AIRS, Trends and Climate

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AIRS Science Team Meeting, Greenbelt Maryland
September 26, 2006
<table>
<thead>
<tr>
<th><strong>Spacecraft:</strong></th>
<th>EOS Aqua</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instruments:</strong></td>
<td>AIRS, AMSU, HSB,</td>
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<td>MODIS, CERES,</td>
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<td></td>
<td>AMSR-E</td>
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<tr>
<td><strong>Launch Date:</strong></td>
<td>May 4, 2002</td>
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<td><strong>Launch Vehicle:</strong></td>
<td>Boeing Delta II</td>
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<td></td>
<td>Intermediate ELV</td>
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<td><strong>Mission Life:</strong></td>
<td>5 years</td>
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<td><strong>Team Leader:</strong></td>
<td>Moustafa Chahine</td>
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**AIRS Project Objectives**

1. Support Weather Forecasting
2. Climate Research
3. Atmospheric Composition and Processes

12 year lifetime predicted July 2006
There are three key steps in generating climate quality data:

Design and build an instrument for climate quality data
  Minimize moving parts
  Thermostat the entire instrument
  “Freeze the calibration”

Create data subsets which are small enough for practical analysis
  It takes 1 hour to read one day of AIRS level 1b data
  We have now almost 1500 days of data
  Subsets a factor 1000 smaller than the L1b data are required.

Analyze the data in the subsets and verify that
  parameters which should not have trends don’t
  parameters with expected trends do
  parameters with unexpected trends can not be explained by hardware or algorithm effects
This afternoon session focuses on the analysis of trends visible in AIRS data.

There are five presentations:

- Aumann: AIRS Calibration Data Subset (ACDS) for Climate Research
- Strow: Zonal co2 trends from AIRS level 1b
- Goldberg: Gridded Data Products for Climate Research
- Susskind: Trends from monthly mean AIRS level 3 data
- Hearty: Trends from AIRS level 2 data
Outline

What absolute calibration accuracy and stability are required for climate applications?

Climatology and anomaly trend

Results from four years of AIRS data

Conclusions
What absolute calibration stability and accuracy are required for climate applications?

Better than 10 mK/year and 100 mK absolute

The stability of the measurements has to be better than the changes due to global warming.

Warming at the surface is happening at 10 mK/year
Warming of the atmosphere is assumed to happen at 10 mK/year
The stratosphere appears to be cooling at about the same rate.

Absolute accuracy of 100 mK absolute calibration is required for transfer of trends between instruments. A 100 mK absolute uncertainty is the equivalent of 10 years of global warming.
Outline

What absolute calibration accuracy and stability are required for climate applications?

Stability and accuracy of the AIRS radiances

Climatology and anomaly trend formalism

Results from four years of AIRS data

Conclusions
Before we analyze trends in AIRS data which may be of climate significance, we have to establish that the accuracy and stability of the AIRS data is of climate quality.

We use the RTGSST in the tropical oceans as reference to establish accuracy and stability of the AIRS data.

The RTGSST is the sea surface temperature on a 0.5 degree grid generated daily by NCEP in support of daily weather forecasting.

In the tropical oceans the RTGSST is verified daily using about 1000 buoys drifting along the equator. The calibration of each drifting buoy at the better than 0.1 K level is NIST traceable.
Data from any infrared sounder can not be interpreted at the better than 100 mK level in the presence of clouds. We restrict our analysis to carefully cloud-filtered ocean data. Four years of these data are available in the AIRS Calibration Data Subset (ACDS). Details in Aumann et al. 2004 Denver SPIE.

Good cloud-filtering requires very high SNR in the individual spectra. Poor cloud-filtering results in erroneous biases. Massive data averages for climate do not require high SNR, but retain any bias in the data.

The key channel for establishing calibration stability and accuracy is the 2616 cm⁻¹ window channel. This channel is used to measure the sea surface temperature, sst2616, using radiative transfer. Details are found in Aumann et al. 2006 JGR paper. No bias tuning or empirical regression is used. This sst2616 is compared with the RTGSST.
Two fairly readable references on trend analysis

Detecting environmental changes and trends

Elizabeth C. Weatherhead a,*, Amy J. Stevermer a, Barry E. Schwartz b

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b National Oceanic and Atmospheric Administration, Forecast Systems Laboratory, Boulder, CO 80305, USA

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The second reference deals with the effects of autocorrelation

H. H. Aumann JPL
4 years of night-time comparisons of 2616 cm⁻¹ with the RTGSST are within 200 mK of the expected value. The trend is +9.0 +/- 2.4 mK/year.

The black dots are the median result from each day. There are no obvious seasonal effects.

The blue curve is the 4 year climatology.

The red dots are the standard deviation of the 5000 clear spectra each day.

Expected bias

Observed bias

200 mK

stdev is only 0.4 K
Establishing the stability of one channel verifies the stability of the on-board calibration source, its thermometry and the detector electronics chain.

Stability thus established is a necessary, but not sufficient condition for the stability of all channels in a grating array spectrometer.
Repeating this analysis for a number of window channels at 1231 cm$^{-1}$, 943 cm$^{-1}$, and 790 cm$^{-1}$ produces similar results.

These three channels are not as good as 2616 cm$^{-1}$ in terms of atmospheric transmission, but they can be used day and night.

In all cases the sst is derived from radiative transfer using 24 climatology profiles with Tsurf $>$ 273 K at six scan angles. Details for sst1231 are found in Aumann et al. 2006.
The AIRS data are stable relative to the RTGSST.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Stability Night (mK/year)</th>
<th>Stability Day (mK/year)</th>
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</thead>
<tbody>
<tr>
<td>790 cm-1</td>
<td>+11.6 +/- 3.9</td>
<td>+11.1 +/- 3.1</td>
</tr>
<tr>
<td>943 cm-1</td>
<td>+12.9 +/- 3.0</td>
<td>+9.2 +/- 3.2</td>
</tr>
<tr>
<td>1231 cm-1</td>
<td>+8.7 +/- 2.7</td>
<td>+6.0 +/- 2.9</td>
</tr>
<tr>
<td>2616 cm-1</td>
<td>+9.0 +/- 2.4</td>
<td>+5.0 +/- 5.0</td>
</tr>
</tbody>
</table>

There appears to be a small trend and a frequency dependence. The trend could be an artefact of the change in the RTGSST software in May 2004.

The frequency dependence could be indicative of a change in the cloud contamination of the cloud-filtered spectra.

*sst2616 not corrected for reflected light*
Now that we have convinced ourselves that the AIRS radiances meet climate quality requirements for accuracy and stability, we can look at 4 year anomaly trends.

The anomaly is the difference between the data and the seasonal climatology (generated from four years of data)

Trend tested for +/-30 degree tropical ocean

1. co2 effect at 2388 cm-1
2. cirrus using the 943-790 cm-1 gradient
3. upper tropospheric water using 1560 cm-1
4. count per day of spectra identified as “clear”
5. predict bt1231 from bt2616 with water correction
The weighting function of 2388 cm$^{-1}$ is due to CO$_2$ absorption and peaks at about 5 km altitude.

The brightness temperature trend at 2388 cm$^{-1}$ (bt2388) shows the cooling expected from about 1.5 ppmv per year increase CO$_2$.

Day and night independently show the same trend.
The brightness temperature trend at 2388 cm$^{-1}$ (bt2388) shows the cooling expected from about 1.5 ppmv per year increase in CO₂.
We consider a trend significant if it exceeds the estimated one sigma trend uncertainty by a factor of two.

No 2 sigma or better unexpected trends were identified by the analysis of the +/-30 degree ocean zone in any not-co2 related quantity.

One has to be very careful with the interpretation of trends from 4 years of data:

1. The tropical oceans are probably the most stable part of the climate system and will show the least trends. Higher latitudes may be better.

2. The presence of inter-annual variability and multi-decadal oscillation create false trends, but the trend uncertainty will also be high.
The ability to predict bt1231 from bt2616 under clear conditions appears to be modulated by some unexpected inter-annual variability. This effect is +/-40 mK.

Did anything noteworthy happen?

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The inter-annual variability shows interesting anomaly correlation

$sst_{2616} - sst_{1231}$ anomaly

AMSU #5 anomaly

What happened?

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Outline

What absolute calibration accuracy and stability are required for climate applications?

4 year climatology and anomaly trends formalism

Results from four years of AIRS data

Conclusions
Conclusions

The AIRS radiance trends can be evaluated with confidence at the 10 mK/year level.

At this level, the effect of the co2 increase on the radiances is the only trend in four years of tropical ocean analysis.

Some interesting inter-annual variability shows up in the anomalies in unexpected places.

There is a good anomaly correlation between AIRS and AMSU.

The strange patterns in the anomalies may be correlated with other major events.
Conclusions (continued)

Climate quality data have to be accurate to 100 mK and stable to better than 10 mK/year

To achieve this with AIRS we

- Minimized moving parts
- Thermostated the entire instrument
  - “Froze the calibration”

Four years of AIRS data have demonstrated that this design approach leads to climate quality data.
Thank you for our attention.

The AIRS data are freely available from the DAAC at GSFC
To learn more about AIRS visit http://www.jpl.nasa.gov/airs

The daily ACDS data since 20020831 is available via FTP from
ftp://g0dps01u.ecs.nasa.gov/AIRS/AIRXBCAL.003/
There is a small trend at night for sst2616-rtgsst

The anomaly shows no significant residual seasonal patterns.

trend for sst2616-rtgsst

= 9.0 +/- 2.4 mK/year
The day time trend for sst2616-rtgsst of 5 +/- 5 mK/year is insignificant. The +0.6 K offset is due to reflected light. The black dots are the median from each day. The blue trace is the four seasonal mean.
The count of clear spectra in the tropical oceans appears to be decreasing day and night by about 1%/year. Less clear = more clouds.

The trend does not meet the 2 sigma significance test.
The decrease in the number of spectra identified as clear is intriguing.

We test the stability of the data by relaxing the clear filter spatial coherence from $cx2616=0.5$ to $cx2616=0.7$. This doubles the yield of “clear” spectra

<table>
<thead>
<tr>
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<th>$cx2616=0.7$</th>
<th>$cx2616=0.5$</th>
</tr>
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<tbody>
<tr>
<td><strong>day</strong></td>
<td>-72 +/-43 in 7000 = -1.0%</td>
<td>-41 +/-26 in 3664 = -1.1%</td>
</tr>
<tr>
<td><strong>night</strong></td>
<td>-116 +/-60 in 9530 = -1.2%</td>
<td>-75 +/-38 in 5325 = -1.4%</td>
</tr>
<tr>
<td><strong>day bias</strong></td>
<td>-0.269 K</td>
<td>-0.244 K</td>
</tr>
<tr>
<td><strong>night bias</strong></td>
<td>-0.668 K</td>
<td>-0.623 K</td>
</tr>
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The result is very consistent.

The $cx2616<0.7$ spectra are obviously not as clear as the $cx2616<0.5$ spectra. During the day the cold bias increases 25 mK, at night 45 mK.

Similar stability is observed with the other trends.
FOUR YEARS OF ABSOLUTELY CALIBRATED HYPERSPECTRAL DATA FROM THE ATMOSPHERIC INFARED SOUNDER (AIRS ) ON THE EOS AQUA:

Trends and trend uncertainties

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24 July 2006

AIRS on EOS Aqua
705 km altitude polar orbit
14 orbits per day

 +/- 50 degree cross-track scanning
2.9 million spectra per day
13.5 km IR FOV at nadir
imaging with 98% overlap

cooled grating array spectrometer
58K detectors
3.7 – 15.4 microns
2378 spectral channels
spectral resolution 1200
spectral sampling 2400 (Nyquist)

NeDT= 50%tile better than 0.2K at 250K
AIRS was designed, built and calibrated for climate quality data.

Designed to achieve better than 3% absolute radiance accuracy between 200K and 360 K and 3.7 – 15.4 microns for 5 years.

- Full aperture wedge cavity blackbody at 308 K (+/-10 mK)
- Spectrometer optical bench cooled to 156 K +/-10 mK
- One blackbody view and four space views every 2.67 seconds

Prelaunch calibration with NIST secondary standard between 220 K and 340 K, at 6 scan angles and at three spectrometer temperatures.
The expectation from AIRS were achieved
Chahine et al. 2006 BAMS 15 July

12 hour forecast impact in 5 days achieved in both hemispheres
Le Marshal et al. 2006 BAMS 15 July

RAOB equivalent accuracy achieved relative to the RAOB matchups
at mandatory levels
Divacarla et al. 2006 JGR
The expectation from AIRS were achieved

Better than 0.2 K absolute accuracy
Tobin et al. 2006 JGR

Stability better than 16 mK/year
Aumann et al. 2006 JGR

The cloud filtered data shown in the following are Level 1b. The L1b calibration has for most detectors not changed since September 2002. The data are available as the ACDS from the DAAC.