Results from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua[1]

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Abstract – The Atmospheric Infrared Sounder (AIRS) was launched into polar orbit on the EOS Aqua spacecraft on May 4, 2002. Following the on-orbit calibration and performance validation phase, AIRS started in September 2002 to routinely gather 4 million upwelling spectra each day for the critical evaluation by the AIRS science team of the calibration and geophysical product retrievals. First results of observations of the oceans under clear conditions reveal the unexpected presence of an aerosol layer with optical depth up to 2%. The comparison of temperature retrievals under clear and cloudy conditions demonstrate that cloud-clearing works and increases the yield in good retrievals by more than a factor of twenty compared to "clear-only" retrievals. Routine distribution to the numerical weather forecasting centers for forecast impact assessment started in October 2002. The AIRS calibrated radiances and level 2 products became available to scientific investigators from the GSFC/DAAC in July 2003.

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1. INTRODUCTION

The Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU) and the HSB (Humidity Sounder Brazil) form an integrated cross-track scanning temperature and humidity sounding system on the EOS-Aqua. AIRS is an infrared spectrometer/radiometer which covers the 3.7 - 15.4 micron spectral range with 2378 spectral channels. AMSU is a 15 channel microwave radiometer operating between 23 and 89 GHz, and HSB is a four-channel microwave radiometer between 150 and 190GHz. In addition to supporting NASA's interest in process study and climate research. AIRS is the first hyperspectral infrared radiometer designed to support NOAA/NCEP's operational requirements for medium-range weather forecasting during its nominal 7-year lifetime. The EOS Aqua was launched on 4 May 2002 from Vandenburg AFB, California, into a 705km high sun synchronous orbit. The overall science objectives and background for AIRS were summarized in a pre-launch paper by Aumann et al (2003). After the nominal on-orbit calibration period (Pagano et al 2003) the AIRS, AMSU and HSB started the routine data gathering mode in September 2002. Calibrated radiances have been distributed to the numerical weather forecasting centers since October 2002 for critical evaluation. The HSB failed in February 2003. The failure is not expected to impact AIRS core products, but will decrease the number of potential research products. As of July 2003 the calibrated radiances from AIRS and AMSU and standard products are produced and archived at the GSFC DAAC and are distributed from there on request. In the following we summarize the AIRS core product definitions and accuracy requirements. We then show results from data validation over ocean between +/- 40 degree latitude. Level 1b validation is discussed using the extremely transparent channel at 2616cm-1 under cloud-free (filtered) conditions. The comparison of temperature retrievals under clear and cloudy conditions shows good results and demonstrates that cloud-clearing works.

2. AIRS STANDARD DATA PRODUCTS

The AIRS Science Team has adopt the concept of a single unified retrieval algorithm that is referred to as the "Unified Team Algorithm" (UTA). The UTA is used to produce all of the "AIRS Core Products" listed in **Table 1**. The IR radiances refer to a 15 km footprint, the VIS/NIR radiances refer to a 2.6 km footprint, while all derived geophysical products refer to a 45 km footprint, consisting of a 3x3 AIRS IR footprint patterns overlaying an AMSU footprint.

Table 1. AIRS Core Products (1999 "EOS Reference Handbook, http://eos.nasa.gov)

	RMS Uncertainty*
AIRS IR Radiance	3%
AIRS VIS/NIR Radiance	20%
AMSU Radiance	.25 – 1.2 K
HSB Radiance	1.0 – 1.2K
Cloud-Clear IR Radiance	1.0 K
Sea Surface Temperature	0.5 K
Land Surface Temperature	1.0 K
Temperature Profile	1 K
Humidity Profile	15%
Total Precipitable Water	5%
Fractional Cloud Cover	5%
Cloud Top Height	0.5 km
Cloud Top Temperature	1.0 K

* Radiance error is defined as temperature error when measuring a blackbody at 250°K.

The pre-launch algorithmic basis for the retrieval of the geophysical products is described in Susskind et al. (2003),

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Goldberg et al. (2003) and Rosenkranz (2000). Version 3.0.8 of the Product Generation System (PGS) was installed at the GSFC DAAC in July 2003. The quality of the data products in terms of noise characteristics, bias and regional validity is assessed in a validation program. The pre-launch approach to validation was described by Fetzer et al. (2003). The Launch + 12 months validation report, available from the GSFC DAAC, describes the performance of the Version 3.0.8 PGS. The status of the validation ranges from "beta" to "provisional" to fully "validated". The infrared level 1b radiances are "provisionally" validated over moderate and tropical ocean at night. Provisionally validated data are useable for scientific investigations within the limits of the validation. caution. The temperature and moisture retrievals are "beta" validated for day/night +/-40 degree clear and cloudy ocean. This means that reasonable results are obtained under the specified regional conditions, but the results are not suitable for climate studies. As of July 2003 none of the AIRS core products are fully validated to achieve the accuracy specified in Table 1. over the full dynamic and geographical range, partly due to the difficulty in finding truth data of equal or better accuracy.

3. IR LEVEL 1B VALIDATION

The IR level 1b validation is based entirely on clear footprints over ocean at night. The effort ranges from the direct comparison of radiances measured during aircraft under-flights in ground-campaigns, to the comparison of matching footprints between MODIS Aqua, to the comparison of sea surface temperature measurements with AIRS to global model temperatures.

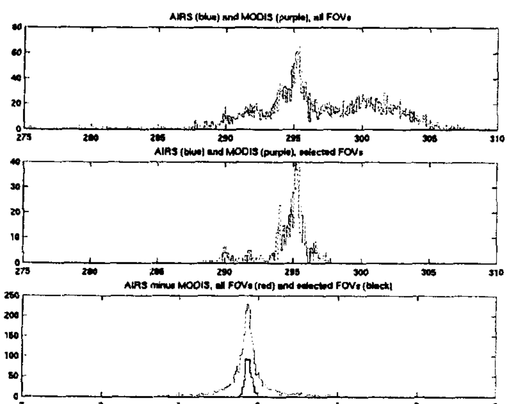

Figure 1. The comparison of AIRS - MODIS Aqua band#22 shows excellent agreement within 0.128K for 502 AIRS clear ocean footprints overlaying MODIS footprints.

Figure 1. shows the result of a comparison between MODIS band#22 and AIRS during the TX2002 campaign on 21 November 2002 (Mueller et al 2003) in the Gulf of Mexico off the coast of South Texas. MODIS#22 covers the 2500-2550 cm-1 region of the spectrum, which is covered by 50 of the high spectral resolution AIRS channels. This allows an accurate emulation of the MODIS signal by AIRS. The 15 km diameter footprint of AIRS can be accurately emulated by the MODIS 1 km footprints. The top panel shows the histogram of the temperature distribution of all data in the overflight area, land and ocean The land has the warmer temperatures. The mid panel shows a subset of the those pixels which are over ocean and are reasonably cloud-free. The bottom panel shows the histogram of the AIRS-MODIS#22 temperature difference for the two cases. The mode of the distributions (the small peak is the ocean subset) is the same. For the 505 AIRS footprints used for this analysis AIRS-MODIS#22 is -0.128K, with an rms value of 0.0427K. This is an excellent agreement. Similarly good results have been achieved with other MODIS channels and with SHIS and NAST-I under-flights of the EOS Aqua. The agreement between the two data sets also demonstrates that for the statistical comparison of the radiometric calibration the choice of the scene is not critical Uncertainties in the exact spatial matchup between AIRS and MODIS appear as outliers in the histogram, but do not effect the mode.

Once consistency of the radiance calibration is established on a local basis, the validation of the IR radiance calibration can move to the global scale. In this validation we use the extremely transparent window channel at 2616cm-1 to estimate the sea surface temperature by explicitly correction for residual atmospheric absorption and emissivity effects from first principles (Aumann and Strow, 2003). The night-time data are cloud-filtered using a 4 micron spatial coherence test and a "low-stratus" test. The resulting sst2616c6 can be compared to the daily sea surface temperature product generated by NCEP from the global buoy network and surface ship reports, interpolated on a 0.5 degree global grid as the daily RTG.SST product (Thiebaux et al.2003). Based on daily validation relative to insitu buoy, it has a global bias of less than 0.1K, with rms of about 0.4K.

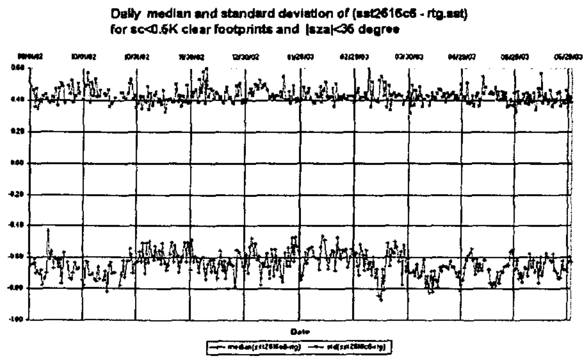

Figure 2. Lower trace: bias of (sst2616c6-rtg.sst)= 0.65K . The bias is stable at the better than 0.1K level. Upper trace: rms of (sst2616c6-rtg,sst)= 0.45K and very stable.

Figure 2. shows the results of the comparisons with the RTG SST for the first ten months of AIRS routine operations, between 1 September 2002 and 31 May 2003. The comparison generates one point per day. Each point corresponds to the comparison of about 8000 clear AIRS footprints over night ocean with the colocated RTG SST.

From Figure 2. it is evident that AIRS sst2616 and the RTG.SST are excellent products, which track with a stability of 0.1K, but with a bias. The AIRS sst is colder than the RTG.SST by about 0.65K. The standard deviation of the data used for each day is typically 0.45K. This is consistent with the standard deviation reported for the rms of typically 0.4K between the RTG SST and the buoy network. Since the RTG.SST is a day/night average product, and the RTG.SST refers to the bulk temperature (at about 1 meter depth), rather than the skin temperature measured by AIRS, a cold bias of about 0.35K was expected. The leaves an unexplained difference of 0.3K. The ability to measure the global ocean skin temperature to within 0.3K using first principles radiative transfer and emissivity corrections is very impressive. While the average amount over global oceans between +/-50 degree is 0.3K, the amount varies regionally on a monthly scale between zero and up to 1K, and appears to be related to regional weather or seasonal patterns (Aumann and Strow 2003). A 1K absorption corresponds to about 2% optical depth at 4 microns. The bias trace in Figure 2. is thus a measure of the global stability or trends in the aerosol over oceans. With global warming being debated at the 0.1K per decade level, the presence of 0.3K of unexpected aerosol may have climate implications.

4. CLOUD_CLEARED RADIANCE VALIDATION

The results for Figure 1. and 2 were based on cloud-filtered AIRS footprints at night. Only about 8000 of the 400,000 AIRS footprints measured over the +/-50 degree oceans at night are cloud-free at the AIRS noise level of 0.2K. This corresponds to 2% of the data. The application of results from cloud free fields of view to weather forecasting and global climate studies requires data which are based on clear and cloudy fields. The AIRS UTC uses cloud-clearing: the combination of infrared and microwave footprints is used to deduce the clear column radiance, i.e. the first order effects of clouds are eliminated. The basic concept and heritage of this algorithm is discussed by Aumann et al. (2003). Ideally, the validity of the cloud-cleared radiance product is established by showing that for whatever geophysical quantity is tested, the quantity id statistically not distinguishable from the same quantity retrieved from cloud-filtered data. In the following we discuss results form one such test: We compare the accuracy of the temperature profiles deduced from cloud-filtered clear footprints relative to the ECMWF analysis with the accuracy of the retrievals obtained with cloud-cleared data. Figures 3. show the rms of (retrieved T(p) - ECMWF.T(p)) from 3600 clear AIRS footprints identified for 6 September 2002 data over day/night ocean using the 11um spatial coherence clear test. The rms value is clearly better than 1K between 850mbar up to an altitude of 10 mbar, but increases to about 1.2K rms between 1000 and 850 mbar.

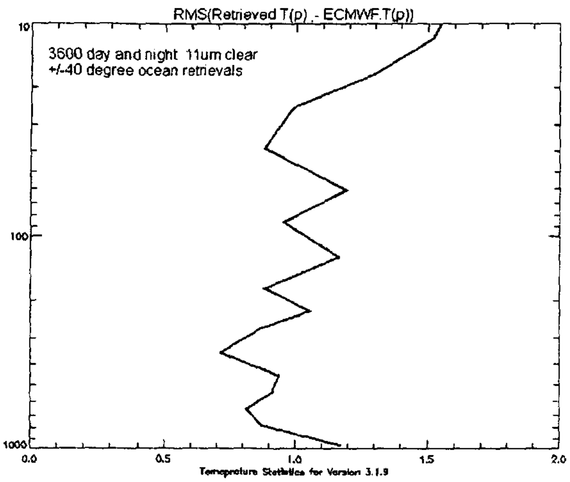

Figure 3. The rms of (retrieved T(p) - ECMWF.T(p)) from 3600 clear AIRS footprints identified for 6 September 2002 data over day/night ocean using the 11um spatial coherence clear test is less than 1K over most of the troposphere.

The retrieval acuracy achieved under clear-filtered conditions has to be contrasted to the retrieval accuracy obtained for the same day (and night) from 62,600 T(p) retrievals obtained under clear and cloudy conditions, using the cloud-cleared radiances. This corresponds to retrievals from about 70% of the footprints.This is shown in Figure 4, based on Version 3.18 of the AIRS PGS. Inspection of Figure 4. shows that the retrieval accuracy is better than 1K rms throughout the troposphere and to the 20mbar level of the stratosphere.

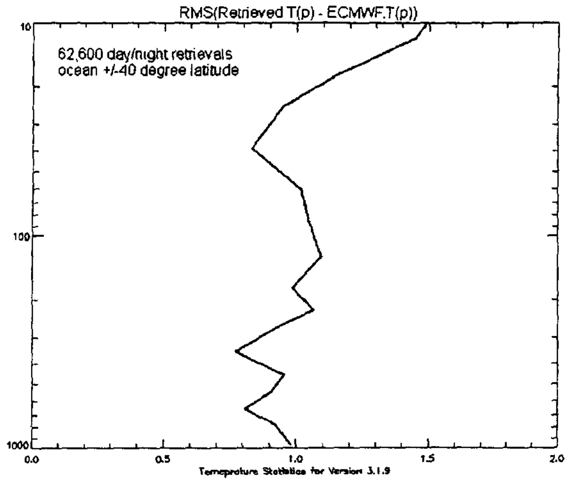

Figure 4. Temperature retrieval results relative to the ECMWF analysis of 62,600 clear and cloudy footprints over +/-40 degree latitude ocean. The character of the retrieval error and the rms accuracy for clear and cloud-cleared retrievals is very similar.

The character of the rms discrepancy between the AIRS retrieval and the ECMWF results for the clear and the cloud-cleared cases is very similar, except near the surface. We attribute the slightly inferior performance of the retrieval for "clear" filtered data to a deficiency in the 11 micron cloud filter. From the analysis of sst2616 data we found the long term average of clear AIRS footprints to be about 8000 at night and 8000 during the day, i.e. about 16000 total. The AIRS retrieval is based on a 3x3 pattern of AIRS footprints, i.e. 16000/9=1800 clear retrievals would be expected, while the 11 micron clear filter identified 3600 data for "clear" retrieval. In addition to the achieved accuracy, the much larger yield in retrievals needs to be appreciated. While the clear filtered data produced only 3600 retrievals for the entire day, the same time period yielded 62,600 retrievals, an increase of about a factor of twenty, and corresponds retrievals obtained from 70% of the data. This large yield of good T(p) profile should result in a significant improvement in the accuracy in the initialization of the numerical weather forecast, and corresponding improvements in the forecast skill. The retrieval performance meets the accuracy of 1K rms requirement stated in Table 1, algorithm refinements are required to meet the 0.5K rms surface accuracy.

5. SUMMARY

The Atmospheric Infrared Sounder (AIRS) was launched on the EOS Aqua on 4 May 2002 into sun-synchronous polar orbit. Since the start of the routine operations phase in September 2002 4 million upwelling spectra are produced each day in support of weather forecasting and climate research. First results of observations of the oceans under clear conditions reveal the unexpected presence of an aerosol layer with optical depth up to 2%, which may have climate implications. The comparison of temperature retrievals under clear and cloudy conditions demonstrate that cloud-clearing works and increases the yield in good retrievals by more than a factor of twenty compared to "clear-only" cloud-filtered retrievals. The large increase in yield of retrievals should improve the initial conditions for weather forecasting. Routine distribution to the numerical weather forecasting centers for forecast impact assessment started in October 2002. The AIRS calibrated radiances and level 2 products became available to scientific investigators from the GSFC/DAAC in July 2003.

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REFERENCES

References from Journals

H.H. Aumann, M.T. Chahine, C. Gautier, M. Goldberg, E. Kalnay, L. McMillin, H. Revercomb, P.W. Rosenkranz, W. L. Smith, D. H. Staelin, L. Strow and J. Susskind' "AIRS/AMSU/HSB on the Aqua Mission: Design, Science Objectives, Data Products and Processing Systems", IEEE TGARS, 41,2, 253-264,February 2003.

H.H. Aumann, Moustafa Chahine and Diana Barron, "Sea Surface Temperature Masurements with AIRS: RTG.SST Comparison", Proc SPIE International Symposium on Optical Science and Technology, San Diego, 3-8 August, 2003.

H. H. Aumann, Diana Barron, and D. Gregorich,"The first six months of AIRS sea surface temperature measurements and climate implications", submitted to J.Climate 2004.

Fetzer, Eric, Larry McMillin, David Tobin, Michael Gunson, Hartmut H. Aumann, W. Wallace McMillan, Denise Haga, Mark Hofstadter, James Yoe, David Whiteman, Ralf Bennartz, John Barnes, Holger Vomel, Von Walde, Michael Newcharch, Peter Minnett, Robert Atlas, Francis Schmidlin, Edward T. Olsen, Mitch Goldberg, Sisong Zhou, HanJung Ding and Hank Reverconb, "AIRS/AMSU/HSB Validation", IEEE TGARS, 41,2, 418-432,February 2003.

Mitchell D. Goldberg, Larry M. McMillin, Walter Wolf, Lihang Zhou, Yanni Qu and Murty Divakarla, "AIRS Near Real-Time Products and Algorithms in Support of Global Data Assimilation for Medium Range Weather Forecasting", IEEE TGARS, 41,2, 379-389,February 2003.

Chris Mueller and David Tobin, "Cross-comparison of the AIRS and MODIS radiometric calibration during TX2002", Proc SPIE International Symposium on Optical Science and Technology, San Diego, 3-8 August, 2003.

Thomas S. Pagano, Hartmut H. Aumann, Denise E. Hagan and Ken Overoye, "Pre-launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS)", IEEE TGARS, 41,2, 265-273,February 2003.

Rosenkranz, Philip W., "Retrieval of Temperature and Moisture Profiles from AMSU-A and AMSU-B Measurements", IEEE TGARS, 41,2, 390-409, February 2003.

Joel Susskind, Chris Barnett and John Blaisdell, "Retrieval of Atmospheric and Surface Parameters from the AIRS/AMSU/HSB Data in the Presence of Clouds", IEEE TGARS, 41,2, 390-409, February 2003.

Tiebaux, Jean, Eric Rogers, Wanqiu Wang, and B. Katz," A New High-Resolution Blended Real-Time Global Sea Surface Temperature Analysis",BAMS, V.84,#5,645-656, 2003.