# Operational Readiness for the Atmospheric Infrared Sounder (AIRS) on the Earth Observing System Aqua spacecraft

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## ABSTRACT

The Atmospheric Infrared Sounder project will measure global atmospheric water vapor and temperature with unprecedented resolution and accuracy. AIRS is an infrared instrument with covering 3.7-15.4 microns in 2378 IR channels. This paper describes the AIRS science objectives, the instrument design and operation, the in-flight operational scenario, and the calibration plan. All aspects of the program are addressed here to demonstrate that the AIRS program is ready to transition to the flight segment of the program. The science objectives are clearly defined. the AIRS instrument meets the majority of requirements established in order to meet these science objectives. A well defined operational approach has been established, and a well defined calibration plan developed to ensure performance throughout the life of the mission.

Keywords: Earth Science, EOS, Aqua, AIRS, Sounder, Calibration, Operations

## 1. AIRS MISSION BACKGROUND AND OVERVIEW

Requirements for atmospheric sounding were first established in the late 1950s. Since the late 70s, NOAA polar orbiting satellite systems have supported operational weather forecasting with the High Resolution Infrared Sounder (HIRS) and the Microwave Sounding Unit (MSU) derived global temperature and moisture soundings. In 1987, after analyzing the impact of the first ten years of HIRS/MSU data on weather forecasting accuracy, the World Meteorological Organization (WMO) determined that significantly improving weather forecasting would require global temperature and moisture soundings with radiosonde accuracy[1,2].

Radiosonde accuracy is equivalent to profiles with 1-K rms accuracy in 1-km thick layers and humidity profiles with 10% accuracy in the troposphere. To meet the WMO requirements, an extensive data simulation and retrieval algorithm development effort was required to establish instrument-measurement requirements in the areas of spectral coverage, resolution, calibration, stability, and spatial response characteristics, including alignment, uniformity, and measurement simultaneity, radiometric and photometric calibration and sensitivity.

The National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) is a space-borne, global observation system designed to obtain comprehensive long-term measurements to help understand Earth processes affecting global change. AIRS is a key facility instrument on Aqua, the first PM (1:30 pm Equatorial Crossing Time) EOS platform. AIRS is designed to provide both new and more accurate data — compared to previous instruments — regarding the atmosphere, land, and oceans. This data will be used for application in climate studies and weather prediction. Among the important parameters to be derived from AIRS observations are atmospheric temperature and humidity profiles and ocean and land surface temperatures.

The AIRS instrument is the first high-spectral-resolution infrared sounder developed by NASA in support of operational weather forecasting by the National Oceanic and Atmospheric Administration (NOAA). Integration of the fully tested and calibrated AIRS flight unit with the EOS Aqua satellite started in December 1999, and is still in progress at the time of the writing of this paper. The EOS Aqua launch is scheduled for early 2002.

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## 2. AIRS SCIENCE OBJECTIVES

The AIRS/AMSU-A/HSB suite of instruments will provide both new and improved measurements of cloud properties, atmospheric temperature and humidity, and land and oceans skin temperatures, with the accuracy, resolution and coverage required by numerical weather prediction and climate models. Such data will be used to study climate change, geophysical processes, and monitor trends. Among the important data sets that AIRS will contribute to climate studies are:

- atmospheric temperature profiles
- sea surface temperature
- land surface temperature and infrared emissivity
- relative humidity profiles and total precipitable water vapor
- fractional cloud cover, cloud spectral infrared emissivity, and cloud-top pressure and temperature
- total ozone burden of the atmosphere
- column abundances of minor atmospheric gases such as $CO_2$, $CH_4$, CO, and $N_2O$
- outgoing longwave radiation and longwave cloud radiative forcing
- precipitation index

The Earth's climate is a complex system with many components and feedback processes that operate on different time scales. The slow components involve the deep oceans, and permanent and semi-permanent ice and snow covers. Their response sets the pace for long-term climate trends and may introduce a delay of 50 years or more in the response of the climate system to external forcing. The fast components encompass the atmosphere, upper ocean layers, and include the biosphere as well as air-land and air-sea interactions. The fast components, however, are controlled by the atmosphere, which drives the whole Earth environment and determines the amplitude and geographical patterns of climate change. The atmosphere controls many feedback processes that involve the interaction of radiation with clouds, water vapor, precipitation and temperature. Thus, a knowledge of the properties of the atmosphere is important not only for understanding processes that occur within the atmosphere itself, but also for understanding the feedback processes among the various components of the entire climate system. Atmospheric and surface measurements from AIRS will be able to provide data about these interactions with unprecedented accuracy.

Among these issues are:

(1) *Improving numerical weather prediction.:* Progress in four-dimensional data assimilation has reached the stage where the accuracy of model-derived atmospheric temperature fields is comparable to or better than that obtained from existing operational satellite soundings, i.e. about 2K. Consequently, further improvements in numerical weather prediction will require corresponding improvement in the accuracy of atmospheric temperature profiles to about 1K. This accuracy will be met by the AIRS/AMSU system.

(2) *Determining the factors that control the global energy and hydrologic cycles.* The study of the global hydrologic cycle and its coupling to the energy cycle is key to understanding the major driving forces of the Earth's climate system. AIRS will measure the major components of these driving forces including the thermal structure of the surface and atmosphere, amount and height of clouds, outgoing longwave infrared radiation, and distribution of atmospheric water vapor.

(3) *Investigating atmosphere-surface interactions.* AIRS super-window-channels will be able to observe the surface with minimum spectral contamination by the atmosphere. In addition, AIRS narrow spectral channels in the short wavelength infrared region will observe the atmospheric layers above the Earth's surface with the highest vertical resolution possible with passive remote sensing. The observations will enable investigations of the fluxes of energy and water vapor between the atmosphere and the surface, and studies of their effect on climate.

(4) *Detecting of the effects of increased greenhouse gases.* The ability to provide simultaneous observations of the Earth's atmospheric temperature, ocean surface temperature, and land surface temperature, as well as humidity, clouds, albedo, and distribution of greenhouse gases such as will enable AIRS to provide a single consistent data set with which to observe the effects of increased greenhouse gases.

(5) *Monitoring climate variations and trends.* Climate change occurs in many predictable as well as unpredictable ways. The AIRS complete infrared coverage from 3.4 to 15.4 µm will provide the flexibility to study different climate processes. For example, emission to space by strong water vapor bands may be a critical climate feedback mechanism. Using spectral features to monitor climate change from AIRS will be a new tool available for research. This is an important feature of AIRS which will support studies of climate change during the next decade and beyond.

The AIRS team is actively collaborating with Numerical Weather Prediction centers to ensure the full impact of AIRS is realized in improving weather forecasting. End to end simulations of AIRS/AMSU/HSB data have been used to fully test the Product Generation System and corresponding algorithms and prepare for the scientific exploitation of this data after launch.

## 3. AIRS INSTRUMENT

### 3.1 Requirements

The 1-K/1-km requirements can only be met by increasing the spectral resolution of the infrared sounder by approximately one order of magnitude, from the $\lambda/\Delta\lambda = 100$ resolving power of HIRS-2 to the hyperspectral $\lambda/\Delta\lambda = 1200$ resolving power of AIRS. Sensitivity requirements, expressed as Noise Equivalent Differential Temperature (NEdT), referred to a 250-K target-temperature range, from 0.14 K in the critical 4.2-µm lower tropospheric sounding wavelengths to 0.35 K in the 15-µm upper tropospheric sounding region.

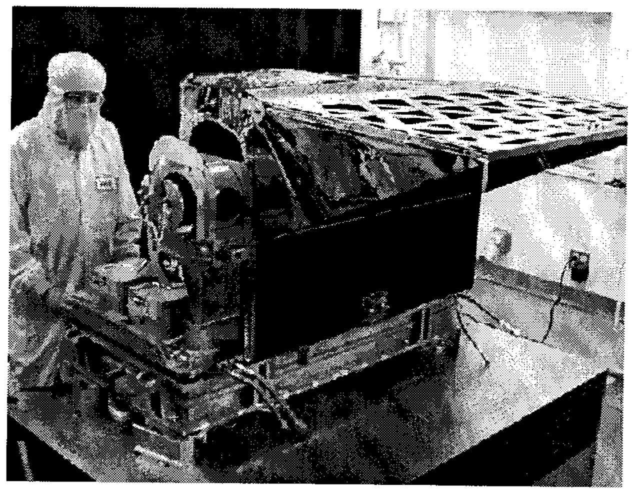

**Figure 1. The Atmospheric Infrared Sounder (AIRS).**

### 3.2 Instrument Overview

The AIRS instrument (shown in Figure 1) incorporates numerous advances in infrared sensing technology to achieve a high level of measurement sensitivity, precision, and accuracy. This includes a temperature-controlled grating, long-wavelength cutoff HgCdTe infrared detectors cooled by an active pulse tube cryogenic cooler.

Full use of the high measurement sensitivity and accuracy capability of AIRS requires very careful pre-launch calibration complemented by routine in-flight monitoring. The extensive pre-launch spectral, spatial, and radiometric calibration of AIRS was made using a test facility located at the BAE SYSTEMS facility in Lexington, Massachusetts, and designed specially for AIRS.

The AIRS Instrument provides spectral coverage in the 3.74- to 4.61-µm, 6.20- to 8.22-µm, and 8.8- to 15.4-µm infrared wavebands at a nominal spectral resolution of $\lambda/\Delta\lambda = 1200$, with 2378 IR spectral samples. A cross section of the scan head assembly is shown in Figure 2. A 360-degree rotation of the scan mirror generates a scan line of IR data every 2.667 seconds. The scan mirror motor has two speeds:

- During the first two seconds, the mirror rotates at 49.5 degrees/second, generating a scan line with 90 footprints of the Earth Scene, each with a 1.1-degree diameter Instantaneous Field of View (IFOV).

- During the remaining 0.667 seconds, the scan mirror completes one complete revolution, with four independent views of cold

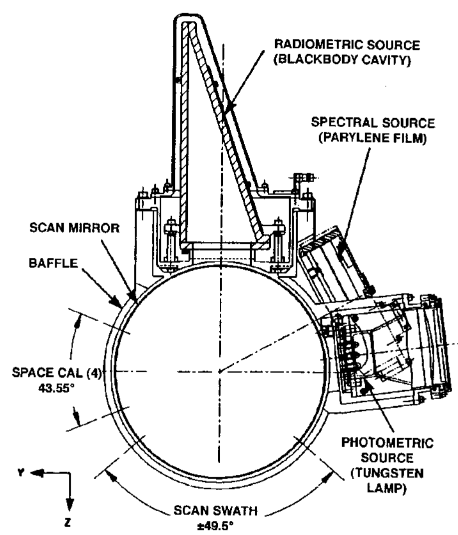


**Figure 2. AIRS Scan Assembly.**

space, one view into a 310 K radiometric calibrator (the On-Board Calibrator [OBC] blackbody), one view into a spectral reference source (Parylene), and one view into a photometric calibrator.

The VIS/NIR photometer, which contains four spectral bands, each with nine pixels along track, with a 0.185-degree IFOV, is bore sighted to the IR spectrometer to allow simultaneous visible and infrared scene measurements.

The diffraction grating in the IR spectrometer disperses the radiation onto 17 linear arrays of HgCdTe detectors (see Figure 3) in grating orders 3 through 11. Each linear array is comprised of **N** elements by two rows (A and B) for redundancy. The spectral ranges, number of elements per module, N, channel ID and quantization levels are shown in Table 1. The IR spectrometer is cooled to 150 K by a two-stage passive radiative cooler.

**Table 1. AIRS Detector and Module Identification Information.**

| Module Number | Module Type | Module Name | Spectral Cuton (μm) | Spectral Cutoff (μm) | Num Bits per Sample | Num Elements | GSS Channel Start | GSS Channel End |
|---|---|---|---|---|---|---|---|---|
| 1 | PV | M1A | 3.7364 | 3.9169 | 14 | 118 | 0 | 117 |
| 2 | | M1B | 4.11 | 4.3291 | 14 | 130 | 118 | 247 |
| 3 | | M2A | 3.9149 | 4.11 | 14 | 116 | 248 | 363 |
| 4 | | M2B | 4.3271 | 4.6085 | 14 | 150 | 364 | 513 |
| 5 | | M3 | 6.9356 | 7.4769 | 13 | 192 | 514 | 705 |
| 6 | | M4A | 6.2003 | 6.4934 | 13 | 104 | 706 | 809 |
| 7 | | M4B | 6.5504 | 6.85 | 13 | 106 | 810 | 915 |
| 8 | | M4C | 7.4745 | 7.7921 | 13 | 94 | 916 | 1,009 |
| 9 | | M4D | 7.8605 | 8.22 | 13 | 106 | 1,010 | 1,115 |
| 10 | | M5 | 8.8073 | 9.4796 | 13 | 159 | 1,116 | 1,274 |
| 11 | | M6 | 9.565 | 10.275 | 13 | 167 | 1,275 | 1,441 |
| 12 | | M7 | 10.275 | 10.985 | 13 | 167 | 1,442 | 1,608 |
| 13 | | M8 | 11.0704 | 11.7512 | 12 | 161 | 1,609 | 1,769 |
| 14 | | M9 | 11.7431 | 12.685 | 12 | 167 | 1,770 | 1,936 |
| 15 | | M10 | 12.7989 | 13.7457 | 12 | 167 | 1,937 | 2,103 |
| 16 | PC | M11 | 13.7377 | 14.5533 | 12 | 144 | 2,104 | 2,247 |
| 17 | | M12 | 14.6672 | 15.4 | 12 | 130 | 2,248 | 2,377 |
| 18 | Vis/NIR | VIS1 | 0.41 | 0.44 | 12 | 9 | 2,378 | 2,449 |
| 19 | | VIS2 | 0.58 | 0.68 | 12 | 9 | 2,450 | 2,521 |
| 20 | | VIS3 | 0.71 | 0.92 | 12 | 9 | 2,522 | 2,593 |
| 21 | | VIS4 | 0.49 | 0.94 | 12 | 9 | 2,594 | 2,665 |

The IR focal plane is cooled to 60 K by a Stirling/pulse tube cryocooler. The scan mirror operates at approximately 265 K due to radiative coupling to the Earth and space and to the 150-K IR spectrometer. Cooling of the IR optics and detectors is necessary to achieve the required instrument sensitivity. The VIS/NIR photometer uses optical filters to define four spectral bands in the 400- to 1000-nm region. The VIS/NIR detectors are not cooled and operate in the 293- to 300-K ambient temperature range of the instrument housing.

Signals from both the IR spectrometer and the VIS/NIR photometer are passed through onboard signal and data-processing electronics, which perform functions of radiation circumvention, gain ranging and offset subtraction, signal integration, and output formatting and buffering to the high-rate science data bus. In addition, the AIRS instrument contains command and control electronics whose functions include communications with the satellite platform, instrument redundancy reconfiguration, the generation of timing and control signals necessary for instrument operation, and collection of instrument engineering and housekeeping data.

The Stirling/pulse tube cryocoolers are driven by separate electronics that control the phase and amplitude of the compressor moving elements to minimize vibration and to accurately control the temperature. Heat from the electronics is removed through coldplates connected to the spacecraft's heat-rejection system.

P. Morse et. al give a more detailed description of the AIRS instrument and testing program[3]. An earlier paper by T. Pagano presents the results of AIRS performance testing[7]. All performance requirements have been meet or accepted by the AIRS science team.

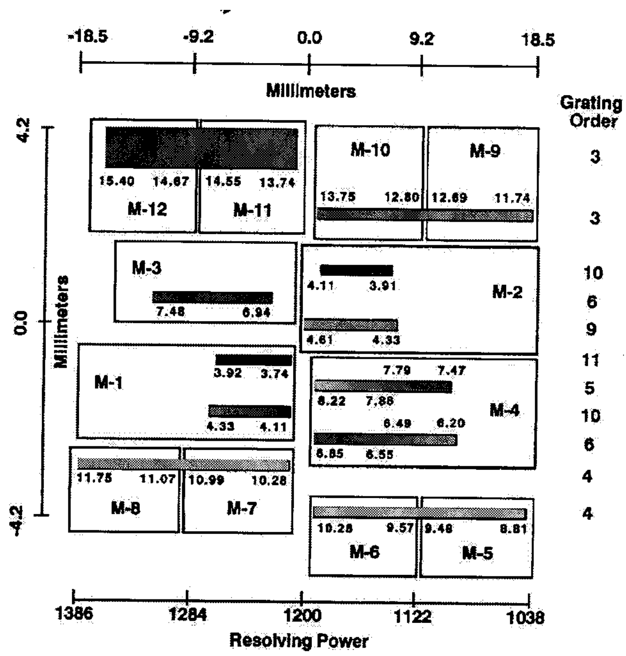


**Figure 3. AIRS FPA Layout.**

## 4. CALIBRATION APPROACH

The calibration of AIRS is critical to the mission success. As such we have implemented a comprehensive calibration plan incorporating extensive pre-flight testing complemented with special calibration tests to be performed at the spacecraft facility, during the Evaluation Phase in orbit, and periodically during the life of the mission. The testing program is complemented by routine monitoring of Quality Assessment (QA) indicators generated by the AIRS Product Generation System (PGS) Level 1B (L1B) software. The Level 1B software runs at the EOS Distributed Active Archive Center (DAAC) and also converts the AIRS data (digital numbers) into calibrated radiances. More detail about the AIRS calibration plan can be found in the AIRS Visible and In-Flight Calibration plan available directly from the author or the AIRS project office[4].

### 4.1 Use of Pre-Flight Data

The algorithms for calibration of the AIRS data can be found in the AIRS L1B Algorithm Theoretical Basis Documents[5,6]. Several paper[7,8,9] are available that present the radiometric, polarimetric and spectral calibration equations and the calibration coefficients and parameters within these that are dependent on the pre-flight calibration. The papers also presents results of the testing in detail. Not much has changed since the writing of these papers therefore we refer the reader to these documents for test results.

A new element in the calibration program is the development of a Level 1B testbed. The testbed allows the AIRS Calibration Team (ACT) to assess the accuracy of the L1B algorithms prior to implementation into the AIRS PGS. We ran the L1B testbed on radiometric data acquired during radiometric calibration at BAE SYSTEMS. The data were not those used to generate the calibration coefficients and were acquired several days later and at a different scan angle. We used the L1B testbed to generate radiances and these radiances were converted to temperature. Temperature sensors on the target

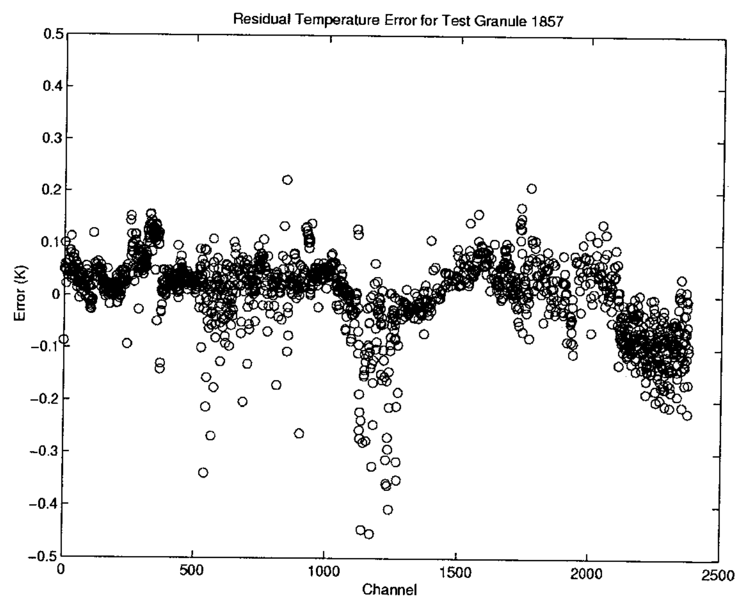


**Figure 4. Pre-launch radiometric residuals at end of scan are less than ±0.1K for most channels**

indicated its temperature to be 265K. The differences between the testbed generated temperatures and the known target temperature are shown in Figure 4. Differences at this level are well within the acceptable error in the L1B for the at-launch data product.

All the AIRS pre-flight test data have been analyzed and are ready for use in the flight operational software.

**4.2 Special Calibration Tests**

A set of special test have been defined that allow us to track the performance of AIRS through all phases of the program[4]. Table 2 identifies these tests. The tests are structured to provide the best spatial, radiometric, and spectral information possible using internal calibration sources and instrument telemetry. The purpose of this testing is twofold: first, to verify the calibration coefficients and characteristics determined pre-flight are still valid in the in-orbit environment and, secondly, to identify any new sources of noise or stray light.

Tests are given an ID with designation AIRS-CX, where X ranges from 1 to 12 and identifies the test. A brief description of each test is provided in the table. The AIRS Calibration Plan[4] requires these tests to be performed during spacecraft thermal vacuum and for the first time in orbit as soon as the optics are cooled. A subset of the tests are performed periodically throughout the life of the mission to obtain trending information on critical performance parameters. Also some tests may be repeated in the event that we loose thermal control of the optics or FPAs in order to obtain the needed characterization data.

Initial versions of all special test command sequences and data reduction software have been developed. These procedures and analysis tools will be demonstrated during thermal vacuum testing prior to use in the flight environment.

**Table 2. AIRS Special Test Procedures to support calibration.**

| Test ID | Name | Description |
|---|---|---|
| AIRS-C1 | Normal Mode / Special Events | Establish normal DCR and Lamp operation. Flag data for special events such as spacecraft maneuvers and Earth Scene targets of opportunity |
| AIRS-C2 | Guard Test | Cycles through A, B and A/B Optimum Gains and acquires data. Data are used to trend the instrument radiometric response and and for determination of x (spatial) and y (spectral) centration. |
| AIRS-C3 | Channel Spectra Phase | Heat and cool spectrometer by ±1K to shift the channel spectra from the entrance filters. Gain data obtained is used to determine channel spectra phase. |
| AIRS-C4 | AMA Adjust | Procedure moves the AMA to the desired x (spatial) and y (spectral) position |
| AIRS-C5 | OBC Cool | Blackbody heater is turned off. Data obtained during the cool down allows determination of the instrument non-linearity |
| AIRS-C6 | Variable Integration Time | Integration time is varied on readout while scanning. This gives a measure of the electronics non-linearity that can be trended over time |
| AIRS-C7 | Space View Noise | The scan mirror is stopped and parked at either the space view or the OBC BB with different A, B and AB optimum gains. Allows noise characterization |
| AIRS-C8 | Radiation Circumvention | Same test as AIRS-C7 but with radiation circumvention turned on. Allows determination of the effectiveness of the radiation circumvention circuitry |
| AIRS-C9 | Scan Profile | The AIRS nominal scan profile is rotated to allow the slow part of the scan to view either the space view or the combined OBC/Parylene view. Allows characterization of any stray light sources. |
| AIRS-C10 | Lamp Operations | Test exercises each of the three lamps by user command at specified time and duration.. |
| AIRS-C11 | Warm Functional | Test runs a test pattern through the electronics to verify data packet integrity. Another sub-test cycles the power on all focal planes to establish functionality |
| AIRS-C12 | Cold Functional | Same as AIRS-C11 except performed cold. This allows more accurate characterization for the focal plane sub-test |

**4.3 Routine Monitoring of the L1B QA Indicators**

The Level 1B Quality Assessment (QA) data provides the necessary indicators to evaluate instrument health status and calibration. The plan for routine monitoring is to develop a system to present summary reports and to perform long-term trending of the QA indicators and telemetry on a regular basis. We will look for changes in instrument performance as a function of orbital position, diurnal and seasonal variations and influences from operational events by the spacecraft and other instruments. The monitoring falls primarily into three categories; radiometric, spectral and telemetry. All QA parameters have been defined in the L1B interface specification and monitoring requirements have been defined in the AIRS Calibration Plan.

Radiometric QA monitoring tracks statistics on gains, offsets, and noise. Gains calculated per scan line in the L1B software, so statistics on the gains are obtained per granule (135 scans). These statistics are monitored vs orbital position and time. Long term trends can identify potential contamination or icing effects. Space view radiometric offsets are calculated from four space views available in the instrument. One of the four space views looks at approximately 70° from the NADIR and will be evaluated for potential earthshine prior to use in L1B algorithms. Every month for approximately 3 days the moon will occur in the space viewport. This event will be identified in the space view QA data as well as DC restores which occur every 20 minutes. Noise monitoring occurs primarily on these space views. Noise levels and anomalous events (e.g. > 4 sigma) are flagged in the QA, and trended vs orbital position and time. We plan to assess the effectiveness of the radiation circumvention circuitry by monitoring the noise QA as AIRS passes through the South Atlantic Anomaly.

The objectives of the in-flight spectral calibration are to determine the band centers and bandwidths of each of the AIRS infrared channels, and to determine the phase of the entrance filter channel spectra ("fringing"). AIRS relies heavily on the use of upwelling Earth Scene radiance spectra for this spectral calibration. An on-board spectral reference source (OBS) consisting of a thin coating (about 25 microns thick) of Parylene on an otherwise low emissivity substrate is also observed once per scanline. Because the spectral features are so much wider in the OBS spectra than in the upwelling scene spectra, the OBS calculations will be used only to provide a "sanity check" on the true spectral calibration (the upwelling feature processing). The calculations of band centers and related QA spectral information is done in the Level 1B. The spectral feature positions will be tracked at first during AMA alignment, but at more regular intervals to identify orbital thermal effects, and seasonal and annual dependencies.

## 5. IN-FLIGHT OPERATIONAL SCENARIO

The post-launch portion of the Aqua mission can be divided into three phases: activation, evaluation, and routine operations. Each of these is described in a separate subsection below. The AIRS operations team will maintain a physical presence at GSFC throughout the activation and evaluation phases.

AIRS is intended to operate in synchronism with two microwave instruments, AMSU-A (Advanced Microwave Sounding Unit A) and HSB (Humidity Sounder for Brazil). Once all three instruments have been checked, calibrated, and declared operational, they will be put into normal scan mode and allowed to run indefinitely. The only exceptions (barring instrument anomalies) are some AIRS visible channel calibration activities, and very occasional IR channel calibration updates.

The AIRS operational philosophy is to get valid science data flowing as soon as possible. However, there are certain constraints which must not be violated. Since parts of AIRS operate very cold, contamination is a possibility. Contamination can arise from materials outgassing from the spacecraft structure and the instrument structures. Also, the spacecraft thrusters put contaminants into the environment whenever they are used. When the AIRS scan mirror is pointed at the radiometric calibrator, its back acts as a door which prevents contaminants from passing into the instrument. Therefore, the scanner must remain stowed in that position until all contamination danger has passed.

Another important constraint is that science data are not of high quality (either for calibration or routine operations) unless the temperatures of both the spectrometer and the focal plane are stable. AIRS was deliberately designed with high thermal inertia. This guards against minor disturbances, but means there is a longer recovery time from major disturbances. Spacecraft roll and pitch maneuvers expose AIRS shields and radiators to non-nominal environments and upset thermal stability. After these maneuvers, data quality suffers until the temperature transients have died out. Depending on the magnitude of the disturbance, this time could range from 1–2 days up to a worst case of 11 days.

Two operations are extremely critical and are handled under special protocols designed to prevent their accidental use and to ensure that individual commands and arguments are approved by the AIRS project manager before use. They are (1) deploying the earth shield and (2) moving the Adjustable Mirror Assembly (AMA). The earth shield must deploy successfully, or the spectrometer cannot reach its desired operating temperature. The AMA will be moved only at the request of the calibration team with approval by the science team and project manager. This device is used to optimize signal strength on the detectors.

**5.1 Activation Phase**
In this phase, expected to last about six weeks, the AIRS hardware is activated, component by component. The above-mentioned constraints determine the duration of this phase.

The first AIRS-related activity, occurring within hours of launch, is for the spacecraft to provide power to both AIRS survival buses These buses power thermostatically-controlled heaters with hard-wired set points. They are intended to prevent components designed to run at or near ambient temperatures from getting too cold. No AIRS commands control these heaters. Once their bus is powered, they operate autonomously. These buses are intended to stay powered on throughout the mission.

Within two days of launch, one of two redundant quiet buses is powered by the spacecraft. When power is supplied to the quiet bus, the AIRS control computer boots up automatically. Within about 30 seconds AIRS is ready to accept commands. Group 1 power within the instrument is on and engineering telemetry is being generated. Most of the instrument is in Group 2. Group 2 power stays off until an AIRS command to turn it on is executed. The coolers and the decontamination heaters, which are powered by the noisy bus, are still off as well.

As soon as possible after the quiet bus is turned on, one of the redundant noisy buses will also be turned on and its decontamination heater activated. This heater is also thermostatically controlled with a hard-wired set point. It is activated to provide extra heating beyond what the survival heaters generate, if that becomes necessary. The decontamination heater will remain active until it is time to cool down the spectrometer by deploying the earth shield.

The remainder of this phase consists of flight software initialization, turning on Group 2 power, and turning on the various hardware components in succession. These include the science data formatter, chopper, radiometric calibrator heater, scanner, photometric calibrator lamps, deploying the earth shield, setting the second stage radiator heater's set point, turning on the cooler, and finally the focal plane.

**5.2 Evaluation Phase**
This phase both overlaps and follows the activation phase. It will end when AIRS is declared operational, nominally 120 days after launch. Part of this phase consists of verification that the software was correctly initialized and that each hardware component is working as expected. Most verifications will be done using engineering telemetry which is available in near real time during contacts, and within an orbit or so for data recorded outside of a contact. Some components (especially the focal plane and the calibrators) will require use of science data for full verification. That data follows a different path and requires different software to process. But it should be available within four to six hours using an EOSDIS-provided data expediting service.

Once AIRS hardware is ready and the temperature has stabilized (expected around day 40 of the mission), an in-depth evaluation and calibration of AIRS will begin. The special command sequences to implement the calibration are described functionally elsewhere in this paper.

**5.3 Routine Operations Phase**
Operations team activities consist of monitoring spacecraft and other instrument activities for possible impacts, watching trends in the engineering telemetry, and performing possible calibration updates every six months or longer. Perhaps once or twice during the mission, due to aging effects leading to a gradual warming of the spectrometer, the set point of the second stage radiator heater will need to be changed and some of the calibration sequences repeated.

During routine operations, one of the three redundant photometric calibrator lamps is activated for eight minutes every other orbit. Since the AIRS flight computer supports periodic commands, only one command need be sent up from the ground to cause this lamp to turn on periodically indefinitely. However, the three photometric calibrators need to be cross-calibrated. In that way, if the primary lamp fails, another can be substituted with no loss of science quality. Every 200 orbits, the periodic activation of lamp #1 will be stopped, and **both** lamps 1 and 2 will be activated (sequentially). Then the lamp #1 periodic activation will be restarted. Every 600 orbits, all three lamps will be turned on (sequentially) in a similar manner.

## 6. PRODUCT GENERATION SYSTEM

The AIRS Science Processing System (SPS) is a distributed parallel system designed to process AIRS data in a heterogeneous network environment. Various AIRS scientific products are generated by a set of independent Product Generation Executables (PGEs). The AIRS SPS will be operating at the Goddard Space Flight System (GSFC)

Distributed Archive Center (DAAC) and also at the AIRS Team Leader Science Computing Facility (TLSCF) at the Jet Propulsion Laboratory (JPL). The TLSCF Data System (TDS) provides an environment for ingest, processing and archiving of the AIRS products at the JPL TLSCF. A separate paper[10] at this conference discusses the AIRS SPS in detail. We refer the reader to this paper for further information on this subject.

## 7. SUMMARY

All aspects of the AIRS program are ready for launch. The science objectives have been clearly established. Science algorithms are in place for retrieval of the important data sets. The instrument is fully developed and performing well above expectations. The calibration approach is well defined. Special calibration test procedures and data reduction software has been developed. A long term QA indicator monitoring plan has been developed and all necessary QA information contained within the L1B and L2 data products. The PGS which develops the standard data products is fully functional and implemented at the GSFC DAAC. An update release will be released shortly after launch to incorporate any new algorithms or information obtained in the interim. Finally, an in-flight operations plan has been defined which includes activation, evaluation and operational procedures to ensure the proper implementation and maintenance of the AIRS instrument in orbit.

## ACKNOWLEDGEMENTS

Much hard work has gone into the preparations for launch of the AIRS instrument and numerous individuals have been involved in this effort; there are more names than can be acknowledged in this paper, but we would like to acknowledge all members of the AIRS team. A truly team spirit exists on the AIRS program and each player has had a vital role in getting us where we are today. The team is anxiously awaiting the launch of AIRS when we can demonstrate the science, operations and calibration methods we have described in this paper. We believe our preparations will make the flight phase of the program quite manageable, thereby allowing more time for the true intention of AIRS; the study of Earth's climate.

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