AIRS — The Atmospheric Infrared Sounder

Bjorn Lambrigtsen (818-354-8932, lambrigtsen@jpl.nasa.gov),
Eric Fetzer, Evan Fishbein, Sung-Yung Lee, Thomas Paganao
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109

Abstract— The Atmospheric Infrared Sounder (AIRS) was launched in 2002, along with two companion microwave sounders. This AIRS sounding suite is the most advanced atmospheric sounding system to date, with measurement accuracies far surpassing those of current weather satellites. From its sun synchronous polar orbit, the AIRS system provides more than 300,000 all-weather soundings covering more than 90% of the globe every 24 hours. Much of the post-launch period has been devoted to optimizing the "retrieval" system used to derive atmospheric and other parameters from the observations and to validate those parameters. The geophysical parameters have been produced since the beginning of 2003 — the first data were released to the public in mid-2003, and future improved versions will be released periodically. The ongoing calibration/validation effort has confirmed that the system is very accurate and stable. There are a number of applications for the AIRS products, ranging from numerical weather prediction – where positive impact on forecast accuracy has already been demonstrated, to atmospheric research – where the AIRS water vapor products near the surface and in the mid and upper troposphere as well as in the stratosphere promise to make it possible to characterize and model phenomena that are key for short-term atmospheric processes, from weather patterns to long-term processes, such as interannual variability and climate change.

1. INTRODUCTION

The Atmospheric Infrared Sounder (AIRS) was launched on the Aqua research satellite, a major component of NASA's Earth Observing System, in May 2002. Together with two microwave sounders – the Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder for Brazil (HSB) – it forms the AIRS Sounding Suite, which makes up about half of the Aqua payload. This suite represents the most advanced sounding system ever deployed in space. Together these instruments make observations that are key to be able address science questions related to climate and global change. They also represent a major step forward in weather observations and will serve as a pathfinder for the next generation of weather satellites and the use of high hyperspectral observations in weather forecasting.

2. OBJECTIVES AND SCIENCE QUESTIONS

The primary AIRS mission is to address various science questions related to climate and global change manifested in the atmosphere. The mission has later been expanded to also encompass weather prediction and atmospheric chemistry. Although atmospheric observations have been made for many years, the accuracy and coverage of these observations have been inadequate to properly address many of the science questions related to climate change. For example, there are thousands of radiosondes released globally every day, but even so they provide only a spotty coverage on a global scale and very sparse coverage over oceans and uninhabited regions. Weather satellite measurements have been available since the late 1970's, but measurement accuracy has not been adequate for climate studies, where very high accuracy and long term stability are crucial. The AIRS system was designed to provide continuous global observations with an accuracy equal to that of radiosondes, and that is now being achieved. As the AIRS data sets begin to be used by the climate research community, significant advances in the body of knowledge about the Earth-atmosphere-climate system can be expected. In particular, the AIRS water vapor measurements – with accuracies and coverage far exceeding what has been available from other sources – will be of exceptional value.

Some of the science questions addressed by AIRS are as follows.

The global water and energy cycle: What is the global distribution and variability of water vapor? Is the cycle of evaporation and precipitation on Earth accelerating?

Climate weather connection: Are current weather anomalies, such as hurricanes and droughts, connected to climate change – and how?

Atmospheric composition: How can AIRS contribute to the measurement of atmospheric chemical species and trace gases such as CO_2, CO, CH_4, SO_2 etc.?

Weather prediction: How can AIRS data be used to improve the accuracy and range of weather forecasts?

To address the last question the AIRS Project has established close working relations with a number of national weather forecasting agencies around the world, including the U.S. National Centers for Environmental Prediction (NCEP) and the European Center for Medium-Range Weather Forecasts (ECMWF), and AIRS data are provided to these organizations in near real time for experimental use in their numerical weather prediction systems.

3. Instrument Concept and Measurements

The Atmospheric Infrared Sounder is an infrared grating spectrometer that operates in the thermal infrared portion of the spectrum, from 3.7 µm to 15.4 µm. It has 2378 channels covering about 3/4 of this range, with a spectral resolution ($\lambda/\Delta\lambda$) of about 1200. Radiometric sensitivity is typically about 0.25 K. This system is used to measure upwelling thermal radiation emitted from the atmosphere and the surface, and by analyzing an observed spectrum it is possible to infer what the vertical distribution of temperature and water vapor is. This is essentially accomplished by inverting the so-called radiative transfer equation (RTE), which models the spectral intensity for a given distribution of the geophysical parameters.

The presence of clouds is a major hindrance, since most clouds are nearly completely opaque in the infrared. Full soundings would then only be possible in cloud free areas and partial soundings above the cloud tops in cloudy areas. In contrast, microwave radiation readily penetrates most clouds, and a microwave sounder can provide full coverage under most weather conditions. However, it is difficult to obtain adequate vertical resolution and measurement accuracy with a microwave sounder, and an infrared sounder excels in those respects. The happy solution is to combine the two, and that is what the AIRS Sounding Suite does. Although such sounding suites have been operated by the National Oceanic and Atmospheric Administration (NOAA), home of the National Weather Service, for many years, the AIRS system represents a giant step forward in capabilities compared with the NOAA systems. In a combined sounding system, the microwave observations are used to characterize the average cloud cover in a small region surrounding a cluster of infrared observations. Typical cloud cover has high spatial variability, and by analyzing the infrared spectra from small portions of this region, with normally different amounts of clouds in each, it is possible to "extrapolate" between a highly cloudy sub-scene and a less cloudy sub-scene to zero cloudiness, with the help of the microwave observations. This process, called cloud clearing, makes it possible to infer a cloud free infrared spectrum for the larger region. This is illustrated in Fig. 1, where the larger circle represents the "larger region" defined by the microwave field of view and the "smaller regions" are defined by the smaller infrared field-of-view circles. The construction and operation of the instruments in the AIRS suite are arranged so that the entire global swaths scanned out can be divided into such clusters.

Once a cloud free infrared spectrum has been determined – in each of the clusters illustrated in Fig. 1, which are about 45 km in diameter directly below the satellite and larger near the edges of the scan swath – it is in principle a simple matter to invert the radiative transfer equation and compute atmospheric profiles and other parameters (such as the surface temperature). In practice, the cloud clearing and inversion of the RTE is combined in an iterative process that is repeated until conversion is achieved radiances predicted with the RTE and those observed. That makes it possible to also solve for cloud parameters.

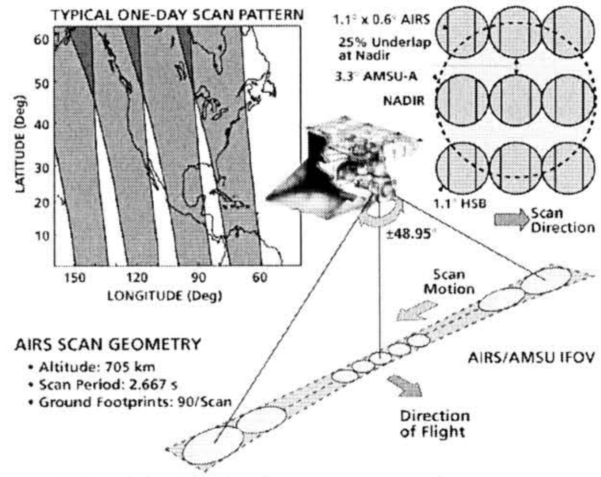

Fig. 1. AIRS viewing geometry and coverage

In addition to temperature profiles – with a vertical resolution of 1 km in the troposphere and an accuracy of 1 K, and water vapor profiles – with a vertical resolution of 2 km in the troposphere and an accuracy of 15%, cloud top height, temperature and fraction within the field of view are determined for up to two cloud layers, and surface parameters, such as temperature and spectral emissivity, are also derived. Profiles of ozone, CO and other minor gases are also produced, and it is expected that CO_2 – not originally on the list of planned products but now being developed due to the great interest in CO_2 among climate researchers. The information content in the AIRS spectra is very large, and one can expect that other products will be developed as the investigation continues. The core sstandard AIRS products are listed in Table 1. The Level 2 data products are arranged in a swath format matching the observational geometry and is quite voluminous. To make it

Table 1. Primary AIRS data products

	Accuracy	**#**	**Spatial res.**
Radiance products (Level 1B)			
AIRS IR radiance	3%	2378 ch.	15x15 km^2
AIRS Vis radiance	20%	4 ch.	2.3x2.3 km^2
AMSU radiance	0.3-1.2 K	15 ch.	45x45 km^2
HSB radiance	1.0-1.2 K	4 ch.	15x15 km^2
Standard products (Level 2)			
Cloud-cleared IR rad.	1.0 K	2378 ch.	45x45 km^2
Sea surface temperature	0.5 K	1	45x45 km^2
Land surface temperature	1.0 K	1	45x45 km^2
Temperature (0 – 45 km)	1.0 K	28 levels	45x45 km^2
Water vapor (0 – 45 km)	15%	28 levels	45x45 km^2
Total precipitable water	5%	1	45x45 km^2
Fractional cloud cover	5%	2 clouds	45x45 km^2
Cloud top height	0.5 km	2 clouds	45x45 km^2

easier for researchers to use AIRS data a Level 3 version – gridded daily, weekly and monthly averages – of many of the key Level 2 parameters will soon be available.

4. Some Results

Fig. 2 illustrates current retrieval accuracy for ocean cases. For temperature (upper panel) the comparison is between AIRS retrievals and ECMWF model forecasts. It shows that AIRS is in general meeting the 1 K per 1 km requirement from the surface to the lower stratosphere (~ 30 mb). The lower panel illustrates water vapor retrieval accuracy for tropical ocean cases. Here the comparison is with radiosondes. It shows that the AIRS retrievals meet the requirements of 15% per 2 km in the lower to mid troposphere. Water vapor retrievals are still being improved, however. In addition, water vapor "truth" is difficult to come by – particularly for the upper troposphere, where radiosondes lose accuracy and forecast fields from ECMWF and others may be questionable. Validation of a system such as AIRS, which is expected to be more accurate than most other available sources, is in general therefore a difficult task.

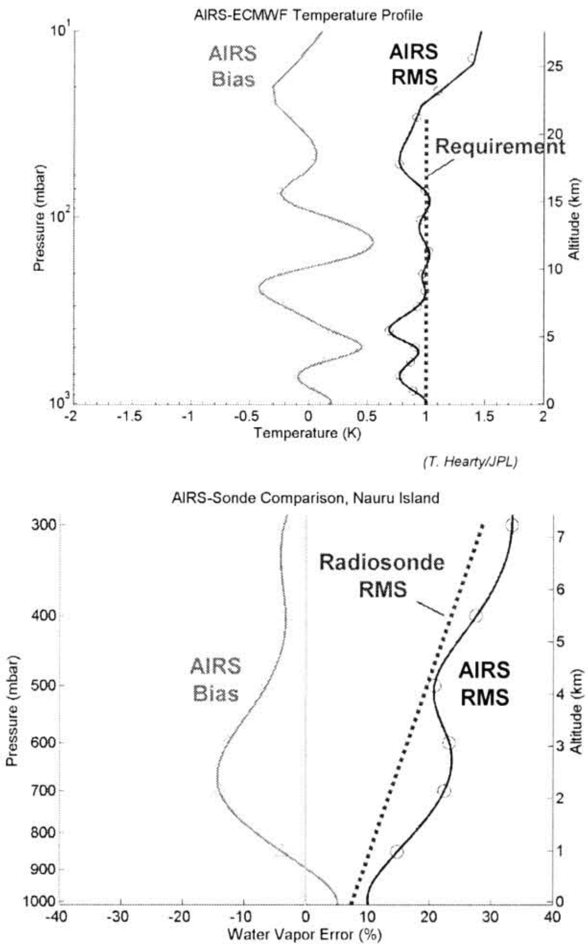

Fig. 2. AIRS retrieved profile statistics
Top panel: Temperature (mid-latitude ocean)
Bottom panel: Water vapor (tropical ocean)

Finally, Figs. 3 and 4 show examples of monthly gridded products that can be generated from the AIRS data. Fig. 3 shows the global distribution of mean surface air temperature – for January 2003 in the upper panel and July 2003 in the lower panel. Fig. 4 shows mean monthly precipitable water above 500 mb – for the same two months as in Fig. 3.

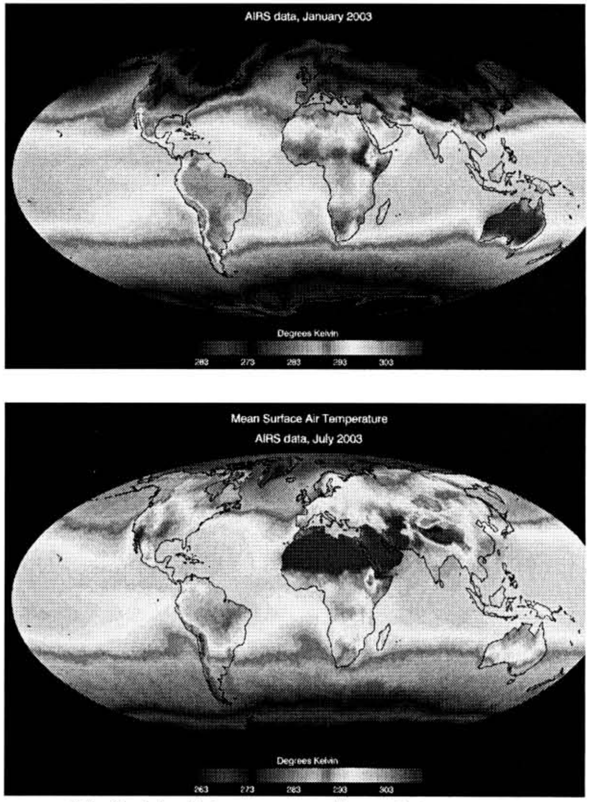

Fig 3. Monthly mean surface air temperature
Top panel: January 2003; Bottom panel: July 2003

5. Conclusions

The AIRS system is performing very well, and the data products are meeting the requirements – even as they are being improved. The data sets coming out of this mission will contribute significantly to atmospheric and climate

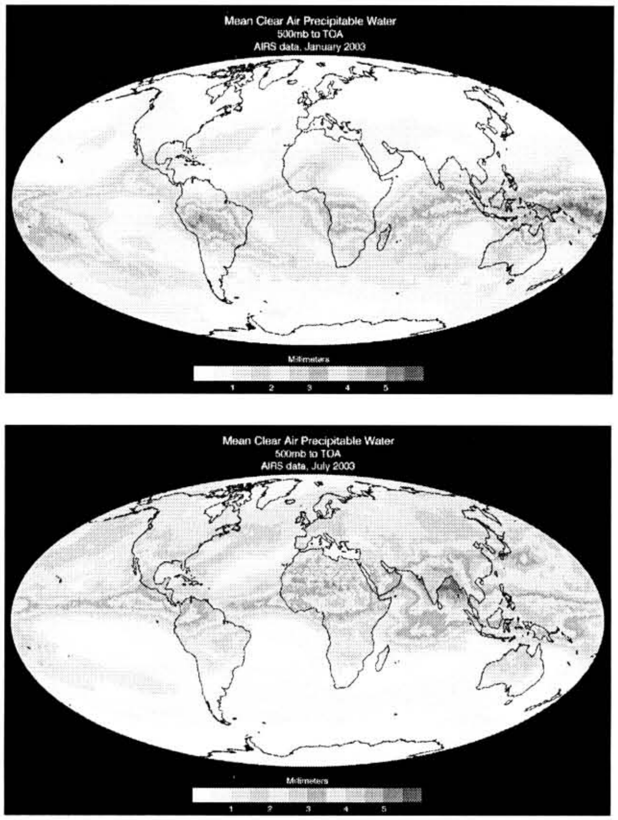

Fig 4. Monthly mean upper atmospheric humidity
Top panel: January 2003; Bottom panel: July 2003

research – and may revolutionize some research areas, with the availability of data such as upper tropospheric water vapor measurements that far exceed what has been available until now, in terms of accuracy, resolution and coverage.

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