AIRS/AMSU/HSB on EOS Aqua: First Year Post Launch Assessment

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU), and Humidity Sounder from Brazil (HSB) are three instruments onboard the Earth Observing System (EOS) Aqua Spacecraft. Together, they form the Aqua Infrared and Microwave Sounding Suite (AIMSS). This paper discusses the science objectives and the status of the instruments and their data products one year after launch. All instruments went through a successful activation and calibration and have produced exceptional, calibrated, Level 1B data products. The Level 1B Product Generation Executables (PGEs) have been given to NOAA and the GSFC DAAC for production and distribution of data products. After nine months of operations, the HSB instrument experienced an electrical failure of the scanner. Despite the loss of HSB, early validation results have shown the AIRS and AMSU are producing very good temperature profiles.

Keywords: Atmosphere, Sounding, Infrared, Spectrometer

1. EXPERIMENT OBJECTIVES

The goal of the AIRS Project is to demonstrate the impact of using AIMSS data on weather prediction and improve the understanding of the global energy and hydrology cycle. This goal is achieved through remote sounding of the atmospheric state with radiosonde accuracy in the presence of clouds. The AIMSS is capable of eliminating the effects of clouds on the AIRS infrared radiances (spectra) in the presence of up to 80% cloud opacity. From the resulting cloud-cleared spectrum we will achieve, worldwide, the same accuracy in temperature as currently possible only with direct measurements by balloon-borne sensors. For moisture, however, the accuracy will exceed that measured by balloon-borne sensors. Globally, the AIRS Sounding System will be able to produce more than 300,000 soundings per day over both land and ocean compared to only 4,000 weather balloon launches, mostly over land, per day. The standard data products produced by the AIMSS are listed in Table 1.

The two scientific goals of AIRS/AMSU/HSB correspond directly to the goals set by NASA Earth Science Enterprise.

1) Helping the nation improve near-term weather prediction using NASA's latest space data and modeling research is a combined vision of both NASA and NOAA. Improvements in weather forecasting have great social and economic value. Making the 5-day forecast with 90% accuracy routine, predicting rainfall accurately 3 days in advance and determining hurricane landfall to within ±100 km at 2 to 3 days are major goals. NOAA/NCEP is ultimately responsible for all of the weather predictions; NASA is assisting NOAA with improved and new measurements, such as those provided by AIRS.

2) The Global Energy and Water Cycle is referred as the "cycle of life" on Earth. AIRS has a unique capability of providing global observations of one component of the cycle: water vapor. Uncertainties in the water cycle are hampering the ability of climate models to describe the cycle and assess the strength of feedback processes needed to predict the impact of climate change on the water cycle and vice versa. AIRS will provide, for the first time, a 3-dimensional distribution of atmospheric water vapor up to the tropopause with an accuracy superior to that obtained by radiosondes. Ultimately, this goal is related to prediction of precipitation for forecasting water supply weeks in advance (actually, before the rain comes down).

Table 1 Uncertainty and Resolution of the Aqua Infrared and Microwave Sounding Suite (AIMSS) Products (from the 1999 "EOS Reference Handbook," http://eos.nasa.gov).

	RMS Uncertainty*	Vertical Resolution	Horizontal Resolution
Radiance Products (Level 1B)			
AIRS IR Radiance	3%	N/A	15 x 15 km
AIRS VIS/NIR Radiance	20%	N/A	2.3 x 2.3 km
AMSU Radiance	.25 – 1.2 K	N/A	45 x 45 km
HSB Radiance	1.0 – 1.2K	N/A	15 x 15 km
Standard Core Products (Level 2)			
Cloud-Clear IR Radiance	1.0 K	N/A	45 x 45 km
Sea Surface Temperature	0.5 K	N/A	45 x 45 km
Land Surface Temperature	1.0 K	N/A	45 x 45 km
Temperature Profile	1 K	1 km below 700 mb 2 km 700-30 mb	45 x 45 km
Humidity Profile	15%	2 km in troposphere	45 x 45 km
Total Precipitable Water	5%	N/A	45 x 45 km
Fractional Cloud Cover	5%	N/A	45 x 45 km
Cloud Top Height	0.5 km	N/A	45 x 45 km
Cloud Top Temperature	1.0 K	N/A	45 x 45 km

* Radiance error defined as temperature error of Plank blackbody at 250°K.

In general, the AIRS/AMSU/HSB data are intended to address more specific issues related to climate and weather:

- How is the global water and energy cycle changing: Is it accelerating and why?
- Determining the distribution and variations of water vapor, Earth's primary greenhouse gas.
- Climate weather connection: Are current weather anomalies (hurricanes, droughts) connected to climate change and how?
- Improving weather prediction: NOAA is a user together with 6 other NWP centers in Europe, America, Australia and Japan.
- Assessing Climate Data Records: AIRS's very accurate spectra, temperature profiles and humidity profiles, combined with Level-3 products, decimated data products and documented product validation, form the essential basic components for formulating Climate Data Records.

2. THE AIRS, AMSU, AND HSB INSTRUMENTS

The Aqua Infrared and Microwave Sounding Suite is comprised of three instruments (see Figure 1): The Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU) comprised of A1 and A2, and the Humidity Sounder from Brazil (HSB). The AMSU and HSB are heritage instruments from the NOAA TOVS series of spacecraft (HSB is identical to the AMSU-B in design); a full description of these instruments can be found in the literature (reference 1, 2, 3).

The AIRS acquires 2,378 spectral samples at resolutions, $\lambda/\Delta\lambda$, ranging from 1086 to 1570, in three bands: 3.74 μm to 4.61 μm, 6.20 μm to 8.22 μm, and 8.8 μm to 15.4 μm. A 360-degree rotation of the scan mirror generates a scan line of IR data every 2.667 seconds.

The VIS/NIR photometer, contained within the AIRS, has four spectral bands, each with nine pixels along track, with a 0.185-degree IFOV, boresighted to the IR spectrometer to allow simultaneous visible and infrared scene measurements.

The AIRS Instrument was developed at BAE Systems in Lexington Mass. Advancement of key component technologies for infrared space remote sensing was a major accomplishment of the NASA AIRS Program. Figure 2 shows key elements of the technology demonstration.

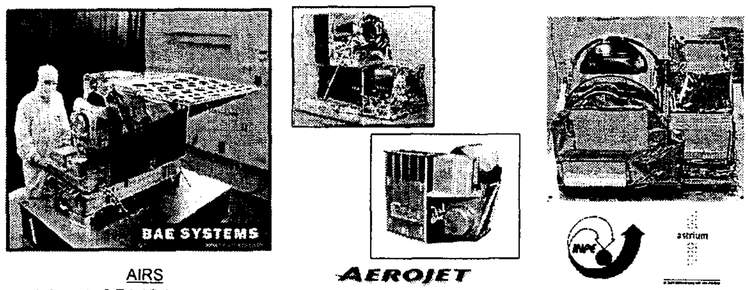

Figure 1. The AIRS, AMSU, and HSB instruments.

The need for high spectral resolution over a broad infrared spectral range, combined with high sensitivity, stability, accuracy and reliability, resulted in the development of a cryogenically cooled (155-K), pupil imaging grating spectrometer (Figure 2a). Pre-flight measurements demonstrated the exceptional spectral resolution and spectral shape of this approach (reference 3). In-flight measurements have shown stability on the order of 2 ppm over a 9-month period (reference 4). The spectrometer has a high degree of polarization; however, because the scan mirror rotates at a constant angle of incidence to the optical axis, only the phase change has to be accounted for (reference 5). Pre-flight calibration has shown that the Level 1B calibration coefficients that correct for blackbody emissivity, nonlinearity and polarization effects achieve a high level of repeatability at all scan angles (reference 5). In-flight measurements have shown AIRS radiometric accuracy to be excellent when compared to airborne systems and other instruments (reference 6).

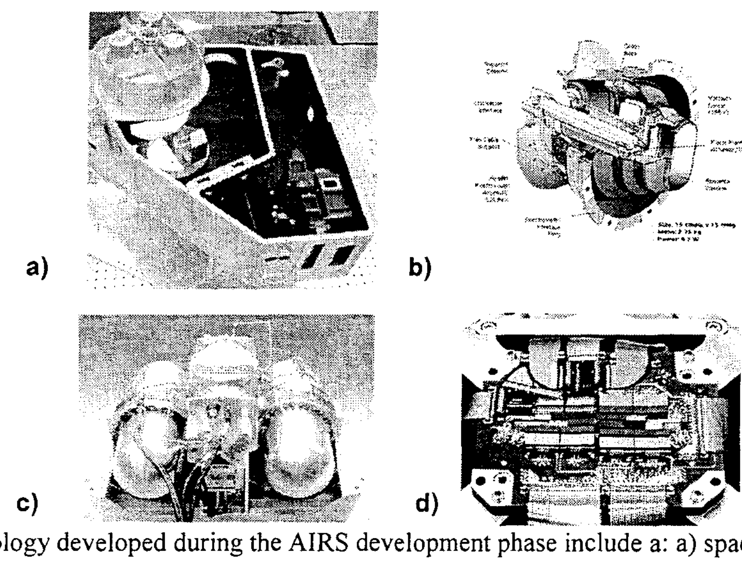

Figure 2. New technology developed during the AIRS development phase include a: a) spaceflight infrared grating spectrometer, b) vacuum cryogenic dewar, c) pulse tube cooler, and d) long-wavelength cutoff HgCdTe photovoltaic infrared detectors.

The grating spectrometer approach provides to every channel its own detector. This results in no moving or active parts in the spectrometer and minimizes signal processing requirements. Signal conditioning electronics (gain and offset) for

detector arrays are significantly simplified by the use of a Readout Integrated Circuit (ROIC). The ROIC allows multiplexing, but can only be used with PhotoVoltaic (PV) HgCdTe detectors. The long-wavelength cutoff of PV HgCdTe was extended to 13.7 microns in the AIRS Focal Plane Assembly (Figure 2d).
Cooling the large number of detectors required a higher capacity than was traditionally available with passive radiators. The advent of the Split Sterling Cycle cooler opened opportunities for "active" space based coolers. TRW (now NGST) developed the Pulse Tube cooler on the AIRS project. Two coolers were developed for the AIRS to be used as a redundant set (Figure 2c). A vacuum encapsulated dewar assembly (Figure 2b) keeps the AIRS detectors protected from moisture, allowing ambient operation during testing while preventing ice build up on the detectors in space.

3. IN-FLIGHT ACTIVATION AND CALIBRATION

Accomplishments since launch include the successful application of the AIRS activation and calibration sequences, functional testing and special calibrations of AMSU and HSB, successful recovery for all three instruments from several early-mission spacecraft survival/safing episodes, performance of an AIRS defrost/ decontamination cycle, and recovery from three AIRS cooler anomalies that resulted in focal plane warmups.

The in-flight calibration of the AIRS instrument is discussed in the literature (reference 7). In general, the results show the performance in-flight to match that of pre-flight spectrally and radiometrically. A shift in the center frequencies and phase of the channel spectra was calibrated in space to account for the launch and cooldown shift of the focal plane. The spaceborne radiation environment caused spikes in the shortwave detector signals that were successfully mitigated by activating the radiation circumvention circuitry. Icing accumulation on the optics was eventually outgassed and did not result in significant signal degradation.

Since the start of routine operations, the JPL AIRS Operations Team has worked on three major non-routine activities. First, in August 2002, an incorrectly implemented cooler software feature called the watch dog timer tripped and shut off the compressor. A patch was inserted into the cooler software initialization procedure to disable the timer.

Second, in November 2002, AIRS changed operating mode to use both coolers simultaneously. Because stress on compressor parts is very non-linear with stroke levels, any lowering of the drive level significantly increases cooler lifetime. Also, as was expected, a slow build up of ice on the cold heads was occurring over time. The icing caused drive levels to steadily increase in order to maintain the target focal plane temperature. Figure 3 shows a plot of the cooler-A drive level before and after switching to two-cooler operation. With both coolers operating simultaneously, analysis shows an improvement in the overall system reliability as well as extending the time between defrosts from 3 months to over 2 years.

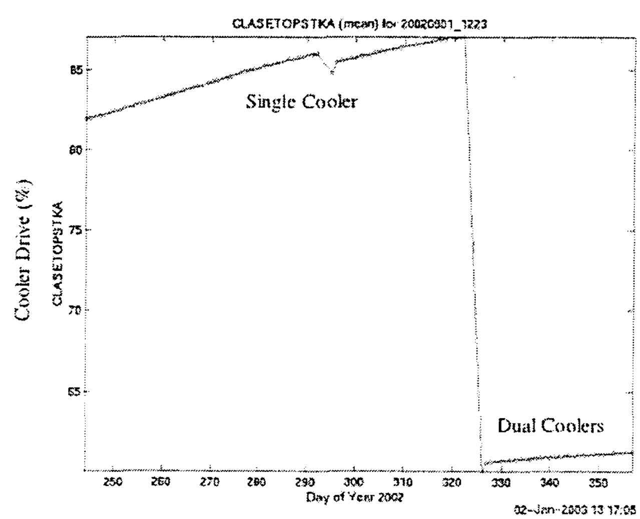

Figure 3. Dual cooler operation significantly reduces cooler drive level resulting in a more reliable system and more time between defrosts.

The third non-routine activity, HSB scanner anomaly investigation, is in progress at this time. On February 5, 2003, the HSB scanner shut down due to an anomalous high current reading. Several failed restart attempts have been made so far. Tests on an AMSU-B engineering model (identical design) have confirmed the failure to be electrical in nature. Additional attempts to restart the scanner are planned pending further analysis.

4. ALGORITHMS AND DATA PRODUCTS

A complete description of the Level 1 and Level 2 algorithms for AIRS can be found in the literature (reference 8). The Level 1A Product Generation Executables (PGEs) convert the raw formatted data from the spacecraft into counts and engineering units for the telemetry parameters. The Level 1B PGEs convert the counts into calibrated radiances for the AIRS and brightness temperatures for the AMSU. The Level 1 algorithms are relatively simple, with few correction terms, and lead to highly accurate products (reference 2, 5).

The integrated system approach pursued by the AIRS Project led the AIRS Science Team to adopt the concept of a single, unified retrieval algorithm for Level 2 products that is referred to as the Unified Team Algorithm (UTA). The UTA is used to produce all of the AIRS Standard Core Products (Level 2) listed in Table 1. Figure 4 shows the algorithm flowchart identifying the major modules in the Level 2 PGEs. Further information is available from the Level 2 ATBD (reference 9).

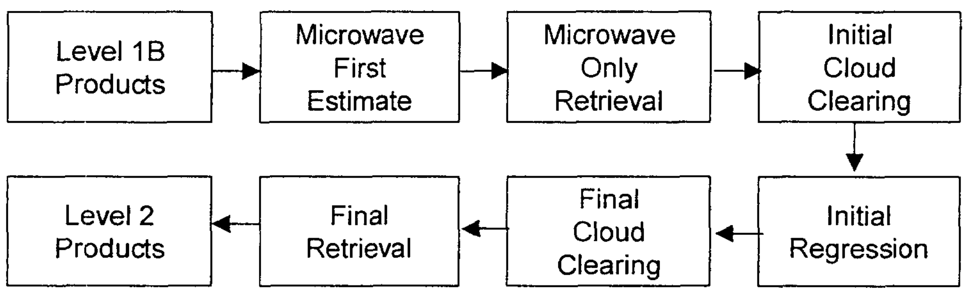

Figure 4. Level 2 retrieval algorithm and PGE flow chart.

All proposed changes or modifications of the UTA follow a procedure that includes integration, diagnostics, testing, and validation prior to implementation at the GSFC DAAC. The UTA is capable of accommodating new products as they move from research to becoming part of the AIRS Core Products. This unified approach has tremendous advantages in configuration management, processing efficiency, and distribution of AIRS Core Products to end users in research and application.

5. VALIDATION

Validation of the AIMSS data products follows a phased implementation, as identified in Table 2. This table illustrates our activation and validation timeline for the various AIRS products cross-referenced to planned operational software deliveries to the GSFC DAAC. The objective being that with each major delivery, we activate and/or improve the validation status of a subset of the products. The products are also validated over a wider temporal and geographical extent with each release. According to AIRS Project policy, we will not release the data to the public until we have completed our validation report, which characterizes the performance of the products produced by the version of the PGE being released.

Our planned phased validation efforts follow the sequence below:

- Validate non-polar nighttime ocean regions.
- Validate non-polar daytime ocean retrievals.
- Validate non-polar nighttime land retrievals (post improvements to land emissivity models).
- Validate non-polar daytime land retrievals (post further refinements to land emissivity models).
- Validate polar retrievals (expected to be quite difficult, but of high interest to the research community).

Table 2. AIMSS Validation Timeline

	Version	3.0	4.0	5.0	6.0	7.0	8.0
	Activation Date	7/1/03	9/17/04	6/24/05	3/24/06	12/15/06	9/21/07
Radiance Products (L1)							
	AIRS Radiance	Prov	Val2	Val4	Val5		
	VIS/NIR Radiance	Prov	Val2	Val4	Val5		
	AMSU Radiance	Beta	Prov	Val2	Val4	Val5	
	HSB Radiance	Beta	Prov	Val2	Val4	Val5	
Standard Products (L2)							
	Cloud-Clear IR Radiance	Beta	Val2	Val3	Val4	Val5	
	Surface Temperature	Beta	Val2	Val3	Val4	Val6	
	Temperature Profile	Beta	Val2	Val3	Val4	Val5	
	Humidity Products	Beta	Val1	Val2	Val3	Val4	Val5
	Cloud Cover Products	N	Beta	Val1	Val2	Val2	Val3

Beta = Not suitable for scientific investigations. Consult with AIRS Project on regional status.
Prov = Provisionally validated. Useable for scientific investigations with caution. Validated for nonpolar night ocean only
Val1 = non-polar day/night ocean. Val2 = Val1 + non-polar night land. Val3 = Val2 + nonpolar day land
Val4 = Val3 + polar night
Val 5= Val 4 + polar day . Only Val5 data are useable for truly global scientific investigations.

5.1 Level 1 Products

Some products are validated quicker than others because they are more mature. The Level 1 products look exceptional at this time. Figure 5 shows a comparison of the AIRS-measured radiances (in terms of brightness temperature) (O) compared to calculations based on the ECMWF forecast (C) using the AIRS Radiative Transfer Algorithm (RTA).

Results show a bias of better than ±1.0 K difference for most of the spectrum with no tuning applied. This comparison tells us that the AIRS radiances are very close to truth, but also that the ECMWF forecast models are very good. Reports by Aumann et al. (reference 10) show agreement of the AIRS superwindow channel at 2616 cm^{-1} with the RTG SST to within 0.32 K, which is mostly attributable to the presence of an absorbing layer that is not detected by our cloud algorithm. Comparison with other instruments and Scanning HIS (reference 6) show better than 0.2 K agreement for most channels.

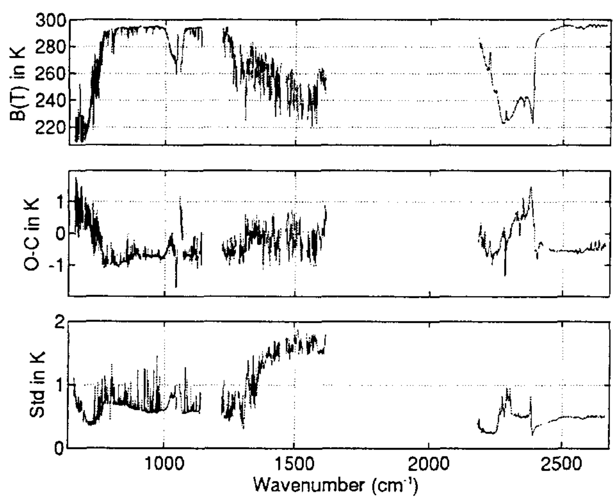

Figure 5. Top (Mean Observation Brightness Temperature). Middle: Mean difference between AIRS Observations (O), and ECMWF Calculations (C), Bottom: Standard deviation between AIRS and ECMWF.

5.2 Level 2 Products

The conditions under which the Level 2 products are validated are for nighttime, ocean FOVs within the latitude band, |lat| < 40° (Prov). Other regions are more difficult to validate due to the retrieval complications or the paucity of validation data. Polar regions have issues with uncertainties in the climatology; land cases have the added complexity of surface emissivity uncertainty. Although results are shown for nighttime, the daytime results are equally as good.

Figure 6 shows the first results from running our Level 2 Product Generation Executables (PGEs) on a full day of nighttime observations in September 2002. Results show retrieval yields of 70% over the entire test area under clear and cloudy conditions. This means that all stages of the retrieval worked successfully, including cloud clearing. Twenty-four percent of the cases were only successful in the first microwave only retrieval; six percent failed the retrieval.

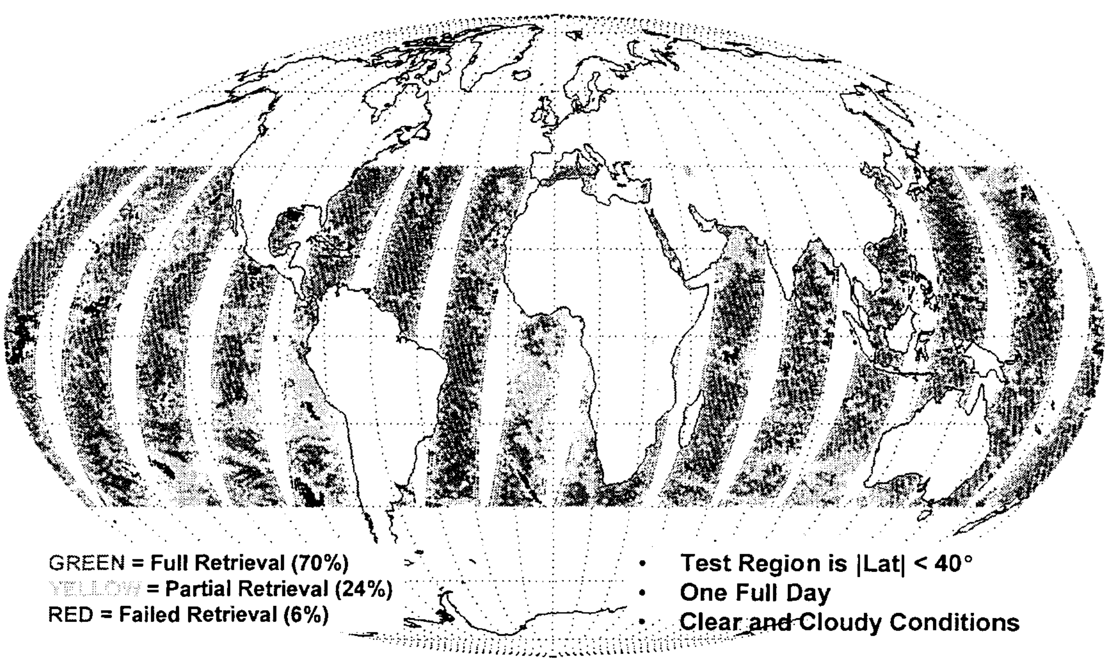

Figure 6. AIMSS Level 2 Data Products Retrieval Yield. Successful retrievals are achieved over 70% of the test cases of |Lat| < 40deg, One Full Day of Nighttime cases, Sept 6, 2002.

Figure 7 shows the statistics of the retrieval for this day. The blue curve is the average of the bias or difference between the ECMWF Analysis-Forecast interpolated to the AIRS overpass time and position. The red curve is the rms deviation between the ECMWF and the AIRS. Our requirement of 1-K accuracy per layer to 30 mb is nearly satisfied. We see some deviation near the surface; this may be due to the presence of an unexplained absorber (reference 10). The deviation around 150 mb is due to the well know difficulty in determining the height of the tropopause.

Figure 8 shows a visualization demonstrating the ability of the AIRS to measure the 3-dimensional distribution of temperature in the atmosphere. The image shows the tropopause from AIRS data acquired over the western Mediterranean Sea on 8 September 2002. The tropopause is a temperature inversion that marks the boundary between the troposphere (lower atmosphere) and the stratosphere. The tropopause is represented by the folded isotherms, or surfaces of equal temperature, at 220 (shown in purple), 215 (blue), and 205 (green) Kelvin. The tropopause is located at 100 mb, or approximately 14 km above sea level. Also in the image, we see the boundary layer 310 and 300 K isotherms, displayed in red and yellow, respectively. The isotherms have been offset a bit for clarity: they are near 1000 mb atm pressure (i.e., near sea level).

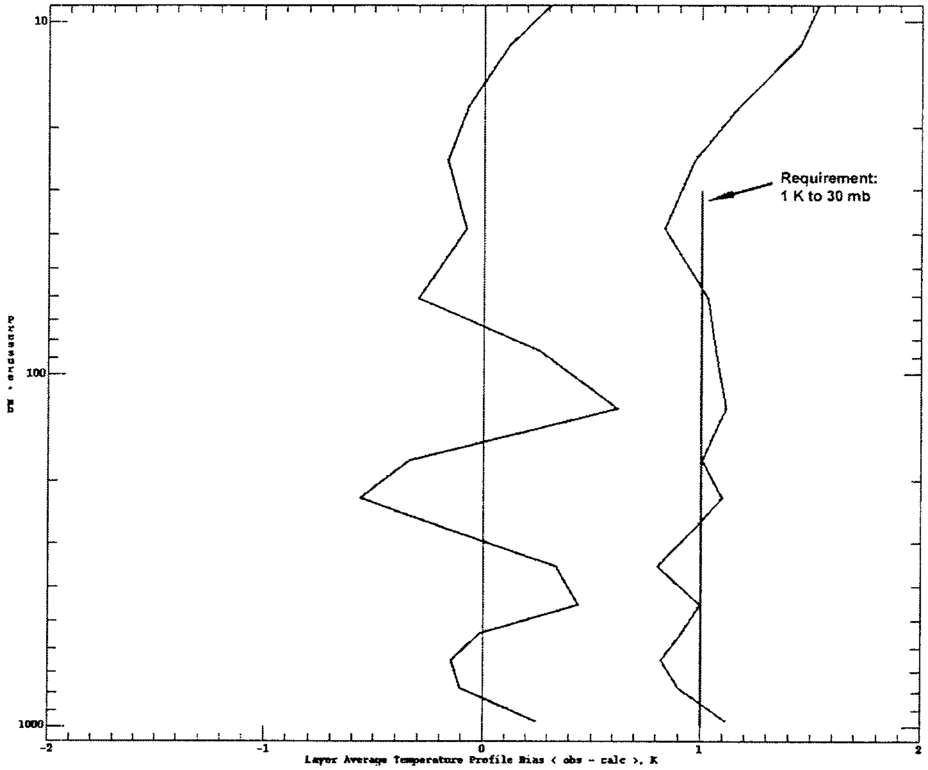

Figure 7: RMS Error and Bias of the AIMSS Level 2 Temperature product vs. altitude (pressure) compared to ECMWF Analysis-Forecast Predictions.

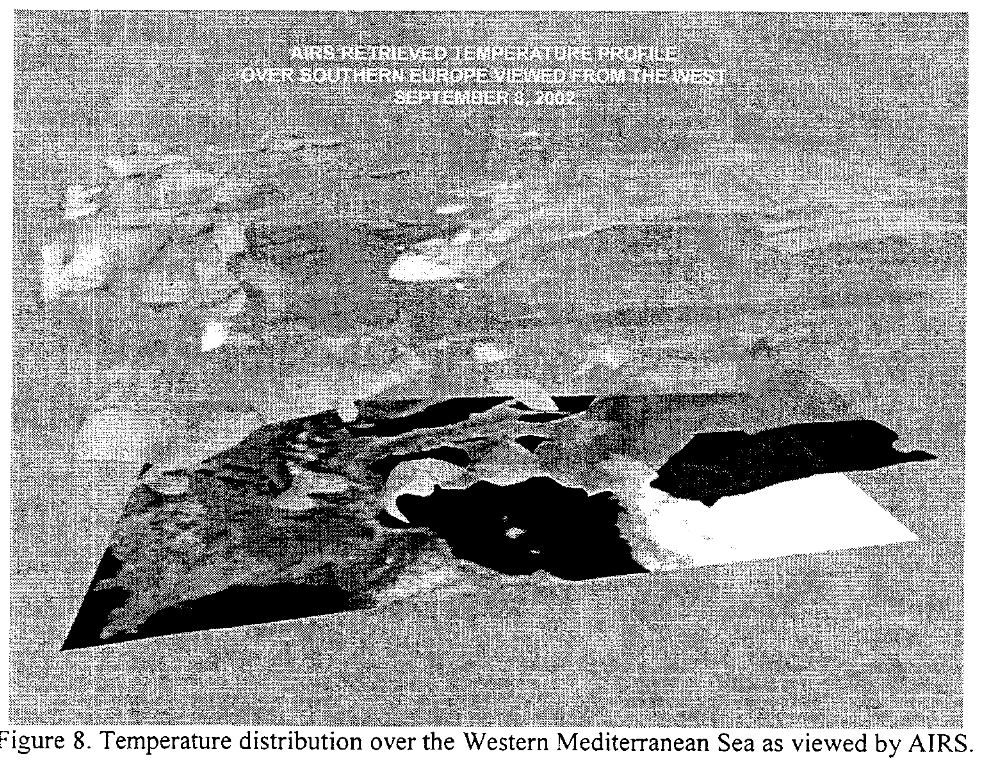

Figure 8. Temperature distribution over the Western Mediterranean Sea as viewed by AIRS.

6. DATA DISTRIBUTION

The AIMSS data products are distributed to three major channels. The first of these is the National Oceanographic and Atmospheric Administration (NOAA) National Center for Environmental Prediction (NCEP). Today, NOAA-NCEP runs the Level 1B PGEs and produces a decimated product in the Binary Universal Form for the Representation of Meteorological Data (BUFR) format that contains approximately 330 channels. The BUFR product is produced within 2 hours, 50 minutes from the time of acquisition and distributed to national weather centers worldwide. The weather centers are in the process of assessing forecast impact when they assimilate the AIRS data.

The PGEs are also run at the GSFC Distributed Active Archive Center (DAAC), where data are archived for climate studies. Currently, the Level 1B data products are run on all AIRS and AMSU data and are made available to the public. Data can be accessed at http://daac.gsfc.nasa.gov. There are four ways to access AIMSS data. The first is the EOS Data Gateway (EDG), where the data are selected by the user in a search and order fashion then sent by tape or pulled by the requestor. The second is a DAAC-specific interface called Web-based Hierarchical Ordering Mechanism (WHOM). The third is by subscription. A fourth way of acquiring data is through a direct broadcast receiving station. At this time, Level 0 data (raw counts) can be received, but the Level 1B software is not yet available to the public. The Level 1B PGEs have been made available to the University of Wisconsin and the GSFC Direct Broadcast Services, who will release the Level 1B PGEs to the public in late 2003.

7. SUMMARY

The AIRS, AMSU, and HSB instruments comprise the Aqua Infrared and Microwave Sounding Suite (AIMSS). Together they produce data products useful for improving weather forecasting and climate change studies. Among the products are calibrated, high-spectral-resolution, infrared radiances from the AIRS. Validation of these radiances has shown calibration accuracy and stability of better than 0.2 K rms. The higher-level products are still under development and should be available in late summer 2003; however, at this time, the temperature profiles look very good. Validation of temperature profiles at this time show that the 1-K/km requirement is met for most altitudes under up to 80% cloudy conditions for mid-latitude oceans under nighttime conditions. The validation of products under a greater latitude range, daytime, and land will occur over the course of the next few years. In the meantime, the data are being sent to the weather centers that are assessing the potential improvement to the forecast accuracy. The exceptional stability in the radiance products indicates that the AIRS data will be extremely useful climate studies.

8. ACKNOWLEDGEMENTS

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