Ultraspectral Infrared Measurements from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft

INTERNATIONAL SYMPOSIUM ON SPECTRAL SENSING RESEARCH 2003 (ISSSR 2003)

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Agenda

- Science Objectives
- AIRS/AMSU/HSB Instruments
- NASA Ultraspectral IR Technology Development
- In-Flight Performance
  - Level 1B Radiances, Level 2 Temperature Products
- Distribution Status
- Early Applications Results
- Future Mission Plans
AQUA MEASURES EARTH'S WATER CYCLE, ENERGY FLUXES, VEGETATION, AND TEMPERATURES

AMSR/E
MODIS
AMSU-A1, -A2
HSB
AIRS
CERES (2)
AIRS/AMSU/HSB MISSION OVERVIEW

Spacecraft: EOS Aqua
Launch Date: May 4, 2002
Launch Vehicle: Boeing Delta II
Intermediate ELV
Mission Life: 5-7 years
Team Leader: Dr. Moustafa Chahine

AIRS/AMSU/HSB EARTH SCIENCE QUESTIONS AND APPLICATIONS

1. The global water and energy cycle: Is the cycle of evaporation and precipitation on Earth accelerating?
2. Determine the distribution and variations of water vapor - Earth’s primary greenhouse gas
3. Climate weather connection: Are current weather anomalies (hurricanes, droughts) connected to climate change and how?
4. Improving weather prediction: NOAA is a user together with 6 other weather prediction centers in Europe, America, Australia and Japan
5. Trace Gasses: Will provide the first satellite global map of the distribution of atmospheric concentration of CO₂
AIRS-AMSU-HSB
Atmospheric Infrared Sounder
Advanced Microwave Sounding Unit
Humidity Sounder for Brazil
Today radiosondes collect data with high accuracy but are mostly over land (Ocean is 70% of Earth’s Surface).

Earlier weather satellites had global coverage but were equipped with less accurate instruments.

AIRS/AMSU/HSB on Aqua achieves global coverage of temperature and water vapor with radiosonde accuracy.

324,000 observations per day (4000 for radiosondes).

Combined IR and Microwave observations permits sounding up to 80% cloudy.

Less than 2% of AIRS/AMSU/HSB Observations are truly clear.
AQUA SOUNDING SUITE

AIRS
- Infrared: 3.74-15.4 μm, 2378 Channels
- IR Spectral Resolution: ≈ 1200 (λ/Δλ)
- IR IFOV: 1.1° x 0.6° (13.5 km x 7.4 km)
- Visible: 4 Channels, 2.3 km
- Scan Range: ±49.5°

AMSU
- Microwave: 23-89 GHz, 15 Channels
- IFOV: 3.3°, 43 km
- Scan Range: ±49.5°

HSB
- Microwave: 150-183 GHz
- 4 Channels
- IFOV: 1.1°, 13.5 km
- Scan Range: ±49.5°
Radiometric Sensitivity is High 
Stable: Launch to Orbit

Temperature Dependence Well Behaved

SRF Shape Well 
Characterized to <10^{-3}
AQUA WAS LAUNCHED ON MAY 4, 2002

- Delta 2 Launch Vehicle
- 6 Strap On Boosters
- Extended Fairing
- 2:55 AM
- Vandenberg Air Force Base, California
- 705.3 km Orbit
- Polar Sun Synchronous
- 1:30 PM Equatorial Crossing
- Ascending Daytime
OPERATIONS AND CALIBRATION STATUS

- AIRS and AMSU Operating normally
  - Icing under control. No need for defrost for a couple years
  - AIRS Radiometric and Spectral Calibration looks good.
  - No change to L1B radiometric calibration coefficients since before launch.
  - Spectral and Spatial Knowledge Determined to Required Accuracy
  - AMSU calibration under review
- HSB Not Operating
  - Feb 5, 2003 Motor stalled
  - Motor Current high
  - Several tests performed in March and April have not been successful
  - Apparent Loss of Motor Winding
## AIRS/AMSU/HSB DATA PRODUCTS

<table>
<thead>
<tr>
<th>Radiance Products (Level 1B)</th>
<th>RMS Uncertainty*</th>
<th>Horizontal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRS IR Radiance</td>
<td>3%</td>
<td>15 x 15 km</td>
</tr>
<tr>
<td>AIRS VIS/NIR Radiance</td>
<td>20%</td>
<td>2.3 x 2.3 km</td>
</tr>
<tr>
<td>AMSU Radiance</td>
<td>0.25-1.2 K</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>HSB Radiance</td>
<td>1.0-1.2 K</td>
<td>15 x 15 km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard Core Products (Level 2)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud Cleared IR Radiance</td>
<td>1.0K</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Sea Surface Temperature</td>
<td>0.5K</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Land Surface Temperature</td>
<td>1.0K</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>1K</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Humidity Profile</td>
<td>15%</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Total Precipitable Water</td>
<td>5%</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Fractional Cloud Cover</td>
<td>5%</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Cloud Top Height</td>
<td>0.5 km</td>
<td>45 x 45 km</td>
</tr>
<tr>
<td>Cloud Top Temperature</td>
<td>1.0 K</td>
<td>45 x 45 km</td>
</tr>
</tbody>
</table>

Vertical Resolution:

1 km below 700 mb
2 km 700-30 mb
2 km in troposphere
LEVEL 1 PRODUCTS
STATUS
Typical Atmospheric Spectrum Obtained From AIRS

Superwindow
Channel at 2626 cm⁻¹
<0.4K Atmospheric Absorption
AIRS RADIANCE DATA VALIDATES ECMWF FORECAST MODELS

ECMWF Bias: Absolute, Bias Derived from Bias vs Secant($\delta$)

AIRS RADIANCE BIAS IS LESS THAN 0.5K ACROSS THE SPECTRUM
SCANNING HIS ON PROTEUS SHOWS RADIANCE AGREEMENT WITH AIRS TO 0.2K ACCURACY
AIRS HAS DEMONSTRATED
EXCELLENT IN-FLIGHT RADIOMETRIC AND SPECTRAL STABILITY

STABILITY IS CRITICAL FOR LONG TERM CLIMATE STUDIES

Radiometric Stability (K)
In Orbit Compared to Global SST

Spectral Stability (%FWHM)
In-Orbit Compared to Global Upwelling Features

The first 6 months of AIRS (sstd2616c6s-tog.sst) analysis
(1 September 2002 through 28 February 2003 data)

Less than 0.2K Variation Since Launch
Observable may actually be seasonal variation.

Less than 0.2% of FWHM of SRF
Drift Since Launch
That's 2 parts per million of center freq!

S. Gaiser

STABILITY PRIMARILY ATTRIBUTED TO USE OF COOLED GRATING SPECTROMETER OPTICS
LEVEL 2 PRODUCTS STATUS
TEMPERATURE PROFILE (LEVEL 2) COMPARED TO VALIDATION SITES: RESULTS LOOK GOOD

AIRS Retrieval (Smooth line)
Dedicated Radiosonde
(Curvy line)

Chesapeake Platform
Sept 13, 2002

Tropopause

35 m

25 m

Chesapeake Platform
50 km grid
50 km radius
SUCCESSFUL LEVEL 2 YIELD OVER 70% OF TEST AREA

- Test Region is $|\text{Lat}| < 40^\circ$
- One Full Day
- Clear and Cloudy Conditions

GREEN = Full Retrieval (70%)
YELLOW = Partial Retrieval (24%)
RED = Failed Retrieval (6%)
AIRS/AMSU/HSB RETRIEVALS SHOW GOOD AGREEMENT WITH ECMWF FORECASTS

- September 6, 2003
- Night, Ocean, |LAT| < 40°
- Clear and Cloudy: 70% Yield
AIRS RETRIEVED TEMPERATURE PROFILE
OVER SOUTHERN EUROPE VIEWED FROM THE WEST
SEPTEMBER 8, 2002
PRODUCT DISTRIBUTION STATUS
AIRS PRODUCT RELEASE STRATEGY

- All radiance products contained in individual files for each instrument
- One file for cloud cleared products
- Remaining Level 2 products contained within
  - \textit{L2 Standard Products File}
  - \textit{L2 Support File (more detail)}
- Each file contains 6 minutes of data
- All products will be released to the public with each delivery (First public release in July 2003)
- Products will be flagged to indicate quality and validation status
- A validation report accompanies each release
AIRS DISTRIBUTION CENTERS

NOAA NESDIS

GSFC DAAC

DIRECT BROADCAST

NWP Centers
- NASA/GSFC/DAO – Bob Atlas
- NOAA/NCEP – Steve Lord
- FNMOC – Naval Research Lab
- ECMWF – Tony McNally
- UK Met Office – Roger Saunders
- Meteo France – Florence Rabier
- Canada Met Service – Clement Chuoinard
- Japan NPD/JMA – Masahide Kimoto
- Australia (B of M) - John Le Marshall

Science Community
- Public

Universities
- Local Weather Stations
- Brazil (INPE)
- China
- DoD
- Other International
• NOAA delivers 100% of rate buffered (RB) radiance data to NWP Centers within 2:50 from acquisition.
  – **Next:** *Distribution of Cloud Clear Radiances or L2*
• Version 2.7 (Level 1B Focus) delivered to NOAA and GSFC DAAC
  – A press release titled “New Data on Weather Prediction” was issued to announce the Level 1B release.
  – **Next:** *Distribution of Level 2 Products to Public, July 2003*
• AIRS/AMSU/HSB L1B Data Now Available at the GSFC DAAC
• Version 3.0 Nearing Readiness for Public Release in Early July
  – Quality Assessment Flags in Preparation
  – Validation Report needs high priority. Must be ready prior to public release.
AIRS FORECAST IMPACT (ECMWF)

RMS of 500hPa geopotential forecast error averaged over 40 days (Dec 02/ Jan 03)

[AIRS error] minus [CTRL error]

The assimilation of AIRS radiances shows a small but consistent positive impact on forecast quality in all areas
FLOODING FROM ISIDORE

Difference between the AMSU Channel 2 on September 28 and September 12 identifies flooding Tropical Storm Isidore. In the difference image, white indicates no difference at all, green is very little difference, blue/purple indicates primarily heavy flooding. Red indicates warming likely due to warmer weather.
HIGH SPECTRAL RESOLUTION ALLOWS QUANTIFICATION OF MINOR GASES

AIRS Channels for Tropical Atmosphere with T\_surf T=301K

*Full Spectrum*

August 2000 AIRS frequencies
AIRS DETECTS SO₂ FROM MT. ETNA
<table>
<thead>
<tr>
<th></th>
<th>MODIS</th>
<th>AIRS</th>
<th>SIRAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km IR IFOV</td>
<td>13.5 km IR IFOV</td>
<td>0.6 km IR IFOV</td>
<td></td>
</tr>
<tr>
<td>3.7-14.2 μm IR</td>
<td>3.7-15.4 μm IR</td>
<td>3.7-15.4 μm IR</td>
<td></td>
</tr>
<tr>
<td>16 IR Channels</td>
<td>2376 IR Channels</td>
<td>1024 IR Channels</td>
<td></td>
</tr>
<tr>
<td>λ/Δλ = 20-50</td>
<td>λ/Δλ = 1200</td>
<td>λ/Δλ = 1000</td>
<td></td>
</tr>
<tr>
<td>NEdT = 0.05 - 0.3 K</td>
<td>NEdT = 0.05 - 0.3 K</td>
<td>NEdT = 0.1 - 0.3 K</td>
<td></td>
</tr>
<tr>
<td>Refractive Optics</td>
<td>Grating Spectrometer</td>
<td>Grating Spectrometer</td>
<td></td>
</tr>
<tr>
<td>± 55° FOV</td>
<td>± 50° FOV</td>
<td>± 15° FOV</td>
<td></td>
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NASA ATMOSPHERIC SOUNDING
FUTURE MISSION PLANS
FUTURE REQUIREMENTS FOR EARTH SCIENCE ATMOSPHERIC SOUNDING

- Continue AIRS Capability
  - 15km LEO: Crosstrack Infrared Sounder (CrlS) by NOAA

- Improve Temporal Resolution
  - 4 km GEO: Geostationary Imaging FTS (New Millenium Program). Technology Demonstration
  - GOES-R: Next Generation NASA GEO Sounder
  - Medium Earth Orbit (Gives Global Coverage)

- Improve Spatial Resolution
  - 1km Horizontal, 1km Vertical Resolution
  - Improved Global Circulation Models (Weather Forecasting) for Hurricane Tracks, Tornados, Regional
  - Improved Minor Gas Quantification
The Spaceborne Infrared Atmospheric Sounder

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

SIRAS
- 0.6 km IR IFOV
- 3.7-15.4 μm IR
- 1024 IR Channels
- $\lambda/\Delta\lambda = 1000$
- Refractive Optics
- Grating Spectrometer
- NEdT = 0.1 - 0.3 K
- ± 30° FOV
TODAYS IR SENSOR DEVELOPMENT
BASED ON AIRS TECHNOLOGY INVESTMENT

AIRS Grating Spectrometer
Miniature Spectrometers (SIRAS)
AIRS Dewar Assembly
Miniature Low-Heat Load Dewars

AIRS Pulse Tube Cooler
Miniature Pulse Tube Coolers
AIRS Focal Plane Assy
Large Format LW PVHgCdTe

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<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2006</th>
<th><strong>Spaceborne Infrared Atmospheric Sounder (SIRAS): 2001</strong></th>
</tr>
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<tbody>
<tr>
<td><strong>Spectral</strong></td>
<td><strong>Complete</strong></td>
<td><strong>In Progress</strong></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>12 – 15.4 μm</td>
<td>7.8 - 12 μm</td>
<td></td>
</tr>
<tr>
<td>Resolution (λ/Δλ)</td>
<td>1000</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>&lt;0.8 cm(^{-1})</td>
<td>&lt;1.2 cm(^{-1})</td>
<td></td>
</tr>
<tr>
<td><strong>Spatial</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOV</td>
<td>16°</td>
<td>13°</td>
<td></td>
</tr>
<tr>
<td>IFOV</td>
<td>1 mr</td>
<td>0.8 mr</td>
<td></td>
</tr>
<tr>
<td>No. Pixels</td>
<td>1 x 165</td>
<td>256 x 256</td>
<td></td>
</tr>
<tr>
<td><strong>Radiometric</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference Temp.</td>
<td>250K</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>NEdT</td>
<td>0.2 K</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.2 K</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>10 x 10 x 14 cm</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>2 kg</td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>
| Cooling              | Liquid                | Active       | 36
WIDE FIELD INFRARED REFRACTIVE OPTICS
MAKE IT POSSIBLE

- Grating Spectrometer
  - No Moving Parts
  - No Metrology Lasers
  - Vibration Insensitive
  - Stable
- Wide Field Refractive Optics
  - Compact
  - Maximum Number of Channels
  - Full Field Imaging
### JPL DESIRES TO FLY SIRAS TO SUPPORT SCIENCE AND TACTICAL APPLICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concepts</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SIRAS</td>
<td>WEDGE</td>
</tr>
<tr>
<td>$\lambda$ (μm)</td>
<td>7.6-13.5</td>
<td>7.6-13.5</td>
</tr>
<tr>
<td>$\lambda/\Delta\lambda$ (μm)</td>
<td>450</td>
<td>70</td>
</tr>
<tr>
<td>$\Delta\theta$ (mr)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>N Spectral</td>
<td>256</td>
<td>32</td>
</tr>
<tr>
<td>N Spatial</td>
<td>256</td>
<td>256</td>
</tr>
<tr>
<td>FOV (deg)</td>
<td>14.6</td>
<td>14.6</td>
</tr>
<tr>
<td>F-Number</td>
<td>1.7</td>
<td>4</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Center</td>
<td>JPL</td>
<td>JPL/SBRS</td>
</tr>
</tbody>
</table>

ER2
- Altitude: 18.3 km
- Resolution: 18.3 m
- Swath: 4.68 km

JPL HAS EXTENSIVE EXPERIENCE IN PASSIVE AIRBORNE PROGRAMS

- AVIRIS (VIS/NIR)
- AIR MISR (VIS Multi-Angle)
- MASTER (Infrared)
- TIMS (Infrared)
- AES (infrared)
- HAMSR (Microwave)
JPL SUPPORTS GROUND BASED SOLUTIONS USING SIRAS "TECHNOLOGY INSERTION"

SIRAS IS COMPACT AND LIGHTWEIGHT

REALISTIC CONCEPT FOR PORTABLE SYSTEM

SIRAS 2006

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SIRAS 2001 Spectra Of Lab Air
SUMMARY AND CONCLUSIONS

- AIRS, AMSU and HSB Launched on the EOS Aqua Spacecraft in May of 2002
- AIRS and AMSU in good health, HSB scanner “off” due to high current reading. Under investigation
- AIRS has good radiometric and spectral sensitivity, stability and accuracy. Suitable for climate studies.
- Temperature products compare well with radiosondes and models over limited test range (|LAT| < 40°)
- Weather centers now receiving AIRS data
- Early trace gas products demonstrate potential of AIRS
- NASA developing next generation of hyperspectral IR imagers
- JPL Ready to participate with US government agencies and US industry to transfer AIRS technology and science experience