 3c are: less than 4% for microwave only retrievals, and less than 2% for full retrievals.

## 4. COMPARISONS WITH RADIOSONDES

Figure 4 shows AIRS full retrievals versus radiosondes at the Tropical Western Pacific site for 15 September 2002 to 29 April 2003. The upper row of Figure 4 summarizes temperature statistics, and the lower row summarized water vapor statistics. The first column of Figure 4 gives the mean fields from AIRS and sondes. Note that the temperature curves nearly overlie each other. The numbers on the right hand side of the first column in Figure 4 give the number of points used in the

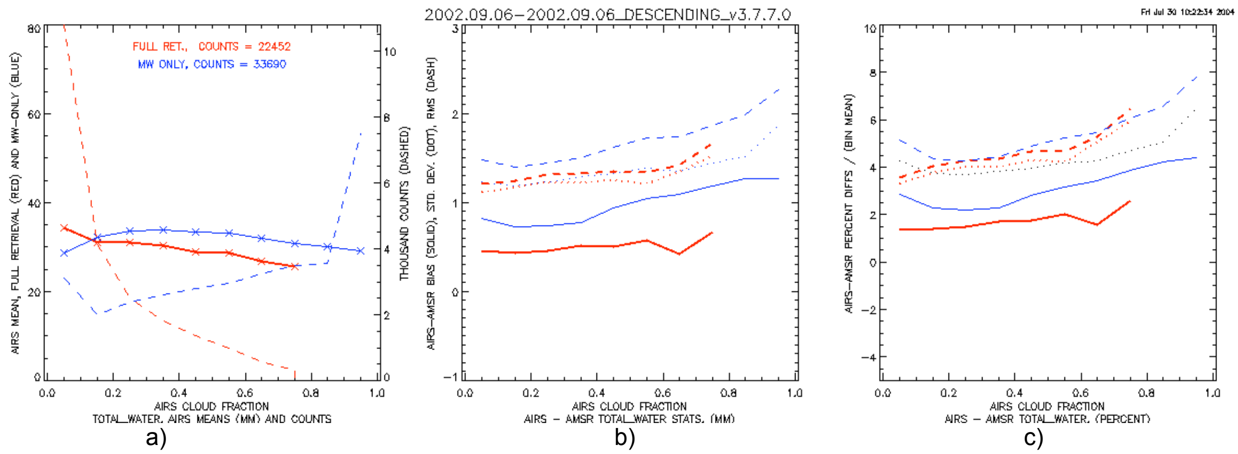


Figure 2. Summaries using same data as Figure 1 of for descending (nighttime) orbits on 6 September 2002. a) Retrieved total water from AIRS (solid lines), and number of retrievals (dashed) for full infrared AIRS retrievals (red) and microwave-only AIRS retrievals (blue). b) Mean (solid), standard deviation (dotted) and RMS (dashed) differences between AIRS and AMSU as a function of AIRS cloud fraction, for full (red) and microwave-only retrievals (blue). c): As in middle panel, but as fraction relative to AIRS means in percent.

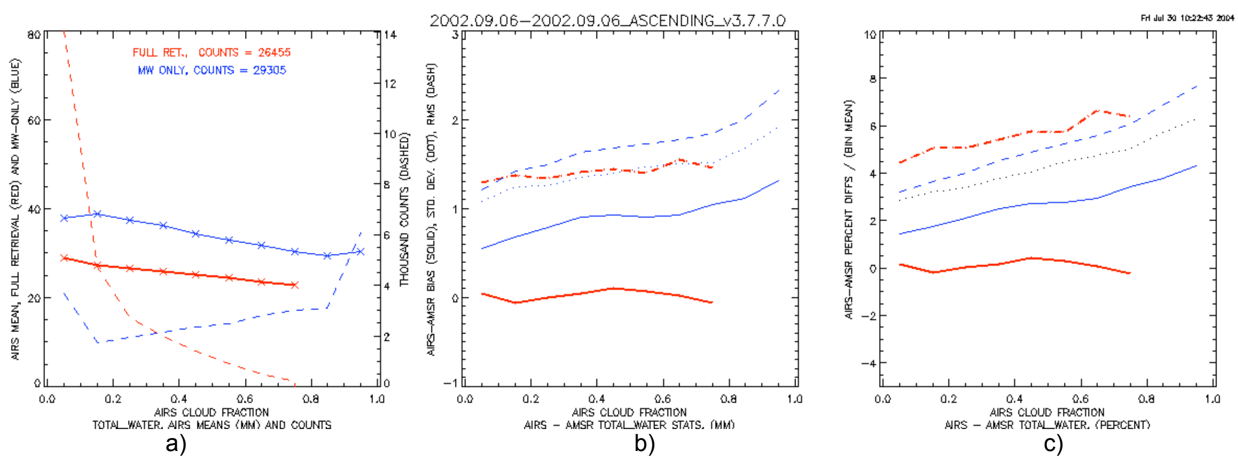


Figure 3. As in Figure 2, but for ascending (daytime) orbits on 6 September 2003.

comparison at each height. The decrease with height reflects different balloon burst altitudes. Each layers shown is roughly 1 km thick.

The center row in Figure 4 summarizes the differences between AIRS and sondes. The bold green lines show the biases and the bold black lines show the RMS. Note that the RMS temperature differences (upper middle panel) are 1 K or less over all the layers in the troposphere. Absolute humidity differences are shown as coefficients of variability (standard deviation divided by AIRS mean), and its mean bias (lower middle panel) is 10% or less.

The left column of Figure 4 depicts the error covariance matrix (values of less than 0.3 not shown). Each element of this matrix is the correlation between AIRS minus sonde differences at the corresponding levels; the diagonal elements are unity, by definition. If the AIRS observations had perfect vertical resolution then the matrices would have only zeroes as off-diagonal elements. Conversely, the size of the off-diagonal elements is therefore a measure of vertical resolution. Note that the matrix is significantly smaller than unity except near and above the tropopause for temperature, and very near the surface and above the tropopause for water vapor. The temperature results demonstrate AIRS cannot fully resolve the tropopause [Gettelman et al. 2004]. The water vapor results show that the surface

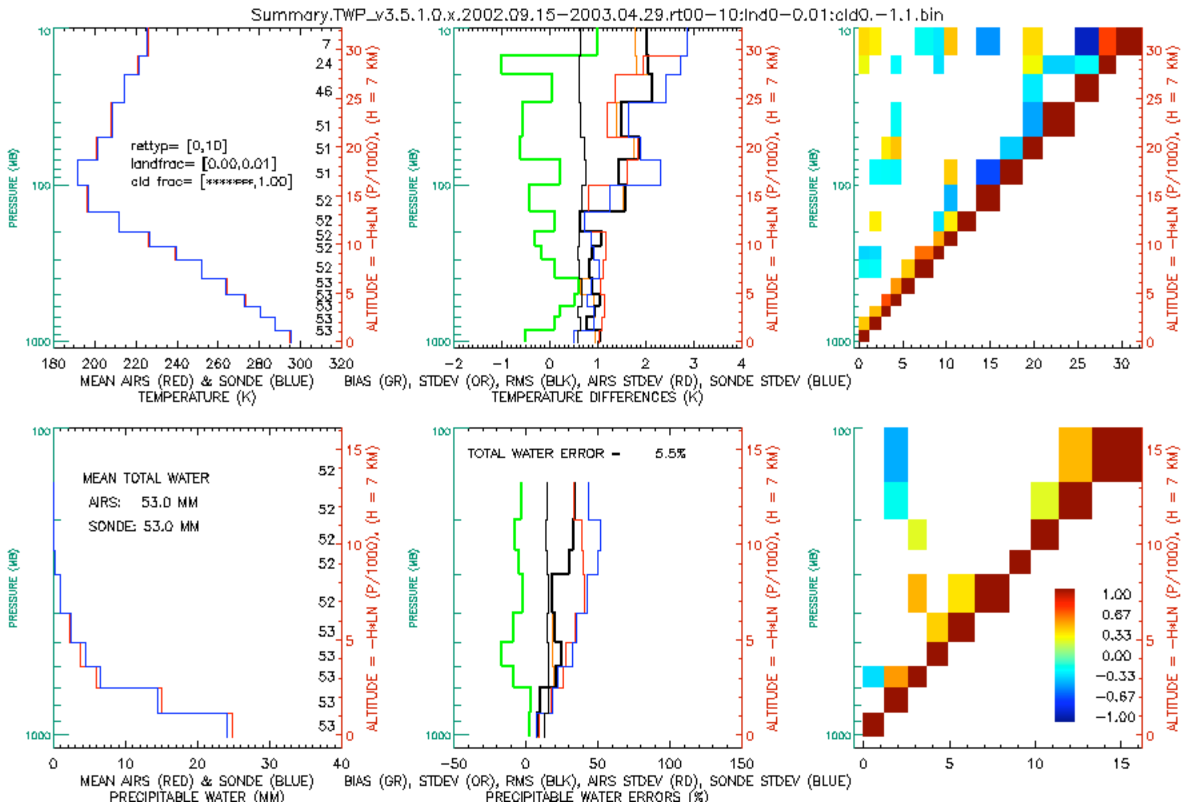


Figure 4. AIRS-sonde statistics at ARM Tropical Western Pacific site.

water vapor is not well resolved, and, that both AIRS and the sondes have no sensitivity to stratospheric water vapor.

We have generated summaries similar to Figure 4 at several locations: the ARM Southern Great Plains Site, the Chesapeake Light Platform, San Cristobal, Galapagos, and a variety of operational sonde launch sites. Those sites are described in Fetzer et al. [2003a].

**5. SUMMARY**

The comparisons shown here demonstrate the following:

- Biases are <2% in total water for all cloud conditions.
- Temperature RMS uncertainties are <1 K averaged into 1 km layers in the troposphere at most location. See Gettelman et al. [2004] similar conclusion in the tropical upper troposphere.
- Humidity RMS uncertainties of ~15% in 2 km layers in the troposphere at the Tropical Western Pacific and other sites.

See Gettelman et al. [2004] similar conclusion in the tropical upper troposphere and lower stratosphere.

Two of conclusions can be reached from comparisons with radiosondes. First, the launch of dedicated sondes has been worthwhile, because only those agree with AIRS to within the 1 K / km and 15% / 2 km specifications. (Operational sondes are generally unbiased against AIRS but the differences show large standard deviations [Fetzer et al. 2003; Fetzer et al. 2004].). Second, even microwave-only retrievals have some vertical information; the exact amount is being investigated using the correlated errors as shown in the right column of Figure 4.

This analysis has not answered one important question: is AIRS height-resolved water vapor unbiased throughout the troposphere, as AMSR-E shows AIRS total water vapor to be? We have not been able to answer that question conclusively for several reasons, including limited radiosondes per site, increasing radiosonde uncertainty with height, and the effect of high natural variability. Constraining the biases in upper tropospheric water vapor is one of the highest priority

AIRS validation activities. Meanwhile, the AIRS water vapor measurements are suitable from studying a wide range of weather and climate phenomena.

## 7. REFERENCES


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