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Radiometric Accuracy and Stability of the Atmospheric Infrared Sounder (AIRS) on Aqua

A31H-36

AGU Fall Meeting, San Francisco, CA

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Thomas S. Pagano*[a], Hartmut H. Aumann[a], Steven E. Broberg[a], Evan M Manning[a], Margie Weiler[b], Larrabee Strow[c]
[a]California Institute of Technology, NASA, Jet Propulsion Laboratory
4800 Oak Grove Dr. Pasadena, CA 91109
[b]ATK Space, P.O. Box 767, Bradford, NH 03221
[c]University of Md. Baltimore County (UMBC), 1000 Hilltop Cir, Baltimore, MD 21250

tpagano@jpl.nasa.gov, (818) 393-3917, http://airs.jpl.nasa.gov

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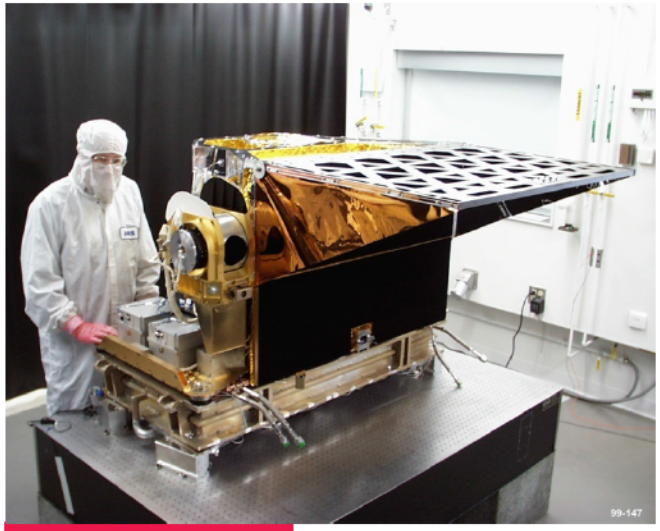
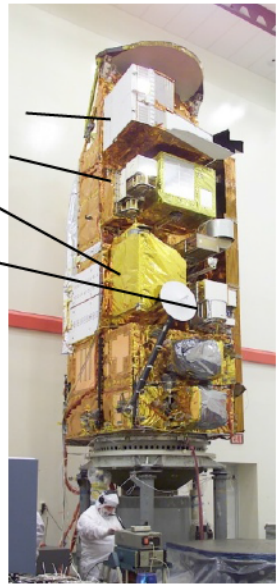
AIRS technologies selected for high accuracy, stability and long life

AIRS Requirements

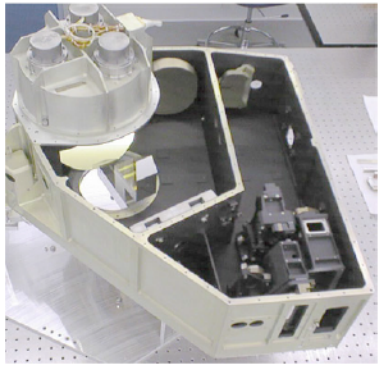
- **Spatial**
  - IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
  - Scan Range: ±49.5°
- **Spectral**
  - 2378 Channels
  - 3.74-4.61 µm, 6.2-8.22 µm, 8.8-15.4 µm
  - $\lambda/\Delta\lambda \approx 1200$
- **Radiometric**
  - Accuracy: < 0.2K
  - Stability: < 10 mK/year
- **Mass: 177Kg**
- **Power: 256 Watts**
- **Life: 5 years (7 years goal)**



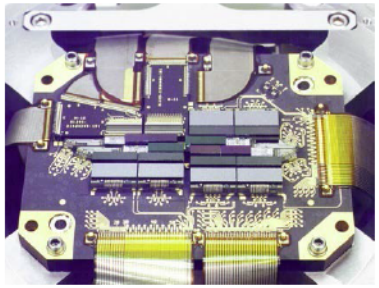


Aqua Spacecraft

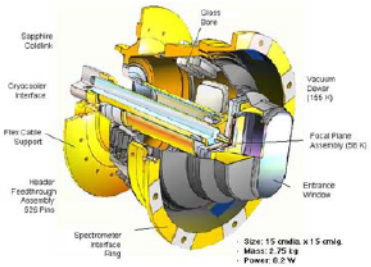
- **IR Grating Spectrometer**
- **155K Operation**



- **FPAs: PV HgCdTe to 13.7 µm, PC HgCdTe to 15.4 µm**



- **Cryogenic Dewar Technology**



- **Focal Plane Cooling using Stirling Pulse Tube**

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AIRS provides global daily coverage of key atmospheric variables: T, H2O and O3

Example: AIRS Ozone product during ozone hole formation in 2014

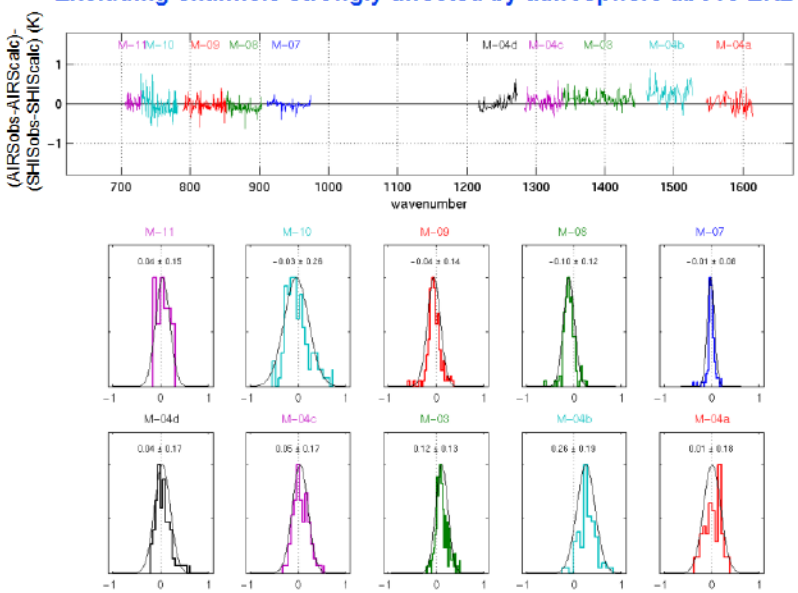
AIRS O3_VMR, 2014. Isosurface at 5 x 10^{-7} ppmv. Altitude Scale: 100, Altitude Offset: 10 km, Max Altitude (above which transparent): 18 km

Early validation show AIRS accuracy better than 200 mK, and stability to better than 10mK/year

Radiometric Accuracy

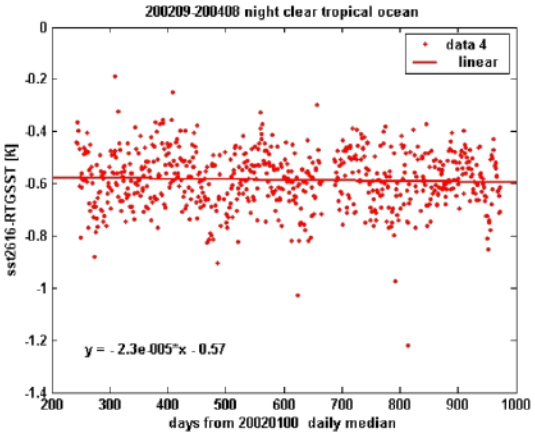
Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

Final "Comparison 2" (21 November 2002)
Excluding channels strongly affected by atmosphere above ER2



Radiometric Stability

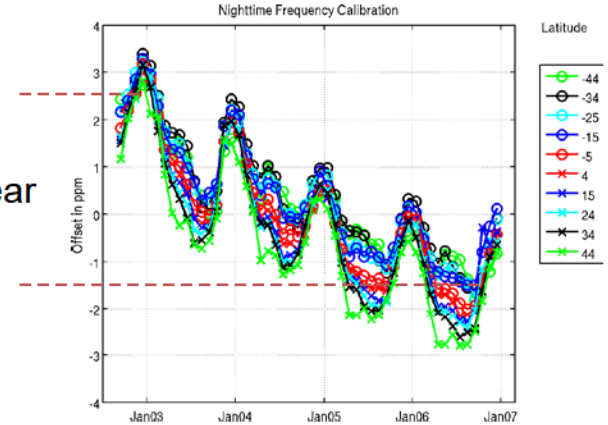
Stable to <8mK/Y – H. Aumann (JPL)



Spectral Accuracy/Stability

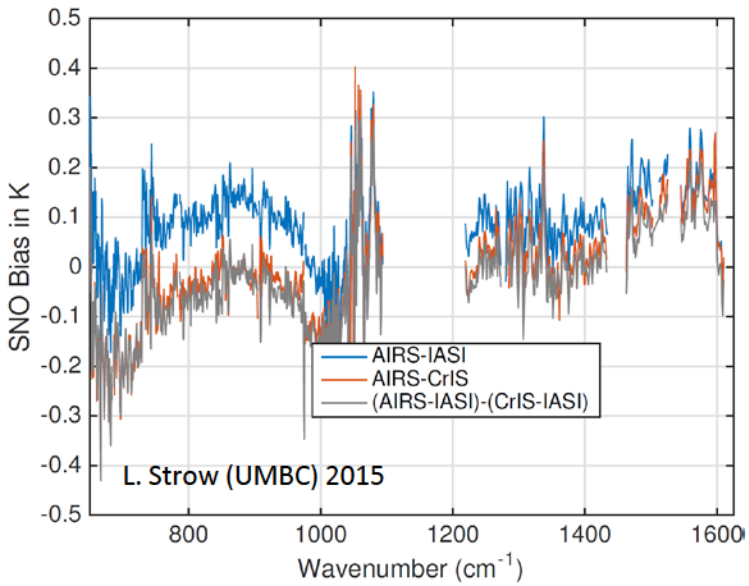
Knowledge to < 1 PPM - L. Strow (UMBC)

< 1 ppm/year



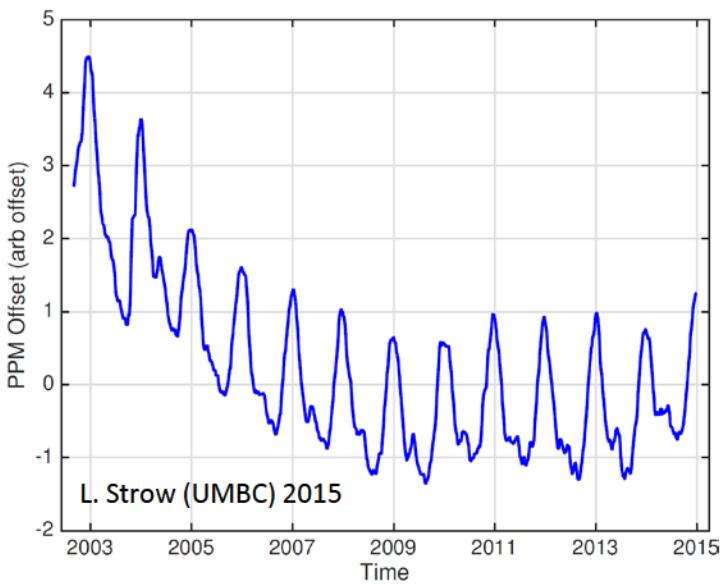
Reference: JGR, VOL. 111, April 2006

Recent updates to validation show high accuracy and stability



AIRS Rad Bias Matches other IR Sounders

- Agreement to < 250 mK most channels
- Simultaneous Nadir Overpasses (SNO)
- Night, Clear, Non-Frozen Ocean

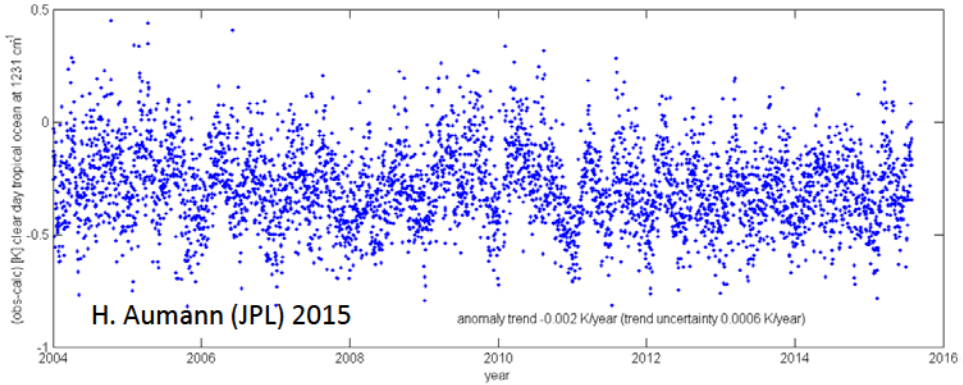


AIRS Spectral Calibration Stabilized

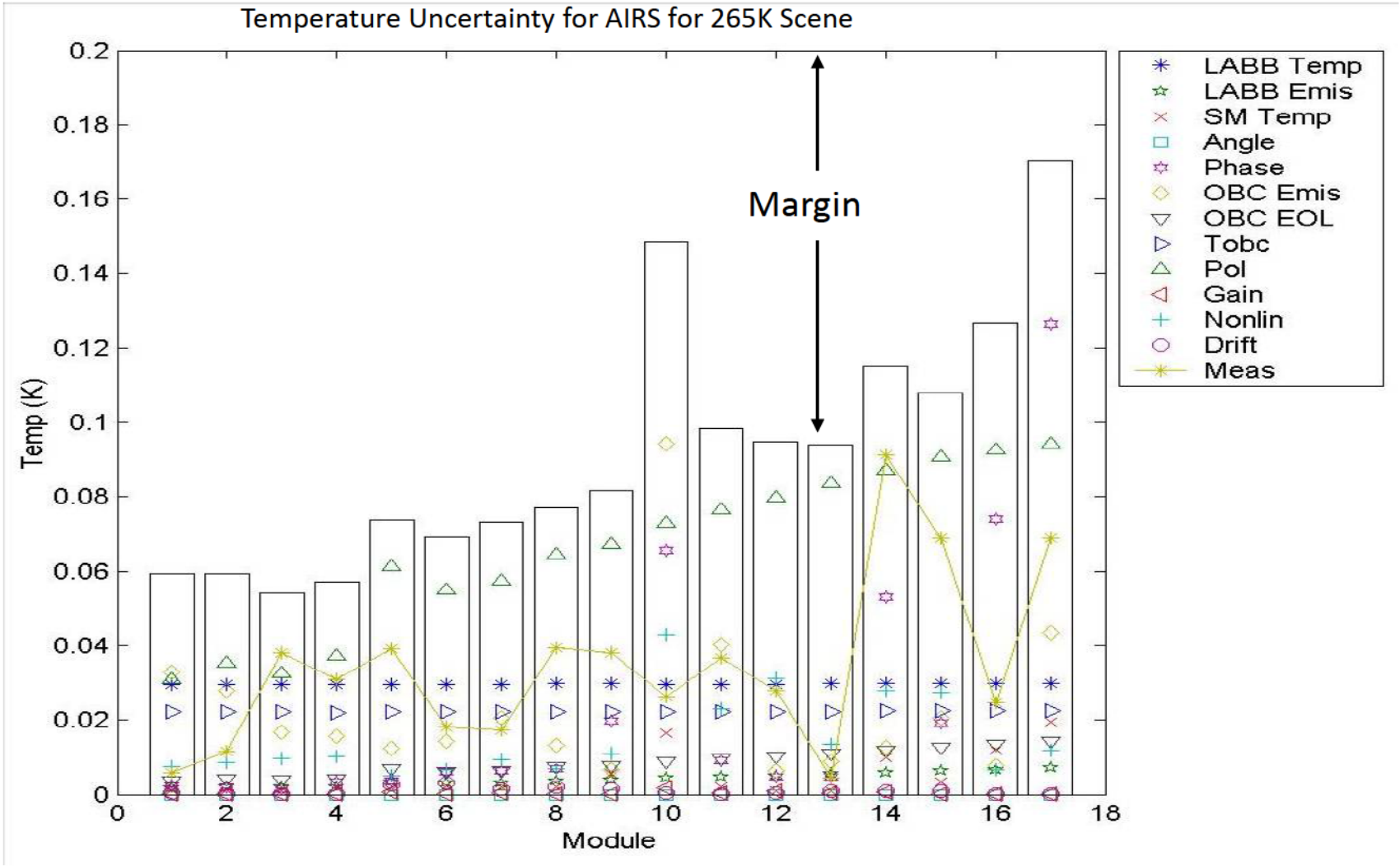
- Uses upwelling atmosphere for calibration
- Less than 1 ppm/year drift at mission start
- Now practically zero drift

AIRS Trend relative to SST

- 1231 cm^{-1} (8.123µm)
- ~0.2K Cloud Contamination
- Trend = -0.002 ±0.0006 K/year
- Clear Daytime Tropical Ocean



Many contributors to AIRS radiometric accuracy. Bottom's up estimates show < 200 mK

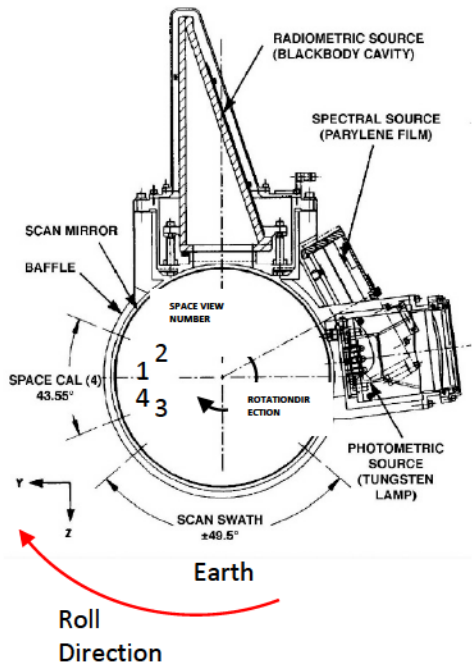


Pagano, T. S., H. Aumann, R. Schindler, D. Elliott, S. Broberg , K. Overoye, M. Weiler, "Absolute Radiometric Calibration Accuracy of the Atmospheric Infrared Sounder", Proc SPIE, 7081-46, San Diego, Ca, August 2008

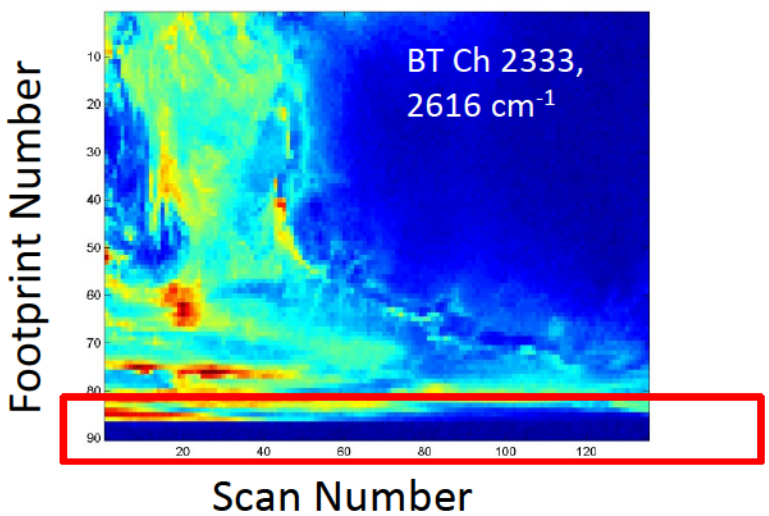
Two recent improvements to AIRS calibration accuracy

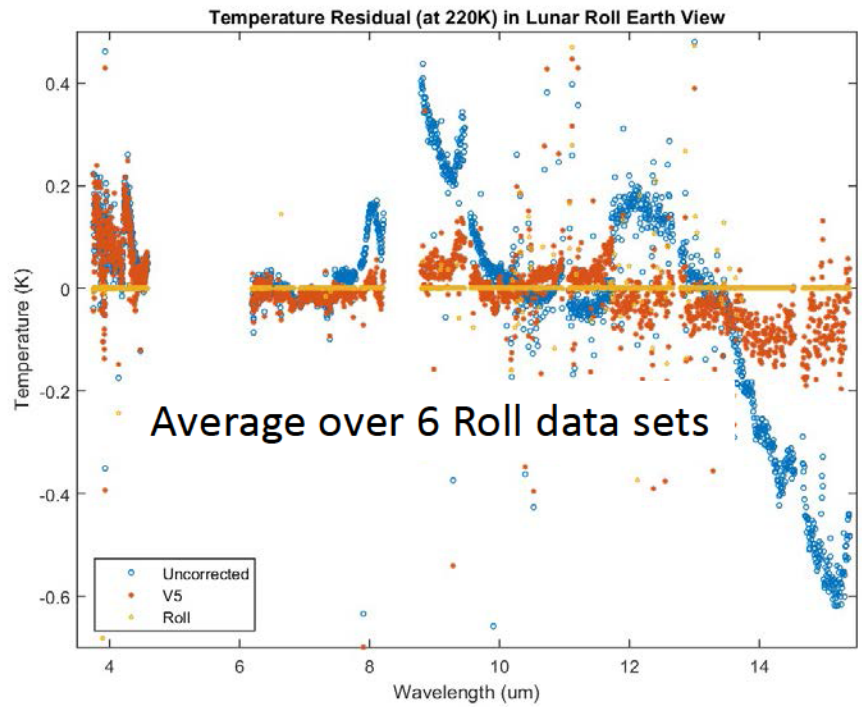
- Cold Scene Bias
  - Polarization coupling between the silver scan mirror and spectrometer causes a small bias if uncorrected.
  - V5 Correction good to < 100 mK
  - Spacecraft roll allows view of cold space. Used to improve calibration
- Spectral Discontinuities in Non-uniform Scenes
  - AIRS spatial response not equal for all channels
  - Results in spectral discontinuities at array boundaries in Nonuniform Scenes on the order of several degrees
  - Only a problem in roughly 1% of scenes (with most cloud variability)
  - Level 1C. Uses PC reconstruction for most affected channels; leaves all other channels unchanged (as L1B)
  - New method uses AIRS PSF and MODIS radiance to flat field AIRS response for all channels
  - Presented at AGU 2014 and SPIE 2015

Small residual cold scene bias removed using space look acquired during roll



- Uncorrected effects is <0.65K at 45°
- V5 Residuals < 200 mK
- **Space Look Zero's out Residual**
- MWIR region limited by noise



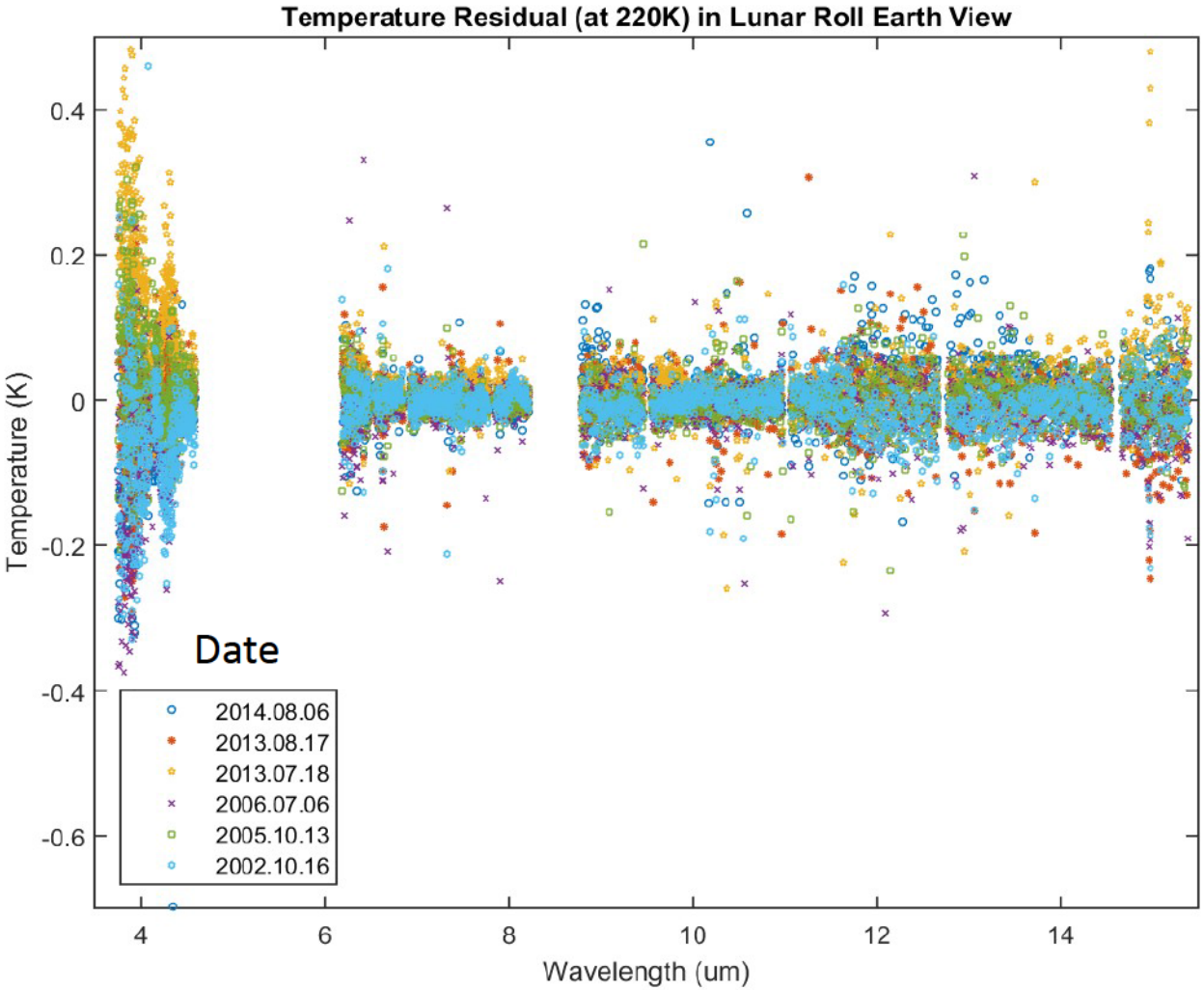


Footprints 88-90 View Cold Space at about 47°

AIRS Shows good cold scene stability over mission life

- Radiance of cold space as viewed by AIRS
- In earth viewport
- Scan Angle: 47.8°
- 6 Tests over 12 Years

- < 100 mK for λ > 4.5µm
- < 200 mK for 4 µm < λ < 4.5 µm
- < 400 mK for λ < 4 µm



MODIS used to remove co-registration error in AIRS in non-uniform scenes

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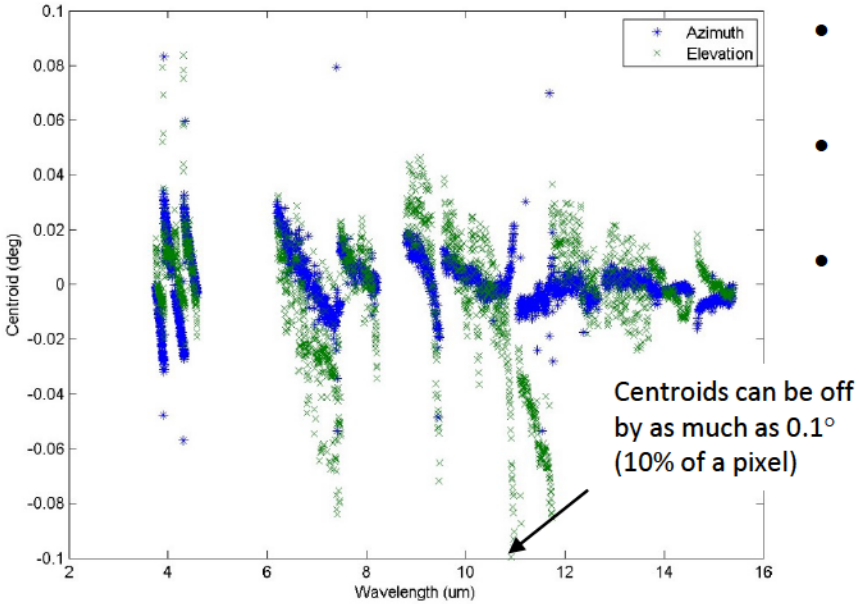
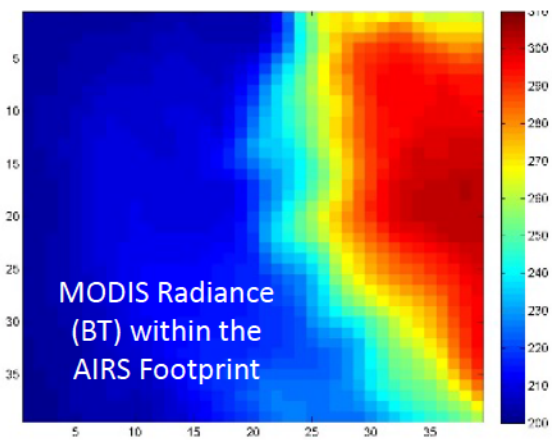
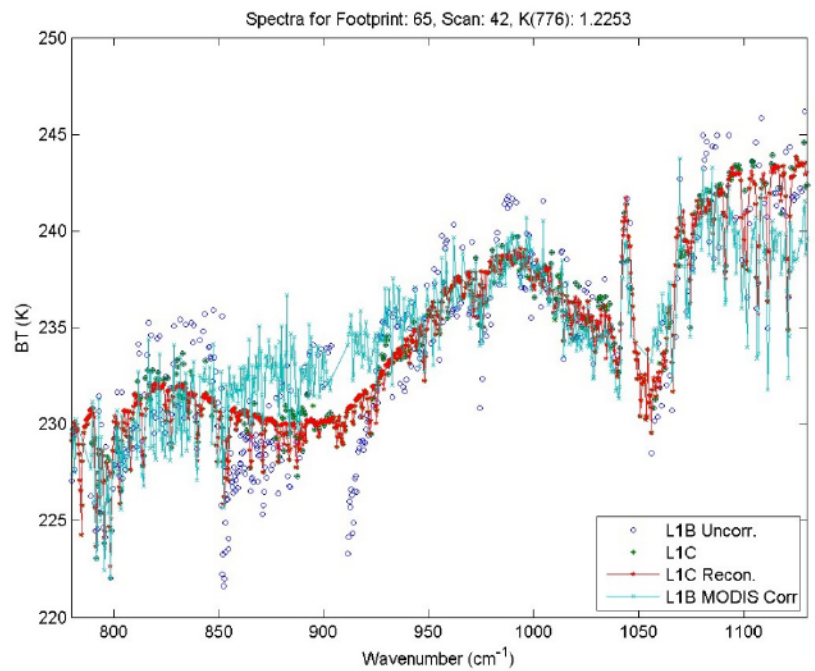
Centroid of AIRS IFOV (IFOV = 1.1°)



- Uncorrected effects is up to 10K in worst Scenes
- Level 1C reduces effect to < 3K most cases using PC reconstruction. Currently available.
- **MODIS Data "corrects" error using MODIS radiances and AIRS PSF for individual channels**
- Implement findings in next version of L1C





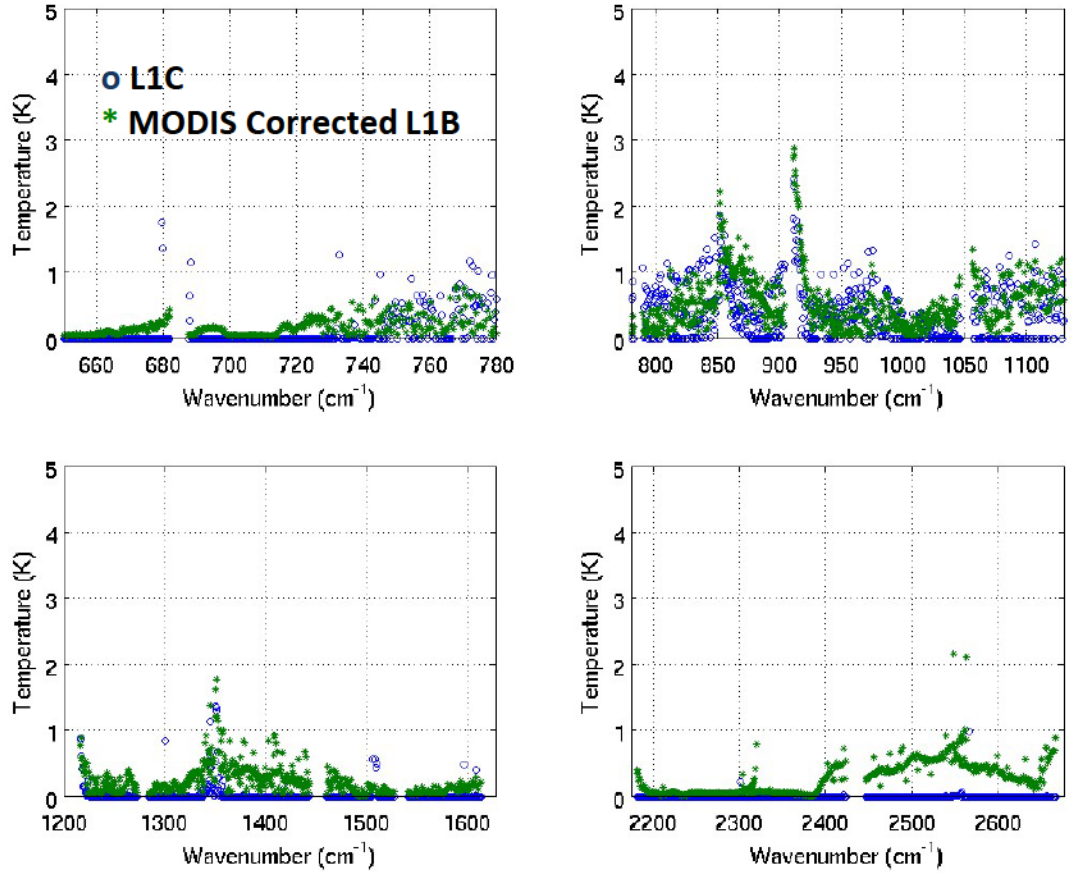
T.S. Pagano, H. Aumann, D. Elliott,, E. Manning, "Improving AIRS radiance spectra in cloudy scenes using MODIS', Proc. SPIE 9607-19, San Diego, CA (2015)

MODIS spatial correction improves more channels than current L1C

- Only high contrast scenes
- One full day of statistics
- Full spectrum shown

- RMS difference relative to L1B
- L1C = PC Reconstructed L1B
- L1M = MODIS Corrected L1B
- Conclusion: L1C applies spatial correction in too few channels
- Future options:
  - Use MODIS correction as prefilter to L1C
  - Train MODIS correction using AIRS radiances

RMS Deviation Relative to L1B for High Contrast Scenes



L1C Correction too for $\nu > 1200$ cm^{-1}

Lessons learned applied to next-generation CubeSat sounder: CIRAS

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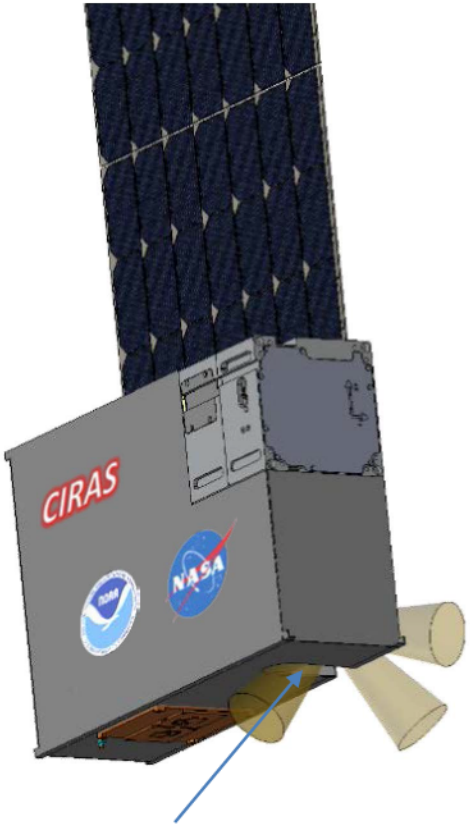
CubeSat Infrared Atmospheric Sounder (CIRAS)

For NASA InVEST, PI: Tom Pagano (JPL)
Sponsor: NASA ESTO
Launch Date: 2018/2019

Parameter	CIRAS
Spatial	
Orbit Altitude	450-850 km
Scan Range	3.0° - 57°
Horizontal Res'n	3.0 km - 13.5 km
Spectral	
Method	Grating
Band 1	4.78-5.09 µm
Res'n / Sampling	0.5 / 0.2 cm^{-1}
Total Channels	625
Radiometric	
NEdT (@250K)	<0.25 K
Resources	
Size	6U Cubesat
Mass	8.5
Power	37.5
Data Rate	0.5 Mbps

CIRAS Measurements

- ***Lower Tropospheric Temperature Profiles***
- ***Lower Tropospheric Water Vapor Profiles***



Gold Scan Mirror to reduce polarization effects

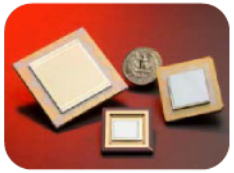
Temperature controlled FPA's and Spectrometer for stability

Micro Pulse Tube Cryocooler (Lockheed Martin)

Field imaging grating spectrometers to reduce co-registration error

JPL GRISM Spectrometer

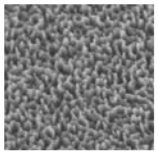
HOTBIRD detectors to reduce outages and noise artifacts



JPL HOT-BIRD Detector

High emissivity blackbody to preserve radiometric accuracy

JPL Black Silicon Blackbody



Summary and Conclusions

- AIRS instrument fully operational and providing excellent hyperspectral radiances for operational weather and science investigations
- Calibration accuracy demonstrated to be better than 200 mK and stable to about 2 mk/year. Spectral < 1ppm/year drift.
- Radiometric calibration not driven by on-board blackbody (for current sounders) but instrument and data processing artifacts.
- Lunar roll test improves calibration in cold scenes
- MODIS used to improve accuracy for worst case channels in highly non-uniform scenes
- Results will be available in AIRS Version 7 Level 1B and Level 1C
- Lessons learned applied to next generation CubeSat sounder (CIRAS) to launch in 2018/2019 timeframe