Validation of AIRS / AMSU / HSB retrieved products

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ABSTRACT

We describe preliminary comparisons of AIRS/AMU/HSB retrieved geophysical products with correlative data sets to constrain retrieval uncertainties. The results are relevant to oceans at latitudes from 40S to 40N where infrared retrievals are completed, or about 70% of retrieval footprints. Comparisons are further limited to those retrievals whose sea surface temperatures (SST) agree with forecast model SST to within ±3 K. Retrieved cloud cleared radiances and those calculated from weather forecast model output agree within 0.5 to 3 K, depending on cloud amount. Retrieved sea surface temperatures at night are compared against model output, with a resulting difference of 0.94 ±0.95 K (a result skewed by the ±3 K selection criterion). Retrieved temperature profiles are compared with model output, and with dedicated radiosondes. Temperature profile uncertainties vary from about 1.3 K just above the surface to less than 1 K in the troposphere, with the random errors dominating. Water vapor is compared against dedicated radiosondes. Under dry conditions retrieved total water vapor agrees with radiosonde total water to within 10%, with small biases. The current retrieval generates SST and water vapor products below system specifications, but AIRS is meeting its 1 K per km requirement for temperature retrievals in the troposphere.

Keywords: validation, retrieval, infrared, microwave, sounding, temperature, humidity

1. Introduction

The AIRS/AMSU/HSB (Atmospheric Infrared Sounder / Advanced Microwave Sounder / Humidity Sounder for Brazil) –AIRS hereafter– retrieval system described in [1] is currently producing geophysical products of temperature and water vapor profiles, cloud properties, surface temperatures, and ozone and other trace gases. The specifications for retrieved and other data products are presented in [2]. These products are scheduled for public release in early August 2003. Validation is the process of comparing these retrieved products with other data sets to constrain the retrieval uncertainties. Retrieved products need be validated at only a preliminary level one year after launch, so we address here only nighttime sea surface temperatures (SST) and over-ocean profiles of temperature and water vapor. Validation of all products under a full range of conditions is an ongoing activity.

The approach for validating all AIRS/AMSU/HSB products is detailed in [3]. Validation results for AIRS, AMSU and HSB observed radiances and the AIRS forward model –not retrieved products but important in their interpretation—are now summarized. AIRS radiances shows agreement with in situ observations to within calibration limits of about 0.1 to 0.5 K in brightness temperature, depending on wavelength. The AIRS radiative transfer forward model described in [4] agrees with in situ observations to within about 0.5 K in brightness temperature at those frequencies whose primary source is the surface or lower troposphere. Validation of the AIRS forward model for upper level vapor is an active area of research. The microwave instruments have known biases of roughly 0.67 to 0.95 K due to uncharacterized sidelobes. These biases propagate into the uncertainties in the retrieved quantities. Microwave random errors are as great as 2.2 K, depending on frequency, within pre-launch calibrations limits. The Humidity Sounder for Brazil instrument ceased operating on 5 February 2003, and has not been restarted.

Several correlative data sources are currently being utilized in the validation of retrieved products, including operational radiosondes, AIRS-dedicated radiosondes, operational marine buoys, and general circulation model assimilation reanalyses. Results presented here are limited to comparisons with model reanalyses and with dedicated radiosondes from two oceanic sites.

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The model reanalyses are interpolated to the locations of the AIRS retrievals using simulation software described in [5]. Generating retrieval statistics against climate models is particularly straightforward since the datasets are in identical formats. The model comparisons have the other major advantage of global coverage; few radiosondes are available from oceanic sites. The model simulations are currently the sole source of correlative information about cloud cleared radiances. Simulations have been generated for eight days during the first year of operations, but we utilize 6 September 2002 in this report. The model temperature fields are of highest quality, with water vapor more problematical. Model clouds are highly suspect for direct validation comparisons.

In this study also utilize operational buoys and operational and dedicated radiosondes. These measurement systems generally have better error characteristics than the model fields. The dedicated sondes are the highest fidelity truth data sets because of minimal mismatch errors.

2. Pre-Filtering by Sea Surface Temperature Retrievals

This report addresses only those retrievals whose SST agrees with the National Center for Environment Prediction (NCEP) forecast SST to with 3.0 K. The motivation for this rejection criterion is illustrated by Figure 1 and Figure 2 below, which show where AIRS retrieved SST differs from European Center for Mediumrange Weather Forecasting (ECMWF) reanalysis SST to within 3.0 K, (blue) and greater than 3.0 K (red). (NCEP and ECMWF SST fields are essentially identical.) White regions show where the retrieval solution reverts to microwave only, generally indicating cloud cover of greater than 70%.

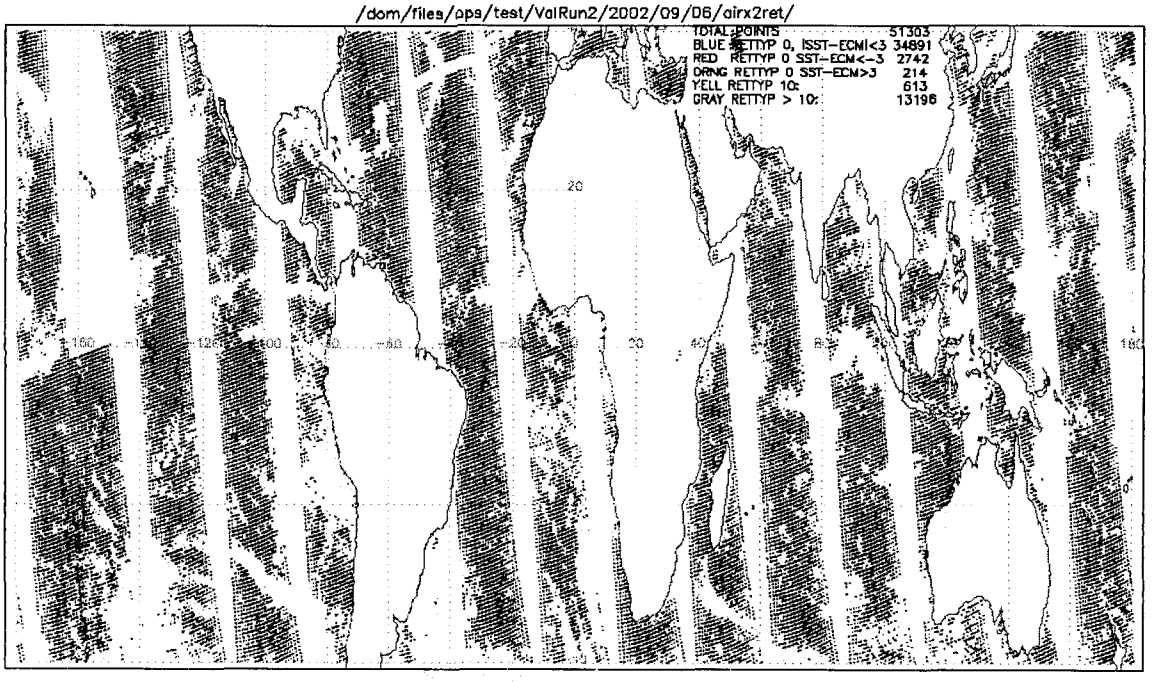

Figure 1. Daytime (ascending orbital node) locations where AIRS retrievals agree with ECMWF reanalysis to within 3.0 K (blue) and more than 3.0 K (red) for oceans between 40 S and 40 N, 6 September 2002. White gives those locations where the full AIRS retrieval reverted to microwave-only due to cloudiness greater than about 70%.

As these figures show, rejection by the SST criterion of 3 K is highly localized, with large regions found off the west coasts of South America, Africa, and Australia. This is apparently due to persistent, low stratus in these regions, a conclusion corroborated by the shape of observed AIRS infrared spectra. Stratus also introduces a diurnal cycle into the retrieval yields, with higher yields in daytime. Yields are 74% for the daytime versus 69% for nighttime for the figures shown, and other days are similar. These differences are consistent with more extensive stratus coverage at night.

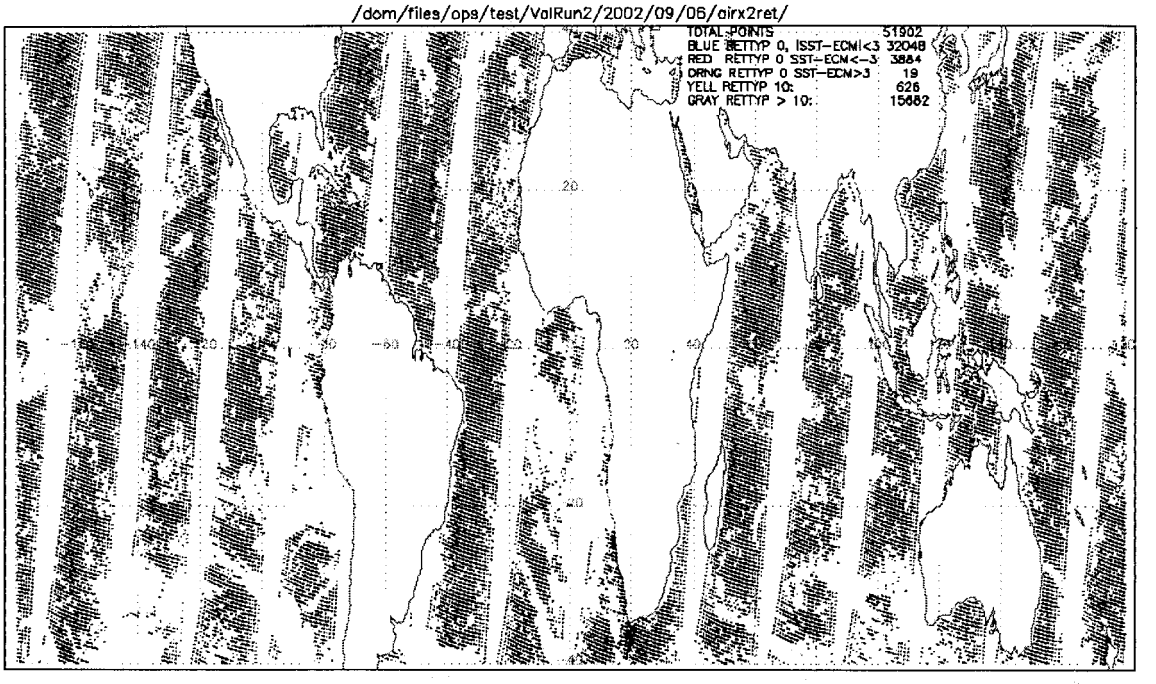

Figure 2. As for Figure 1, but for daytime (descending orbital node).

Another known cause of retrieval rejection is dust. AIRS spectra from west of Africa on 6 September 2002 exhibit a strong silicate signature in the 800 to 850 wavenumber infrared spectral band. Dust is therefore a presumed contributor to the higher retrieval rejection rate over the Atlantic off West Africa. Yet another known cause of retrieval rejection is cirrus clouds, described in the AIRS data in [6]. Optically thick cirrus is a presumed cause of retrieval rejection on the edges of the cloudy regions in the tropics and midlatitudes away from the subtropical stratus regions. Also, certain cloud configurations give inhomogeneous detector response, with consequent spurious temperature differences with frequency. Finally, certain types of clouds lead to degenerate retrieval solutions, as discussed in [5].

Note that more than one of these factors may be in effect simultaneously. For example, Saharan dust appears to be leading to retrieval rejection in regions of stratus near westernmost Africa, and of cirrus in the Bight of Benin. All three effects may be at play in some retrieval footprints off Africa. Similarly, cirrus clouds, highly inhomogeneous fields of view, and degenerate cloud structures may be leading to retrieval rejection along the edges clouds in non-stratus regions.

3. Cloud-cleared infrared radiance

The AIRS system retrieves cloud cleared radiance –the radiation emitted by the cloud free part of a scene– using a combination of one AMSU microwave spectrum and nine AIRS infrared spectra [1]. Cloud cleared radiance correlative observations are estimated by calculating radiances with a forward radiative transfer model using forecast model fields as input, but not calculating the cloud contribution. This yields a large set of spectra for comparison with AIRS retrieved radiances.

The upper panel of Figure 3 shows the AIRS retrieved cloud cleared radiance and the ECMWF model calculated radiances on 6 September 2002 for nighttime scenes with retrieved cloud fractions of 0.2 to 0.3 less. The lower panel is the mean bias and the standard deviation of the difference. Restricting the comparison to nighttime reduces the effect of surface reflection and non-local thermodynamic equilibrium at shorter wavelengths. The cold biases of about 1 K in the window regions around 750-100 and 2500-2650 cm^{-1} have three possible sources. First is a misrepresentation of model SST, known to be warm by roughly 0.5 K at night. The second possible cold bias source is AMSU sidelobes, discussed above. Finally, misidentified clouds are usually colder than the underlying surface, leading to a cold bias in cloud cleared radiances. Similar figures to Figure 3 for cloud fractions near zero are essentially identical, suggesting minimal cloud contribution for low cloudiness scenes. Errors from misrepresented of clouds grow for cloud

fractions greater than 0.5, however, and can contribute up to 3 K rms for cloud fraction of 0.7 to 0.8. So, given the known model skin effects, the biases in the window region in Figure 3 are about 0.5 K.

Other spectral regions of Figure 3 show systematic differences due to known model problems. Most notably, the water vapor bands around 1400 to 1600 and 2300 to 2400 cm^{-1} are biased warm. This is caused by a known dry bias in the ECMWF model in the upper troposphere. Similarly the cold bias in the ozone band around 1000 to 1100 cm^{-1} is from model misrepresentation of ozone, and the warm biases on the far left of the curve are from a cold upper stratosphere in the ECMWF model.

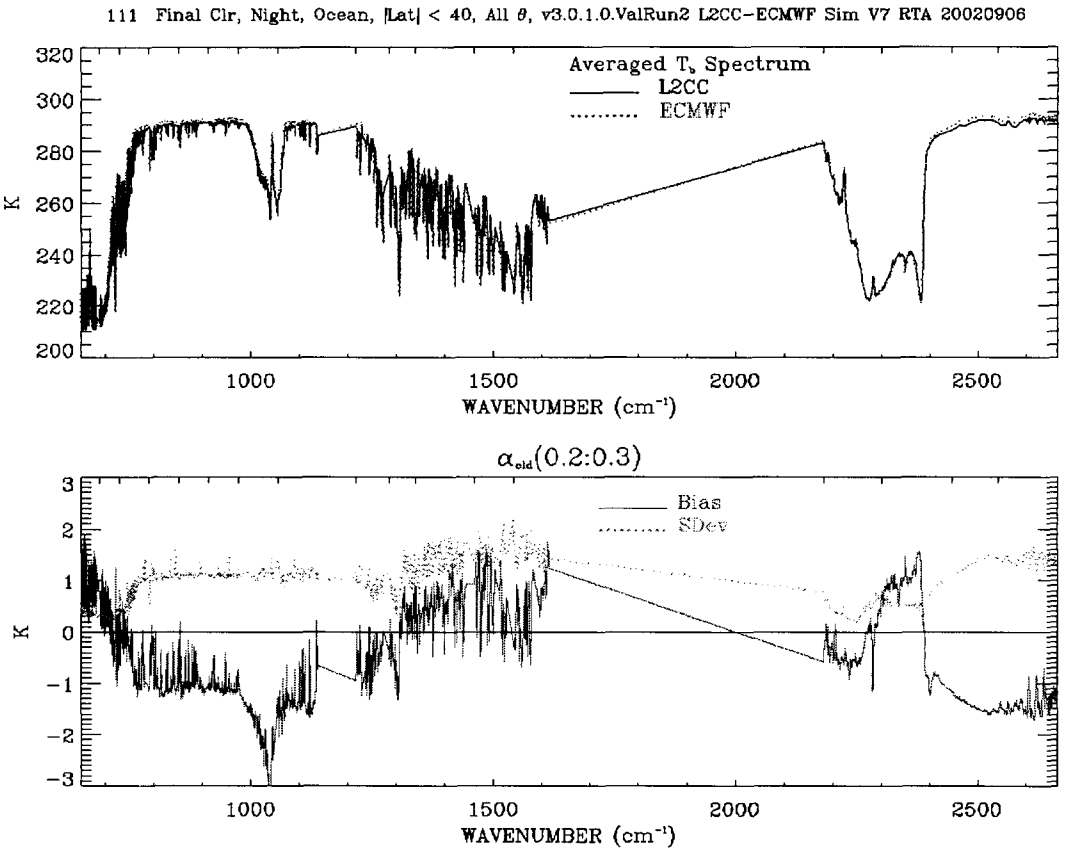

Figure 3. Upper panel: mean retrieved cloud cleared radiances and ECMWF-generated cloud free radiances, 6 September 2002 nighttime over ocean, 40S to 40N. Lower panel: statistics of differences.

4. Sea surface temperature

Maps of SST differences between retrievals and ECMWF for nighttime on 6 September 2002 are shown in Figure 4, and the associated distribution is shown in

Figure 5. Nighttime-only retrievals are shown because reflected sunlight contributes large uncertainties during daytime in the current retrieval system. The cut-off at -3 K in the distribution is due to the 3 K rejection threshold discussed above. The global distribution of SST error is not uniform. Retrievals tend to be biased cold in the north Atlantic and southern Indian oceans. Blue areas, or retrievals biased cold by more than 2 K, off the west coasts of North Africa and Australia may be associated with stratus clouds in those regions. Warm biases are generally tropical and presumably associated with convective clouds. The association between warm biases and tropical convection is supported further by the extensive patch of orange (retrieval warm biases greater than 2 K) southeast of the tip of Baja California associated with Tropical Storm Henriette and Hurricane Gil. Both tropical disturbances were active in the eastern Pacific on 6 September 2002.

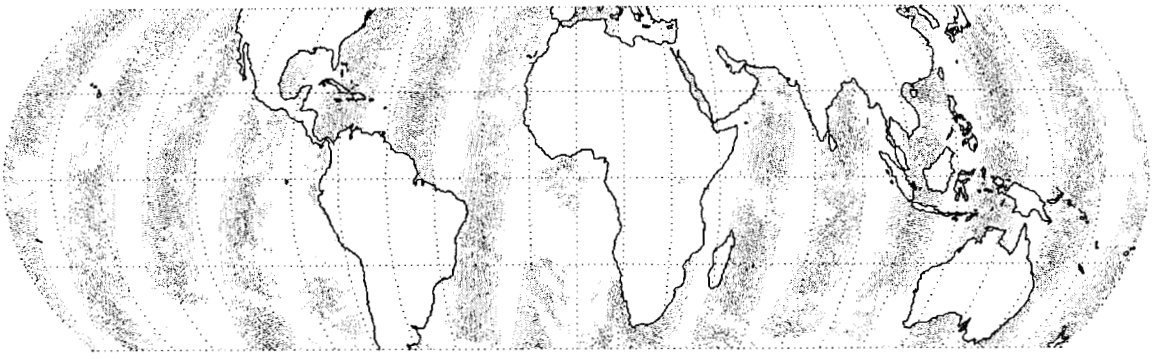

Figure 4. Differences between nighttime retrievals and ECMWF SST for 6 September 2002. Color scale is at top of figure. White areas are either have retrieved cloud cover greater than 70%, or retrieved SST deviating from forecast by more than 3 K. Compare with Figure 1 and Figure 2 showing regions of retrieval rejection.

As Figure 5 shows, the retrievals are biased cold by 0.94 K. Part of this bias is due to a known nighttime disagreement between skin and bulk temperatures of about 0.5 K. The remainder of the uncertainty is due to errors in cloud clearing procedure.

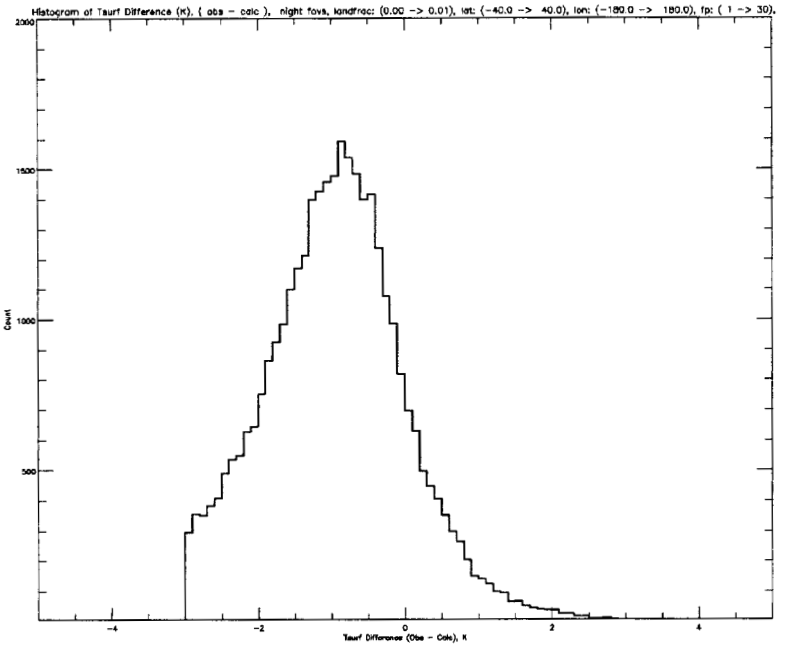

Figure 5. Histogram of the SST differences mapped in Figure 4. The abscissa range is –5 to 5 K. The mean of and standard deviation of this distribution are –0.94 ± 0.95 K.

5. Temperature profiles

Figure 6 shows the nighttime-only rms difference between AIRS and ECMWF temperature profiles on 6 September 2002 over ocean from 40S to 40N, where SST agrees with NCEP to ±3 K. Figure 7 gives results for daytime. These figures are each generated from about 50,000 AIRS retrievals. The red curves are the full infrared retrieval result. Between about 850 mb and 200 mb the agreement is better than 1 K rms. The higher uncertainty in the bottom of the atmosphere is likely from errors propagating from the microwave sidelobe biases. The slightly better statistics during nighttime may be due to reduced convective activity at night. Convective clouds degrade retrievals through scene homogeneity and associated cirrus cloud.

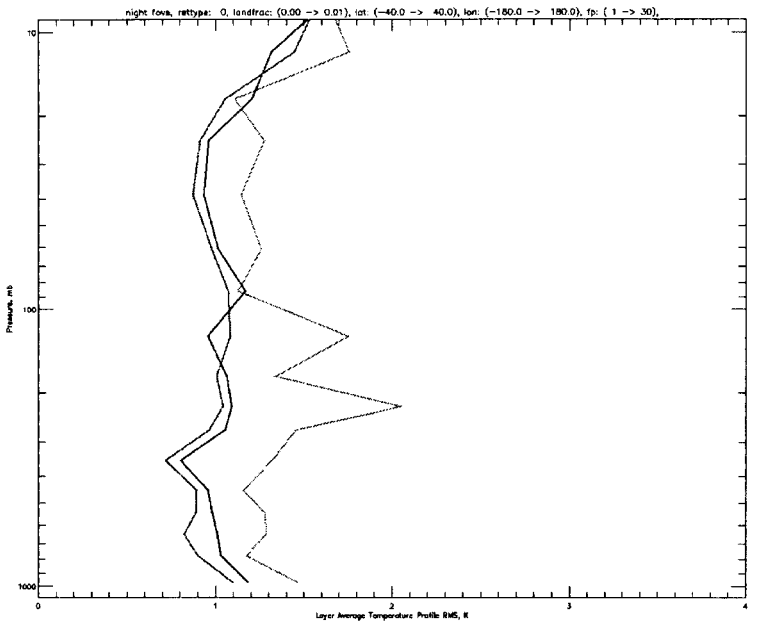

Figure 6. Nighttime only root-mean-square difference over 1 km layers between AIRS retrievals and ECMWF reanalyses for 6 September 2002. Statistics are for oceans between 40S-40N, where retrieval SST agrees with NCEP forecast to 3.0 K. Green is for the microwave-only retrieval solution, blue is for the regression retrieval solution, and red is the final retrieval solution. Abscissa range is 0 to 4 K; ordinate range is 1100 to 9 mb.

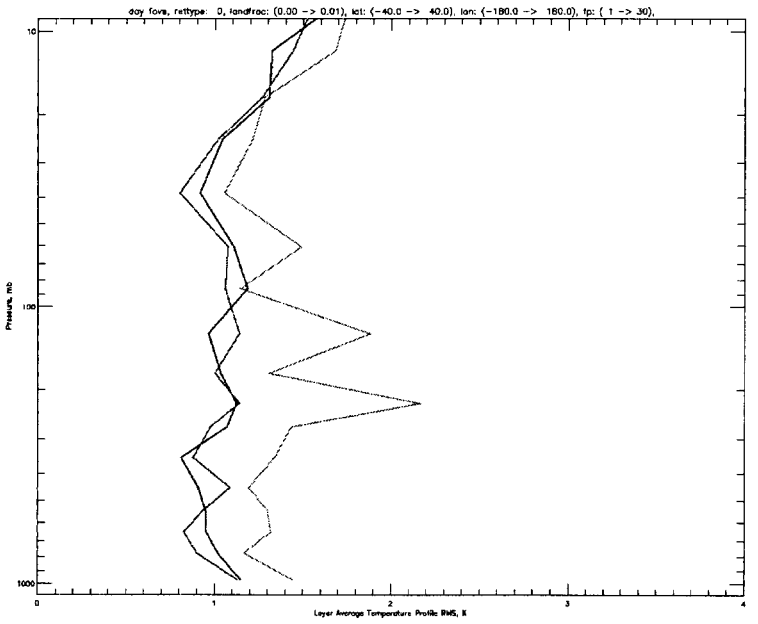

Figure 7. Same as Figure 6 except daytime.

Figure 8 shows a comparison between AIRS retrieved temperatures and dedicated radiosonde temperature observations at the Chesapeake Light Platform. These sondes were launched during Aqua spacecraft overpasses to minimize spatio-temporal mismatch errors. Because the atmosphere may change rapidly under certain conditions, the dedicated radiosondes are the highest quality correlative data sets for validation. The strong similarities between the previous two figures and Figure 8 is confirmation that ECMWF temperature analyses are of high quality.

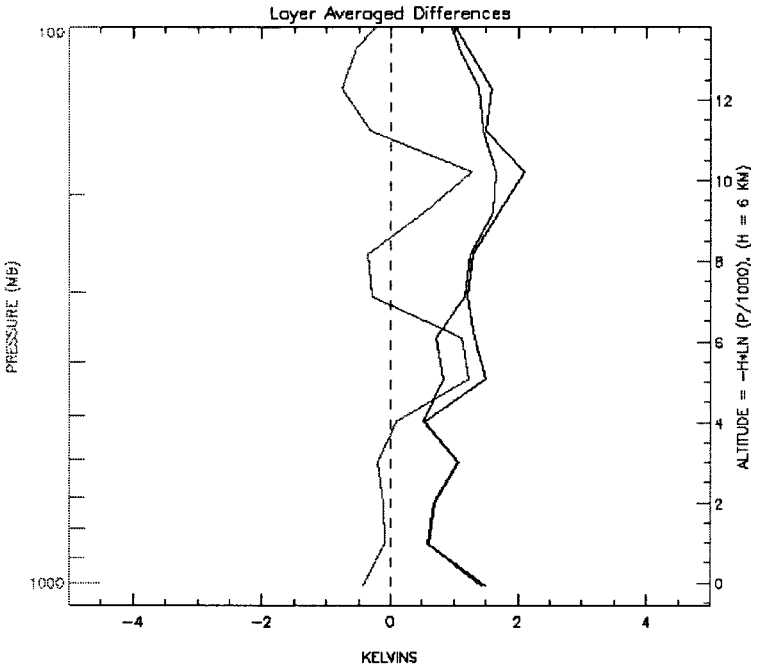

Figure 8. One-kilometer thick layer average temperature difference between AIRS retrieval and 30 radiosondes launched from Chesapeake Light Platform between 4 September and 5 October 2002. Red curve is bias, blue is standard deviation, and black is rms.

6. Total water vapor

Sea surface temperature and atmospheric temperature are well resolved in forecast models, especially for the condition where AIRS retrievals are valid. In contrast, water vapor varies more rapidly in space in time than does temperature, making its representation in models more difficult. This variability also makes water vapor validation more problematical than temperature. Dedicated radiosondes therefore have the best error characteristics for water vapor validation. Models, however, do constrain the total water vapor well, so are useful for this comparison.

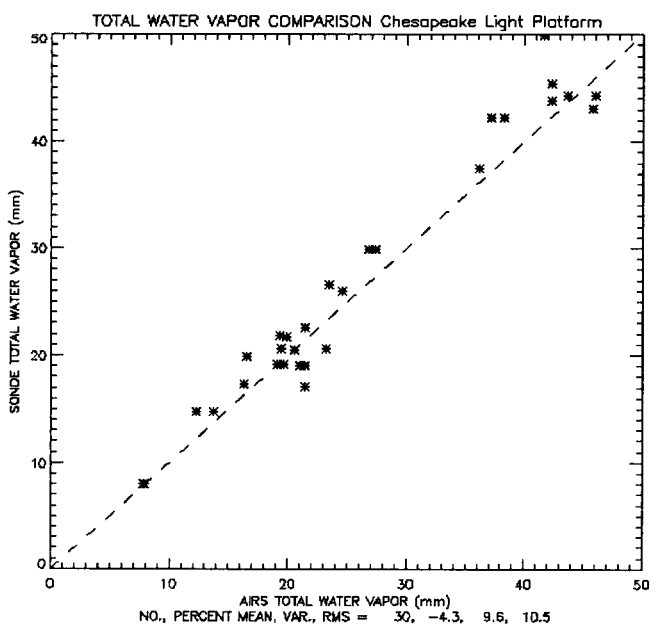

Figure 9. AIRS retrieved total water vapor versus radiosonde observed total water vapor at the Chesapeake Light Platform. The mean and standard deviation for 30 sondes are –4.3 ± 9.6% and the rms is 10.5%

Figure 9 shows AIRS retrieved total water vapor versus radiosonde observed total water vapor for the Chesapeake Light Platform, situated 15 km from the mouth of Chesapeake Bay. The sondes were launched between 1 September and 5 October 2002, and the retrieved water vapor is from the nearest AIRS ocean-only locations within 70 km. Note: this plot is not representative of all water vapor present, but only water within the altitudes of coverage by the balloon. Agreement between AIRS retrievals and sondes in this case is close to the system requirement of 10%. This result is bolstered by a comparison with ECMWF total water vapor in the North Atlantic in the region 25 to 40 N and 40 to 80 W on 6 September 2002: mean difference of -7.9 ± 18.4 %.

6. Summary and Conclusions

The AIRS/AMSU/HSB retrieved products are currently being compared against a variety of in situ observations. The goal of this validation activity is to characterize the retrieval uncertainties and, ultimately, to meet the system specifications in [2]. We describe here some validation results for cloud cleared radiances, sea surface temperature, temperature profiles and total water vapor. These results apply to oceans at 40S to 40N latitude, with SST constrained to agree with forecast by ±3 K. Retrieved quantities are compared here with ECMWF model reanalyses and operational radiosondes. SST retrieval uncertainties are approximate 0.8±1.0 K. Temperatures profile rms uncertainties are about 1 K averaged over 1 km thick layers in the troposphere for both ECMWF comparisons and for dedicated radiosondes. Water vapor retrievals are currently biases slightly dry by about 5 %. The temperature retrieval performance in the troposphere meets the AIRS/AMSU/HSB system specification.

The results presented here show only some of the validation analyses being performed with AIRS retrieved products. Algorithm improvements are ongoing, and offer the promise of soon meeting system specifications of 10 % in total water vapor over oceans. Data releases in the next year will extend to land, and then to higher latitudes. These conditions are increasingly complex, and hence more challenging to the retrieval system. Validation over land will be more straightforward, however, since land areas are very rich in correlative data sources, particularly operational radiosondes.

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