

Atmospheric Soundings of Temperature, Moisture and Ozone from AIRS

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Introduction

The NASA EOS AQUA high-spectral resolution Atmospheric InfraRed Sounder (AIRS) and the Advanced Microwave Sounding Unit (AMSU) were successfully launched into a low earth sun-synchronous polar orbit on May 13, 2002 at an altitude of 705 km. Five months later, NESDIS started to distribute spatially and spectrally thinned radiances to Numerical Weather Prediction (NWP) centers. The thinned dataset contains 324 out of 2378 channel radiances for every 18th AIRS fields of view (fovs). (There are 3x3 AIRS 15 km fovs within every AMSU 42 km fov; the 18th fov is the center AIRS fov associated with every other AMSU fov.) Each dataset include observations from a six minute period, hence there are 240 such “granules” per day. The thinned granule dataset also include all AMSU channels. The impact of AIRS at ECMWF was been reported to be “small, positive and persistent” (McNally, private communication) and the data are now used operationally. The impact at NCEP was reported to be slightly positive, and much smaller than the impact from assimilating the first NOAA AMSU sounder data in 1998. One of the first questions that come to mind is how can a technically advanced high-spectral resolution infrared sounder like AIRS with its excellent signal to noise performance and relatively high vertical resolution have such a small impact. The answer may be due to spatial thinning and the current state of science for radiance assimilation, which is to use only cloud-free radiance observations. The percentage of assimilated AIRS channel radiances can range from 100% for channels peaking in the upper stratosphere, above the clouds, to 5% for channels peaking in the lower atmosphere. However, because the 1 km vertical resolving power of AIRS is concentrated in the lower atmosphere, the lower peaking and likely cloud contaminated AIRS channel radiances are the most important. Given the very small areal coverage of AIRS data being assimilated, due to clouds, the small impact of AIRS, especially in the lower troposphere, is to be expected. So how can AIRS have a larger impact? We believe the answer is to use more AIRS data by assimilating cloud-contaminated or cloud-cleared radiances. Another option is to assimilate the AIRS retrievals of atmospheric temperature, moisture and ozone profiles, which will become available in near real-time during 2004. A key reason for distributing AIRS products to NWP centers is to enable the NWP community as well as the product generators to learn how to best produce and utilize high-resolution infrared sounder data prior to the operational CrIS and IASI instruments. So the

disappointment of a small impact should be followed by intensive activities to use more AIRS data. One of the goals for 2004 from the AIRS Science Team is demonstrate the high quality of AIRS cloud-cleared data and deliver it to the NWP community. The yield of successful cloud-cleared fofs is about 50%. The purpose of this paper is to show the large improvement in retrieval accuracy using AIRS, when compared to AMSU, in the presence of clear and partly cloudy fofs, and also for cases that have been cloud-cleared. We hope the outstanding performance of AIRS retrievals shown in this paper will encourage the NWP community to assimilate cloud-cleared radiances. The algorithms for deriving products, including clear detection and cloud-clearing, from AIRS /AMSU can be found in the special AQUA IEEE issue (Goldberg et al. (2003), Susskind et al. (2003)).

Retrieval Accuracy in Clear and Partly Cloudy Conditions

The clear fov detection techniques and how they are applied are described in greater detail in Goldberg et al. (2003). There are three key tests. The first test predicts a single AIRS channel at 2390 cm^{-1} , which peaks near 850 mb, from AMSU channels 4, 5 and 6, the second test computes the spatial variability of the 2390 cm^{-1} for a 3 x 3 array of AIRS fofs, and the third test, ocean only, compares the AIRS sea surface temperature (SST) retrieval with the NWP model SST. The results shown in this paper will be based on regression, trained using the ECMWF analysis. The regression algorithm is based on principal component analysis (PCA) and details are also given in Goldberg et al. (2003). Eighty five principal component scores (PCS) along with AMSU brightness temperatures are used for linear regression predictors. The first experiment was to generate a set of coefficients for "clear" fofs. The ECMWF data used for training is screened for outliers, because we cannot assume that the model is perfect everywhere. However for many situations the model analysis is rather accurate. The outliers are determined by removing cases with large differences between measured and computed radiances. We also generated coefficients for clear to partly cloudy situations. These cases were determined by simply using test 1. If the difference between the predicted AIRS minus the observed 2390 cm^{-1} AIRS is larger than 2 K, the fov is determined not to be too cloudy (clear, partly cloudy or low clouds). This accounts for about 60 % of the data. The fofs declared clear are approximately 5% of the data. Figure 1 compares retrieval accuracies from clear-only and partly cloudy situations. The figure also compare AIRS vs AMSU-only retrieval accuracies. The "accuracy" curves shown in this figure is the root mean square (rms) difference between the retrieval and ECMWF analysis for an independent ensemble. The solid curves are the retrieval rms differences for ocean clear only cases, whereas the dashed curves are the rms differences for global non-clear cases. The results demonstrate the large improvement of AIRS over AMSU, as well as the very good performance of AIRS even in the presence of cloud contamination. The coverage for the clear - partly cloudy areas area shown in Figure 2.

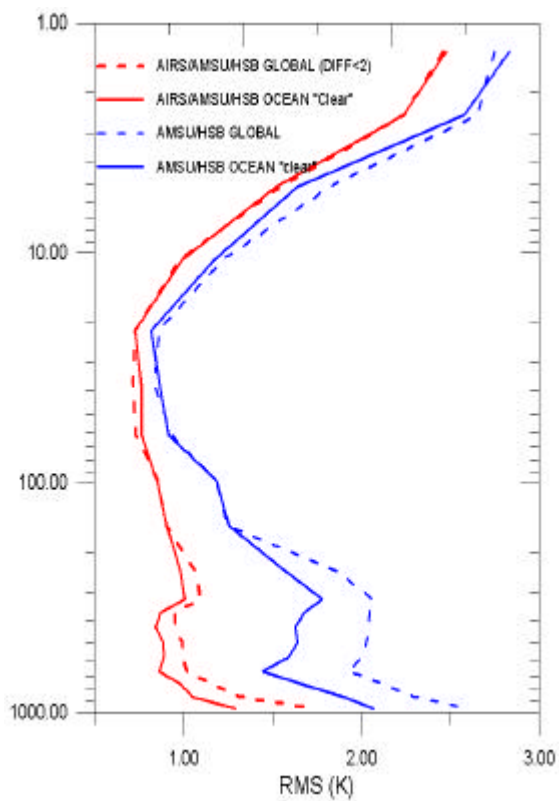


Figure 1 Retrieval RMS Errors

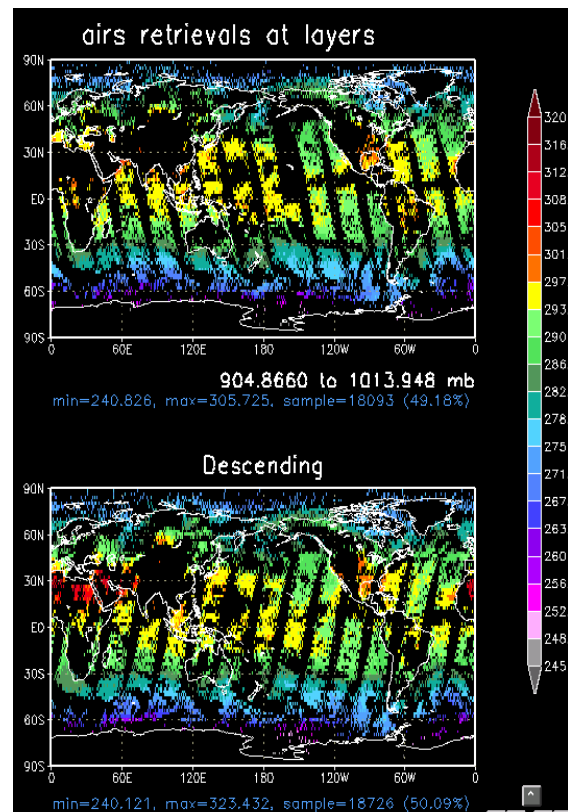


Figure 2: Coverage of partly cloudy regions

Retrieval Accuracy from Cloud-Clearing

The cloud clearing algorithm is described in Susskind et al. (2003). Cloud-clearing begins with an AMSU retrieval of atmospheric temperature, moisture and skin temperature. The retrieval is used as the first guess in the cloud-clearing algorithm. After the AIRS radiances are cloud-cleared, the cloud-cleared radiances are transformed into principal component scores (PCS), and the PCS are used as regression predictors for deriving the AIRS/AMSU temperature, moisture and ozone retrieval. The conversion of radiances to PCS also yields the reconstruction score (RS). The RS provides a measure of how well the radiances can be reconstructed, when compared to the input radiances. A reconstruction score of unity indicates that the reconstruction fit is at the noise level. For cloud-cleared radiances, the score can vary from 0.33 to a number much greater than one. The RS is near 0.33 when the entire 3x3 array of AIRS fovs is clear and the cloud clearing algorithm simply averages the radiances from the 9 fovs. When the score is greater than one, the cloud clearing has amplified the noise with respect to a single fov. Figure 3 shows maps of RS for different ranges of RS. The map on the upper left (RS<0.5) show the areas (~5%) that have been declared clear (i.e. all 3x3 fovs are clear). The map on the upper right show the areas where the cloud-cleared radiance have adjusted noise characteristics that are not larger than the original instrument single fov noise (RS< 1). This area is about 60% of the total. So we

can restrict the use of cloud-cleared radiances to cases with “zero” single fov noise amplification, and still achieve a very good yield. The lower left shows areas where the score is less than 2, and we have observed that the larger RS are near the edge of clouds.

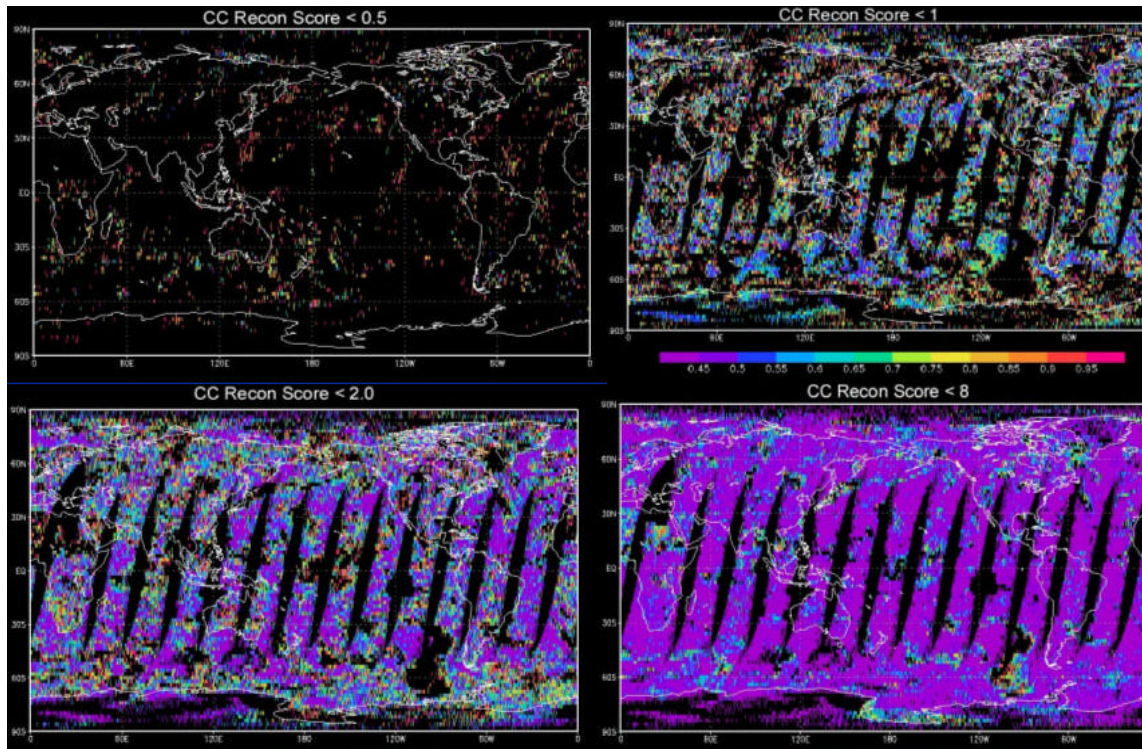


Figure 3 Cloud-Cleared Reconstruction Scores

Regression coefficients were generated from a training set of cloud-cleared radiances collocated with the ECMWF analysis of temperature, moisture and ozone. The ECMWF data are screened by requiring a 2 K agreement between measured and computed radiances for 12 channels: 702.7, 706.7, 711, 712.7, 715.9, 724.8, 746.0, 759.57, 965.4, 1468.83, 1542.35 and 1547.88 cm^{-1} . The training set was derived from three different days (from September 2002, January 2003 and June 2003). Figure 4 shows the a typical training population for a given day. The retrieval accuracy, compared to ECMWF for dependent and independent ensembles are shown in Figure 5. The RMS differences are similar to those obtained from clear fovs, which were shown in Figure 1. We also generated retrieval rms differences based on collocated radiosondes. Figure 6 show the results, along with retrieval rms errors from ATOVS. The AIRS retrieval errors are significantly lower than ATOVS, including the systematic bias. The larger errors for the lower tropospheric temperature are probably due to uncertainties arising from collocation temporal and spatial differences. However, the difference between the ATOVS and AIRS retrieval remains large. Previous simulation studies have found that AIRS generally reduces the retrieval error by about 0.5K, and this appears to be holding for the radiosonde comparison. For moisture, the retrieval errors are significantly smaller than ATOVS. The natural large variability of water vapor combined with uncertainties in radiosonde-observed water vapor will prevent us to yield the 10-15% accuracies often reported in simulated studies.

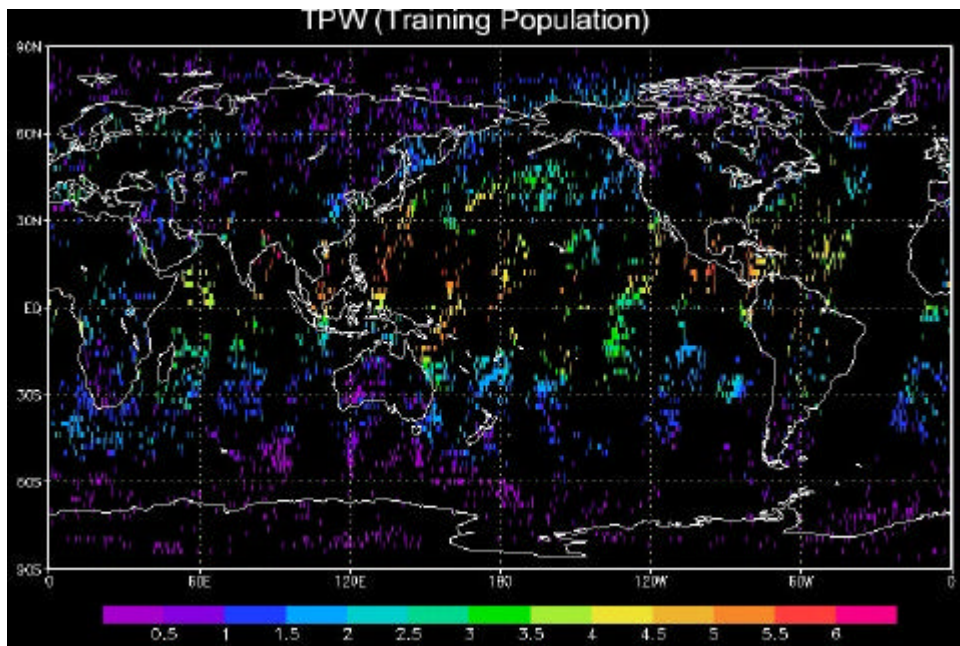


Figure 4. Distribution of collocated AIRS and ECMWF data used in generating regression coefficients.

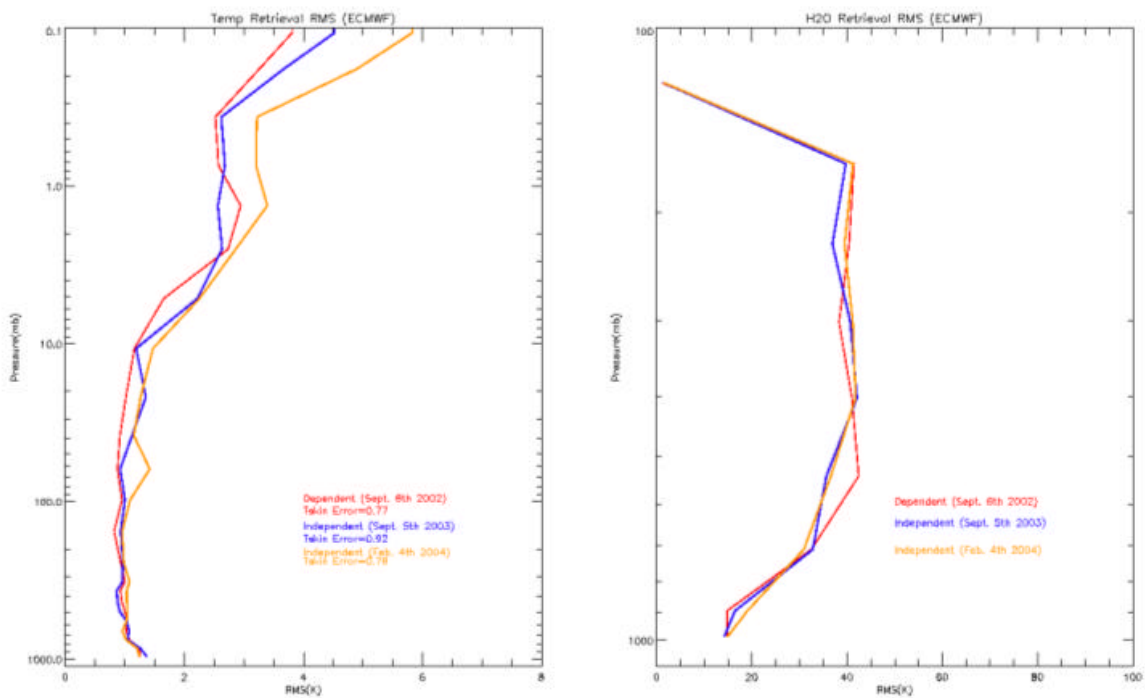


Figure 5 Temperature (K) and Water Vapor (%) RMS difference between AIRS retrieval and ECMWF

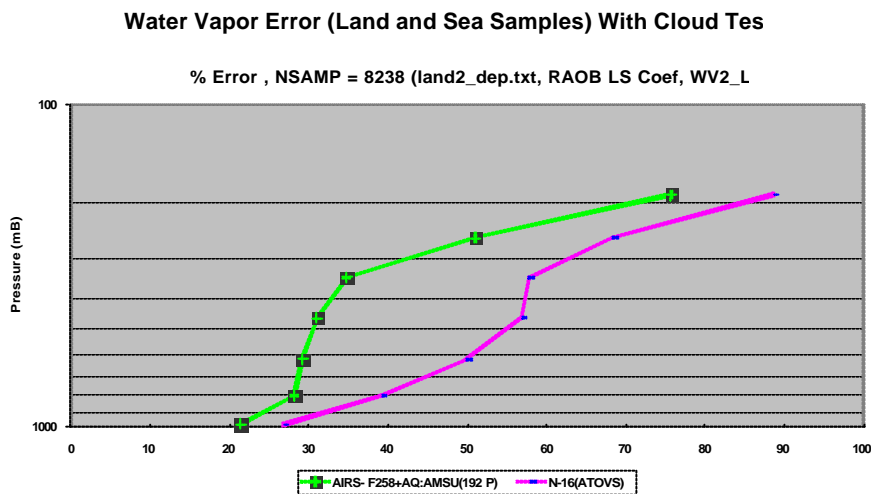
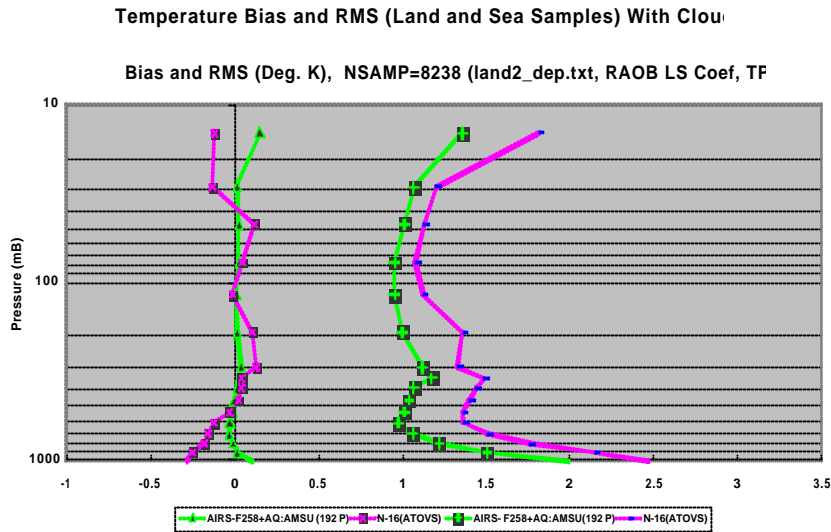


Figure 6 Temperature (K) and Moisture (%) RMS differences between retrieval and collocated radiosonde.

Summary

We have demonstrated very good retrieval performance from AIRS in clear, partial cloudiness and cloud-cleared fogs. The impact in NWP will likely remain small, unless AIRS cloud contaminated or cloud-cleared radiances are assimilated. The challenge for the NWP satellite data assimilation community is to assimilate AIRS data in the presence of clouds, otherwise the full impact of high spectral resolution infrared observations will not be realized. Another option, of course, is to assimilate AIRS retrievals, which are also derived in near real-time.

References

- Goldberg, M.D., Y. Qu, L.M. McMillin, W. Wolf, L. Zhou, and M. Divakarla, 2003: AIRS near-real-time products and algorithms in support of operational numerical weather prediction, *IEEE Trans. Geosci. Remote Sensing*, vol.41, pp 379-389, Feb. 2003
- J. Susskind, C. Barnet and J. Blaisdell, Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data under cloudy conditions, *IEEE Trans. Geosci. Remote Sensing*, vol.41, pp 390-410, Feb. 2003