AIRS: The Atmospheric Infrared Sounder

By Moustafa T. Chahine

A major objective of the study of global change is the development of accurate long-term data sets of the Earth's climate system. To accomplish this, a wide range of observations will be carried out by the NASA Earth Observing System (EOS). The Atmospheric Infrared Sounder (AIRS) is a facility instrument selected by NASA to fly on the first polar orbiting platform, EOS-A1. The same platform will also carry the NOAA operational Advanced Microwave Sounding Unit (AMSU-A) and the Microwave Humidity Sounder (MHS). The AIRS/AMSU/MHS system will provide both new measurements not previously achievable and measurements with a greater degree of accuracy and resolution than are currently available.

AIRS, the chief atmospheric sounder on EOS, is designed to meet the requirements of both the NASA Earth science research programs and the NOAA operational plans. These requirements are based on more than 25 years of experience with operational satellite data. They were defined through extensive simulation studies conducted by NASA, NOAA, and the European Center for Medium-Range Weather Forecasts (ECMWF).

During the past 20 years, considerable progress has been made in passive infrared remote sensing of temperature profiles. Currently, the NOAA operational weather sounders provide atmospheric temperature profiles with an average accuracy of about 2.2K and a vertical resolution of 3 km in the troposphere. However, this accuracy falls short of the requirements for numerical prediction models because, during the past decade, models have evolved more rapidly than the capabilities of temperature sounders. For example, four-dimensional data assimilation by current General Circulation Models 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.

There is general agreement now that further improvements in numerical weather prediction will require additional improvements in remote sensing data. For atmospheric temperature profiles, the needed improvement was determined to be 1K in 1 km thick layers. To meet this accuracy and vertical resolution, it is essential to vastly increase the spectral resolution of infrared sounders, increase the number of usable sounding channels, and maintain high signal to noise ratios of measured radiances. In addition to the infrared channels, complementary microwave and visible channels are required to account for the effects of clouds.

AIRS meets all of these requirements. Its high spectral resolution covers the range from 3.4-15.4 μm (corresponding to 649-2941 cm^{-1}) and provides more than 3600 spectral measurements at a resolving power of $\lambda/\Delta\lambda = 1200$. The corresponding noise equivalent change in temperature (NEΔT) is equal to 0.2K when viewing a scene of 250K mean temperature. In addition, the AIRS instrument includes six visible and near infrared channels defined by bandpass filters in the range 0.4-1.7 μm. AIRS visible channels are selected for detecting prevalent low-level clouds, while the AMSU microwave channels provide the capability to eliminate the effects of mid-level and high clouds, as well as to improve the temperature retrievals in the middle and upper atmosphere.

Optical design

AIRS instrument design consists of two pupil imaging, multi-aperture grating spectrometers that provide contiguous spectral coverage throughout the observed spectral range. The short wavelength spectrometer (3.4-8.6 μm) and the long wavelength spectrometer (8.6-15.4 μm) each contain an echelle grating and use several grating orders. Several design approaches were investigated, including a cross-dispersed spectrometer and a multi-aperture spectrometer. The multi-aperture design was selected because it offered more uniform efficiency across spectral orders with less scatter and provided the focal plane flexibility crucial to optimize the performance of the sounder.

The spectral order separation in the selected design is accomplished by subdividing the telescope entrance pupil into several apertures, each with its own out-of-band rejection filter. The radiation passing through these apertures is reimaged to the spectrometer entrance slit plane, collimated and then dispersed by the echelle grating before the apertures are reimaged onto a series of arrays, as shown in

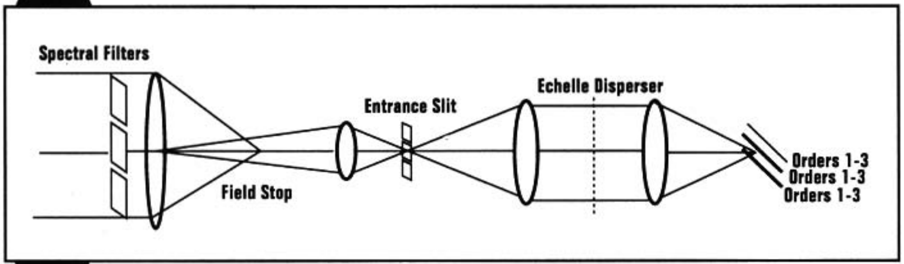

FIGURE 1
AIRS MULTI-APERTURE SPECTROMETER DESIGN.

Figure 1. The arrays are parallel to each other and their separation is determined by adjusting the spacing between the entrance apertures. In this design, each aperture and its corresponding array may be individually adjusted to provide the required signal to noise ratio.

The focal plane/dewar assembly drives the performance requirements of other AIRS components such as detector coolers. It consists of optical filters, infrared detectors, multiplexers, and dewar elements with stringent performance and alignment requirements. The focal plane/dewar assembly is mounted along with the spectrometers on the optical bench. There are two focal planes mounted within a common dewar; both operate at 60K. The dewar assembly isolates the 60K focal planes from the 155K optical bench. Focal plane cooling is provided by a split Stirling cycle cooler. The focal plane for the short wavelength spectrometer, shown in Figure 2, is comprised of linear mercury cadmium telluride (HgCdTe) detector arrays. Each linear array is covered by a different optical bandpass filter to isolate the proper grating order and reject stray radiation.

Every 2.667 seconds, AIRS will scan a ±49.5° swath across nadir in a direction perpendicular to the EOS satellite's ground track. The scanner employs a continuously rotating 45° mirror, and provides a spectral calibration and a two point radiometric calibration. The scanner is mechanically and thermally mounted to the outer frame of the AIRS mechanical structure and operates at 293K. The AIRS instantaneous field of view (IFOV) is 1.1°, providing a 13.5 km footprint at nadir from a 705 km orbital altitude. As shown in Figure 3, the dimensions of AIRS are 80 × 95 × 116 cm, its mass is 114 kg, and it requires 295 W of power. AIRS will transmit its full data at the rate of 2 Mbps.

AIRS global data products

The AIRS/AMSU system will provide both new and improved measurements of clouds, atmosphere, land, and oceans, with the accuracy, resolution, and coverage required by future weather and climate models. The selected infrared sounding channels are located away from unwanted absorption lines while taking advantage of the unique spectral properties of several regions, such as the high J-lines in the R-branch of the 4.3 μm CO_2 band[1] and the clear "super-windows" near 3.6 μm region. AIRS provides 3600 spectral measurements from which to select the manifold of sounding channels required for high vertical resolution. The amalgamation of visible, infrared, and microwave measurements permits simultaneous determination of a large number of parameters under partly cloudy conditions, even in the presence of multiple cloud formations, without requiring any field of view to be clear. Among the important geophysical data sets that AIRS will contribute to climate studies are:

- Atmospheric temperature profiles with an average accuracy of 1K in 1 km thick layers;
- 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;
- Mapping the horizontal distribution of minor atmospheric gases such as methane, carbon monoxide, and nitrous oxide;
- Surface albedo and surface energy balance;
- Outgoing longwave radiation and longwave cloud radiative forcing; and
- Precipitation index.

It should be noted here that simultaneous retrieval of several parameters is needed to achieve the required accuracy. For example, in the case of temperature retrieval, the measured radiance is a function of the surface emission, atmospheric emission, reflected thermal downward-flux, and the reflected solar flux, as well as hazes and clouds that are always present in the field-of-view even under the clearest conditions.[2] All of these terms must be taken into account to achieve accurate and reliable results. Thus, to retrieve the temperature profiles, it is necessary to simultaneously solve for the first six parameters listed above.

Application to the study of global change

The Earth's climate is a complex system with many components and feedback processes in which the atmosphere plays a very important role. The atmosphere determines the amplitude and geographical patterns of climate change and 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 provide data about these interactions with unprecedented accuracy.

This makes AIRS/AMSU the primary source for investigating several interdisciplinary climate problems. Among these is improving numerical weather prediction and extending its useful range from 7 to 10 days. Another climate problem is determining the factors that control the global energy and hydrology cycle and its coupling to the energy cycle as key to understanding the major driving forces of the Earth's

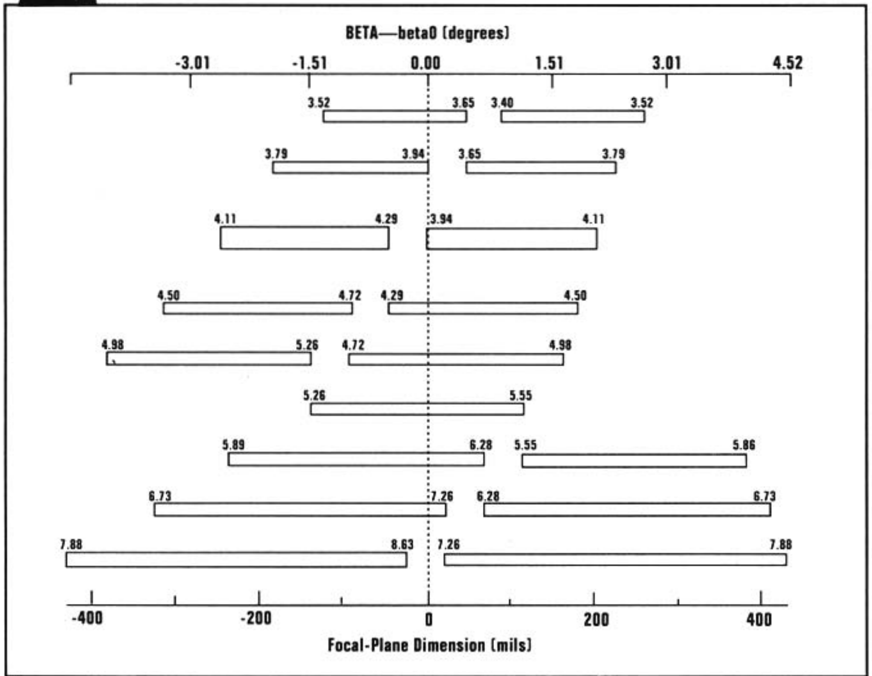

FIGURE 2
LAYOUT OF THE SHORT WAVELENGTH FOCAL PLANE DETECTOR ARRAYS

climate system. AIRS super-window channels will make it possible to observe the surface with minimum spectral contamination by the atmosphere, which will enable investigation of the fluxes of energy and water vapor between the atmosphere and the surface. 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, makes AIRS the primary space instrument to observe the effects of increased greenhouse gases. Finally, AIRS' complete infrared coverage from 3.4-15.4 μm provides the comprehensive database that will allow us to study new climate anomalies as they become recognized.

Acknowledgement

The author wishes to thank F. O'Callaghan, H. Aumann, R. Haskins, R. Pagano, and R. Schindler of the Jet Propulsion Laboratory (JPL), California Institute of Technology, and J. Bates, P. Morse, and C. Miller of Loral Infrared and Imaging Systems (LIRIS) for their individual contributions to AIRS. The AIRS instrument is the result of joint efforts carried out at JPL in Pasadena, Calif., and at LIRIS in Lexington, Mass., where the AIRS instrument is being built. This research was funded under contract with NASA.

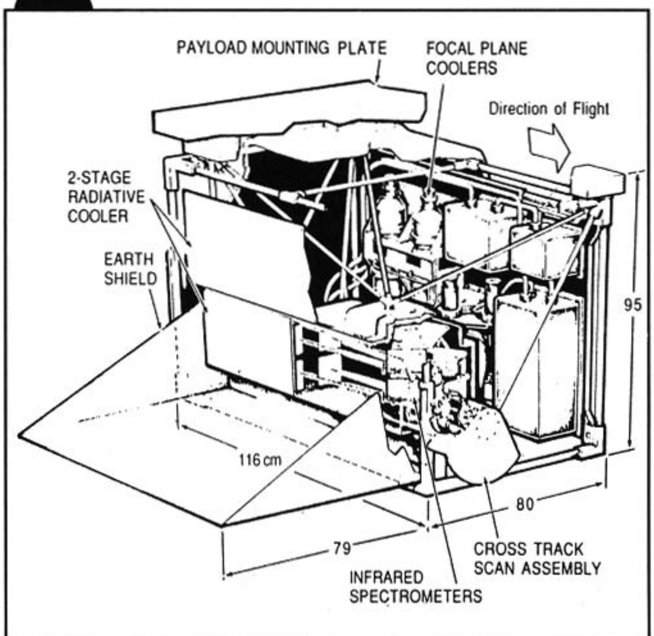

FIGURE 3
PERSPECTIVE DIAGRAM OF THE AIRS INSTRUMENT.

References

1. L.D. Kaplan *et al.*, "Spectral band passes for a high precision satellite sounder," App. Opt., **16**, 1977, 322-325.
2. M.T. Chahine *et al.*, "Requirements for a passive IR advanced moisture and temperature sounder," App. Opt., **23**, 1984, 979-989.

Moustafa T. Chahine *is chief scientist at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.*