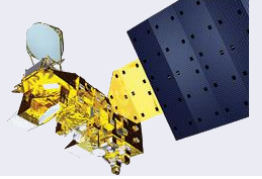

Updates to the Absolute Radiometric Accuracy of the AIRS on Aqua

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NASA Sounder Science Team Meeting

October 4, 2018

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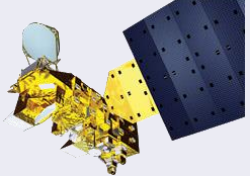
AIRS Designed for High Accuracy and Stability

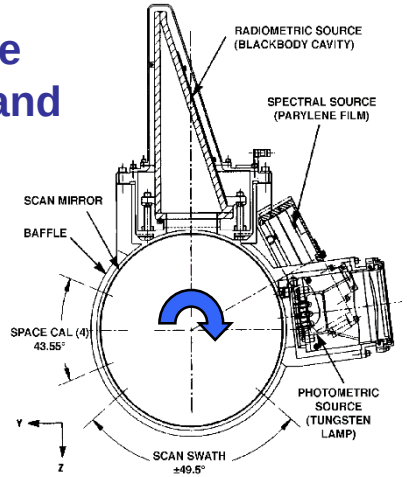


AIRS Features

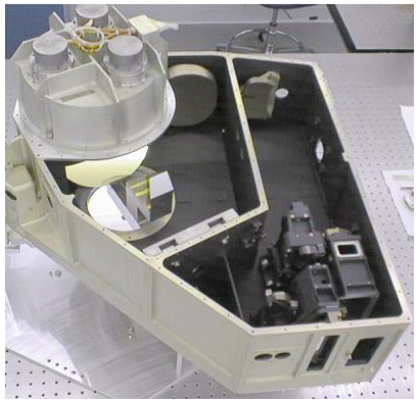
- Orbit: 705 km, 1:30pm, Sun Synch
- Pupil Imaging IFOV : 1.1° x 0.6° (13.5 km x 7.4 km)
- Scanner Rotates about Optical Axis (Constant AOI on Mirror)
- Full Aperture OBC Blackbody, ε>0.998
- Full Aperture Space View
- Solid State Grating Spectrometer
- Temperature Controlled Spectrometer: 158K
- Actively 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



Active Detector Cooling



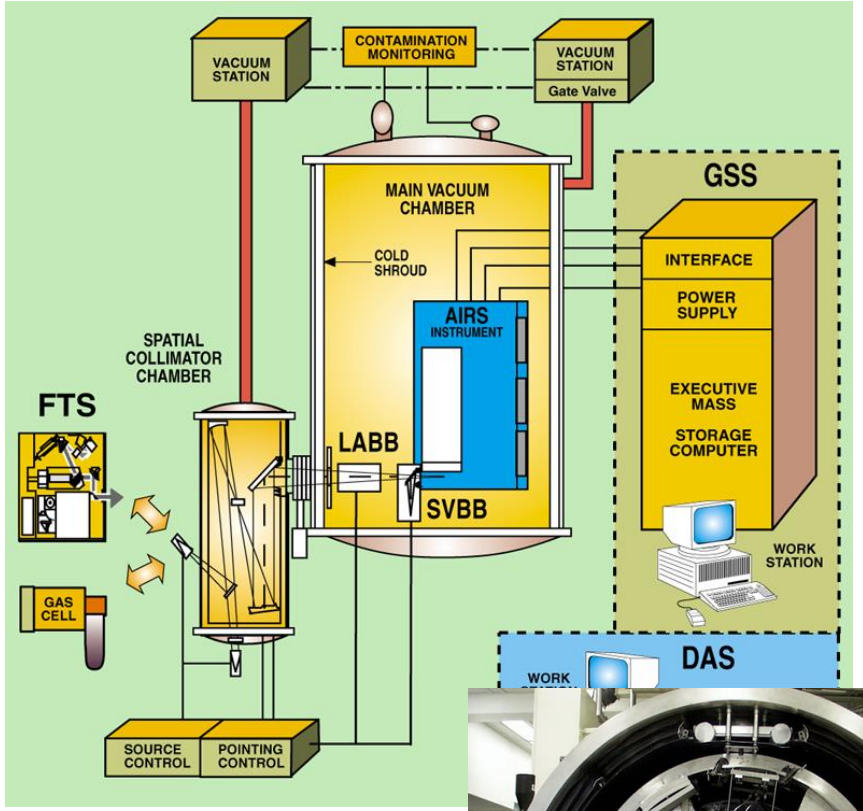
Grating Spectrometer

Temperature Controlled Instrument

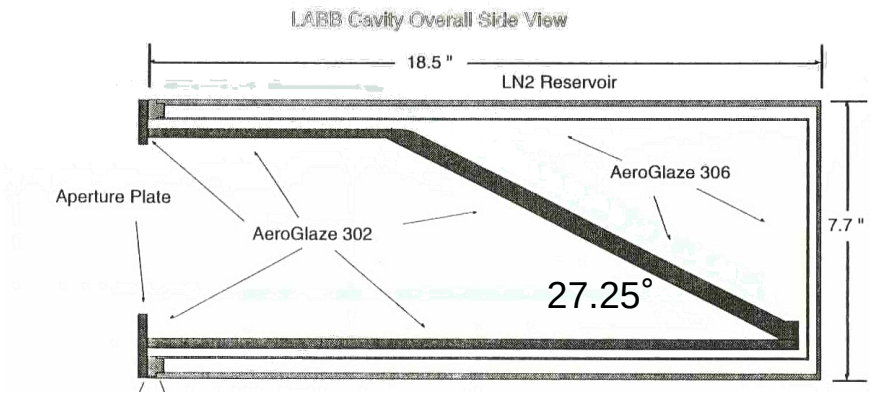
IR Spectral Range:
3.74-4.61 µm, 6.2-8.22 µm, 8.8-15.4 µm
IR Spectral Resolution:
≈ 1200 ($\lambda/\Delta\lambda$)
No. IR Channels: 2378 IR

Extensive Pre-flight Calibration on AIRS Ties to NIST Standards

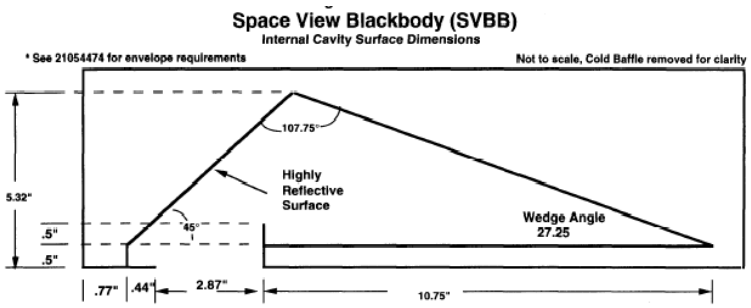
- Radiometric Response
  - Emissivity, Nonlinearity
  - Stray Light, Polarization
  - Scan Angle Dependence in TVAC
  - Transfer to On-Board Blackbody
  - 2 TVAC Cycles
- Spectral Response
  - SRF Characterization with FTS
  - Channel Spectra Characterized
- Spatial Response
  - Top-hat Functions All Channels
  - Stray Light Excellent
  - Far Field Response Excellent
- Good Documentation
  - Over 400 Design File Memos



NIST Traceable External Large Area Blackbody (LABB) and Space View (SVBB)

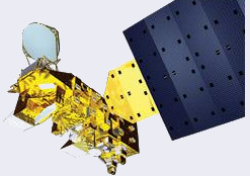


- Large Area Blackbody (LABB)
- T = 190K to 360K
- ε > 0.99998
- NIST Traceable PRTs (Rosemont)
- T_precision = 0.01K
- T_accuracy = 0.027K

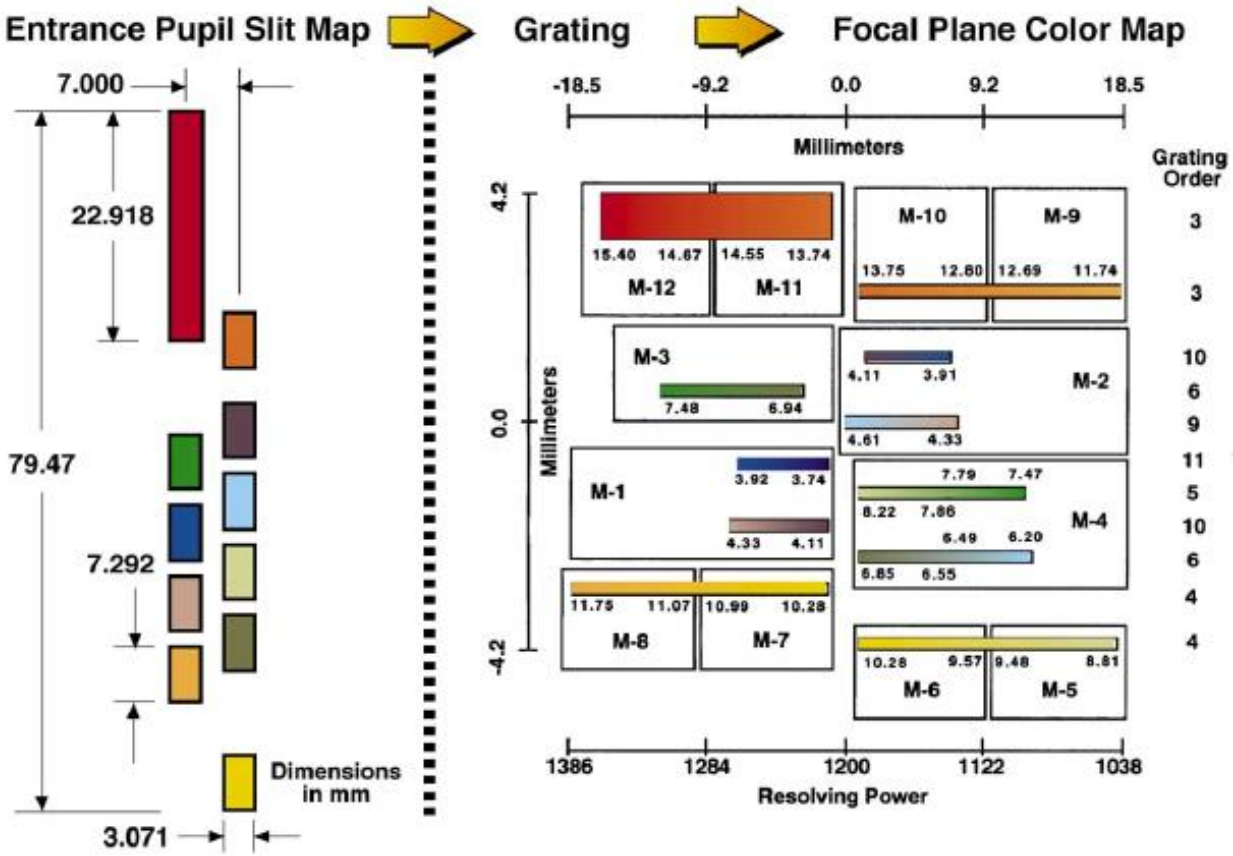


- Space View Blackbody (SVBB)
- T < 80 K
- ε > 0.99998
- T_precision = 0.01K
- T_accuracy = 0.5K

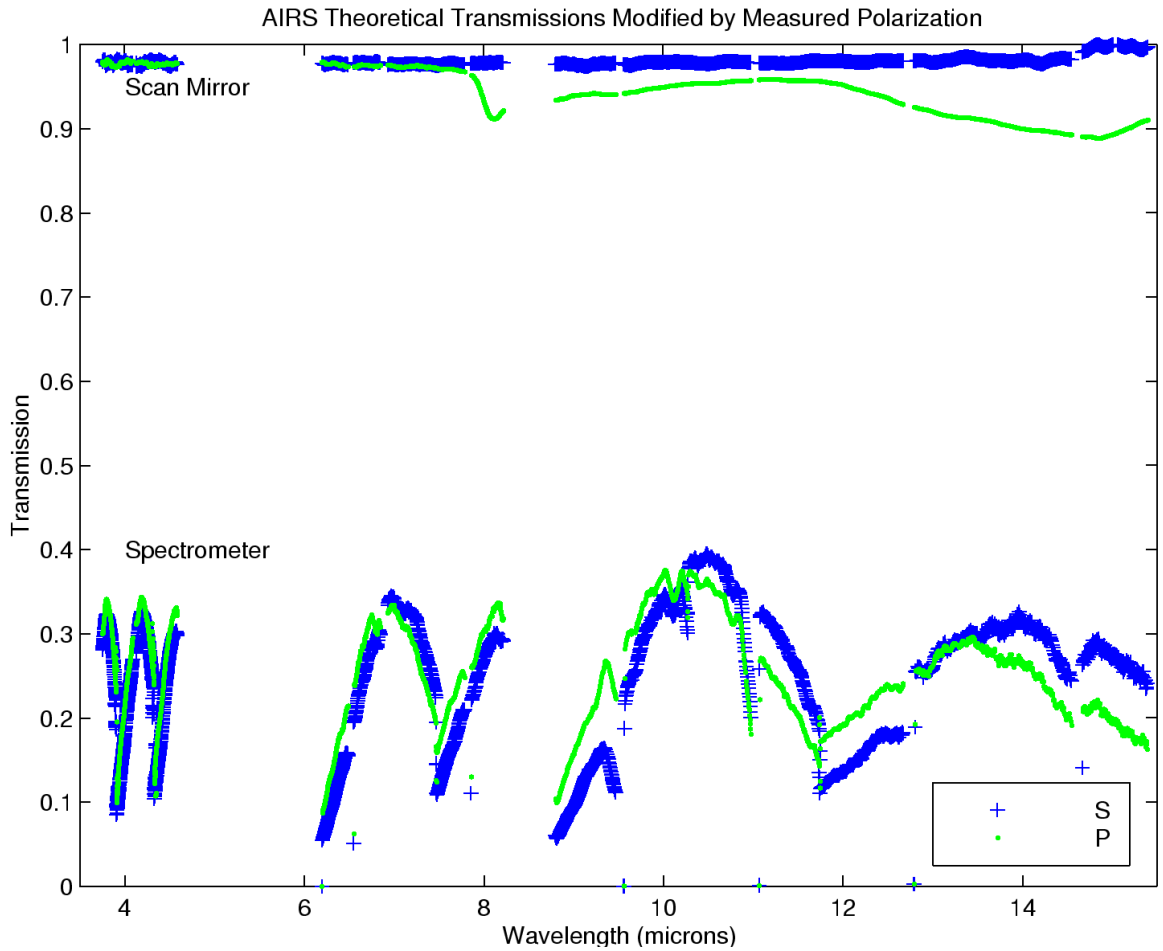
AIRS Images Pupil with Multiple Linear Arrays

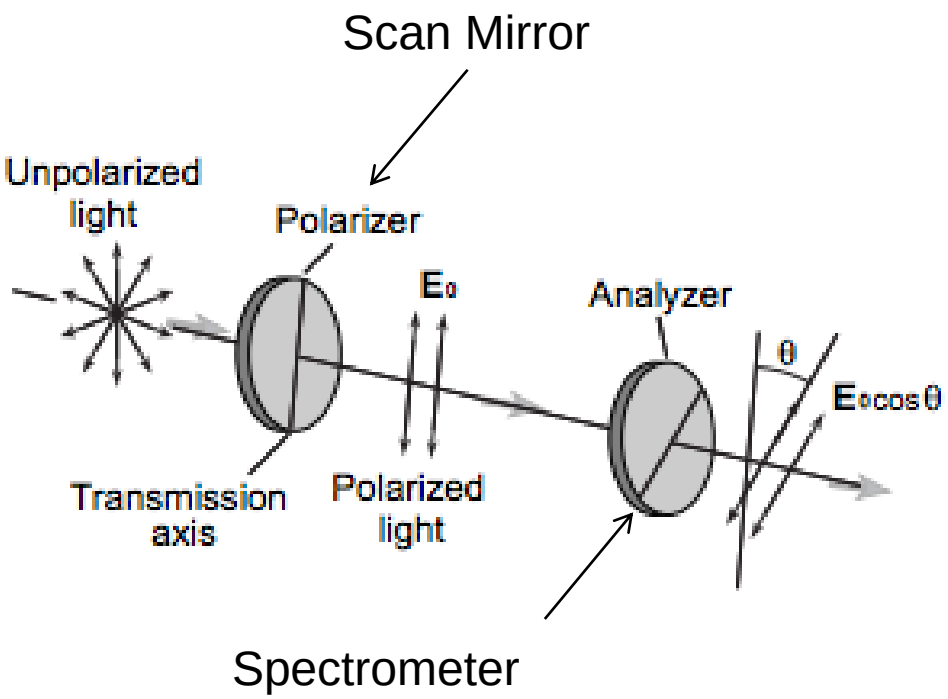


AIRS Module Spectral Band Limits					
		λ1	λ2	v1	v2
		(μm)	(μm)	(cm^{-1})	(cm^{-1})
1	M1a	3.752	3.934	2541.9	2665.2
2	M1b	4.127	4.348	2299.8	2422.8
3	M2a	3.891	4.088	2446.2	2569.8
4	M2b	4.301	4.584	2181.5	2325.0
5	M3	6.930	7.473	1338.2	1443.1
6	M4a	6.196	6.489	1541.1	1613.9
7	M4b	6.549	6.848	1460.3	1527.0
8	M4c	7.469	7.786	1284.3	1338.9
9	M4d	7.858	8.217	1217.0	1272.6
10	M5	8.798	9.469	1056.1	1136.6
11	M6	9.558	10.269	973.8	1046.2
12	M7	10.264	10.974	911.2	974.3
13	M8	11.065	11.744	851.5	903.8
14	M9	11.731	12.670	789.3	852.4
15	M10	12.790	13.735	728.1	781.9
16	M11	13.728	14.543	687.6	728.4
17	M12	14.663	15.394	649.6	682.0



AIRS Scan Mirror and Spectrometer Act Like Polarizer and Analyzer





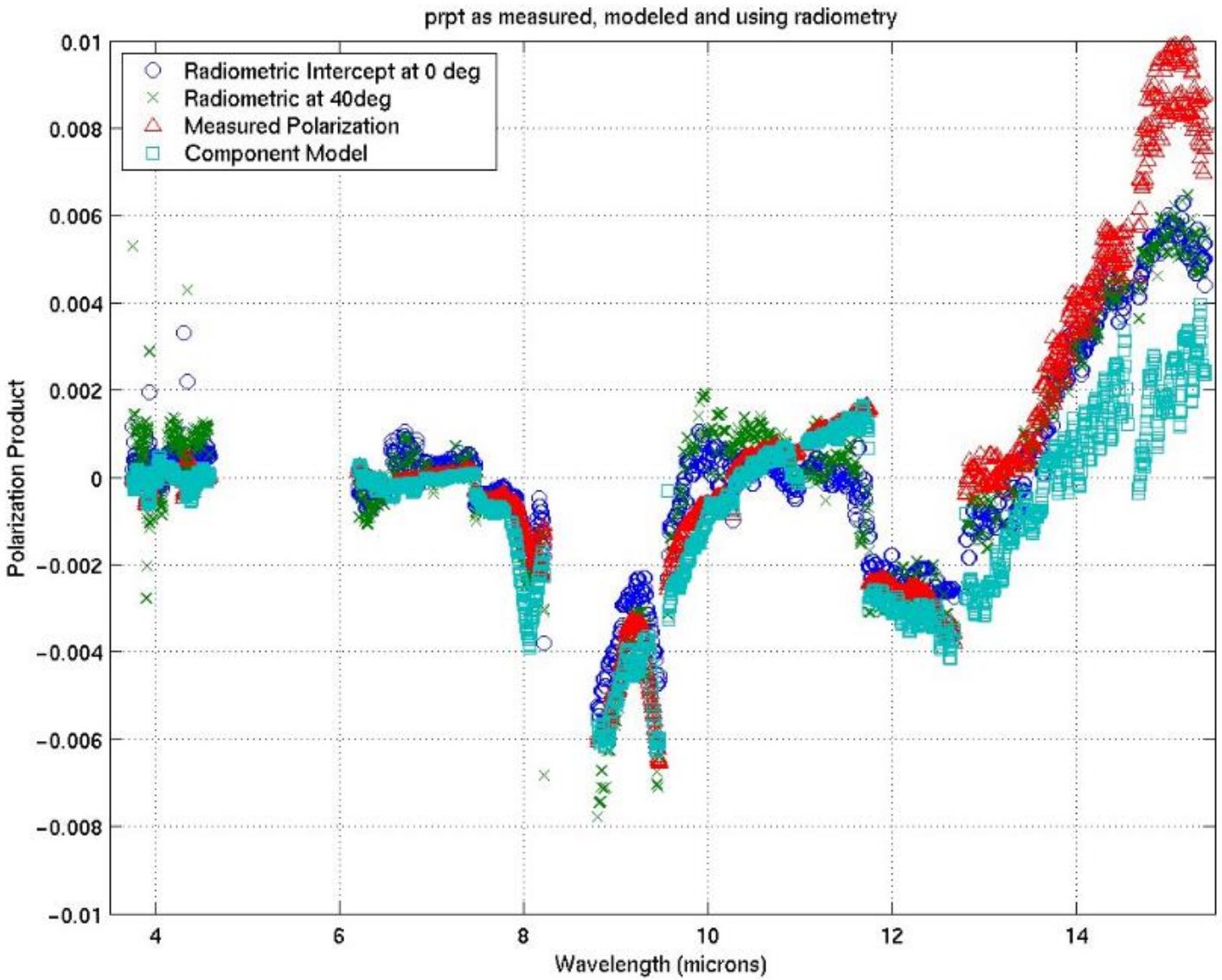
$$L_{ev} = L_o(\theta) + \frac{c_0 + c_1'(dn_{ev} - dn_{sv}) + c_2(dn_{ev} - dn_{sv})^2}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Assumes all space views at 90°

$$L_o(\theta) = \frac{L_{sm} p_r p_t [cos2(\theta - \delta) + cos2\delta]}{[1 + p_r p_t cos2(\theta - \delta)]}$$

Multiple Methods Used to Determine $p_r p_t$ in V5

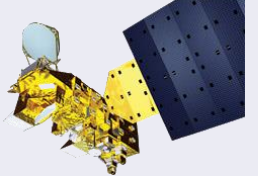
V5 Coefficients Determined Pre-Launch and Not Changed Since



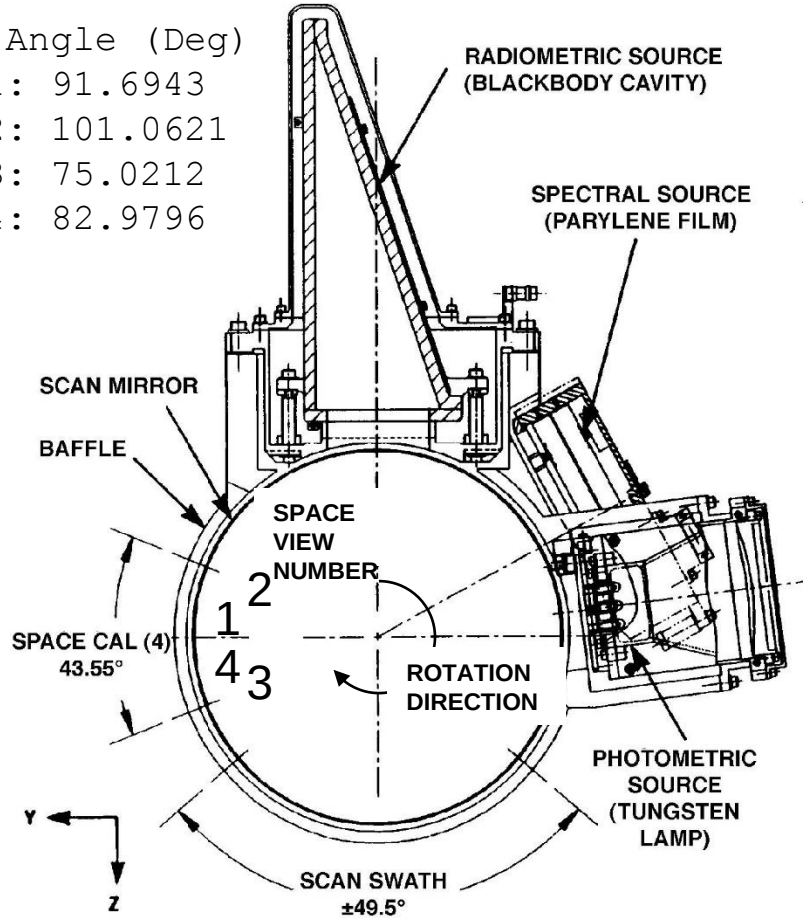
High Uncertainty Especially in LWIR

V5 is average of "Measured" and "Modeled" polarization, with Phase = 0

New Method Uses Multiple Space Views

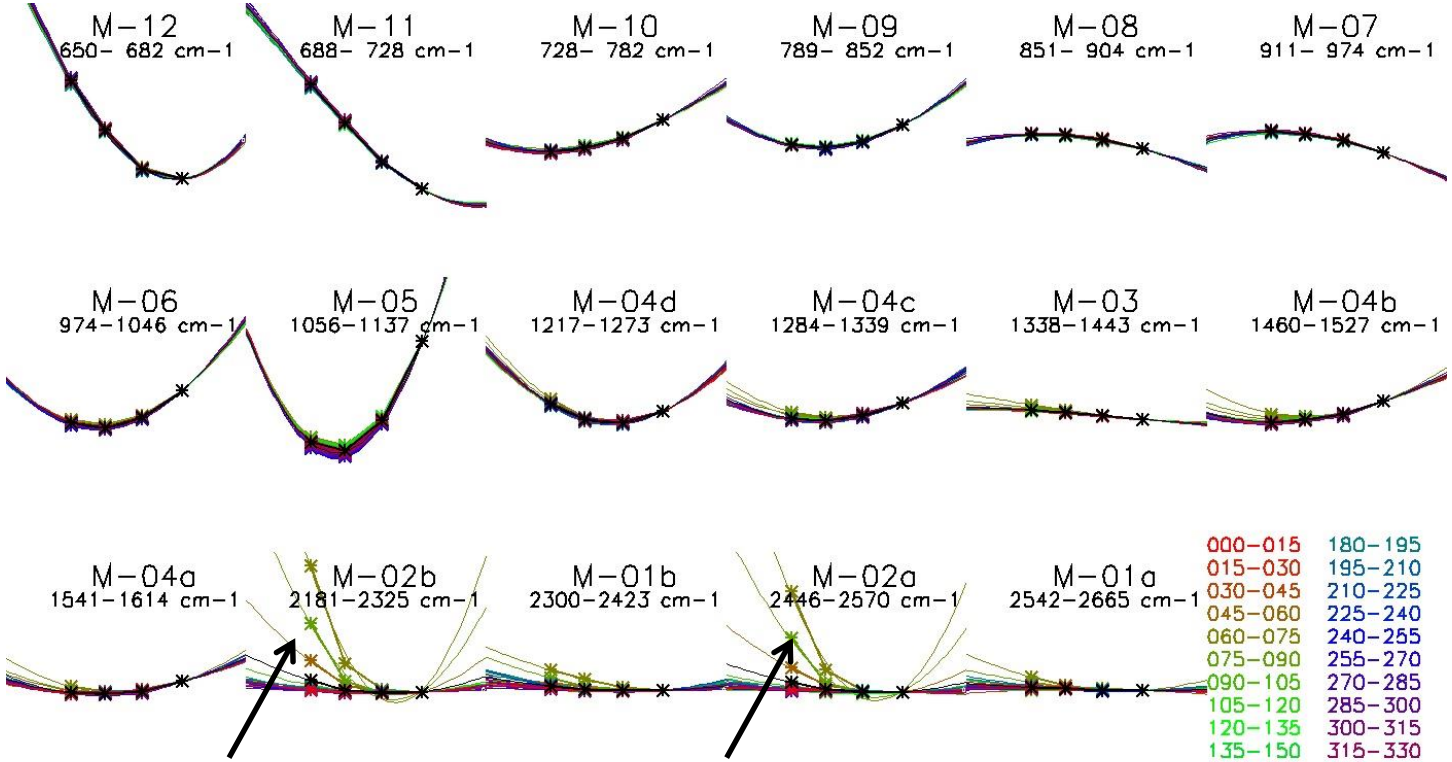


SV Angle (Deg)
SV1: 91.6943
SV2: 101.0621
SV3: 75.0212
SV4: 82.9796



Earth

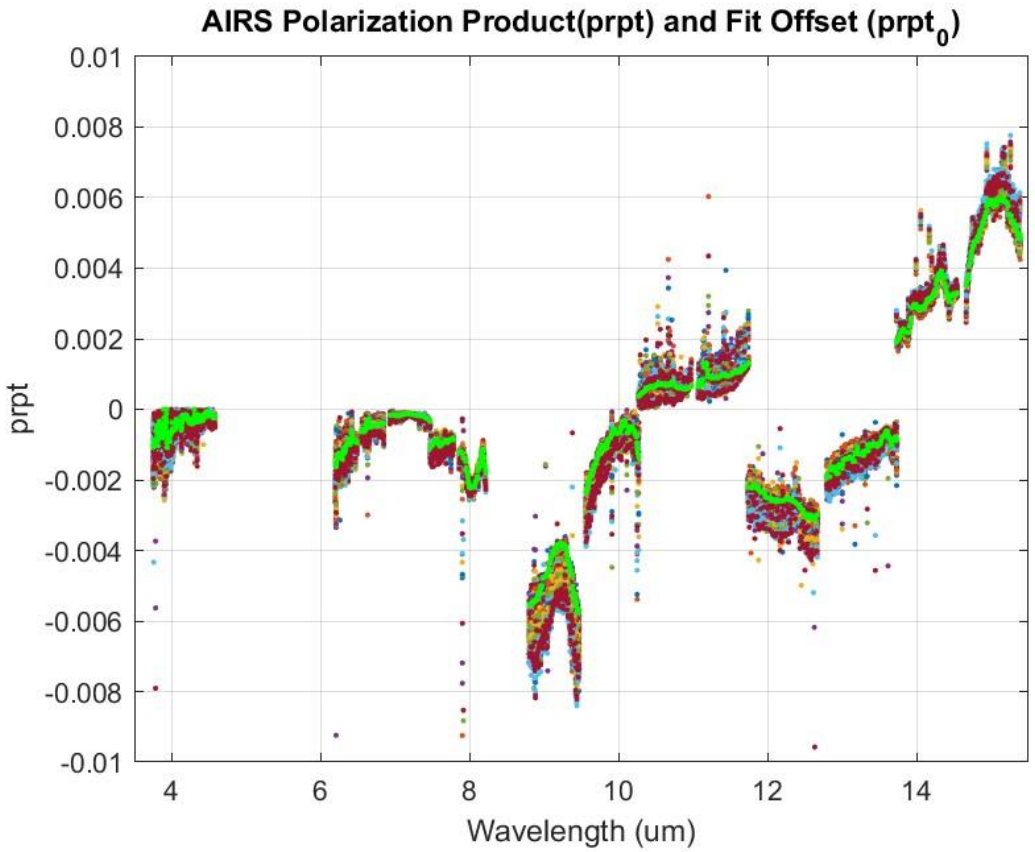
Every space view in the mission used to give 171 monthly averages

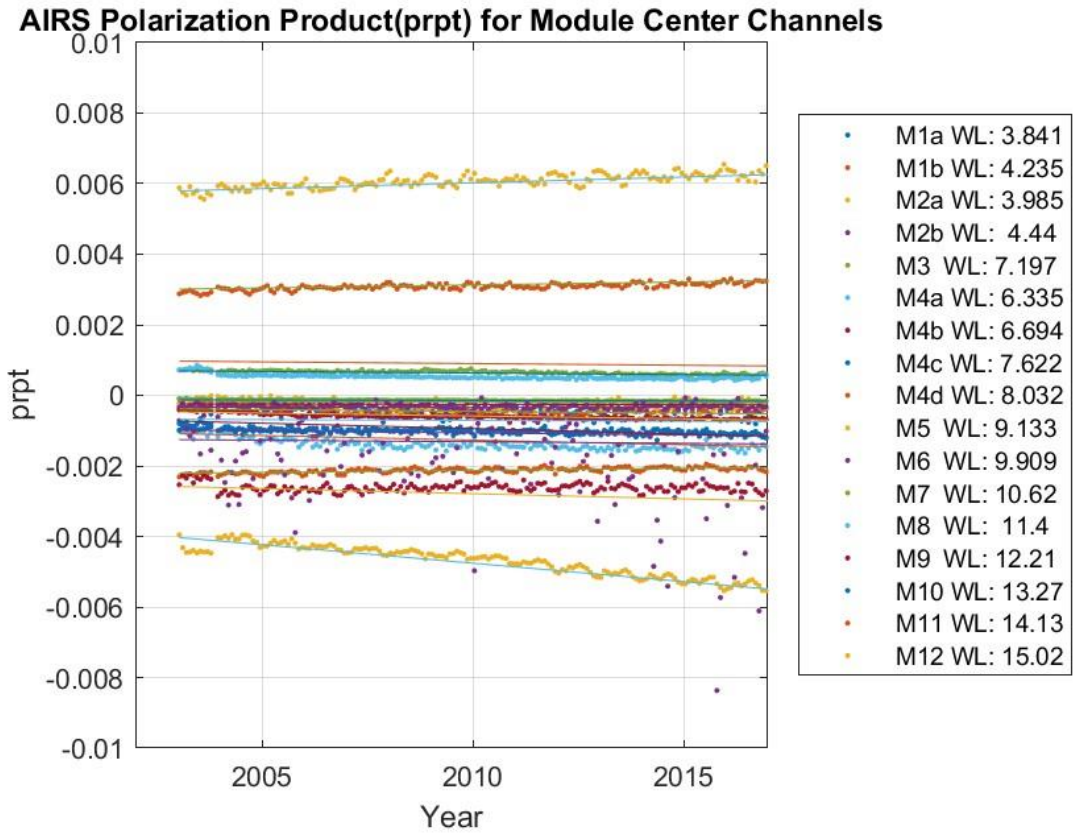


Care taken to omit anomalous readings

$$\left(dn_{sv,i} - dn_{sv,1}\right)c_1{}' = -L_{sm}p_r p_t\left[cos2\theta_{sv,i}cos2\delta + sin2\theta_{sv,i}sin2\delta + cos2\delta\right]$$

Polarization Parameters Calculated Over Mission Life

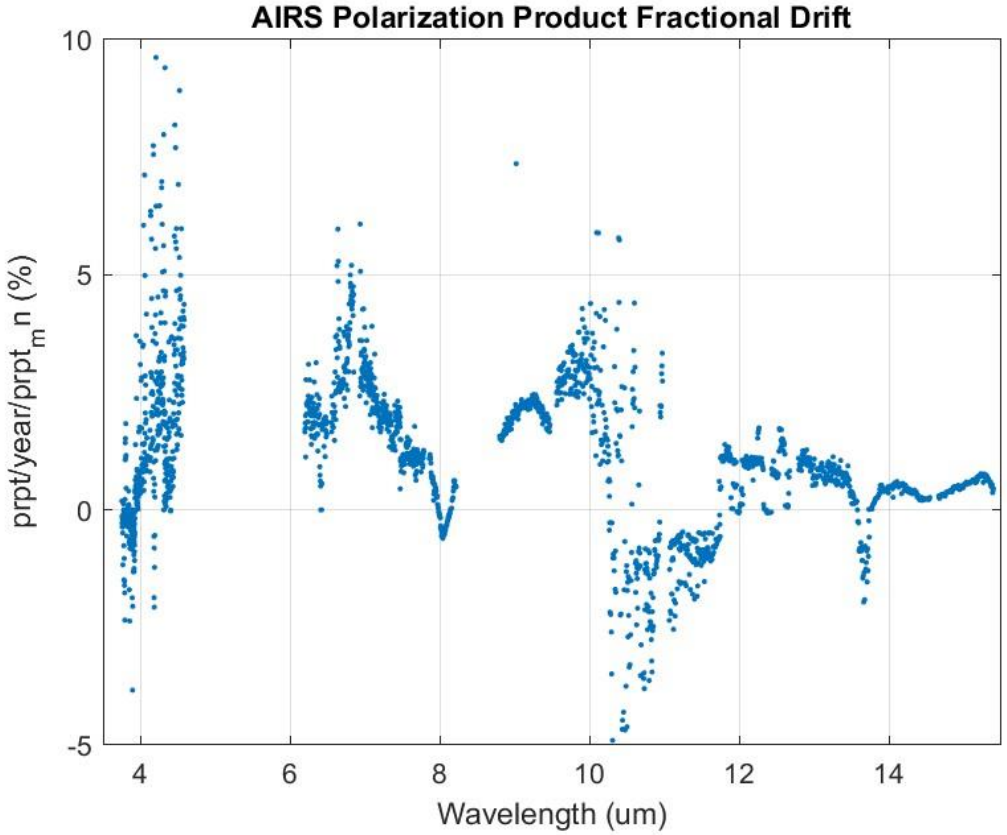




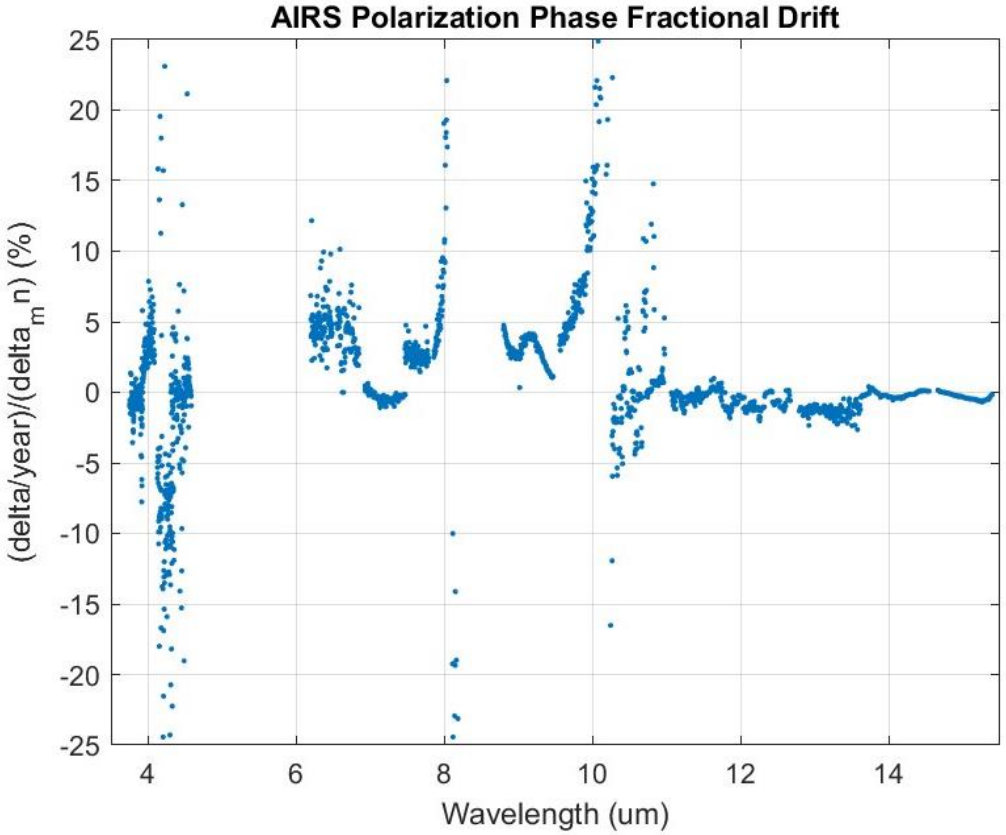
Polarization and Phase in V7k are Time Dependent Using Linear Fit Offset and Slope

V7k Annual Change in Polarization and Phase

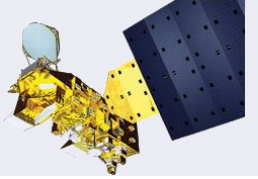
$$\frac{\Delta p_r p_t / \Delta t}{p_r p_t} \ (\%)$$



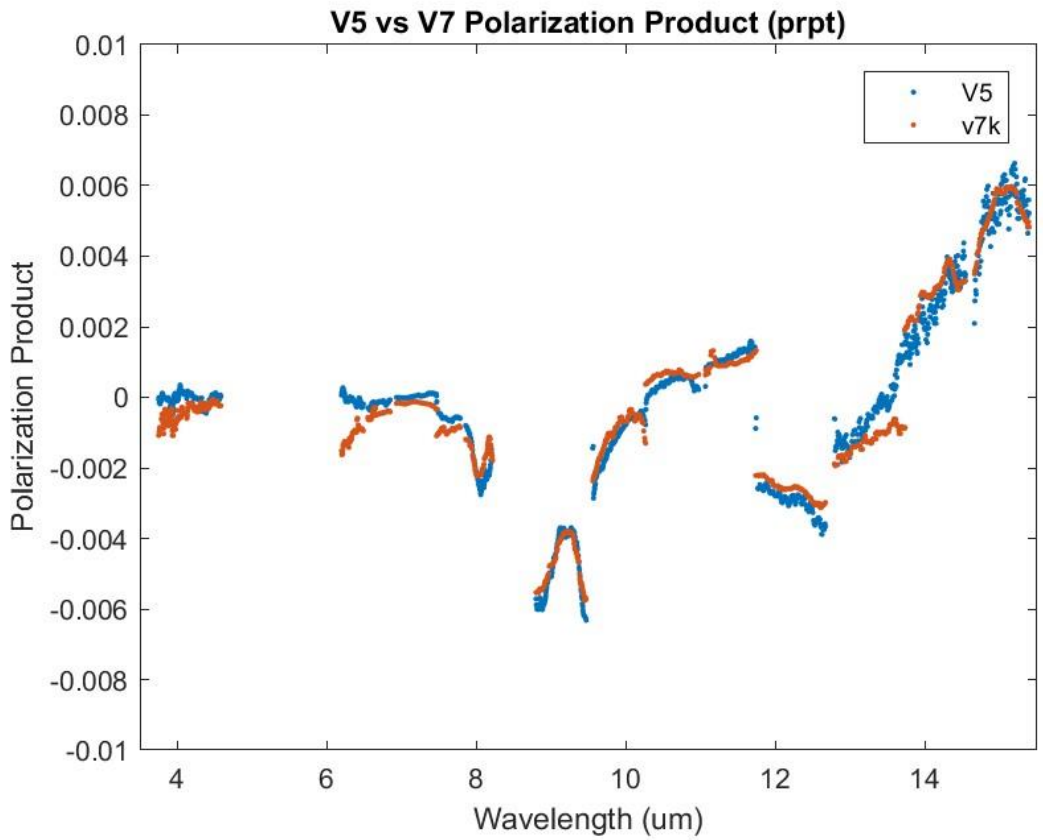
$$\frac{\Delta \delta / \Delta t}{\delta} \ (\%)$$



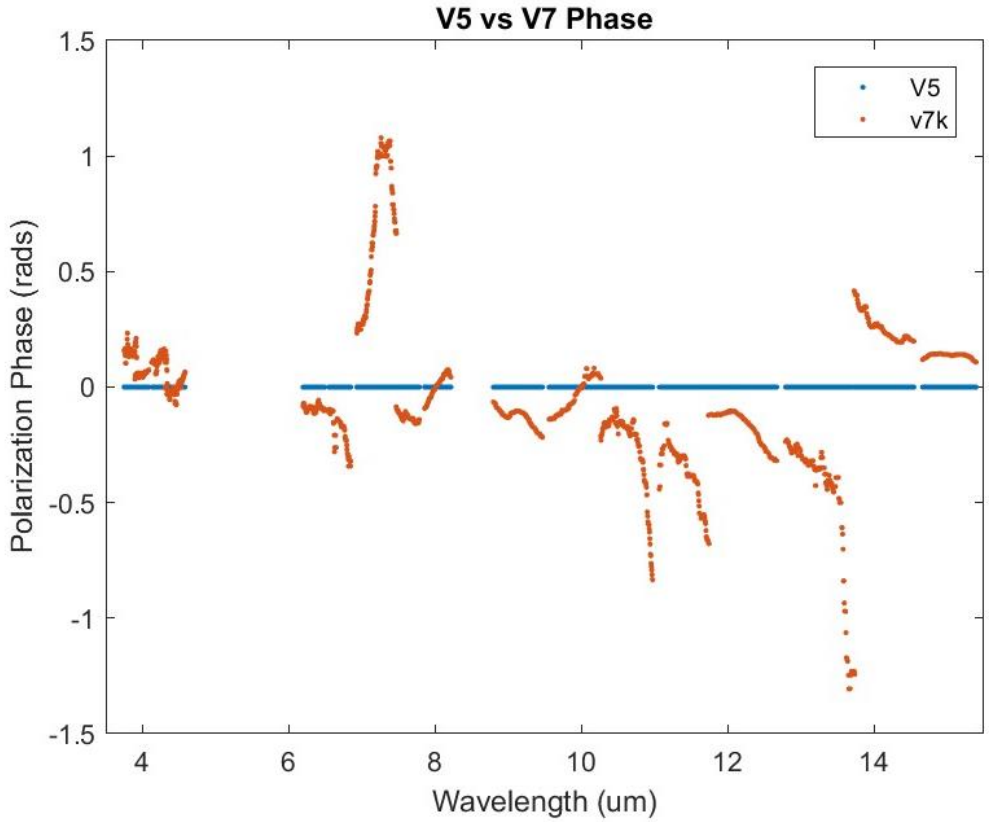
V7k Compared to V5: Polarization and Phase



$p_r p_t$

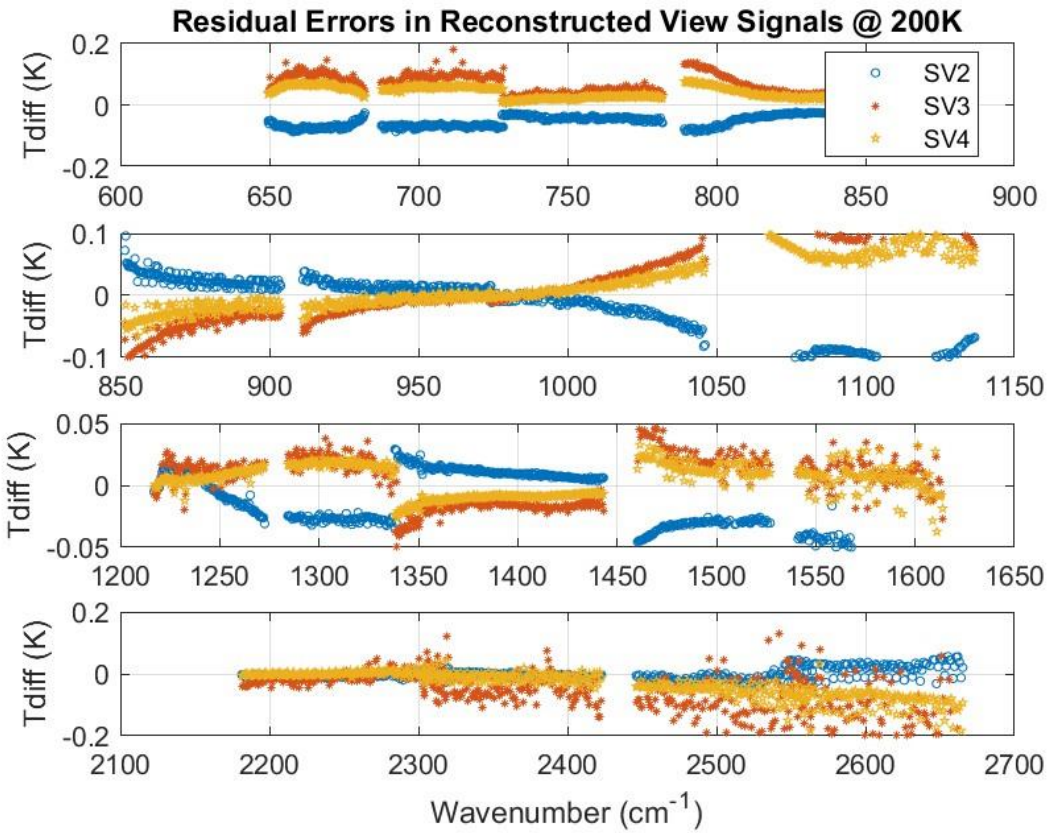


phase

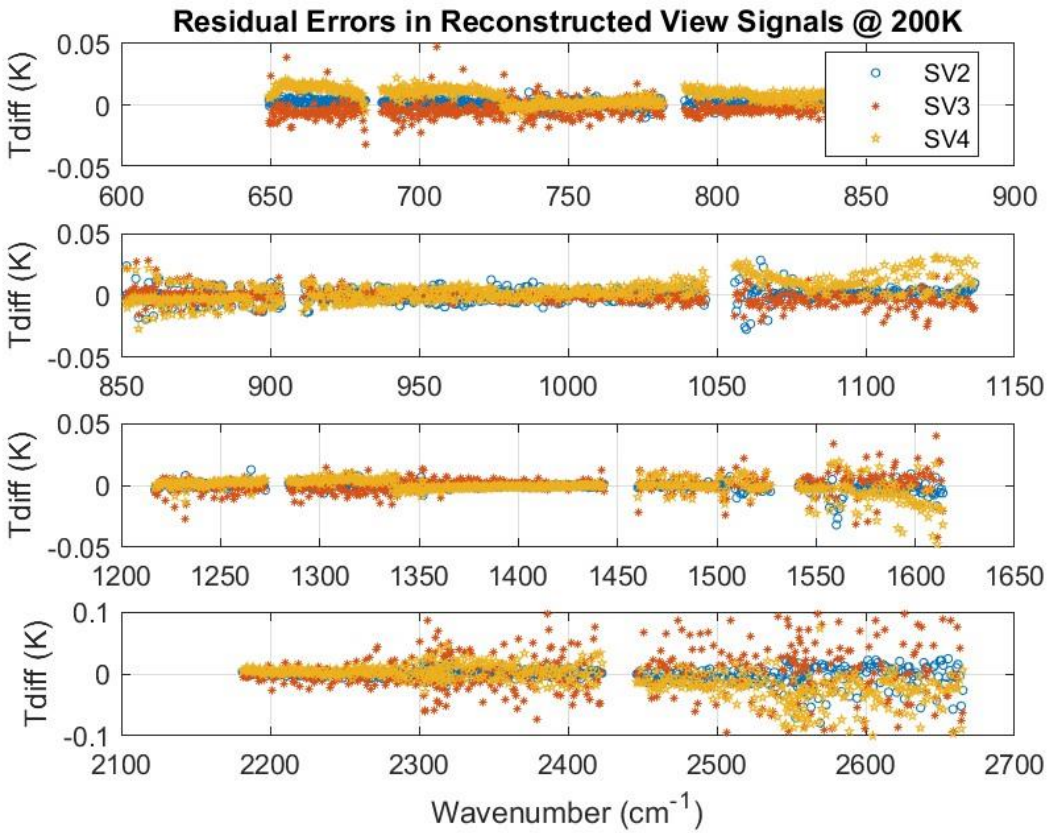


Residual fit to space views better in V7k

V5

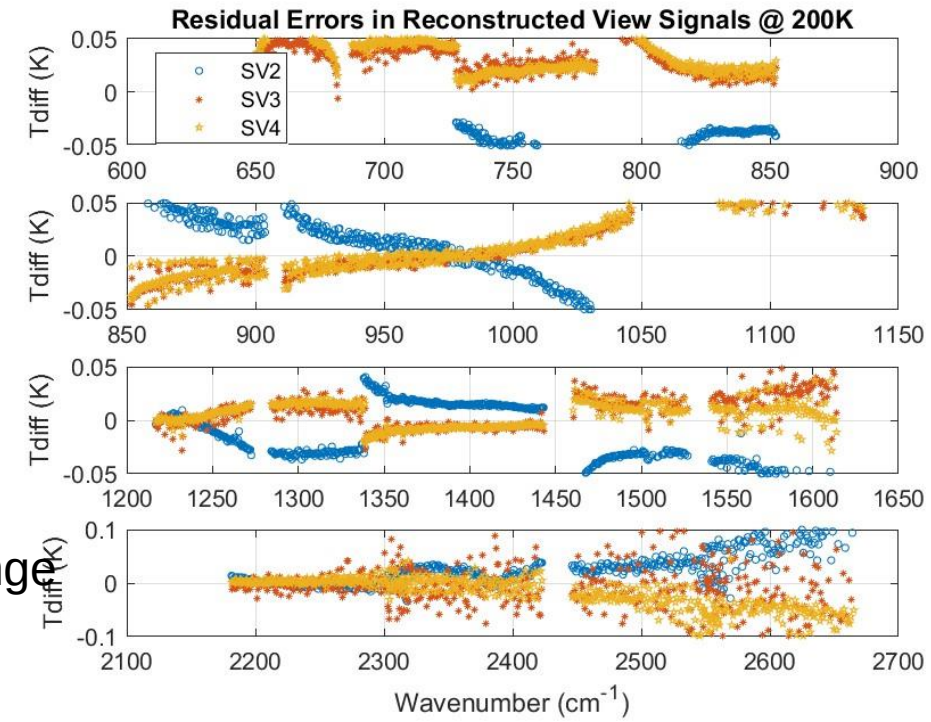


V7k

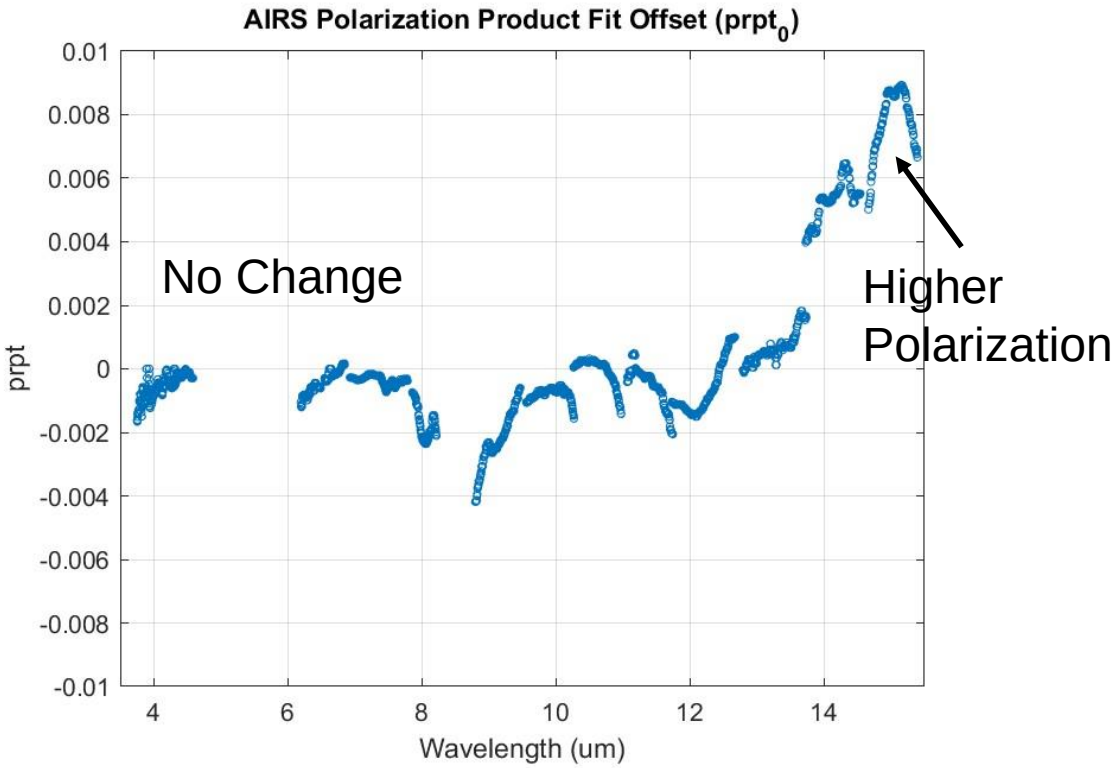


What if we assume 0 Phase like V5?

- Concern of L/R Asymmetries see in DCC data
- Focus on v > 2100 cm^{-1} and v < 870 cm^{-1}
- Small Change in “shortwave”; Higher polarization and higher residual errors in “longwave”



Small Change

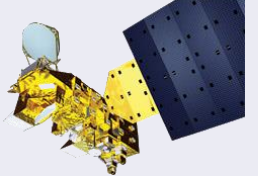


$$(dn_{sv,i} - dn_{sv,1})c_1' = -L_{sm}p_r p_t[cos2\theta_{sv,i}cos2\delta + sin2\theta_{sv,i}sin2\delta + cos2\delta]$$

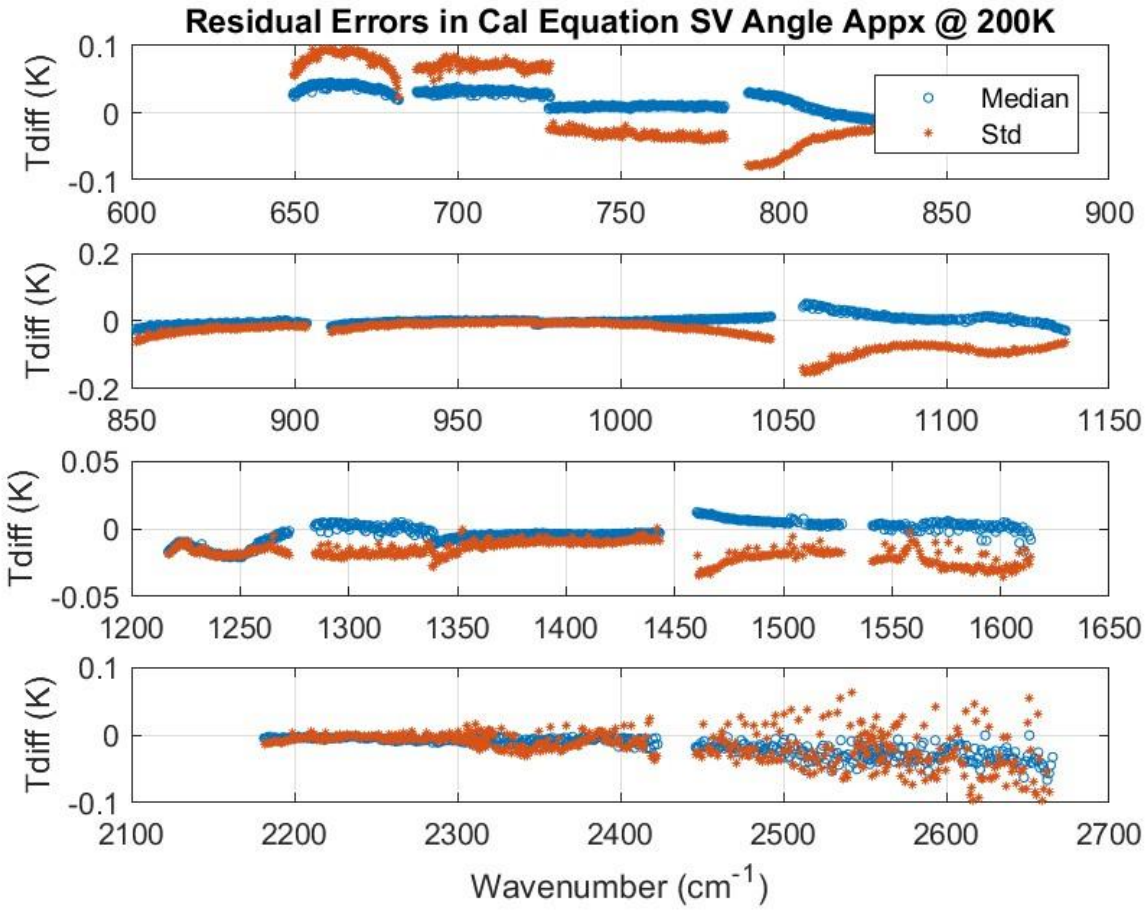
$$\delta = 0\,; \qquad (dn_{sv,i} - dn_{sv,1})c_1' = -L_{sm}p_r p_t[cos2\theta_{sv,i} + 1]$$

$$\frac{-(dn_{sv,i} - dn_{sv,1})c_1{}'}{L_{sm}} = d_1(1 + cos2\theta_{sv,i})$$

Correction Required to SV Prior to Median



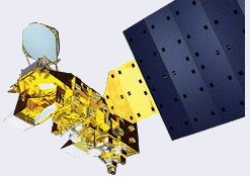
Corrected-Uncorrected SV Median and SV Std



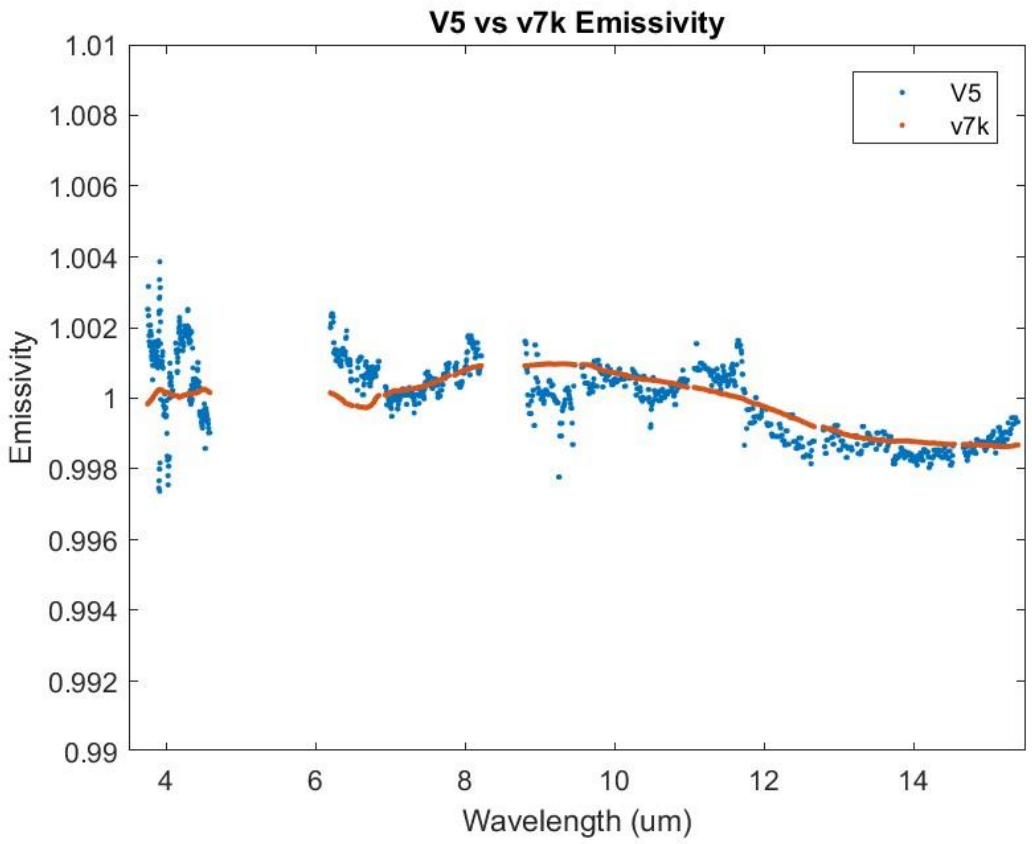
- AIRS takes median of space views prior to subtracting from earth view
- Version 5 assumes all SV's at 90°
- Residual error results when taking median
- Standard deviation amongst space views goes down with correction
- Note: gain negative for $v_n < 725$ cm^{-1}
- Correction follows polarization offset formula

$$dn'_{sv,i} = dn_{sv,i} + P_{sm} p_r p_t \left[cos2\left(\theta_{sv,i} - \delta\right) + cos2\delta\right]/c_1{}'$$

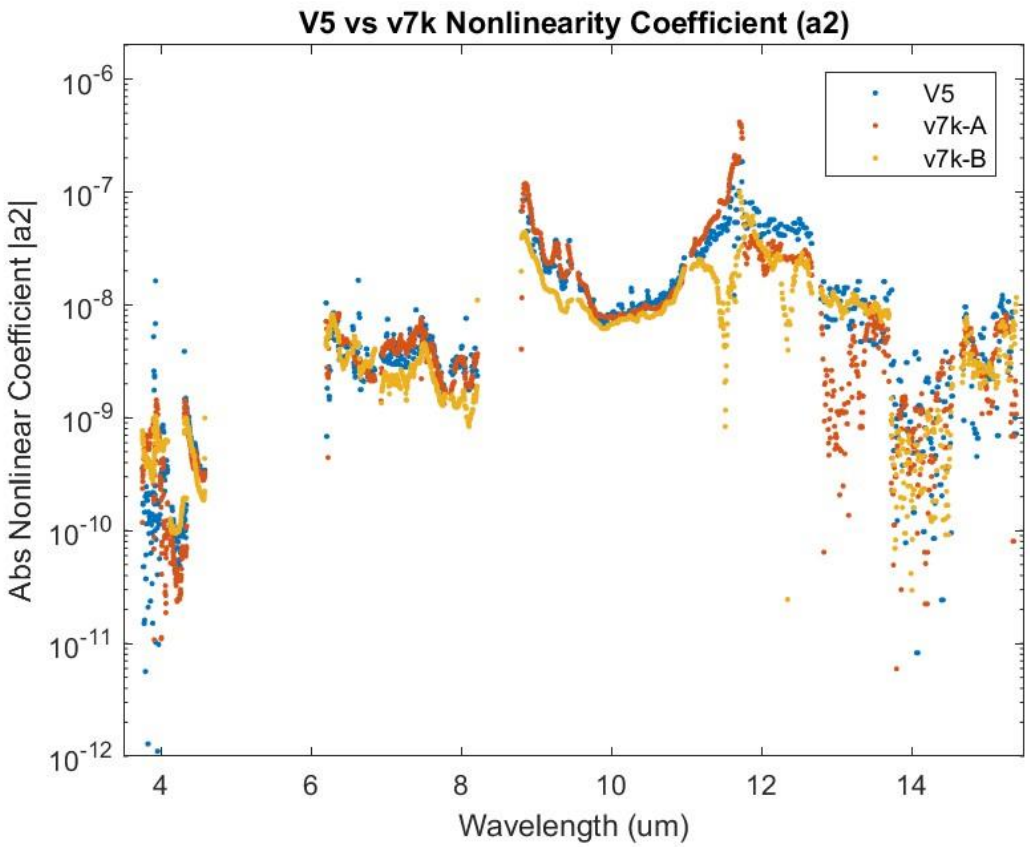
Changes Made to Emissivity and Nonlinearity



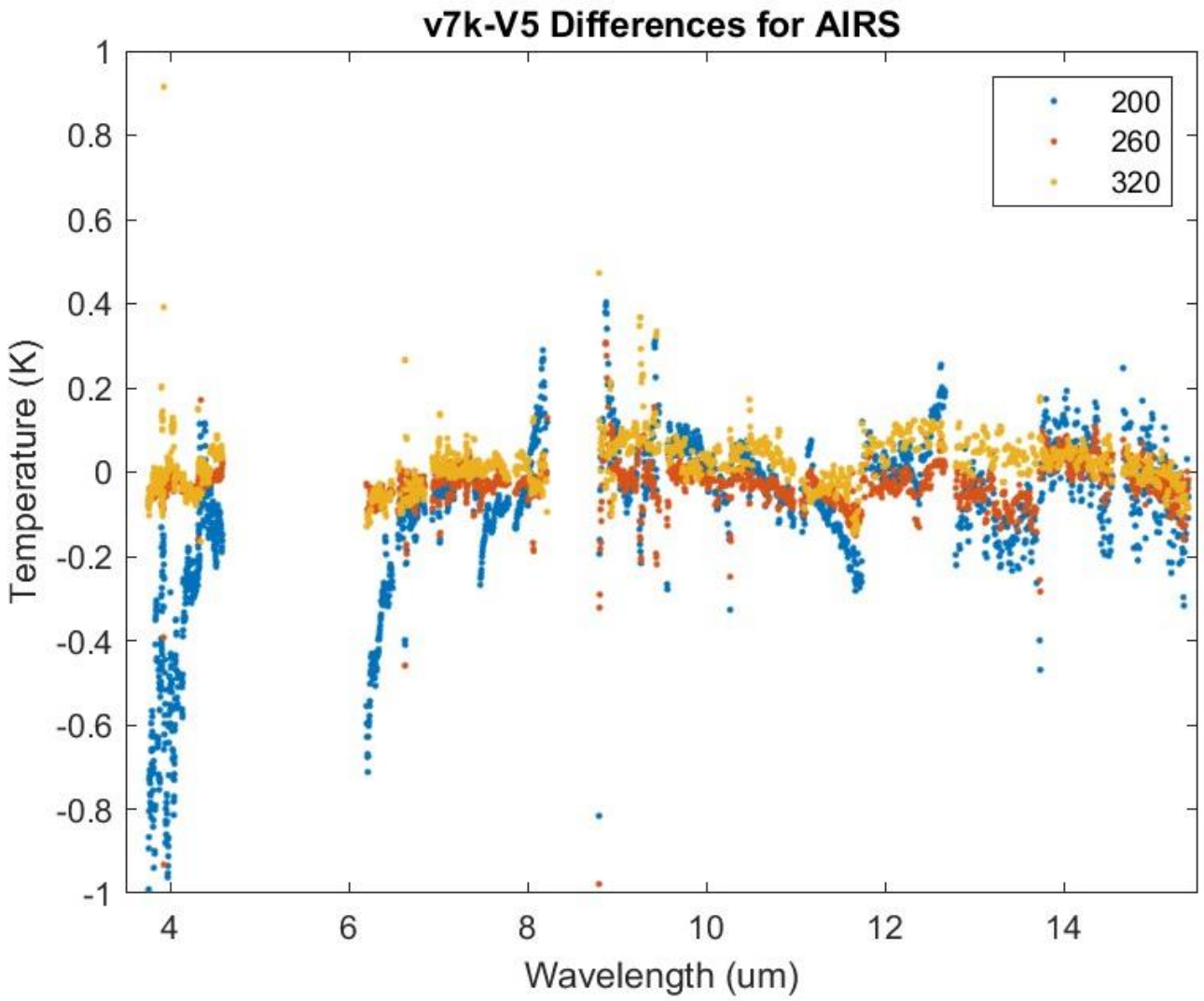
V7k Emissivity Smoothed over Channels



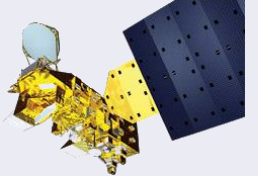
V7k Uses Separate A & B Nonlinearity



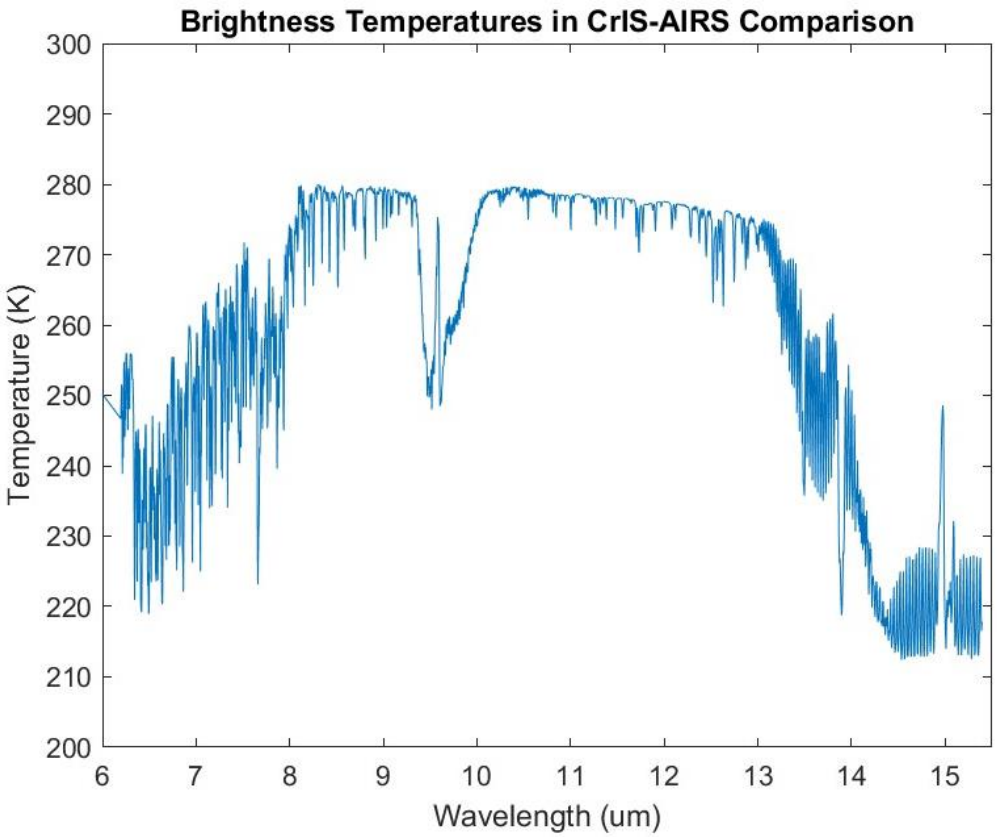
V7k Shows Biggest Differences for Cold Scenes



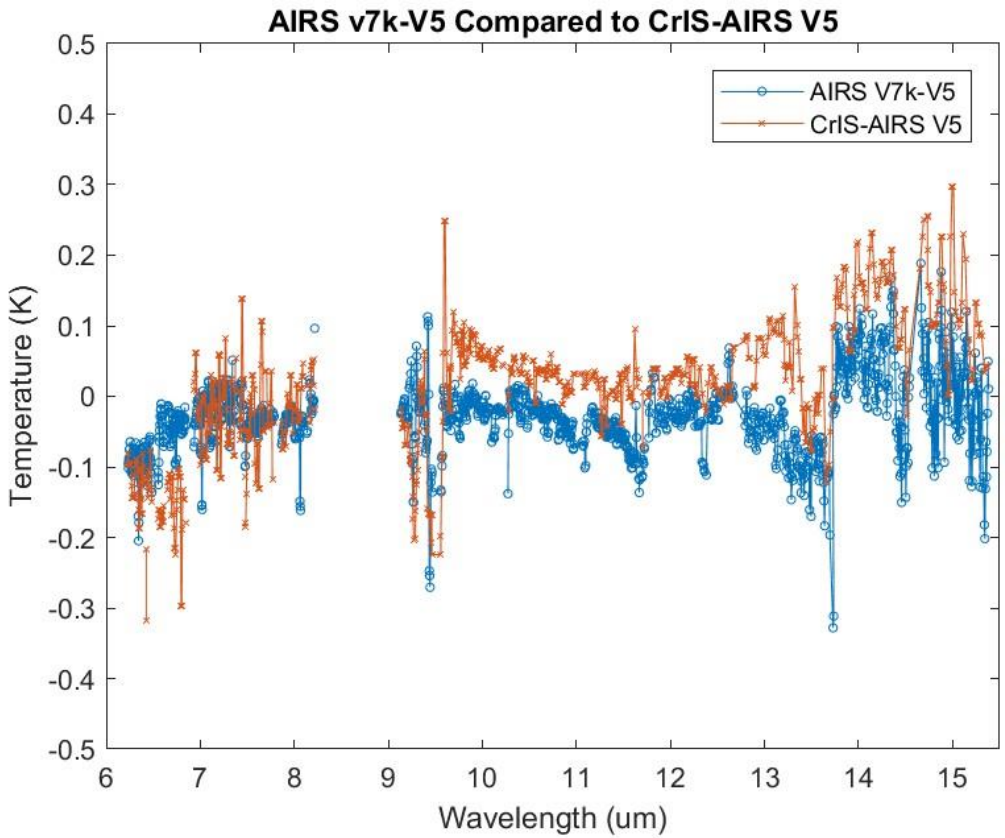
New Version Agrees Better with CrIS on SNPP



Average Scene Radiance of Difference



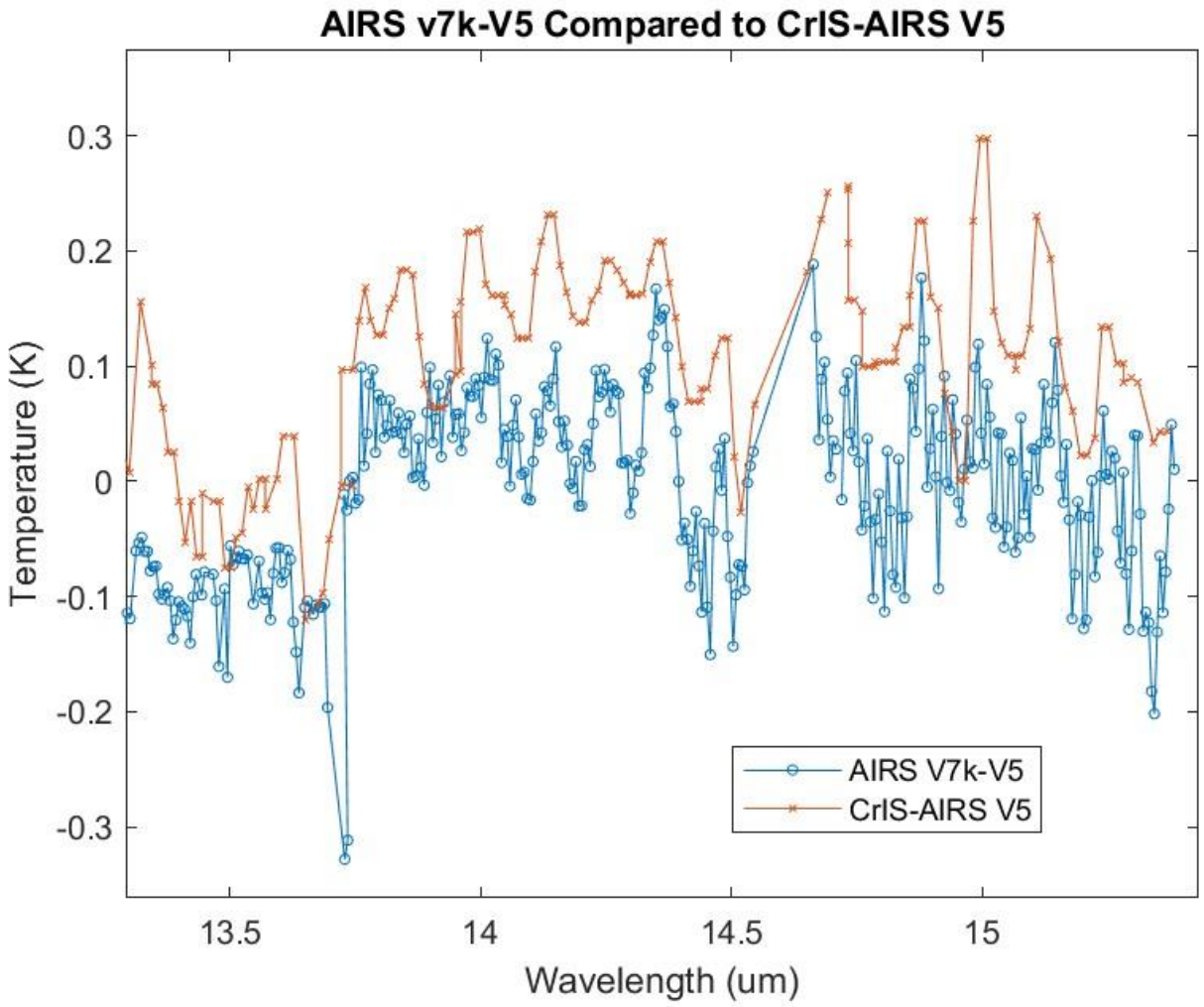
Random Sample Differences



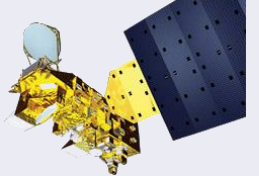
Crosstrack Infrared Sounder (CrIS) on the Suomi NPP Satellite

Note: No correction for SV Angles
Prior to taking median

Zoom in on LW shows wiggles may be improved

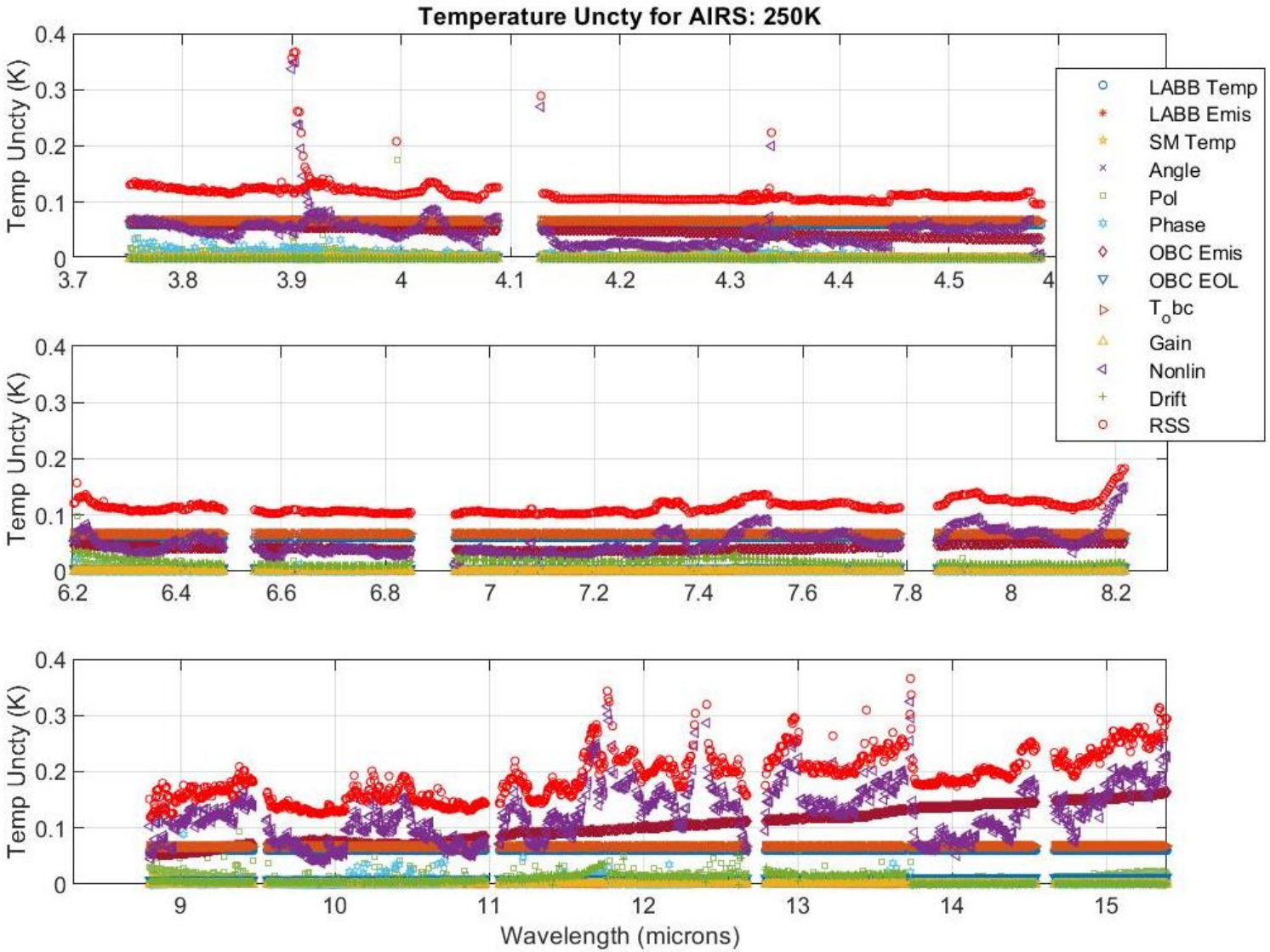


Contributors to Accuracy at 9.1µm



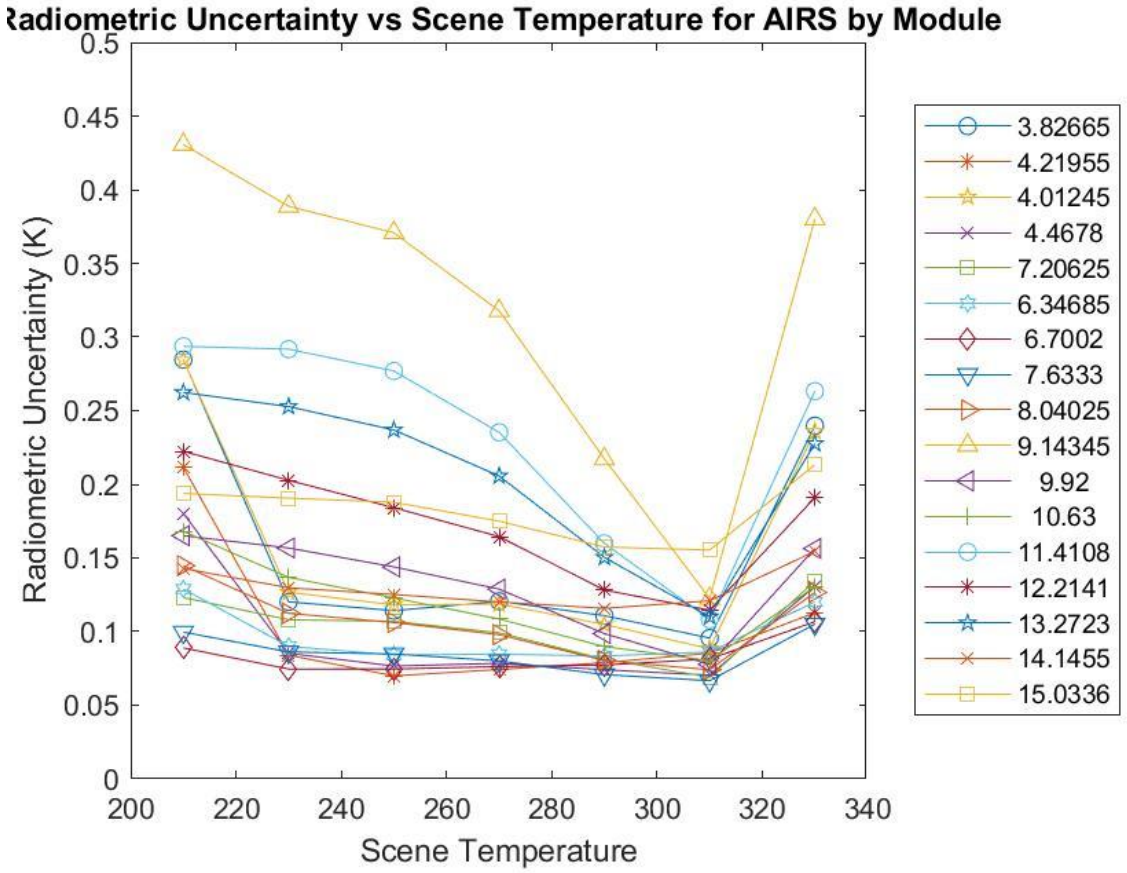
Parameter	2-σ Parameter Uncty	2-σ Parameter Uncty	2-σ Radiometric Uncty (K)	2-σ Radiometric Uncty (K)
Version	V5	V7k	V5	V7k
Uncertainty in LABB Temperature	0.03K	0.06K	0.030	0.060
Uncertainty in LABB Emissivity	0.0001	0.0001	0.004	0.004
Uncertainty in Scan Mirror Temperature	1.00K	1.00K	0.007	0.007
Uncertainty in Polarization Amplitude	0.0013	0.0003	0.076	0.017
Uncertainty in Polarization Phase	0.118 r	0.013 r	0.015	0.001
Uncertainty in OBC Blackbody Emissivity	0.0017	0.0015	0.065	0.059
Uncertainty in OBC Blackbody Emissivity (EOL)	0.0002	0.0002	0.008	0.008
Uncertainty in OBC Blackbody Temperature	0.05K	0.10K	0.033	0.067
Uncertainty in Nonlinearity	4.09%*	1.29%*	0.340	0.120
Uncertainty in drift in space view	0.08dn	0.08dn	0.004	0.004
Total Uncertainty at 250K			0.371	0.165

Contributors to Radiometric Uncertainty All Channels (2-Sigma)

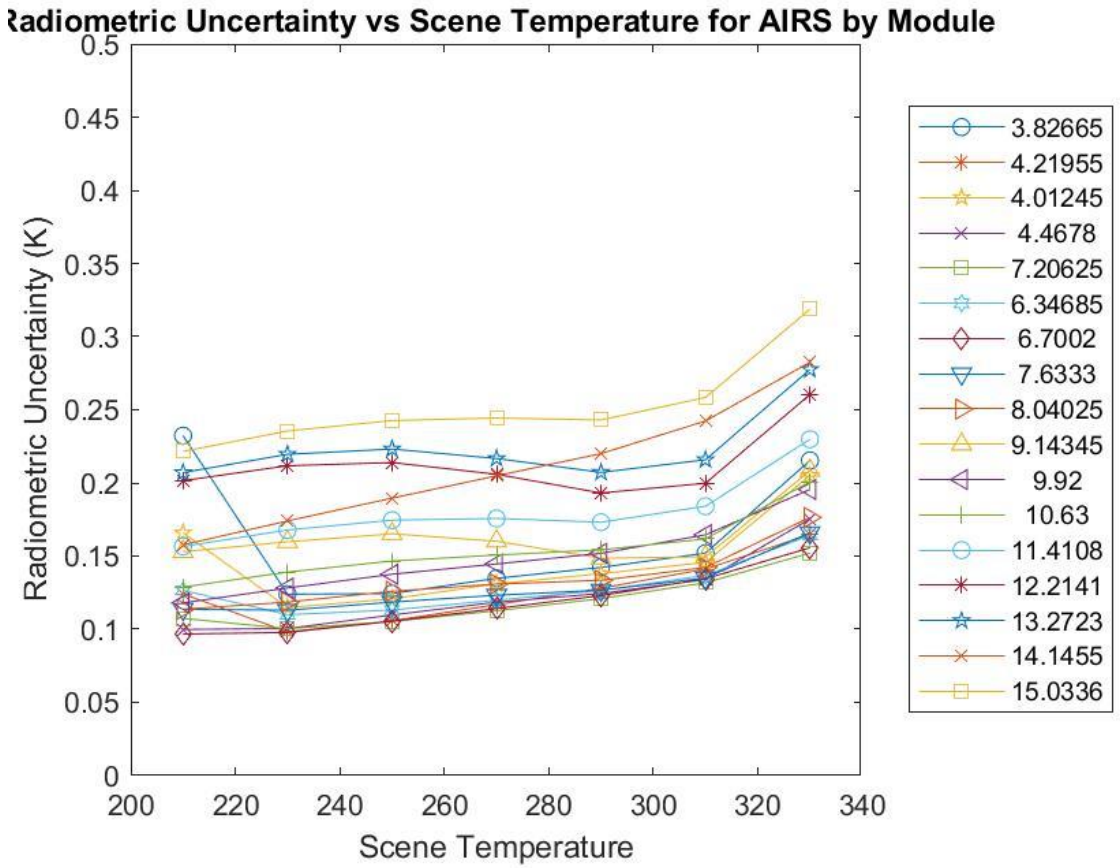


Radiometric Error vs Scene Temperature 2-Sigma

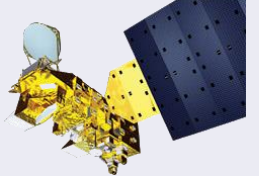
V5



V7k



Summary and Conclusions



- AIRS designed for high accuracy and stability
- 16+ years of data now available for science investigations
- New Version of radiometric calibration coefficients developed: V7k
  - New time dependent polarization and phase
  - Smoothed emissivity
  - Separate A and B side nonlinearity. Uncertainty looks still looks high.
  - Better agreement with CrIS on SNPP
  - New coefficients under evaluation by AIRS calibration team for V7 release in 2019
- Radiometric Accuracy
  - Revisited accuracy of all contributors compared to 2008 analysis
  - New estimates relate to V7k. Compared to V5.
  - Some areas worse: Increase in LABB and OBC temperature uncertainty
  - Some areas better: Reduction in errors due to polarization
- AIRS, CrIS agree well, within the uncertainties estimated