AIRS Radiometric Accuracy and Stability and Level 1 Product Updates

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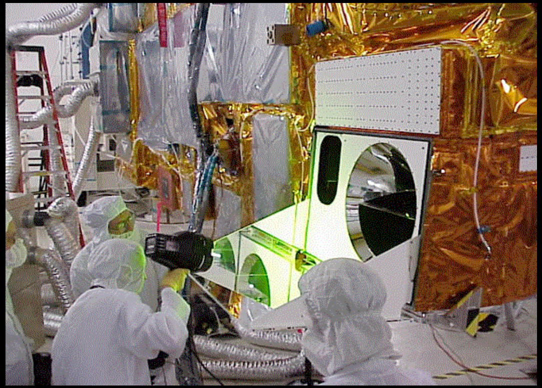
American Geophysical Union (AGU) Fall Meeting

December 11, 2019

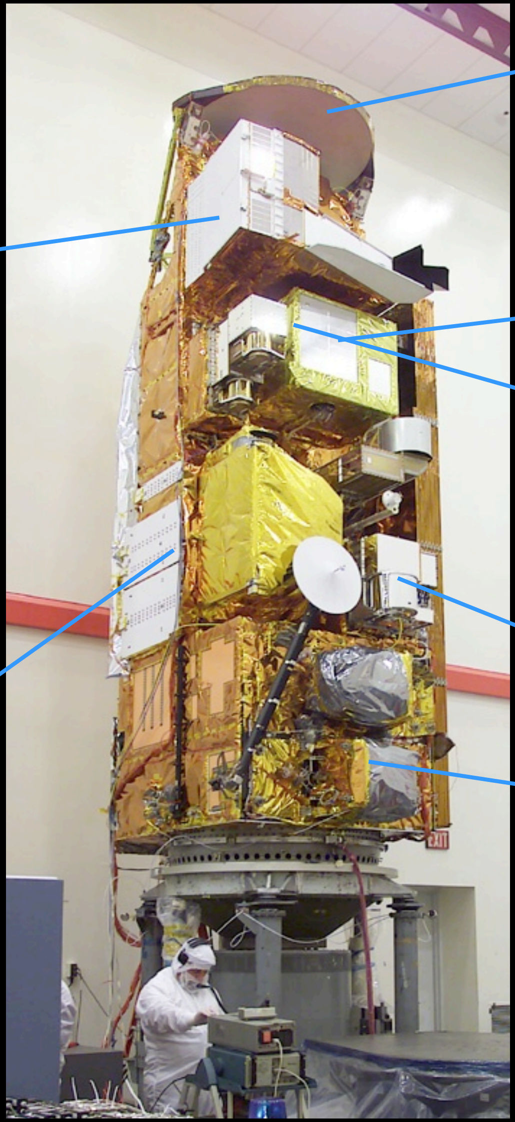
The Aqua Spacecraft

Launched May 4, 2002



Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon

Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS

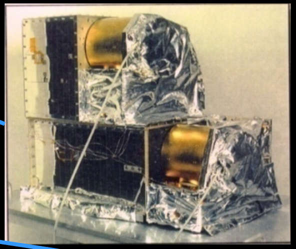


AQUA Spacecraft
GSFC/NGST

Advanced Microwave Scanning Radiometer (AMSR-E)
MSFC/JAXA

Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet

Humidity Sounder from Brazil (HSB)
JPL/Aerojet



Clouds and Earth Radiant Energy System (CERES)
LaRC/NGST

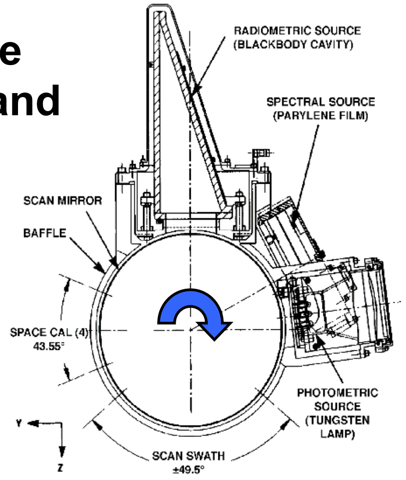
AIRS Demonstrates Key IR Sounding Technologies

AIRS Features

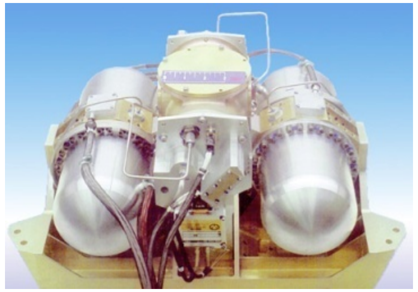
- Orbit: 705 km, 1:30pm, Sun Synch
- Pupil Imaging IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Scanner Rotates about Optical Axis (Constant AOI on Mirror)
- Full Aperture OBC Blackbody, ε>0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
- Temperature Controlled Spectrometer: 158K
- Actively Cooled FPAs: 60K
- No. Channels: 2378 IR, 4 Vis/NIR
- Mass: 177Kg,
  Power: 256 Watts,
  Life: 5 years (7 years goal)

Full Aperture Blackbody and Space View

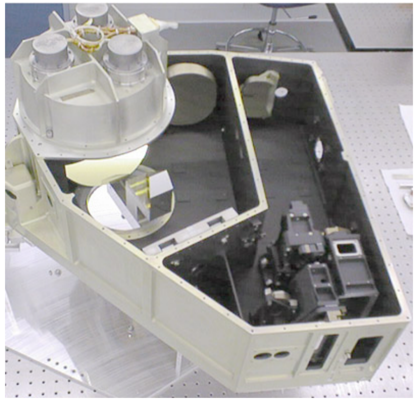
Isolated Scan Cavity



Temperature Controlled Instrument



Active Detector Cooling



Grating Spectrometer

IR Spectral Range:
3.74-4.61 µm, 6.2-8.22 µm,
8.8-15.4 µm
IR Spectral Resolution:
≈ 1200 (λ/Δλ)
No. IR Channels: 2378 IR

AIRS Radiometric Transfer Equations

Scene Radiance

$$L_{ev} = L_o(\theta) + \frac{c_1'(dn_{ev} - dn_{sv}) + c_2(dn_{ev} - dn_{sv})^2}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Mirror Polarization Contribution

$$L_o(\theta) = \frac{L_{sm} p_r p_t \left[cos2(\theta - \delta) - cos2(\theta_{sv,i} - \delta)\right]}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Gain Term

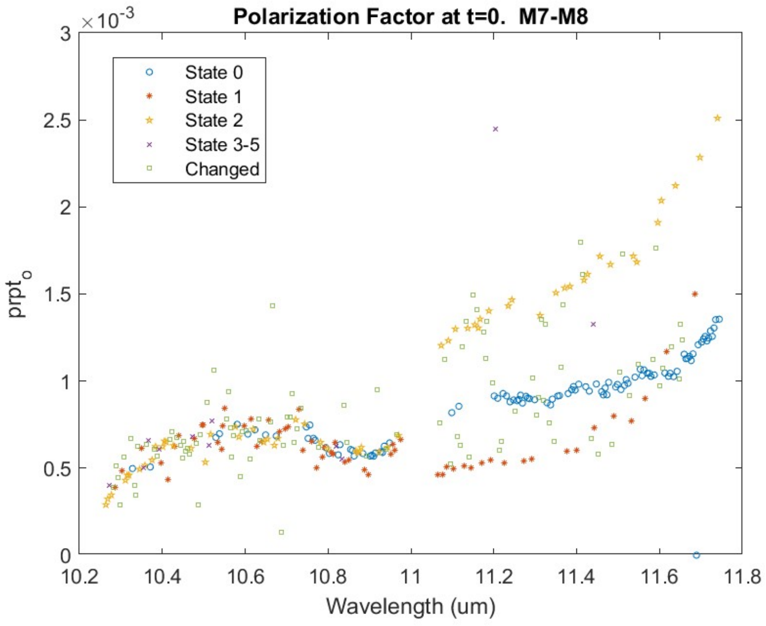
$$c_1{}' = \frac{[\varepsilon_{obc} P_{obc} - L_o(\theta_{obc})][1 + p_r p_t cos2\delta] - c_2(dn_{obc} - dn_{sv})^2}{(dn_{obc} - dn_{sv})}$$

- T. Pagano et al., "Reducing uncertainty in the AIRS radiometric calibration", Proc. SPIE 10764-23, San Diego, CA (2018)
- T. Pagano et al., "Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS)," IEEE TGRS, Volume 41, No. 2, February 2003, p. 265
- T. Pagano, H. Aumann, K. Overoye, "Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003

V7k

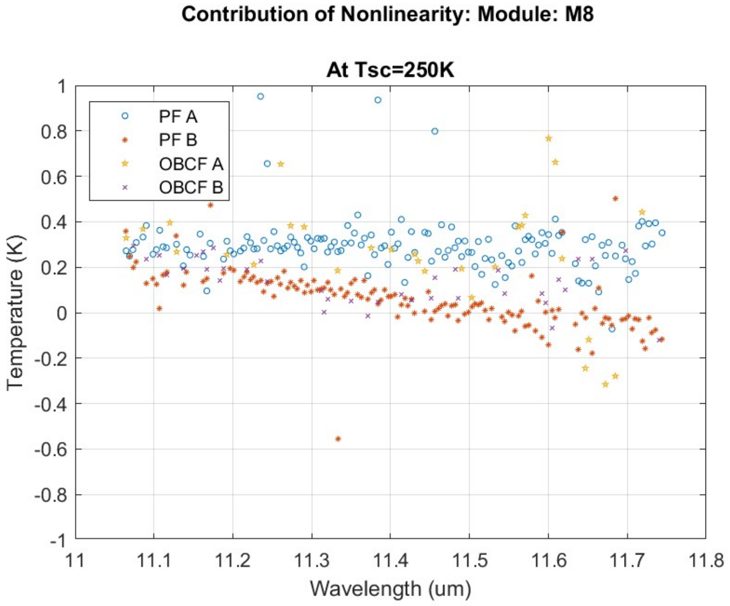
L_{ev} = Spectral Radiance in the Earth Viewport (W/m2-sr-μm)
L_{sm} = Spectral Radiance of the Scan Mirror for Unity Emissivity at T_{sm} (W/m^2-sr-μm)
L_o = Spectral Radiance Correction for Scan Mirror (W/m^2-sr-μm)
c_1 = Instrument gain (W/m^2-sr- μm-counts)
c_2 = Instrument nonlinearity (W/m^2-sr- μm-counts^2)
dn_{ev} = Digital counts while viewing Earth for each footprint and scan (counts)
dn_{sv} = Digital counts while viewing Space for each scan (counts)
$p_r p_t$ =Product of scan mirror and spectrometer polarization diattenuation (unitless)
θ = Scan Angle measured from nadir (radians)
δ = Phase of spectrometer polarization (radians)
P_{obc} = Plank Blackbody function of the OBC blackbody at temperature T_{obc} (W/m^2-sr-μm)
T_{obc} = Telemetered temperature of the OBC blackbody (K) with correction of +0.3K.
ε_{obc} = Effective Emissivity of the blackbody
dn_{obc} = Digital number signal from the AIRS while viewing the OBC Blackbody

Updates to L1B Radiometric Coefficients



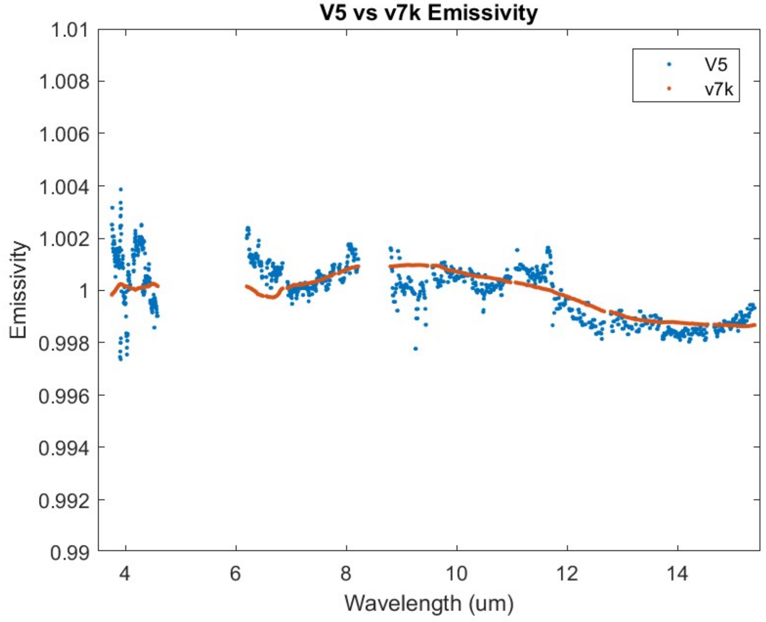
Nonlinearity Coefficients

- Re-Analysis of Pre-flight Calibration Data
- Separate A and B



Emissivity

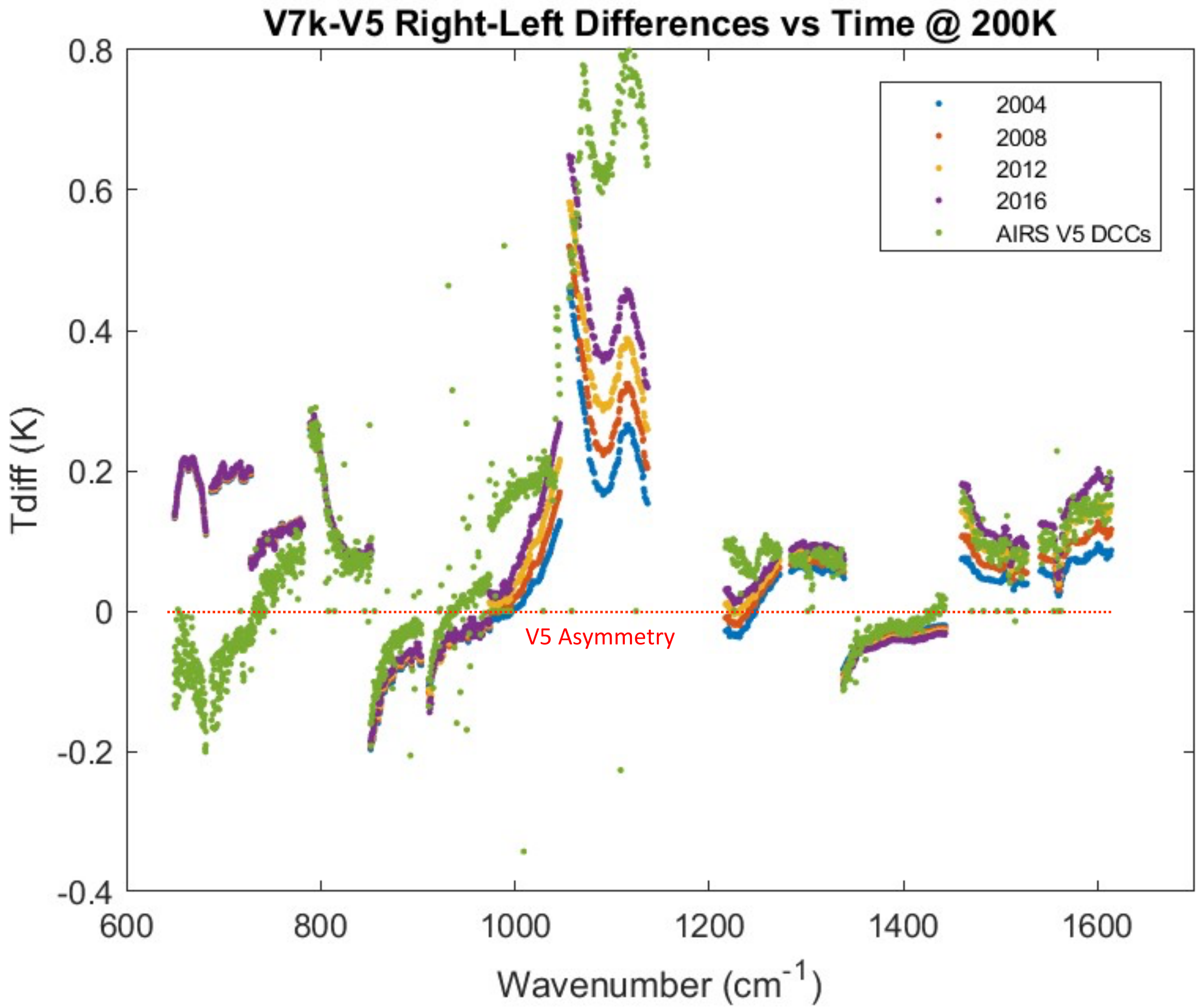
- Re-Analysis of Pre-flight Calibration Data
- Smoothed vs channel
- No A/B Difference



Polarization Coefficients

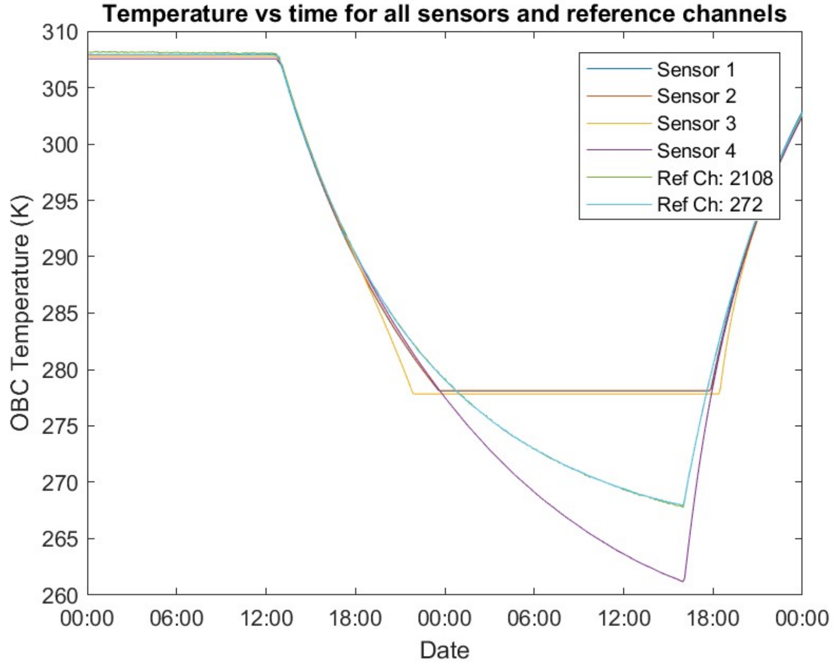
- Based on In-Flight Space Views
- Time Dependent
- Separate A and B

L/R on DCCs Confirm New Polarization Coefficients

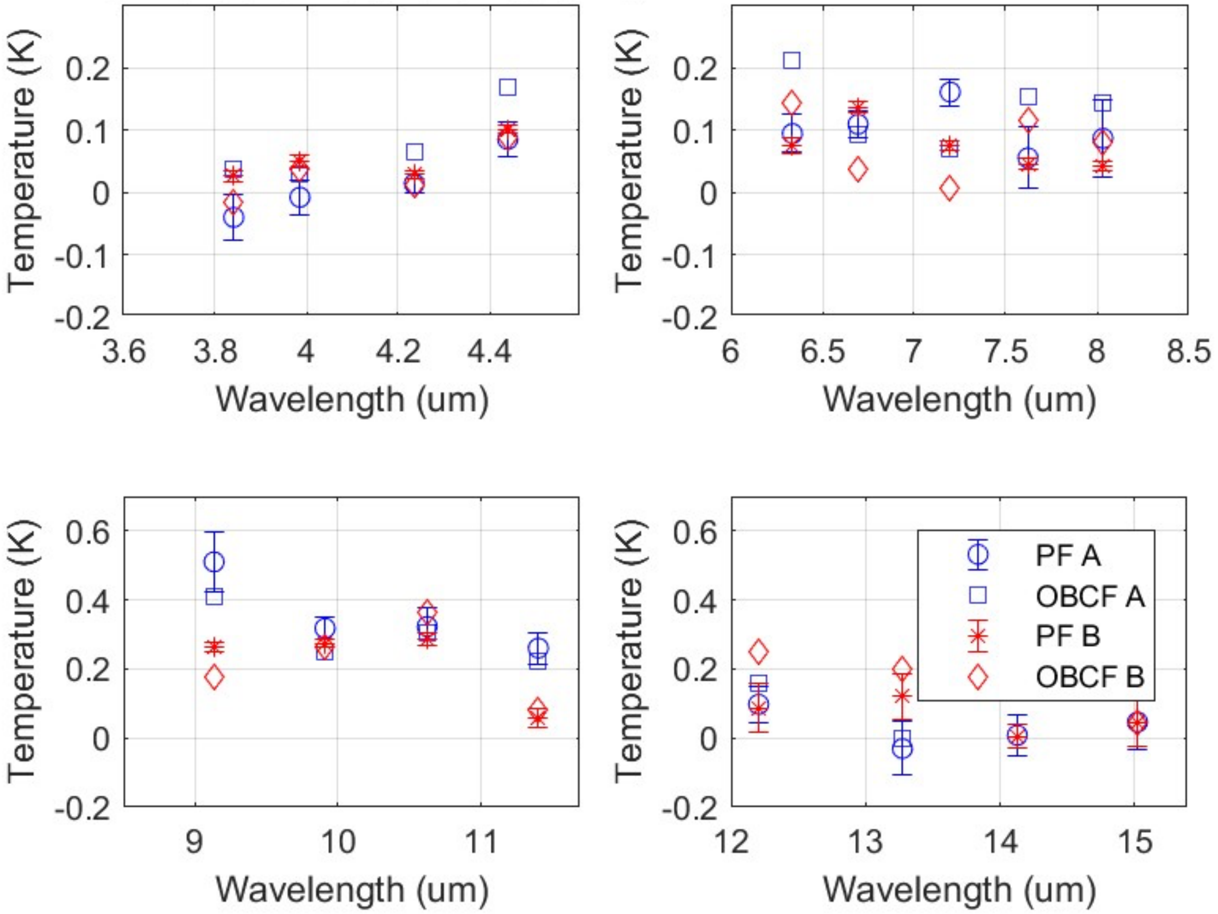


OBC Float Test Confirms Separate A/B Nonlinearity

OBC Float Test
Performed in July 2002
Temperature Sensor Issue Resolved Using Highly Linear Reference Channels



Nonlinearity Contribution at 250K
Error Bars are 1-sigma Uncertainty Pre-Flight



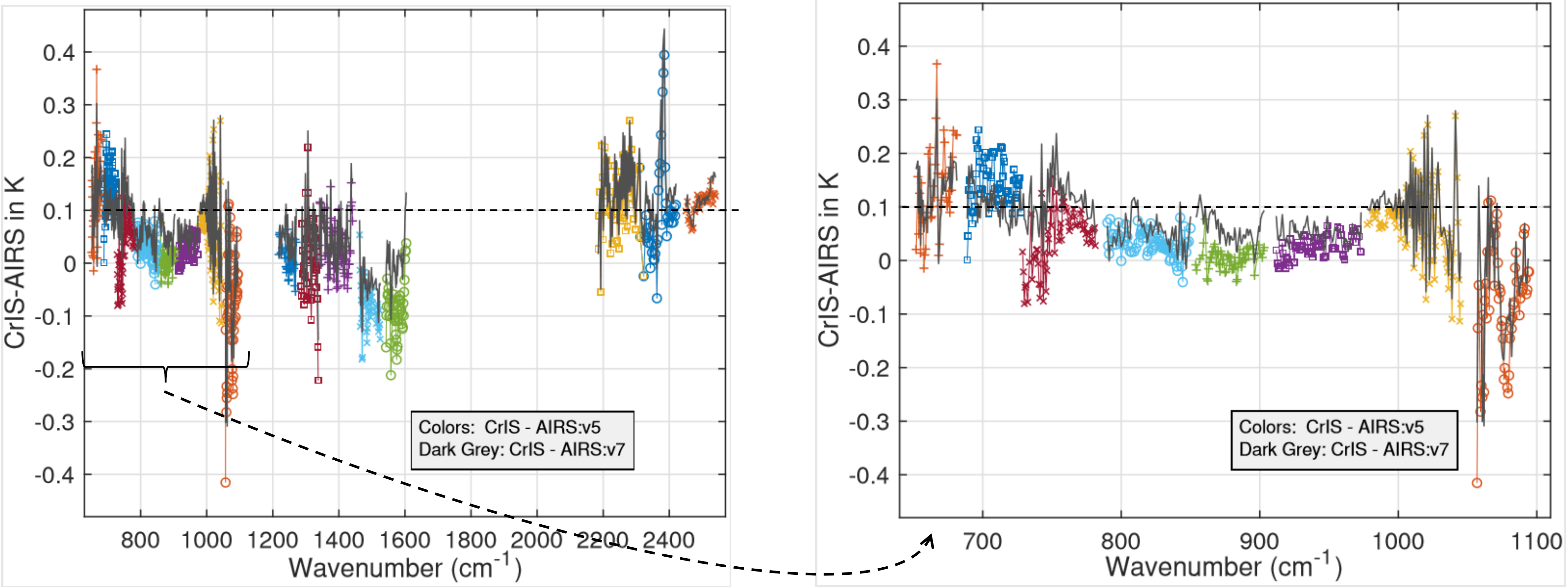
Pagano, T. S. et al., "Checking AIRS nonlinearity in flight", Proc SPIE 11127-43, San Diego, CA (2019)

CrIS-AIRS Shows Bias Improvement with V7k

- Improvement of 50-200 mK seen in all modules
- **Mostly due to smoothed emissivity**
- Reduction of Module Boundary Differences
- Residual CrIS-AIRS bias seen approaching 100 mK

Module Boundary Differences

Module	M5	M6	M7	M8	M9	M10	M11
Module	M6	M7	M8	M9	M10	M11	M12
(cm-1)	1045.5	973.2	903.3	851.6	781.3	727.9	681.8
V5 (mK)	300	50	5	100	50	80	250
V7k (mK)	300	10	5	0	5	0	60

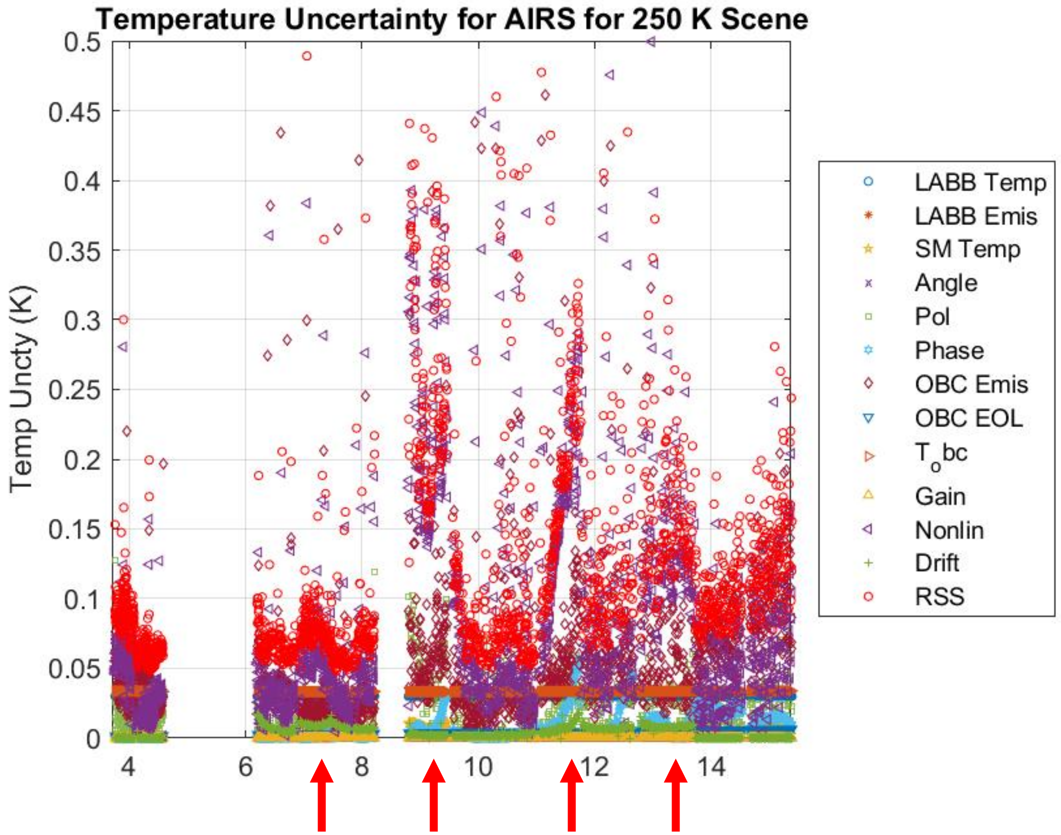


Original figures and analysis by L. Strow

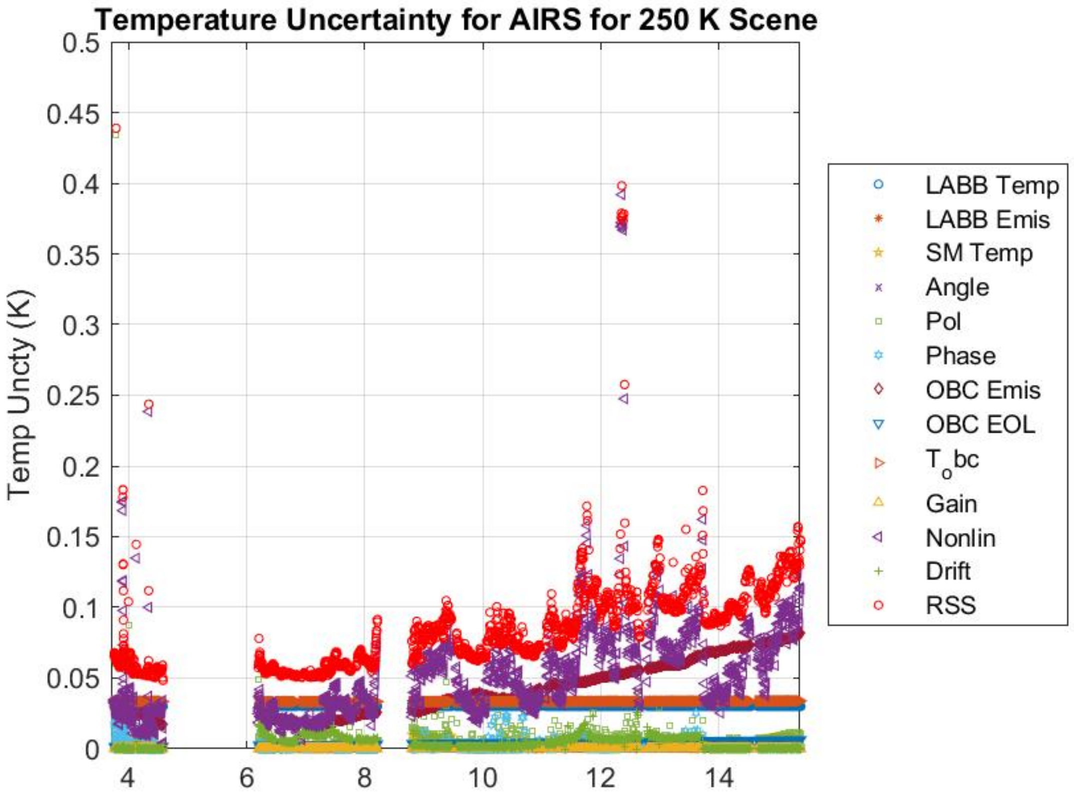
V7k Reduces Radiometric Uncertainty (1σ)

- Accuracy assumes A and B differences in nonlinearity seen pre-flight are real
- OBC Float Test Needed to Verify A vs B Nonlinearity

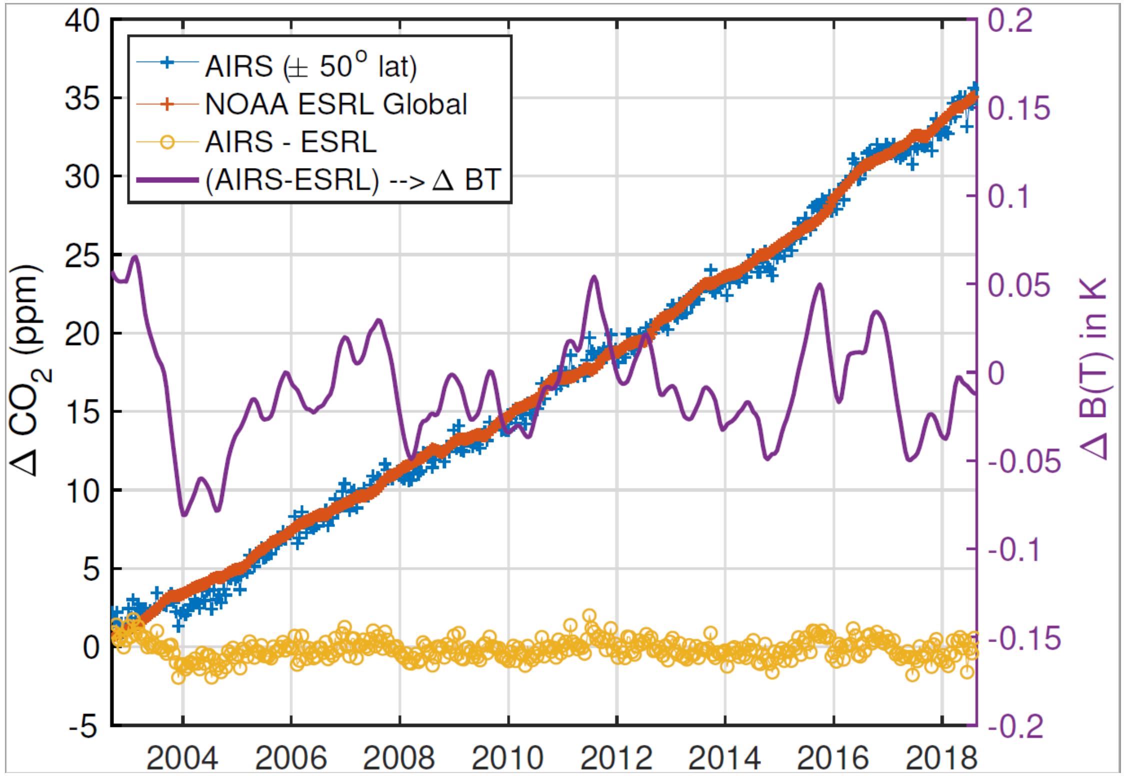
V5



V7k



AIRS Radiometric Stability via CO_2 Trends



- CO2 well mixed and can be used for AIRS stability tests
- CO2 in-situ measurement stability below 1mK/year in B(T) units (16 years)
- Collect AIRS ocean-only clear scenes and create 16 day averages (over 40 latitude bins).
- Remove seasonal variability and form B(T) anomaly.
- Use an optimal-estimation retrievals to compute $CO_2(t)$, other trace gases, and T(z,t), $H_2O(z,t)$, $O_3(z,t)$, SST, etc.
- Compare retrieved CO_2 ramp to in-situ (SI traceable) CO_2 measurements from NOAA ESRL

- Results show good agreement.
- Offsets near Nov 2003 understood.
- Results suggest near zero trends with a statistical uncertainty of about 0.004K/year.

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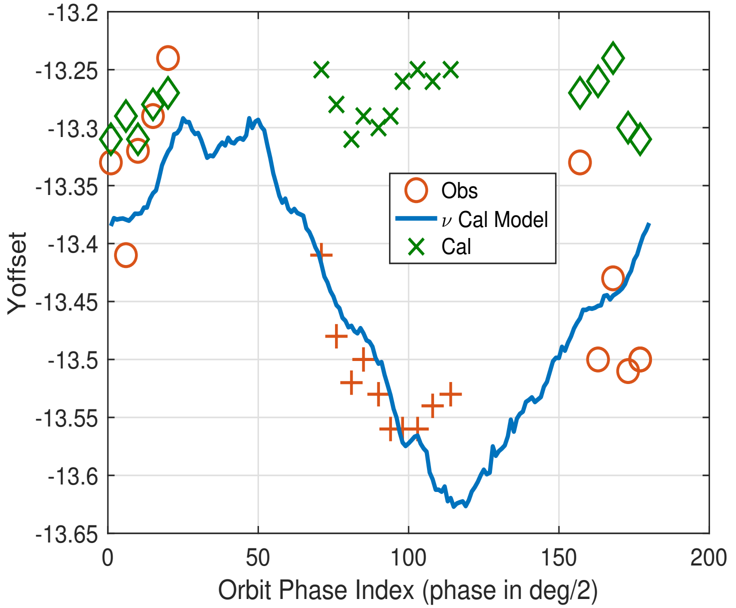
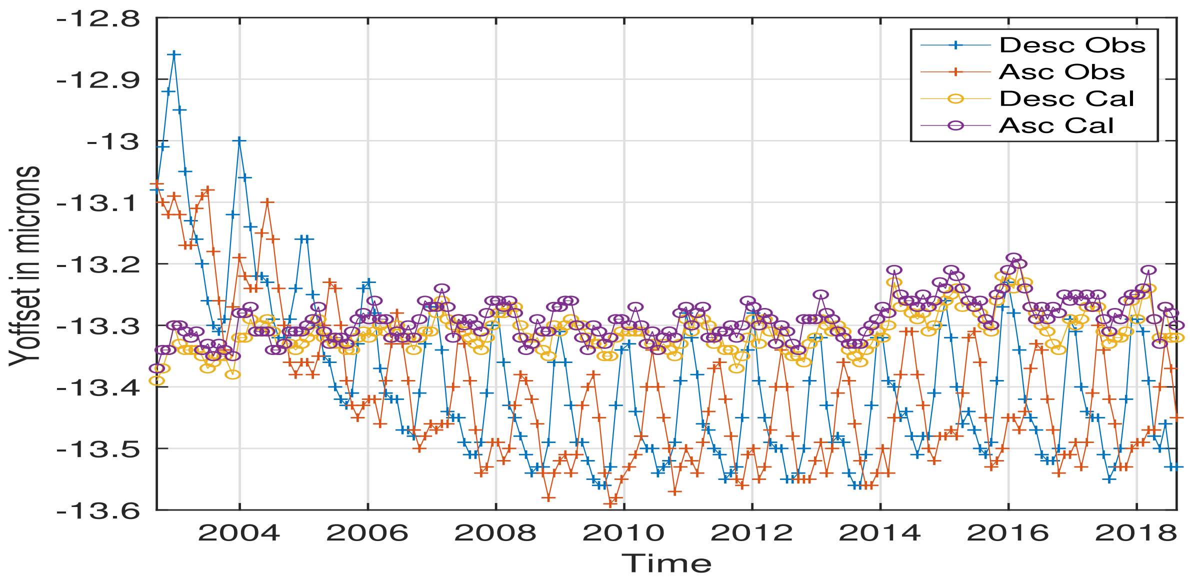
Spectral Calibration Enables Correction to Constant Frequencies

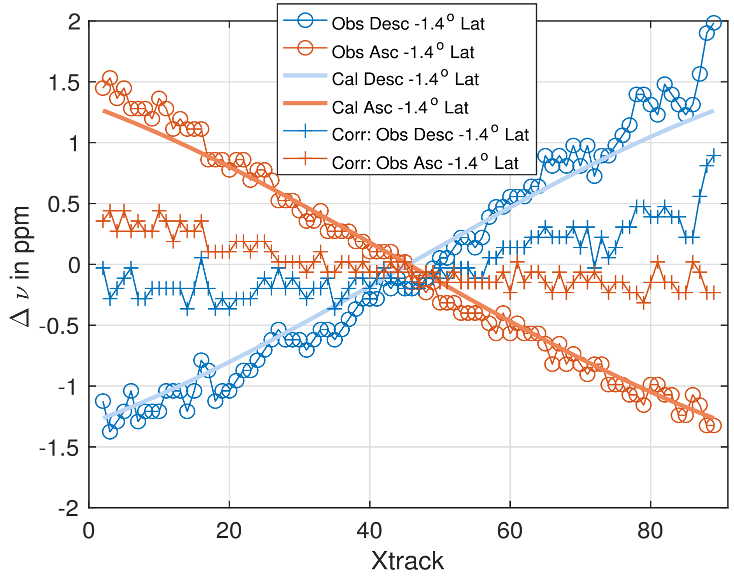
Improved Correction for Orbital Variations



Resulting calibration good to <0.2 micron



Improved Correction for Doppler Effects



We use this information in L1C V6.6 to resample the entire mission to a common frequency set.

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L1C Cleans-up AIRS Spectra

<u>Version 6.0</u>

- Designed to facilitate use of AIRS Level 1 radiances
  - For Comparison to other Hyperspectral IR
  - For Comparison to Broadband Imagers
  - For Ingest by L2 Retrievals
- Version 5 L1B for all "good" channels
- Fills Dead Channels with PC Reconstruction (PCR)
- Fills bad Cij (Co-registration) Pixels with PCR
- Fills Gap with PCR
- Fills Very High Noise Pixels with PCR
- All filled channels are flagged

<u>Version 6.6</u>

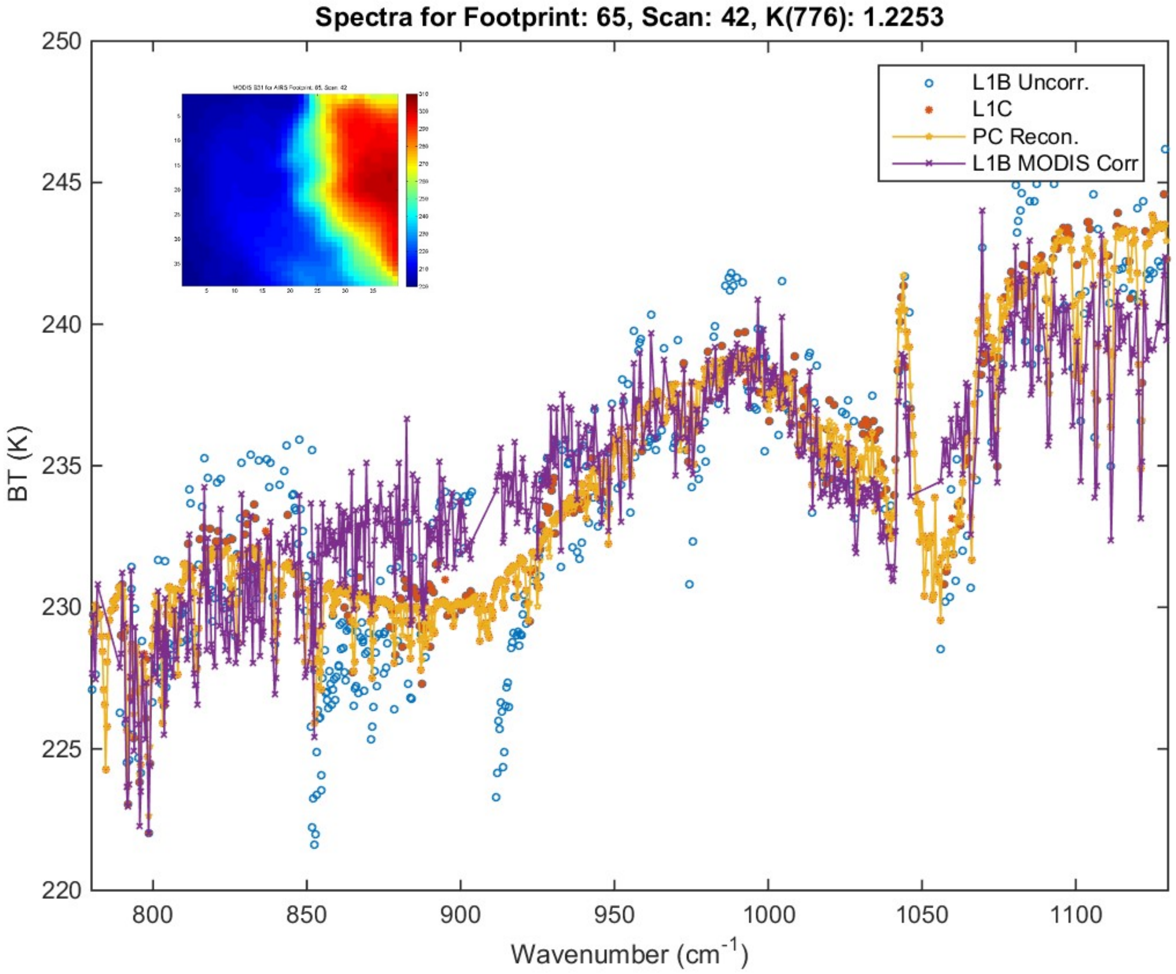
- Same as Version 6.0 but with…
- Constant Frequency Grid (does not change with time)

<u>Version 7.0</u>

- Updated filling algorithms
- Version 7k Radiometric and Polarization Coefficients
- netCDF Output

- L1C V6.0 available on a 1-mo rolling basis.
- V6.6 & V7 Available in 2020

High Contrast IFOVs Have Significant L1B Cij Errors.
Current L1C Substitutes Affected Channels with PC Reconstruction



Summary and Conclusions

- NASA AIRS on Aqua in excellent shape through life of satellite
  - Successful demonstration of grating spectrometer technology and science of hyperspectral IR sounding
- Radiometric calibration coefficients updated for V7
  - Separate A/B calibration coefficients for polarization and nonlinearity
  - Improves fit to pre-flight data and space views observed on-orbit
  - Improves radiometric accuracy
- Verified on-orbit
  - Using DCC’s, OBC Float Test, and Comparisons with CrIS
- The AIRS instrument is remarkably stable
  - Validation of stability shows near zero trends within 4mK/year
  - AIRS 17+ year record is an important baseline for climate studies.