Three Years of Hyperspectral Data from AIRS: What have we learned?

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Outline

A quick introduction to AIRS

What did we expect

What have we learned

What would we improve in a future hyper-spectral sounder

Conclusions
**Spacecraft:** EOS Aqua  
**Instruments:** AIRS, AMSU, HSB, MODIS, CERES, AMSR-E  
**Launch Date:** May 4, 2002  
**Launch Vehicle:** Boeing Delta II Intermediate ELV  
**Mission Life:** 5 years  
**Team Leader:** Moustafa Chahine

**AIRS Project Objectives**  
1. Support Weather Forecasting  
2. Climate Research  
3. Atmospheric Composition and Processes
AIRS on EOS Aqua
705 km altitude polar orbit
14 orbits per day

AIRS uses minimum moving parts.

+/- 50 degree cross-track scanning
with 13.5 km IR FOV at nadir

Cooled grating array spectrometer
58K detectors
156K optical bench

The radiometric and spectral calibration
are frozen into the design.

3.7 – 15.4 microns
2378 spectral channels
spectral resolution 1200
spectral sampling 2400

NeDT 50%tile better than 0.2K at 250K

AIRS takes 2.9 million spectra per day
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We expected a minimum of three years of data. This has already been exceeded.

We expected and achieved laboratory grade absolute accuracy and stability of the AIRS radiances (Aumann 2006 JGR paper)

We expected and achieved forecast impact. NCEP has achieved 6-12 hours of forecast impact with AIRS clear radiances in the Northern and Southern Hemisphere. (Chahine 2006 BAMS paper)

We expected and achieved essentially RAOB accuracy, day/night land and ocean (Divacarla 2006 JGR paper using NOAA 16 mathups). Divacarla works for NOAA, not NASA!
Achieved, but not expected

AIRS Level 1b radiances were ready on 31 August 2002, less than 4 months after launch, and have been essentially unchanged since then.

We have CO maps (JGR paper by McMillan)

We have day/night ozone maps (Irion JGR paper)

We have CO2 retrievals (Chahine GRL paper and others)

We have an SO2 flag used by the FAA for near real-time aircraft warning (DeSouza GRL paper)

Aerosol maps, and more.
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Lessons from AIRS

1. Instrument stability is critical

2. Clouds and effective system noise

3. Data Assimilation
Lessons from AIRS

1. Instrument stability is key to the success of AIRS.

A design with minimum moving parts yield a stable instrument.

A stable instrument leads to stable software

Stable software permits reliable analysis of bias and noise.

Reliable bias and noise estimates are key to the optimal near-real-time data assimilation, and data product generation
Lessons from AIRS

1. Instrument stability continued....

Instrument accuracy and stability have to be established relative to NIST traceable measurements.

The AIRS calibration accuracy and stability evaluation uses observations of the night time tropical oceans under cloud-free conditions using the 2616 cm-1 super window channel to derive a surface temperature, sst2616.

The comparison sst2616 to the RTGSST connects AIRS calibration to the floating buoy calibration, which is NIST traceable.
Of the -0.64 K observed cold bias relative to the RTGSST, 0.4 K was expected due to known day/night and skin buoy effects. There is 0.24 K of residual cloud contamination!

May 2004 RTGSST software change

Stability in the software is critical to the interpretation of trends. In this case it is the stability of the RTGSST software.
Lessons from AIRS

1. Instrument stability evaluation. Continued....

The next best window channel to 2616 cm$^{-1}$ is at 1231 cm$^{-1}$
The comparison relative the RTGSST is a little noisier
but statistically comparable

This is important for IASI and CRIS, which do not
have a usable 2616 cm$^{-1}$ channel.
At 1231 cm\(^{-1}\) expected -0.4 K bias at night, found -0.62 K.
Expected 0 bias during day, found -0.24 K.

The night bias in sst2616 and sst1231 are consistent.

Note the periodic signal imbedded in the bias!
The day and night bias in sst1231 are consistent

<table>
<thead>
<tr>
<th></th>
<th>day</th>
<th>night</th>
</tr>
</thead>
<tbody>
<tr>
<td>sst2616-rtgsst</td>
<td>mean bias = +0.64 K***</td>
<td>mean bias = -0.23 K*</td>
</tr>
<tr>
<td></td>
<td>trend = -3 +/-4 mK/year</td>
<td>trend = +8 +/- 2 mK/year</td>
</tr>
<tr>
<td>sst1231-rtgsst</td>
<td>mean bias = -0.24 K**</td>
<td>mean bias = -0.22 K*</td>
</tr>
<tr>
<td></td>
<td>trend = +3 +/- 3 mK/year</td>
<td>trend = +11 +/- 2 mK/year</td>
</tr>
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</table>

*  corrected for 0.4 K of expected night bias
** corrected for the expected day/skin bias
*** 0.8 K due to reflected sunlight
Details on the sst2616 RTGSST comparison using data from 200209-200508 are found in Aumann et al. JGR July 2006
For the analysis of the accuracy and stability of all other AIRS channels we analyze bias(obs-calc), where calc is based $T(p)$ and $q(p)$ from ECMWF.

The bias(obs-calc) is usually subtracted from the data in the assimilation or retrieval process with the assumption that it is stable.

If the data are accurately calibrated, the elimination of a bias relative to the perceived true $T(p)$, $q(p)$ diminishes the potential impact of the data on the forecast.
The bias(obs-calc.ECMWF) is typically less than 0.3K except in stratospheric temperature, Ozone and water channels.

For 2253 of the 2388 channels (obs-calc)=0.06 +/-0.28 [K] (excluded NeDT>1K)
  min=-1.3 max=1.5 K
We evaluate the stability of the AIRS data using the difference between the mean for year1 and year2.

The direct difference of year1-year2 simply shows inter-annual differences. We have to use double differences.

\[ \text{bias(obs-calc)} \text{ year1-year2} \]

The January 2003 Radiative Transfer Algorithm and the 200209 frequency table are used for AIRS.

AIRS data were not actively assimilated by ECMWF until year2.
The shift in the bias between the first and the second year of AIRS data in \((\text{obs-calc})\) in uncontested spectral areas is less than 20 mK.
2. Clouds and system noise

All real cloud-filters have some cloud-leak.

The variability of the cloud residuals leaking through the cloud filter is a source of noise.

This noise is characterized by the exponential distribution, i.e. the standard deviation equals the mean bias, (see Aumann et al. 2006 JGR paper).
Cloud-noise is due to the variability of the cloud-type which leaks into the cloud-filter.

Cloud-noise has an obvious seasonal component.
Lessons from AIRS

2. Cloud noise continued ...

The seasonal modulation of the mean 0.24 K cold bias in the tightly filtered (1% yield) “clear” AIRS data is a manifestation of cloud noise.

This noise sets the floor for the system performance. For the AIRS grating spectrometer design, this noise affects only channels with weighting functions at or below the cloud level.

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Lessons from AIRS

2. Clouds and system noise continued ....

System noise can be evaluated using stdev(obs-calc)

For this we replace TSurf.ECMWF with sst2616

This eliminates most cloud noise
\textit{stdev(obs-calc)} for channel where ECMWF is reliable agrees well with the NeDT reported by the Level 1b.

\textit{stdev(obs-calc)} for channels where ECMWF is not reliable is grossly inflated.

\textit{NeDT evaluated at the mean spectral brightness temperature}
Lessons from AIRS

3. Data Assimilation

AIRS data achieved forecast impact in spite of

using less than 1% of the data for assimilation

the use of the inflated noise from the stdev(obs-calc)
in the empirical noise covariance matrix.

Further improvements are possible
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Potential improvements

The data from the past four years show the advantages of hyper-spectral sounding, but much higher spatial resolution is needed to get a higher yield of “clear” support meso-scale sounding decrease sensitivity to water vapor and emissivity inhomogeneity pinpoint the physical origin of spectral features identified in the data (air quality)
A vision for the future sounder:

AIRS calibration quality data with 1km spatial resolution
ARIES: MODIS Spatial Resolution with AIRS Spectral Resolution and NEdT

**MODIS**
- 1 km IR IFOV
- 3.7-14.2 µm IR
- 16 IR Channels
- $\lambda/\Delta\lambda = 20-50$
- NEdT = 0.05 - 0.3 K
- Refractive Optics
- ± 55° FOV

**AIRS**
- 13.5 km IR IFOV
- 3.7-15.4 µm IR
- 2378 IR Channels
- $\lambda/\Delta\lambda = 1200$
- Grating Spectrometer
- NEdT = 0.05 - 0.3 K
- ± 50° FOV

Future Concept

**ARIES**
- 1 km IR IFOV
- 250 x 250 km imaging
- 3.6-15.4 µm IR
- 4800 IR Channels
- $\lambda/\Delta\lambda > 1500$
- Refractive Optics
- Grating Spectrometer
- NEdT = 0.1 - 0.3 K

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Conceptually, the 34 MODIS channels are replaced by 3400 “AIRS like spectral channels.

The 100 fold increase in potential data volume is handled by ground selectable on-board data filtering
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The AIRS design is paying off in stability and accuracy

AIRS has already achieved what was expected

We are learning from the data, but it is a slow process

The analysis of global and regional trends is just starting

We see the limitations due to the 13 km footprint size and have a concept for 1 km spatial resolution with AIRS spectral resolution and SNR
The next generation hyperspectral sounder could be even better

Thank you for your attention

For more information about AIRS visit

http://jpl.nasa.gov/airs

The AIRS Calibration Data Subset (ACDS) which was used for the trend and (obs-cal) analysis is available from the DAAC (factor 250 smaller than the original set)
Between the first and the second year of AIRS data, \( \text{stdev(\text{obs-calc})} \) has decreased in channels sensitive to water.

ECMWF is a better fit to the AIRS water spectrum in the 2nd year. Related to assimilation of AIRS at ECMW?
AIRS Radiance Assimilation Improves Operational Weather Forecasting for NOAA

Improved Forecast Prediction
(6 hours in 6 Days)
Northern Hemisphere*

“This AIRS instrument has provided the most significant increase in forecast improvement in this time range of any other single instrument,”

Retired Navy Vice Admiral Conrad C. Lautenbacher, Jr., Ph.D., under secretary of commerce for oceans and atmosphere and NOAA administrator.

LeMarshall et al. 2005
15 km resolution AIRS 1231 cm⁻¹
1 km resolution MODIS band 31