



Results of Calibration/Validation efforts for the Cross-track Infrared Sounder (CrIS) on Suomi-NPP

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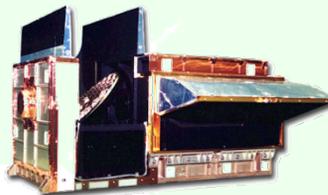
WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON



LEO (& Aircraft) Sounders

1978-

HIRS
(20 ch)



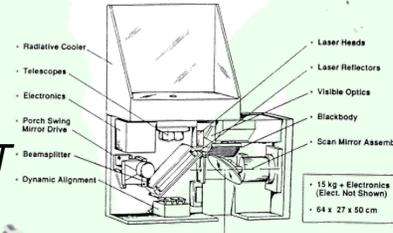
1986-

**HIS,
S-HIS,
NAST-I**



1990/91

**ITS
(~CrIS)**
UW/EUMETSAT
Design Study



2002-

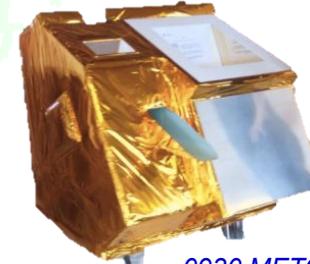
AIRS
(2378 ch)



1330 Aqua

2006-

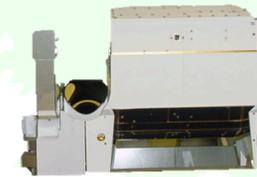
IASI
(8461 ch)



0930 METOP-A

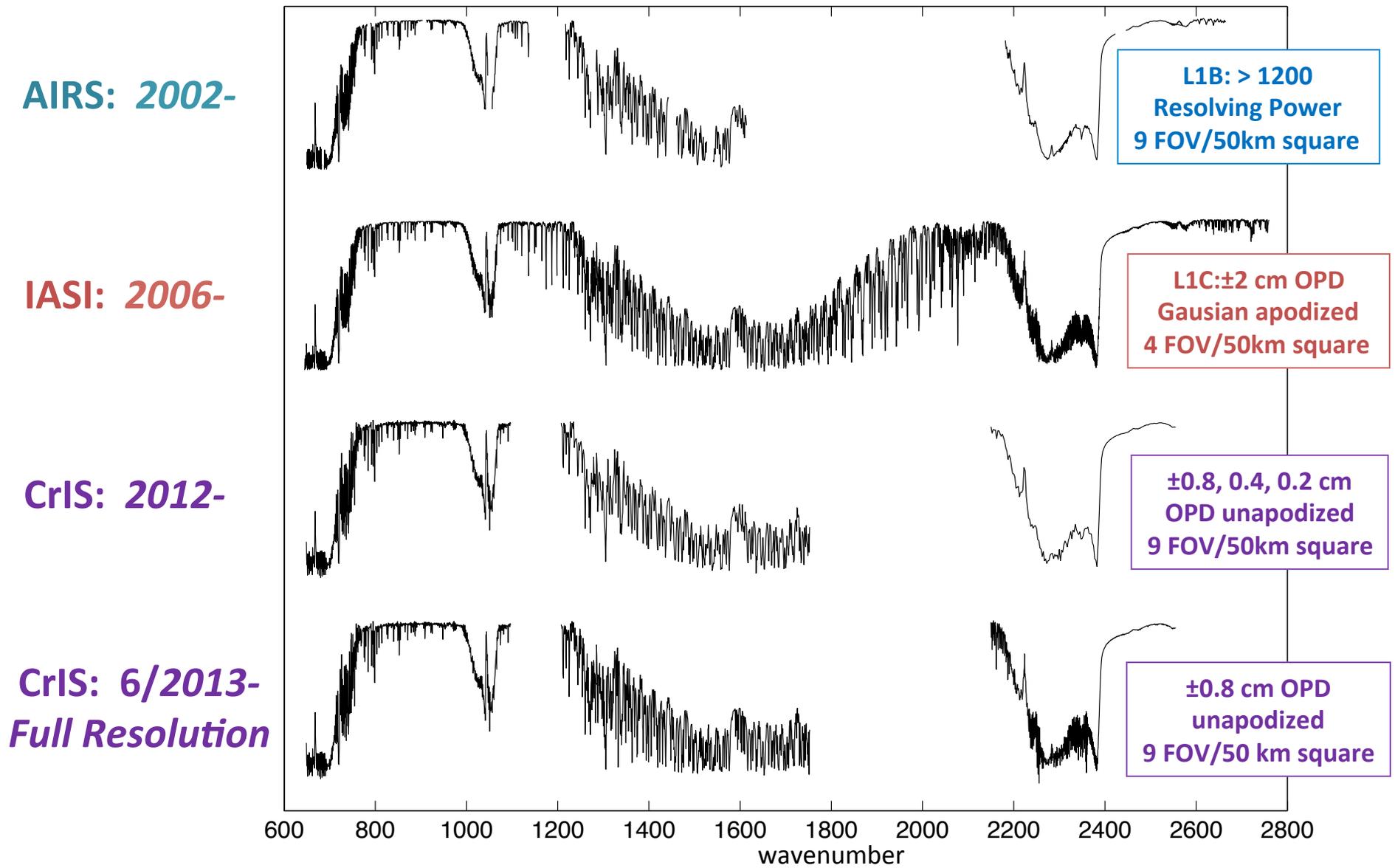
2011-

CrIS
(2211 ch)



1330 Suomi-NPP

Spectral Coverage and Resolution Comparison



CrIS Radiometric Uncertainty Specification

- **CrIS Radiometric Uncertainty specification**

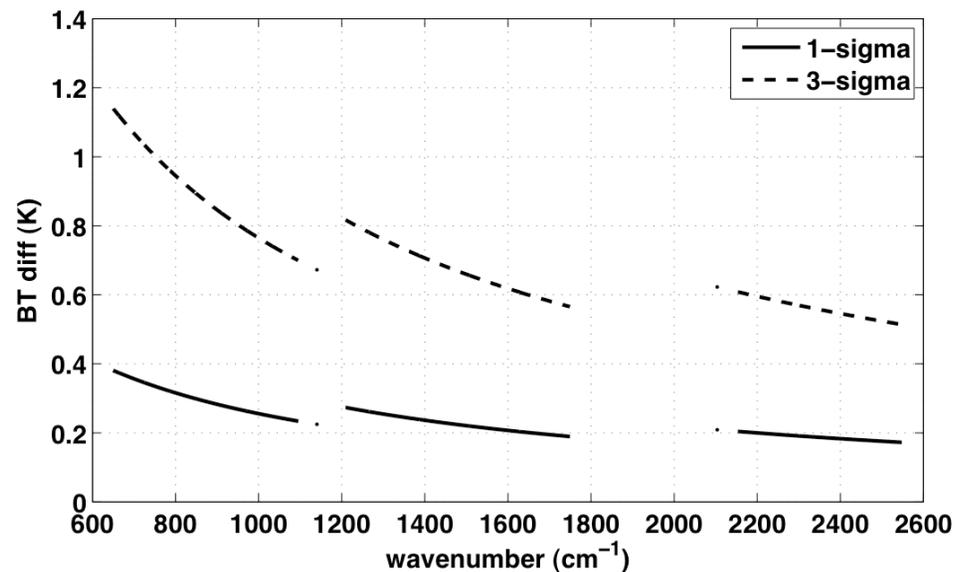
(circa 1990) is primarily driven by NWP applications. Expressed as 1-sigma percent radiance uncertainty with respect to Planck 287K radiance [i.e. $100 \cdot dR/B(287K)$]:

- Longwave: 0.45%
 - Midwave: 0.58%
 - Shortwave: 0.77%
- for B(233K) to B(287K)

- **Climate (and NWP) Applications**

typically require better accuracy

CrIS Radiometric Uncertainty spec, expressed as 1 and 3 sigma brightness temperature differences



Pre-Launch Radiometric Uncertainty Budget

with component uncertainties based on pre-launch analysis/testing

On-orbit calibration equation:

$$R_{Earth}(v_{user}) = SRA \left[SA^{-1} \left(\text{Re} \left\{ \frac{C'_{Earth}(v_{sensor}) - \langle C'_{Space}(v_{sensor}) \rangle}{\langle C'_{ICT}(v_{sensor}) \rangle - \langle C'_{Space}(v_{sensor}) \rangle} \right\} R_{ICT}(v_{sensor}) \right) \right]$$

with $R_{ICT} = e_{ICT} B(T_{ICT}) + (1 - e_{ICT}) R_{ICT,Reflected}$ $C' = C / (1 - a_2 V_{DC})$

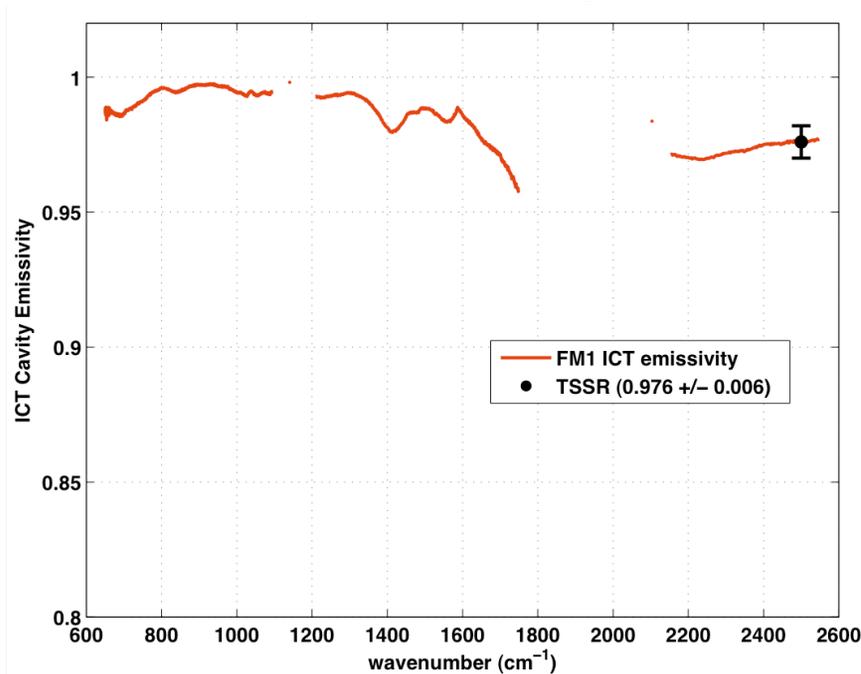
Parameter	1-σ uncertainty	3-σ uncertainty	Source/Comment
T _{ICT} (K)	37.5 mK	112.5 mK	Bomem/ITT eng. estimate (w/o known readout issue)
ε _{ICT} ()	0.01	0.03	Independent measurement (TSSR) at 2500 cm ⁻¹ plus Analysis
T _{refl,measured} (K)	0.5 K	1.5 K	Temperature monitored components (Frame, OMA, BS, ICT Baffle)
T _{refl,modelled} (K)	2 K	6 K	Worst case estimate of unmonitored SSM Baffle T variations
a ₂ (1/counts)	9.6% Longwave 15.5% Midwave	28.8% Longwave 46.5% Midwave	DM and ECT view analysis

Other contributions, such as scan mirror polarization and stray light, are not included here. Other studies, by ITT/Exelis, show these do not contribute significantly to the total RU.

ICT Predicted Radiance

$$R_{ICT} = \epsilon_{ICT} B(T_{ICT}) + (1 - \epsilon_{ICT}) R_{ICT, Reflected}$$

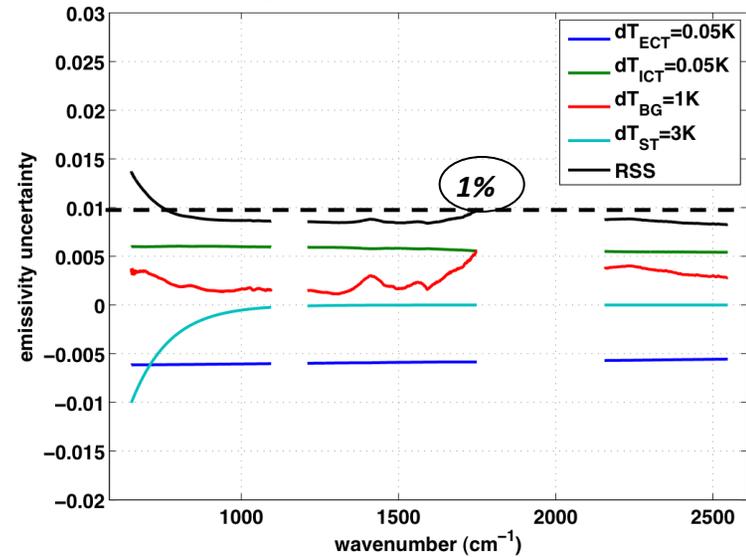
ICT Emissivity



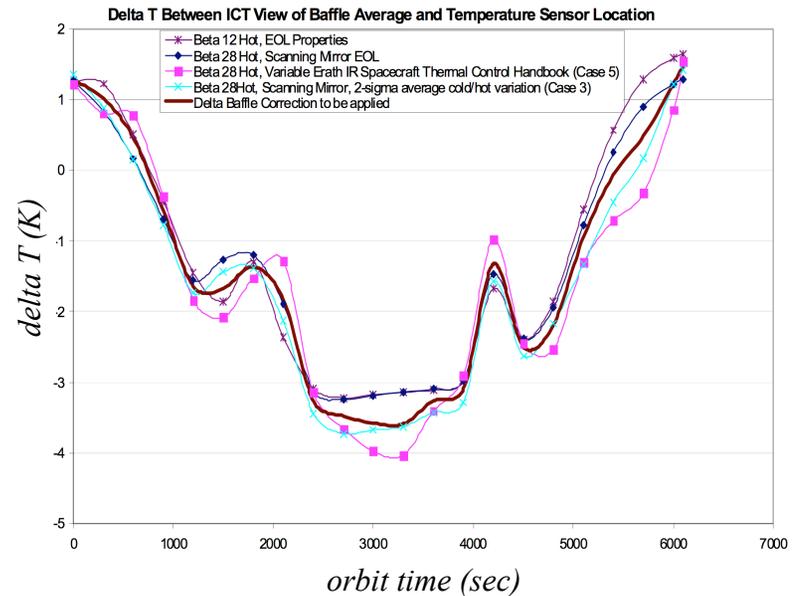
- Prediction includes a modeled component of the reflected radiance which varies with orbit phase
- Effect is expected to be small, but largest for warm scenes in SW band and edge of MW band

ICT Emissivity Uncertainty

ICT emissivity retrieval uncertainty simulation
 $T_{ECT}=T_{ICT}=310K, T_{BG}=318K, T_{ST}=107K$



$T_{refl, modeled}$

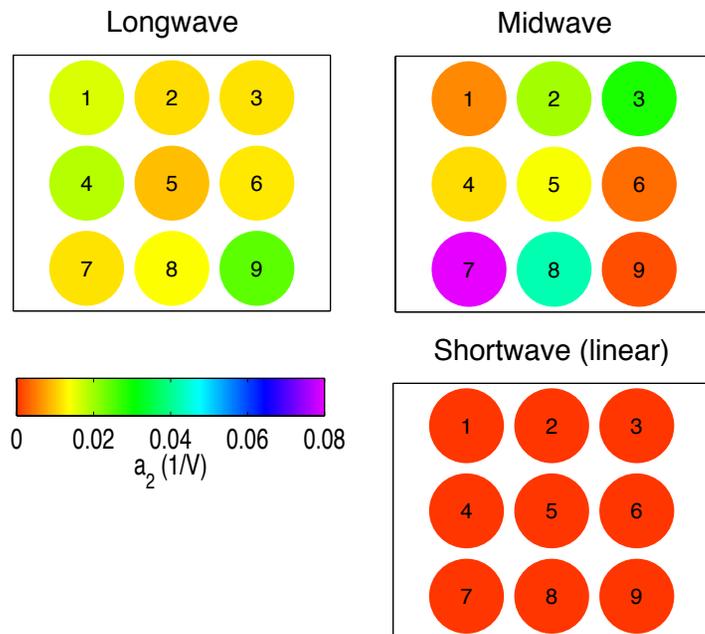


Non-Linearity Corrections

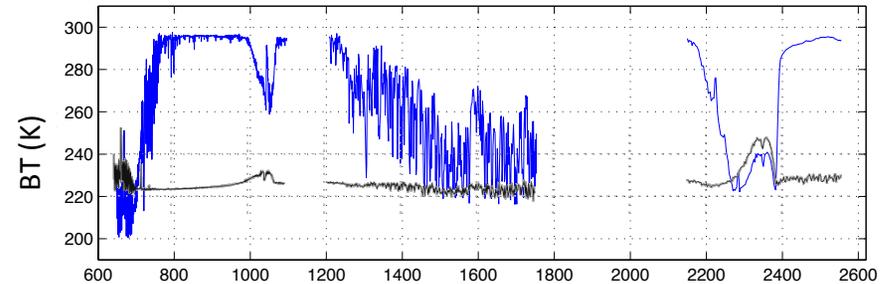
- The CrIS RU budget and SDR algorithm did not originally include NL contributions; Significant quadratic NL was realized for LW and MW (PV MCT) bands and characterized only with system level TVAC testing. SW band (InSb) is linear.
- The correction is FOV#, band, wavenumber, and scene dependent
- The NL magnitude was observed to change between TVAC cycles, particularly for certain MW FOVs.
- A post-launch strategy to refine the on-orbit NL was developed using out-of-band harmonic analysis of ICTand Space views and FOV-2-FOV consistency of Earth views.

Corrected Raw Complex Spectrum = Raw Complex Spectrum \times (1+ 2 a_2 V)
 where V is DC level voltage at 1st stage of preamplifier

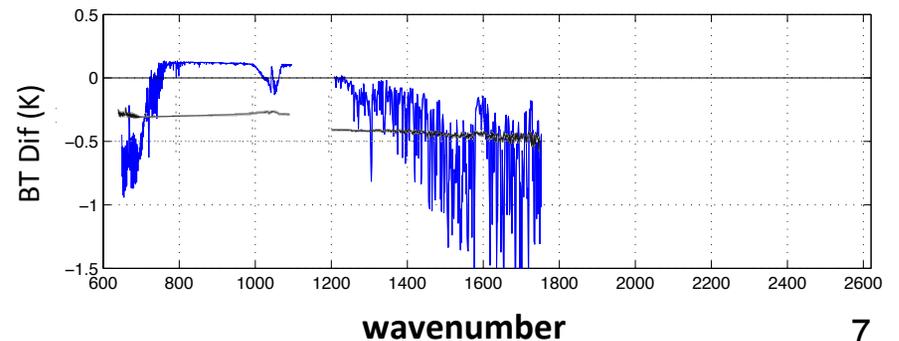
Correction Coefficient, a_2



Example corrections



NLC effect

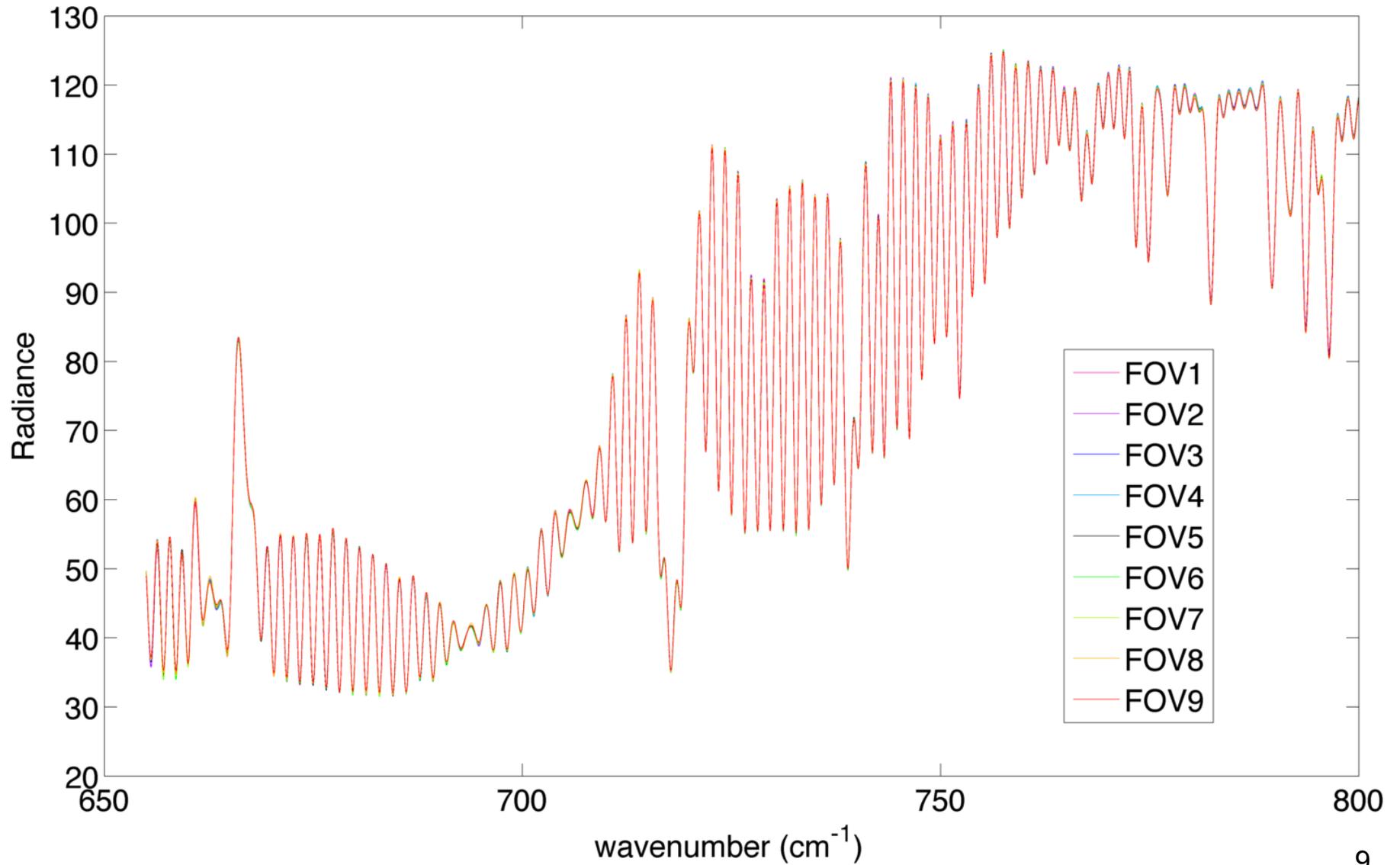


Schedule Overview

- ◆ **Suomi-NPP launched on 28 October 2011**
- ◆ **CrIS powered on and first light data on 20 Jan 2012**
- ◆ **April 2012:**
 - ◆ **v33 Engineering Packet upload and NF fix**
 - ◆ **First valid spectra from the operational processing system**
 - ◆ **SDR (aka L1B) “Beta” status**
- ◆ **CrIS SDR “Provisional” status in October 2012**
- ◆ **June 2013:**
 - ◆ **Full resolution mode**
 - ◆ **“Final” refinements to calibration coefficients**
 - ◆ **CrIS SDR “Validated” status**

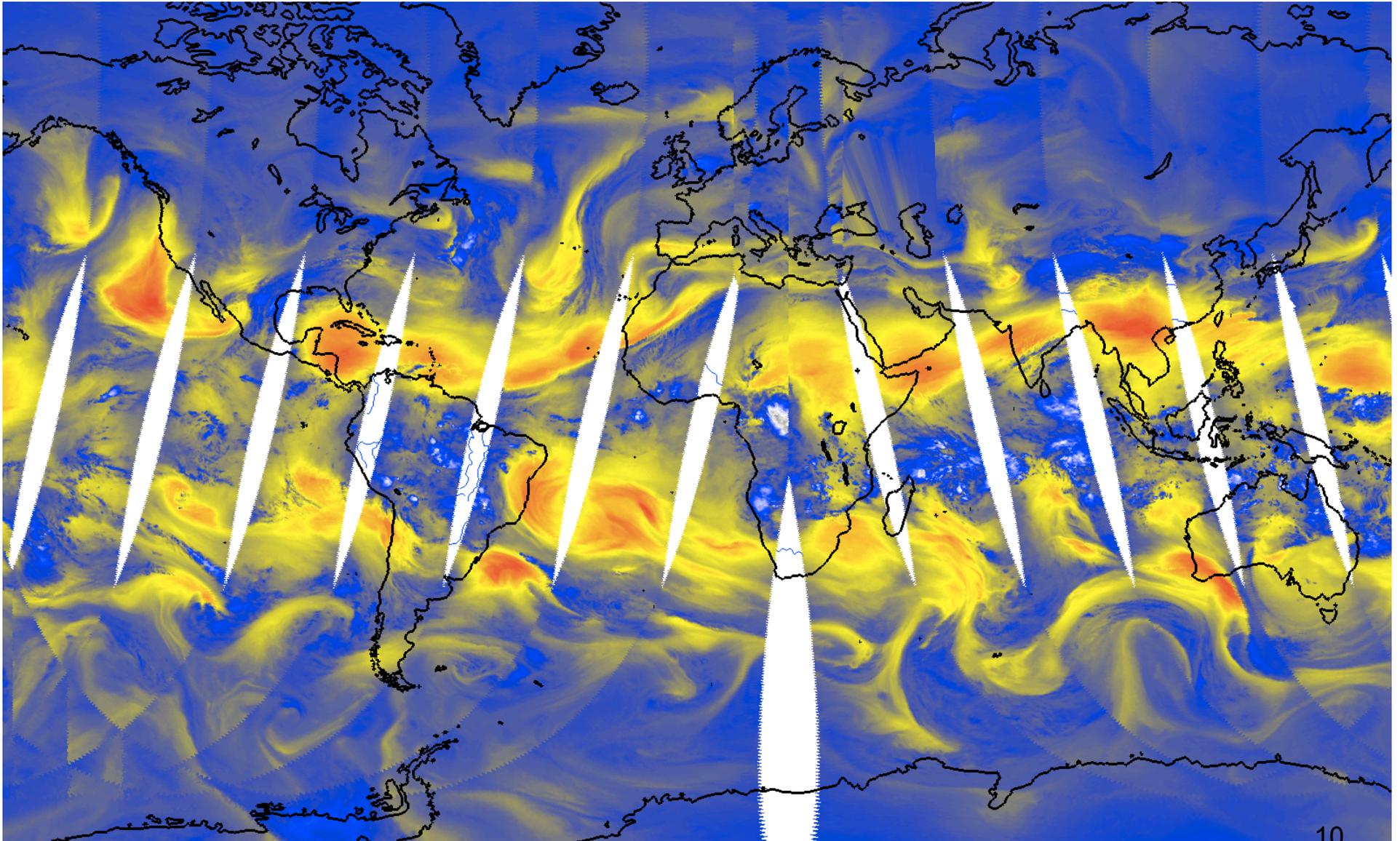
Sample “1st Light” spectra (20 January 2012)

Overlays for a uniform 3x3 FOR



Water Vapor Map from CrIS

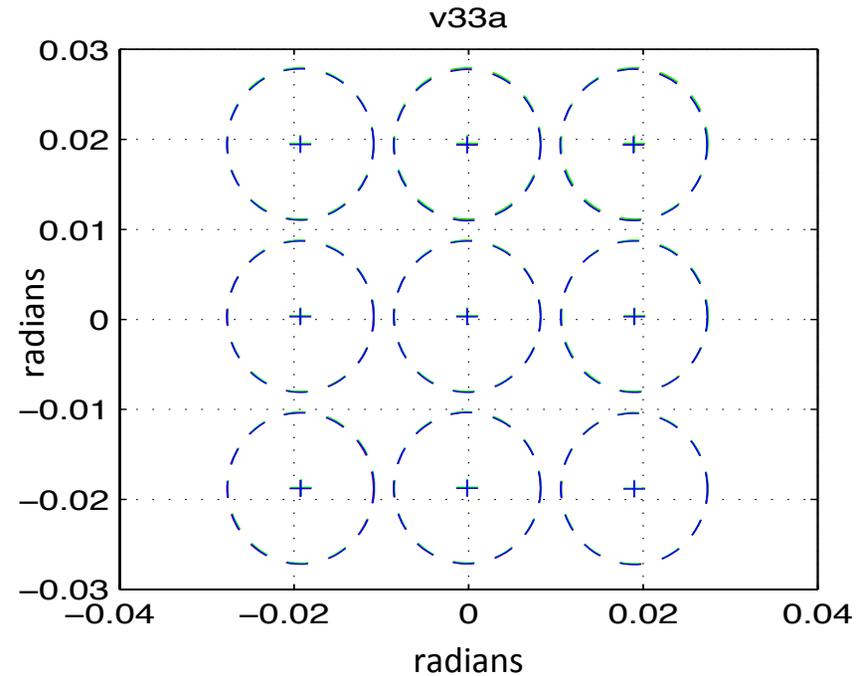
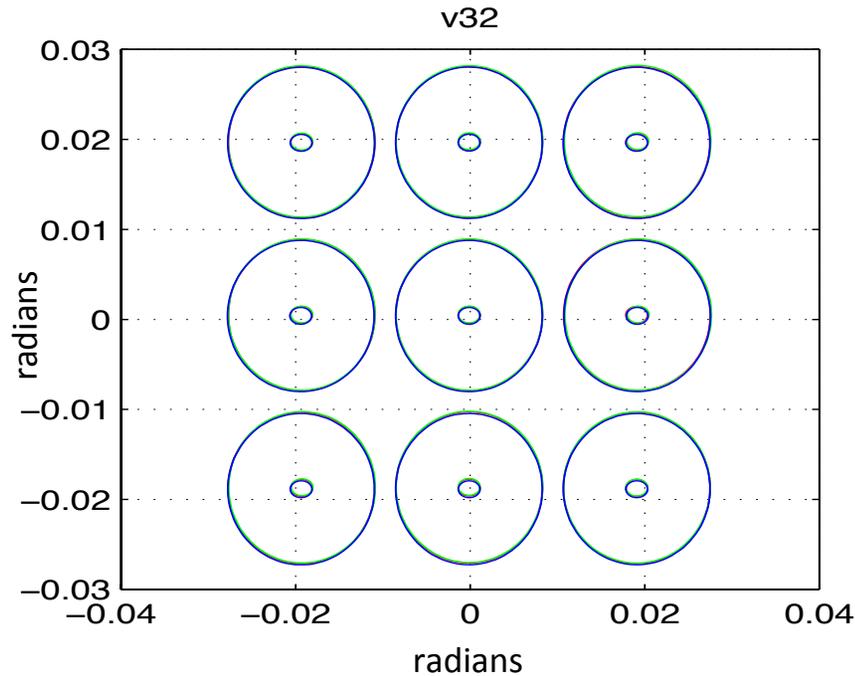
24 February 2012, 1580 cm^{-1} BT



On-orbit Spectral Calibration Summary

- Small FOV position adjustments were made to produce **inter-FOV spectral calibration** agreement of a few tenths ppm, which is very stable with time.
- Both the internal Neon lamp views and Earth view analyses show **overall spectral calibration** variations (in the operational processing) with a range of ~ 1.5 ppm to date.
- **Non-uniform scene effects** on the ILS behave as expected (based on prior IASI experience). Mean spectra of large ensembles are unbiased due to this effect.
- **Additional Gibbs effect artifacts** present in the unapodized spectra, largest at edges of spectral bands, are currently under investigation.

v32 (Pre-launch) and v33 (In-flight) ILS parameters



FOV Radii: 8403 μ rad

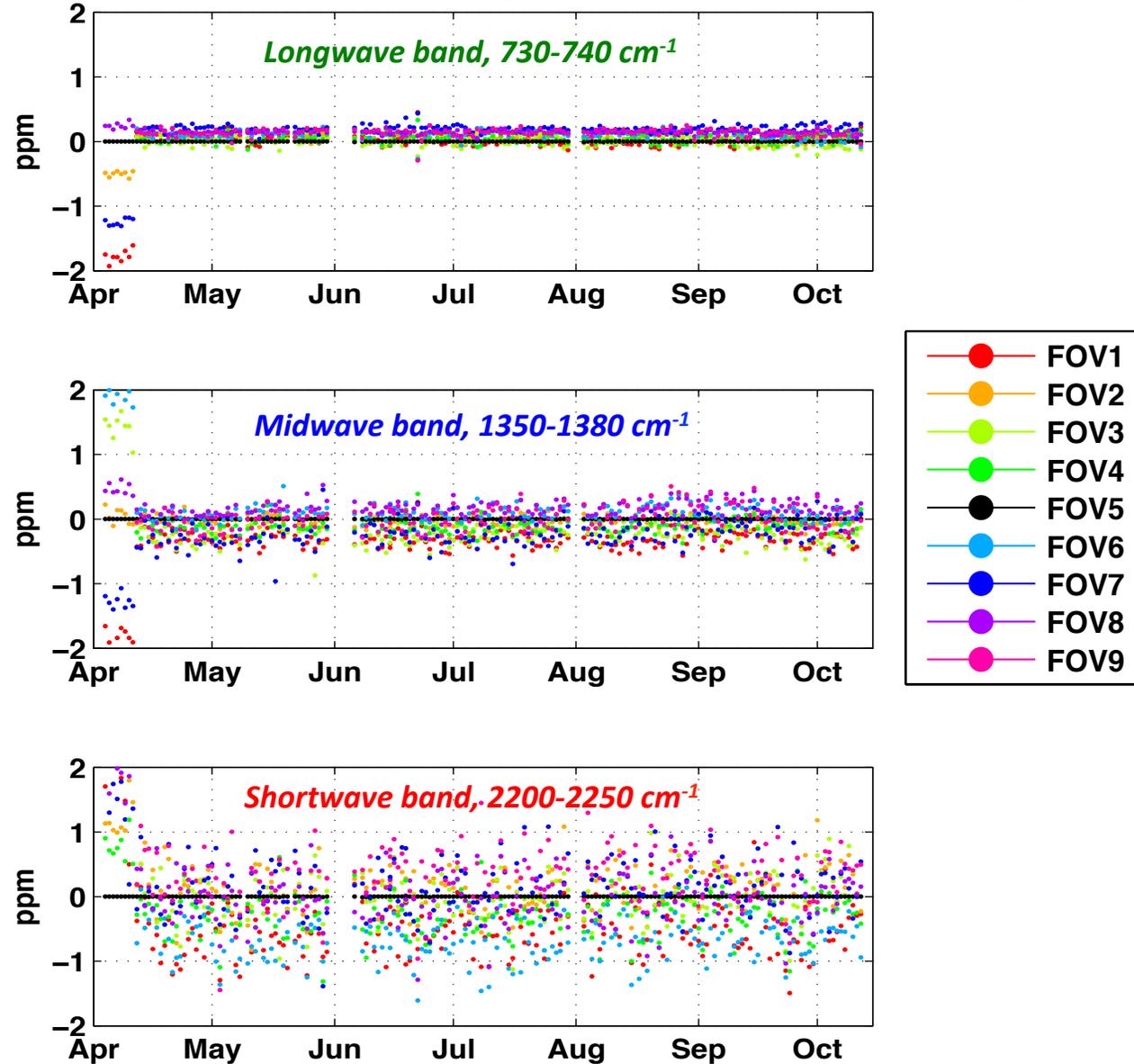
v33 FOV5 offsets from FTS axis: LW: 393 μ rad, MW: 419 μ rad, SW: 345 μ rad

Ratio of v32 off-axis angles to v33 off-axis angles:

FOV:	1	2	3	4	5	6	7	8	9
LW:	0.9999	1.0033	1.0055	0.9986	1.3008	1.0106	1.0005	1.0054	1.0097
MW:	1.0013	1.0070	1.0058	0.9974	1.2923	1.0119	1.0018	1.0079	1.0107
SW:	1.0058	1.0073	1.0066	1.0067	1.1620	1.0127	1.0040	1.0093	1.0100

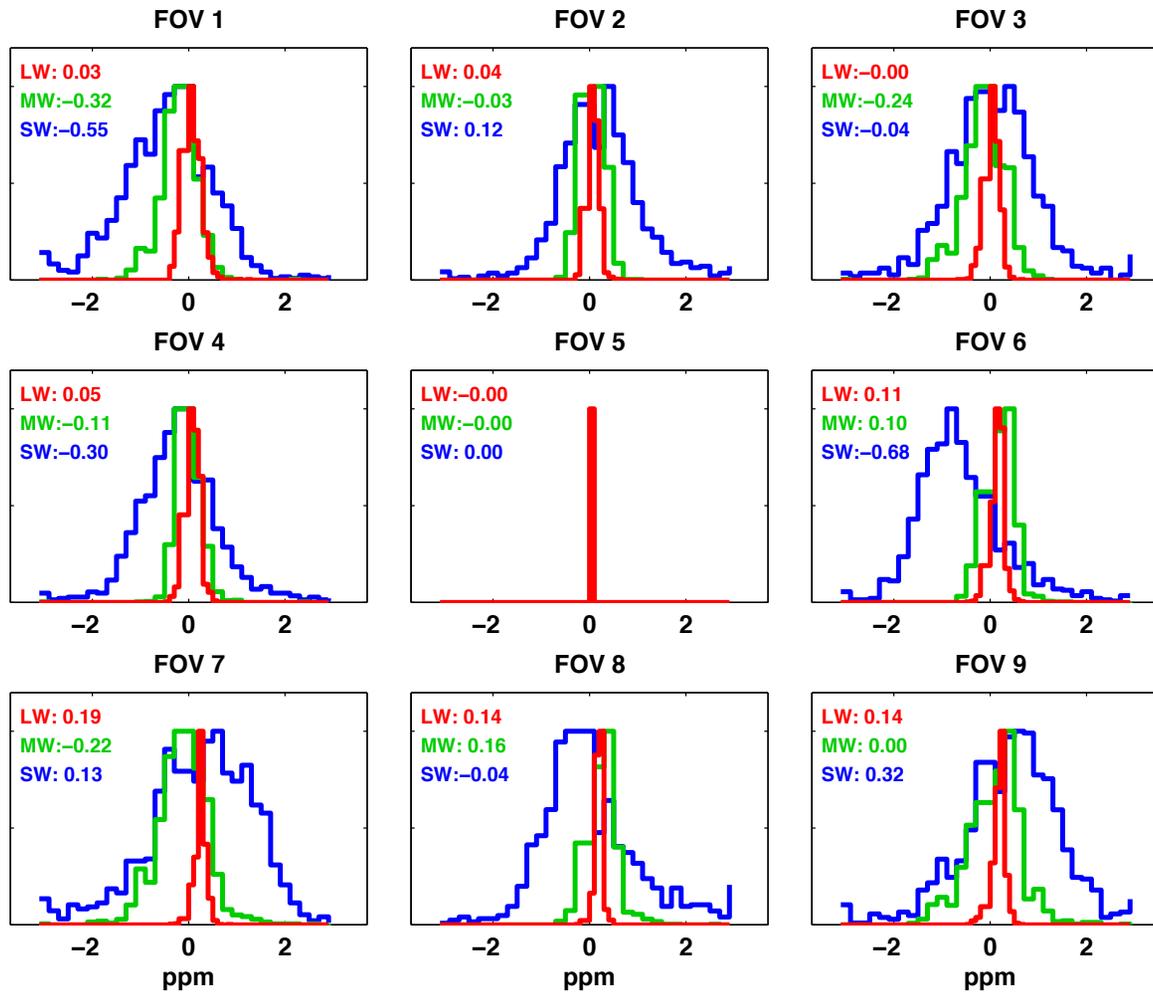
Inter-FOV Spectral Calibration Assessment

Shifts wrt FOV5 derived from spectral correlation analysis:



Inter-FOV Spectral Calibration Assessment

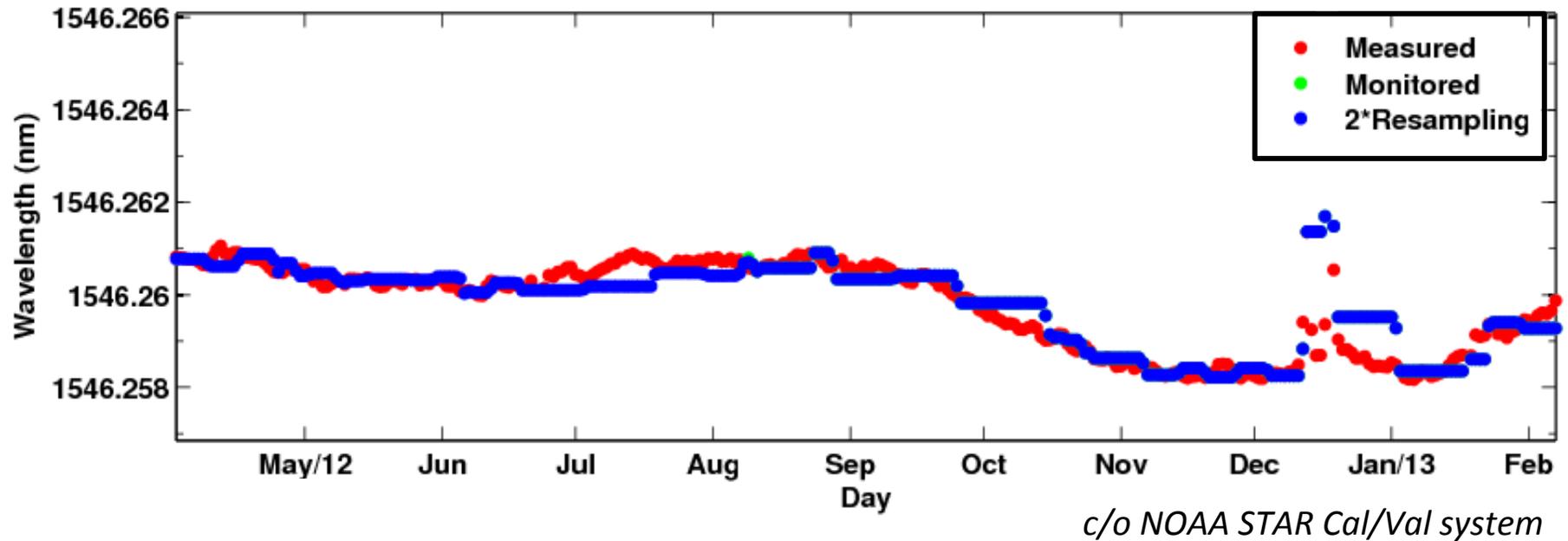
Inter-FOV Spectral Cal w/r/t FOV5;
Mean values over last 6 months:



V1
V2
V3
V4
V5
V6
V7
V8
V9

-2
Apr May Jun Jul Aug Sep Oct

Metrology laser wavelength deviations, derived from Neon lamp views and laser temperature monitoring



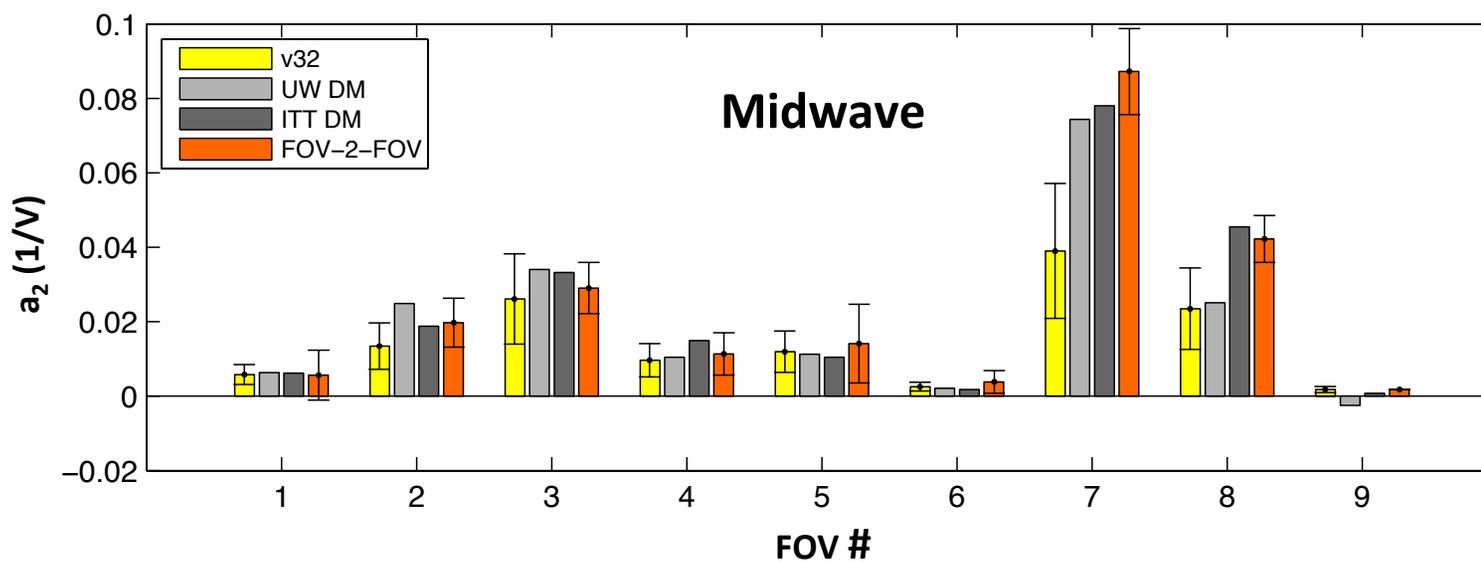
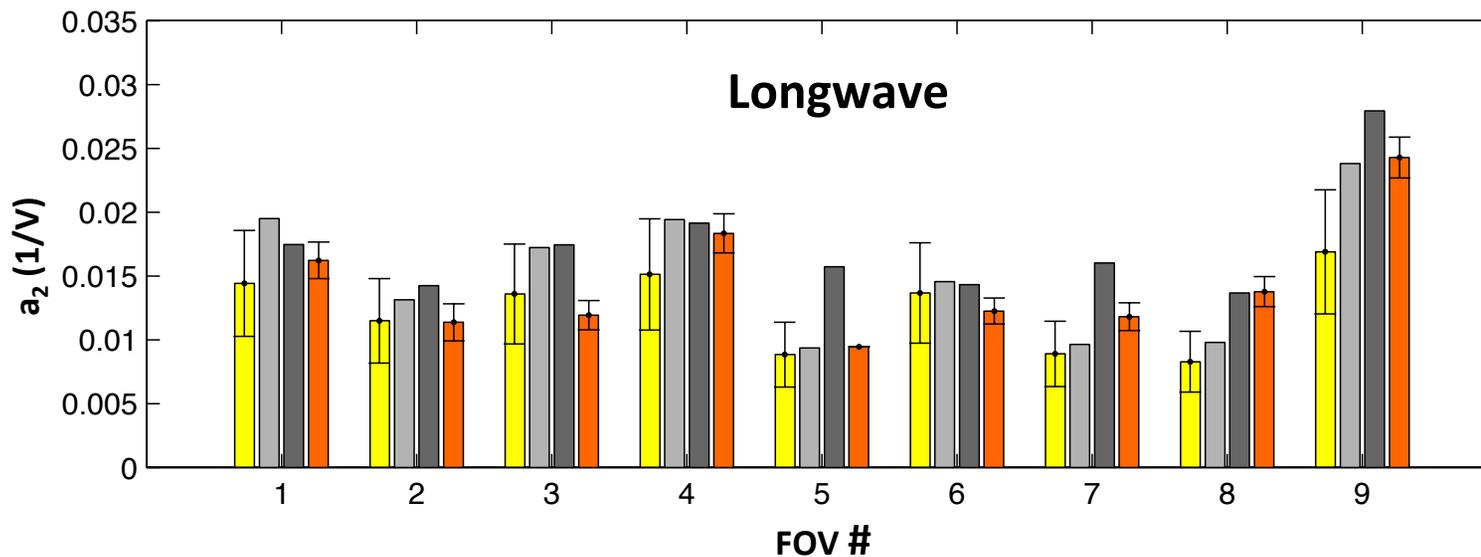
***Range is 1.6 ppm to date.
(Operational processing should update for
 Δ of 2ppm threshold and processing re-start)***

On-orbit Radiometric Calibration Summary

- Not finding artifacts due to the lower ICT emissivity and ICT reflected temperature variations over an orbit.
- Longwave and Midwave band nonlinearity a_2 coefficients were refined using in-flight Diagnostic mode (un-decimated) and Earth view data.
- **Overall Radiometric Uncertainty** estimates are generally less than 0.2K 3-sigma.
- **Agreement with IASI and AIRS** is generally less than a few tenths K; Larger differences are observed in the Shortwave band for cold scene radiances.

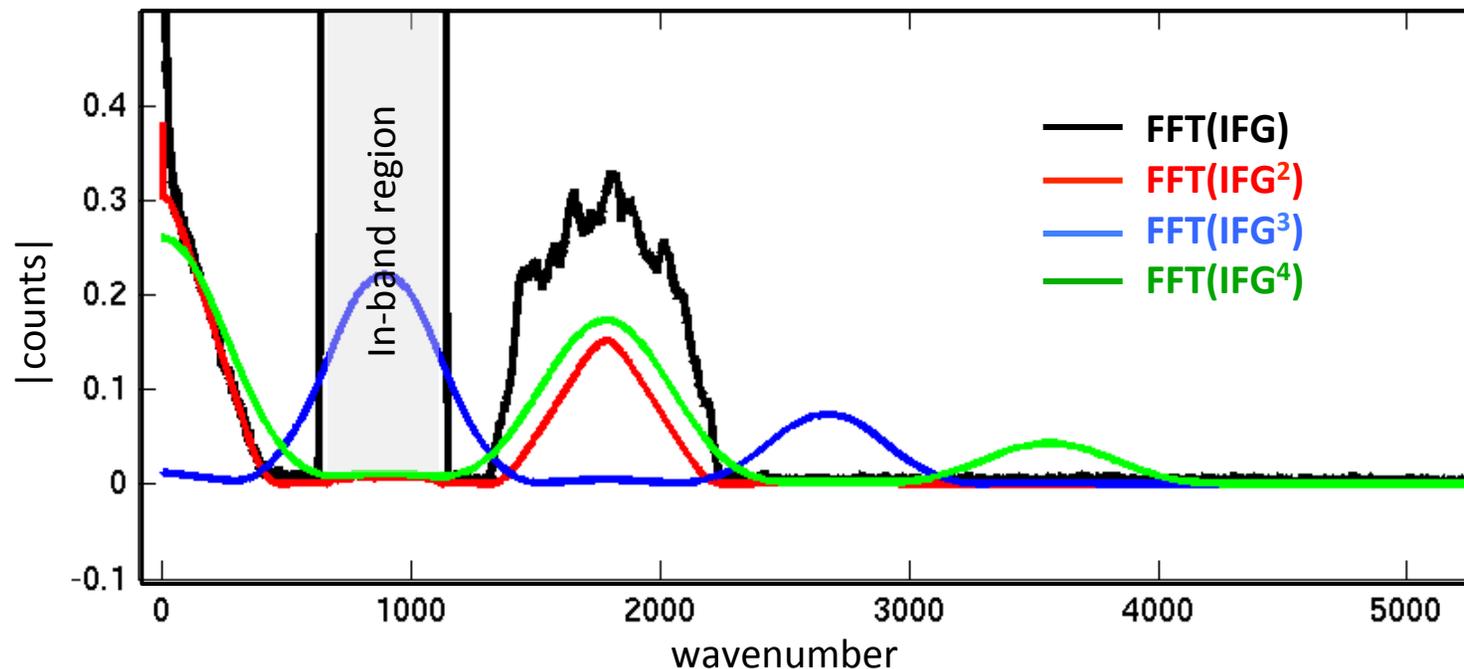
Radiometric Nonlinearity Coefficient Adjustments

v32 (Pre-Launch, yellow) and v33 (In-orbit, orange) a_2 values



Out-of-Band Harmonic Analysis

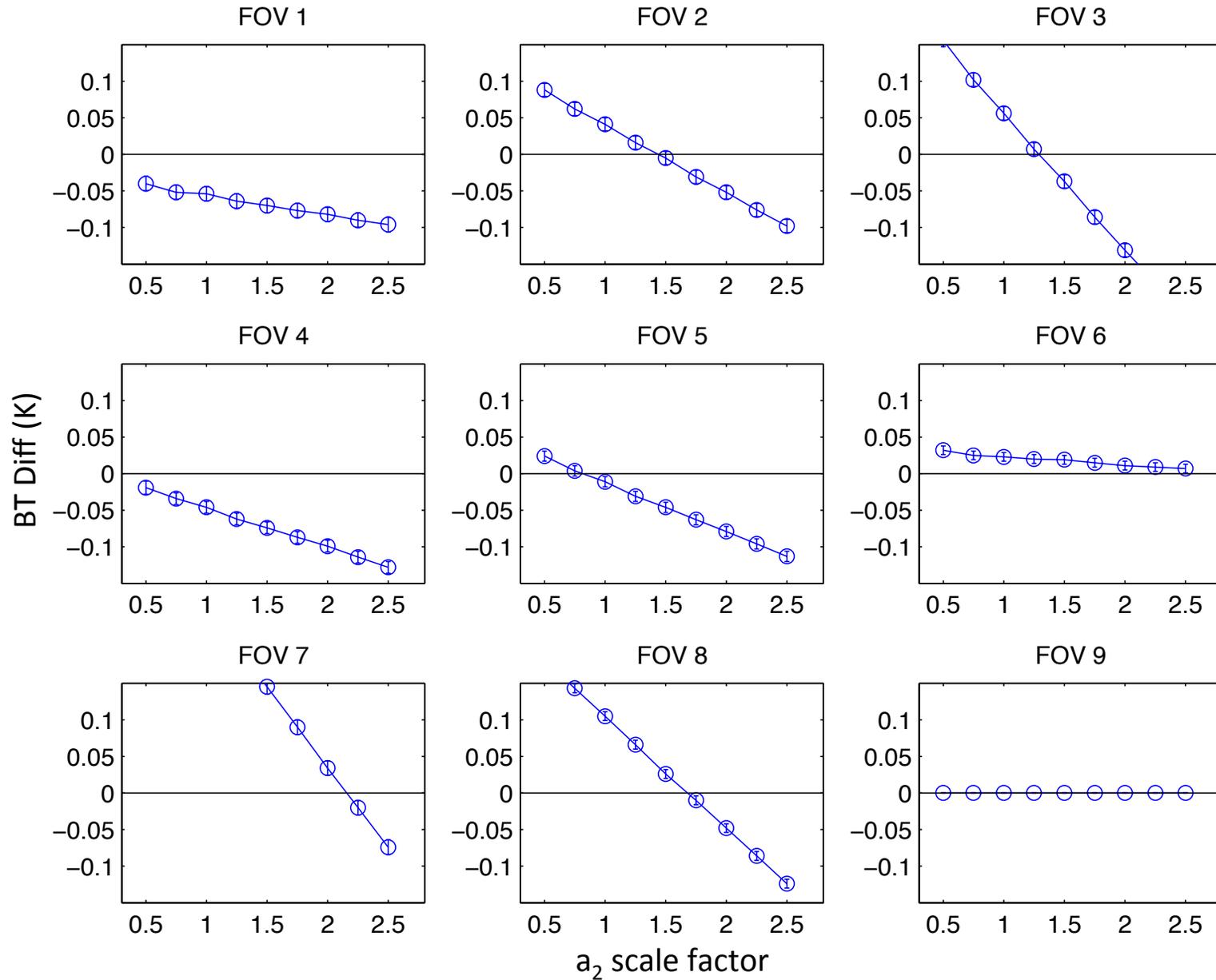
Example Longwave Band “Diagnostic Mode” spectrum:



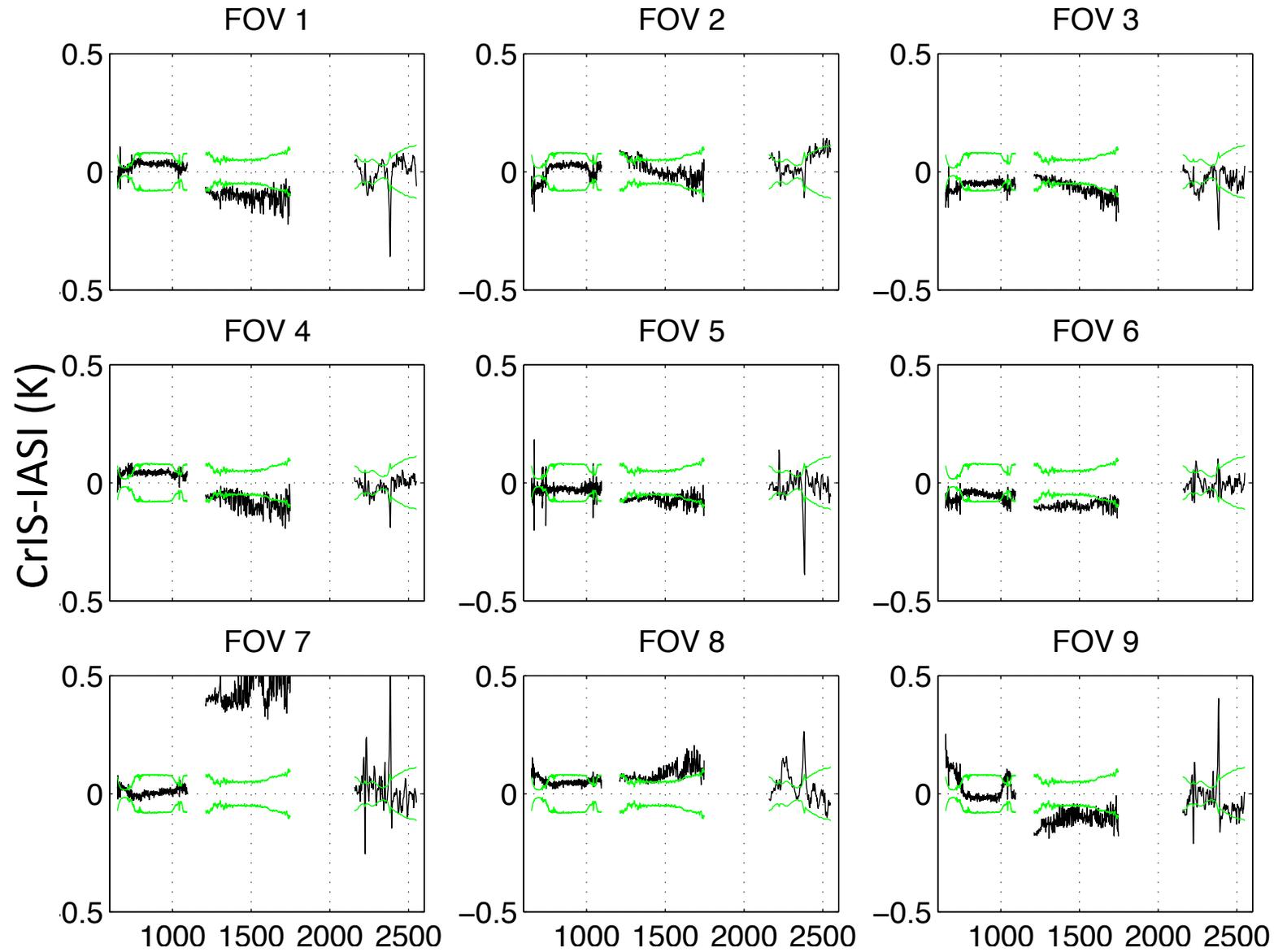
- Quadratic Nonlinearity observed for CrIS Longwave and Midwave detectors.
- For the CrIS bandpasses, the nonlinearity correction simplifies to $C' = C + 2 a_2 V C$, where V is DC level voltage at 1st stage of preamplifier and a_2 is the magnitude of the quadratic nonlinearity
- $\text{FFT}(\text{IFG}^2)/\text{FFT}(\text{IFG})$ in the low wavenumber region (~ 50 to 200 cm^{-1}) provides an estimate of a_2

Nonlinearity Refinement using FOV-2-FOV consistency analysis

Midwave 1580 cm^{-1} Differences wrt FOV 9 as a function of NL coefficient, a_2 :



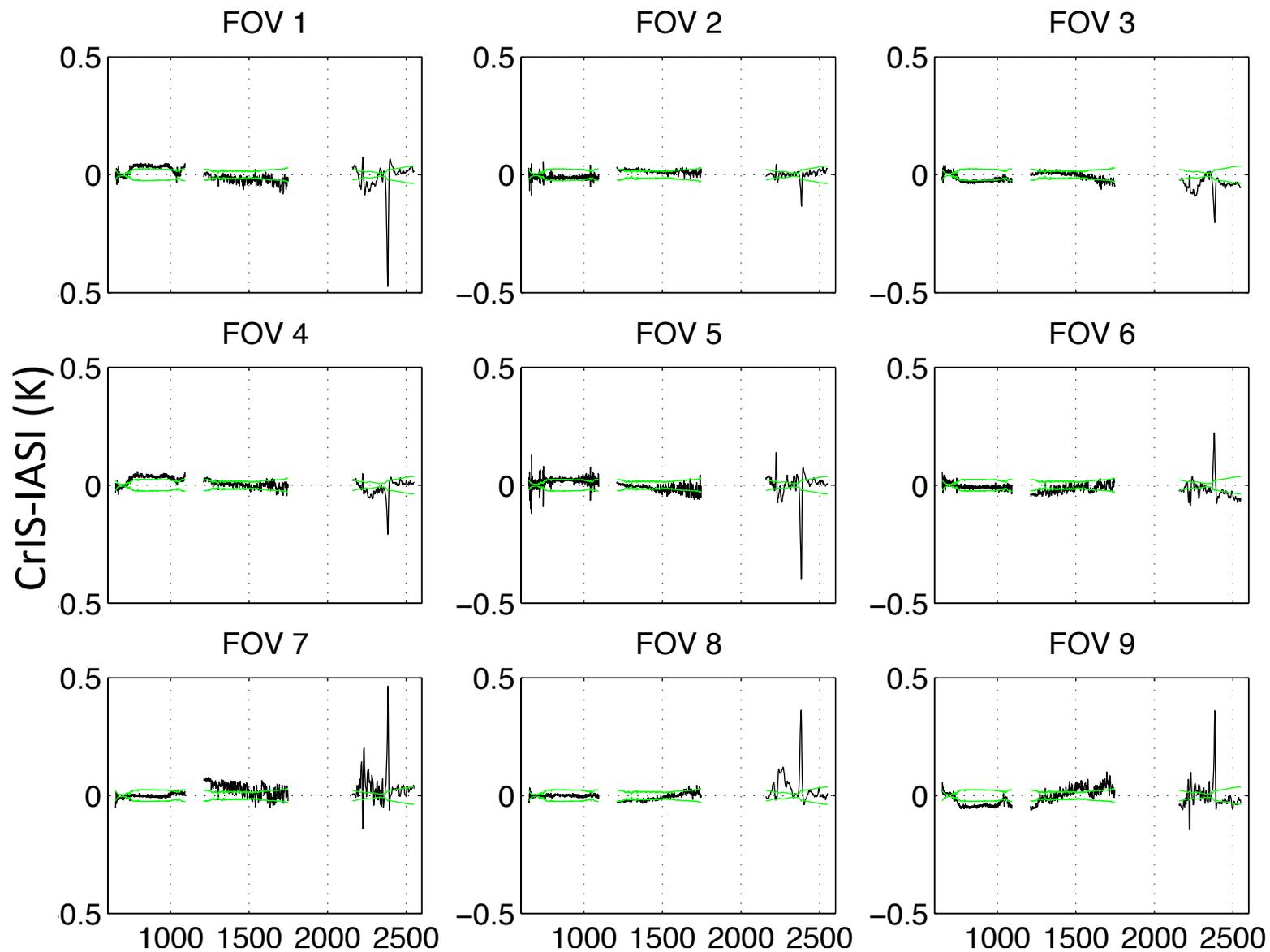
CrIS/IASI Northern SNOs, by FOV, prior to Apr 12 (v32 Eng Packet)



Weighted Mean (FOV i) minus Weighted Mean (all FOVs)

Weighted Mean Uncertainty

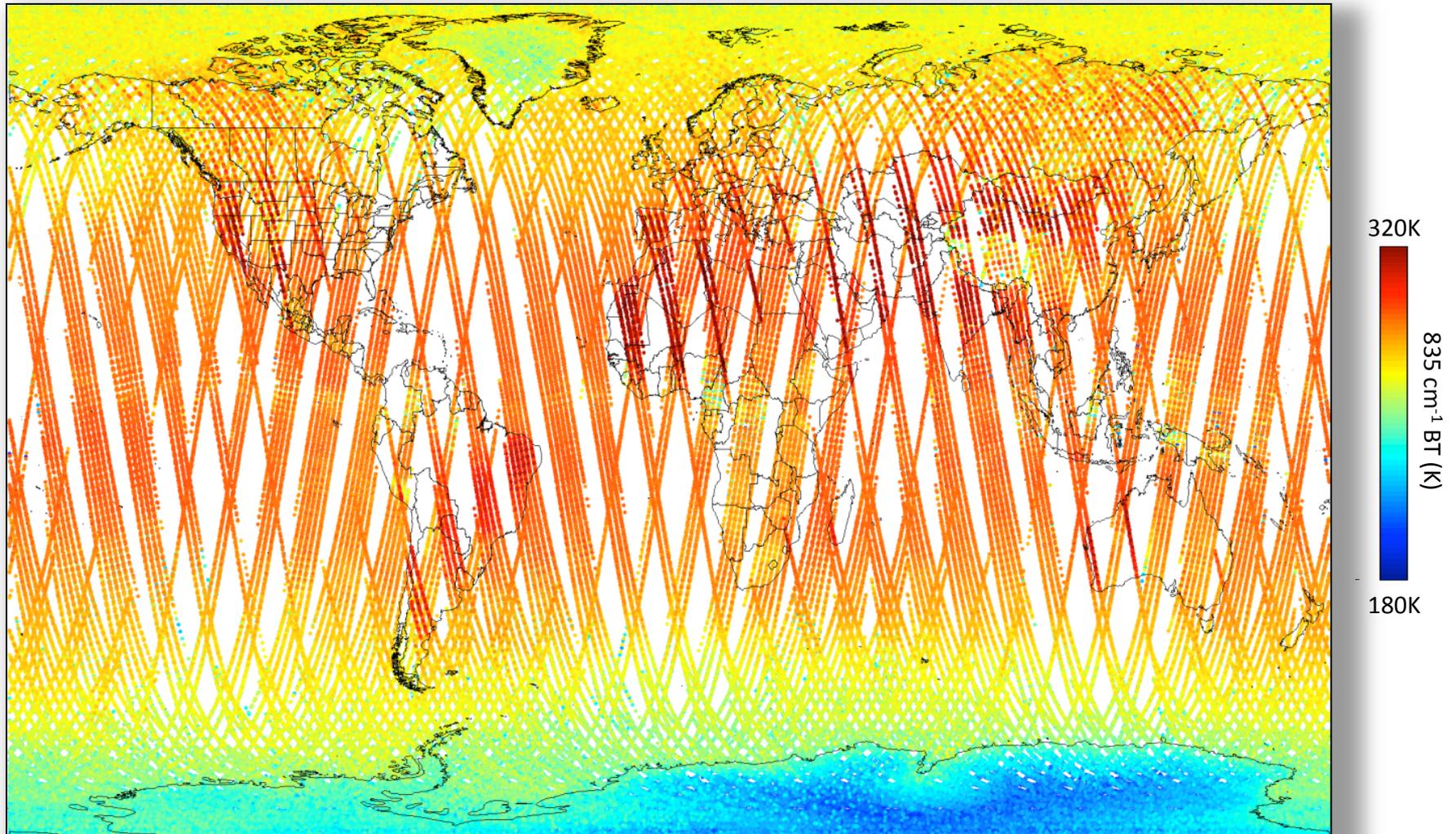
CrIS/IASI Northern SNOs, by FOV, post Apr 12 (v33 Eng Packet)



Weighted Mean (FOV i) minus Weighted Mean (all FOVs)

Weighted Mean Uncertainty

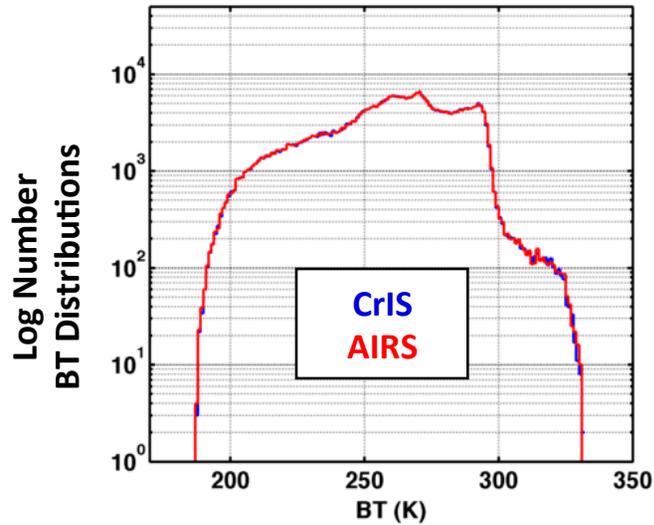
CrIS/AIRS Inter-comparison dataset



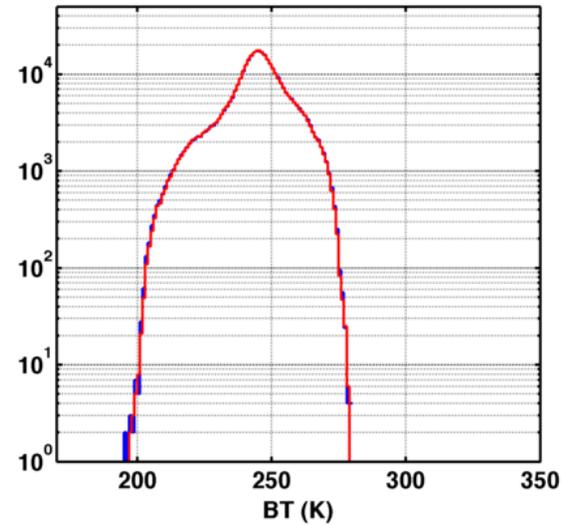
- 598,083 “big circle” samples, 25 Feb to 18 Dec
- Scan angles $\leq 30^\circ$; Scan angle difference $\leq 3^\circ$; Time Diff ≤ 20 min
- AIRS data is L1B v5; CrIS data is ADL (CSPP v1.1) with native Eng. Packets
- Daily processing c/o UW PEATE

CrIS/AIRS comparisons for Sample Wavenumber Regions

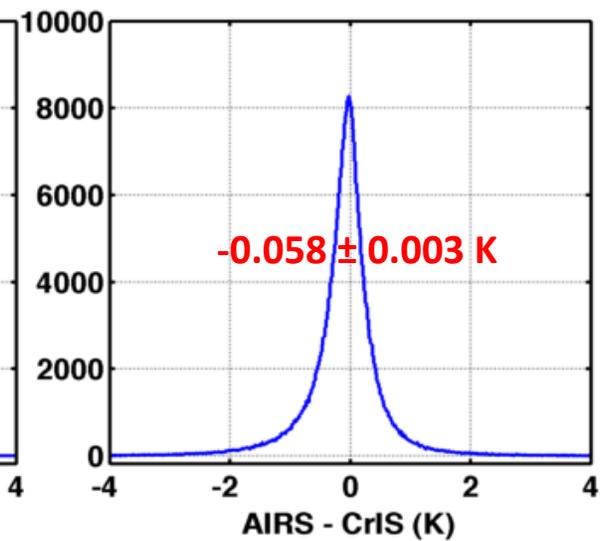
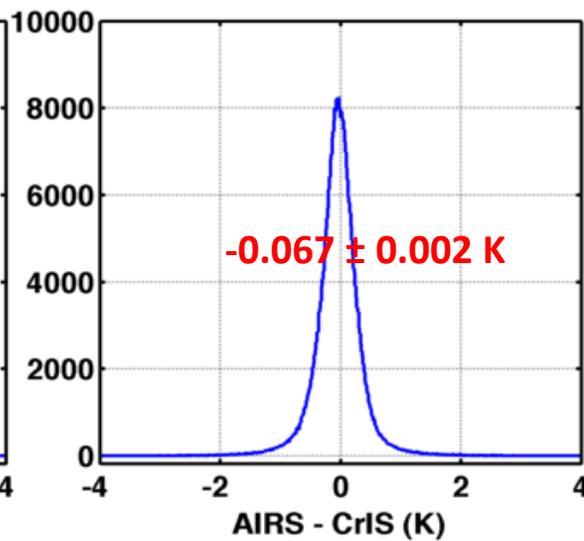
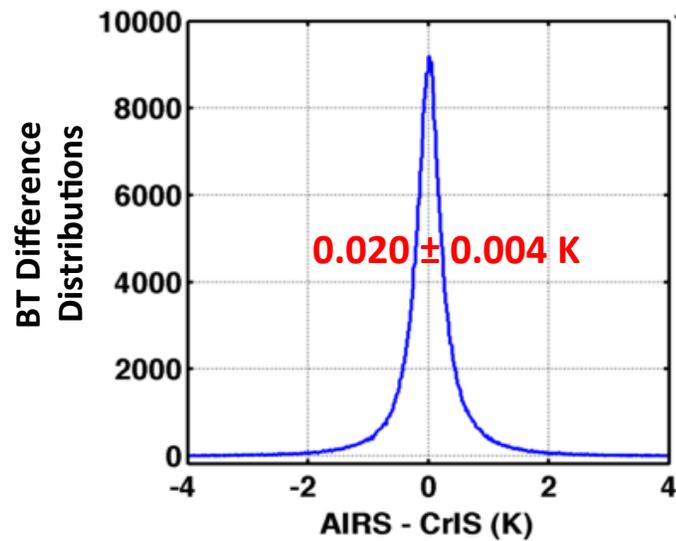
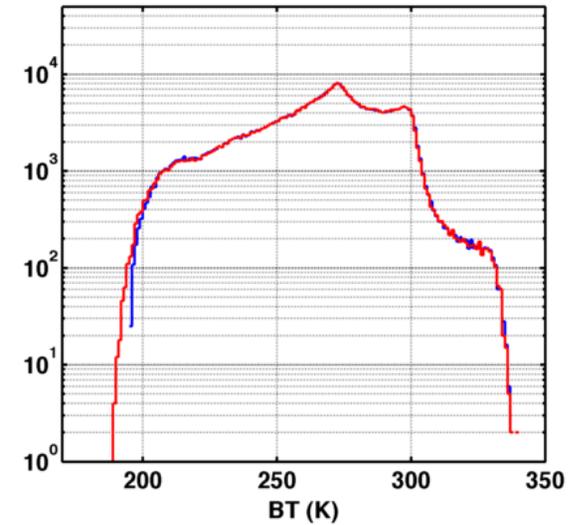
LW window
830-840 cm^{-1}



Upper Trop H₂O
1580-1595 cm^{-1}



SW window
2510-2520 cm^{-1}

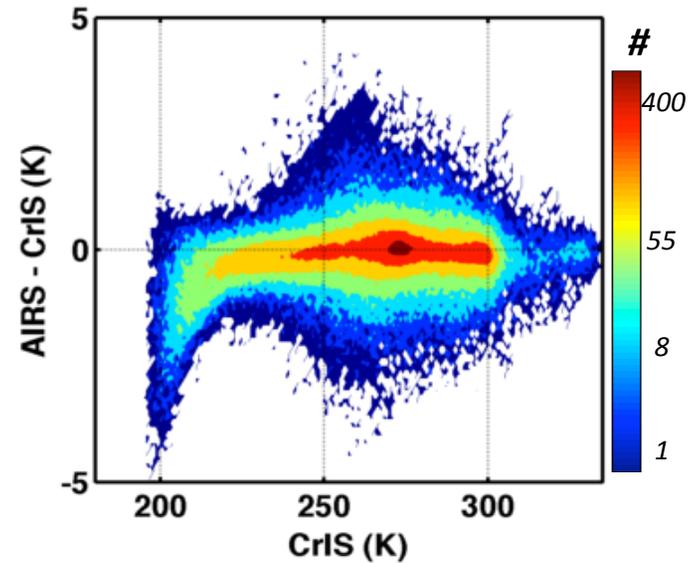
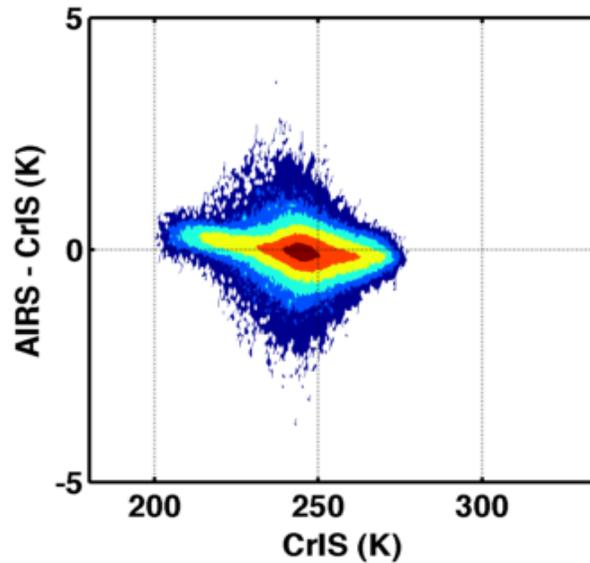
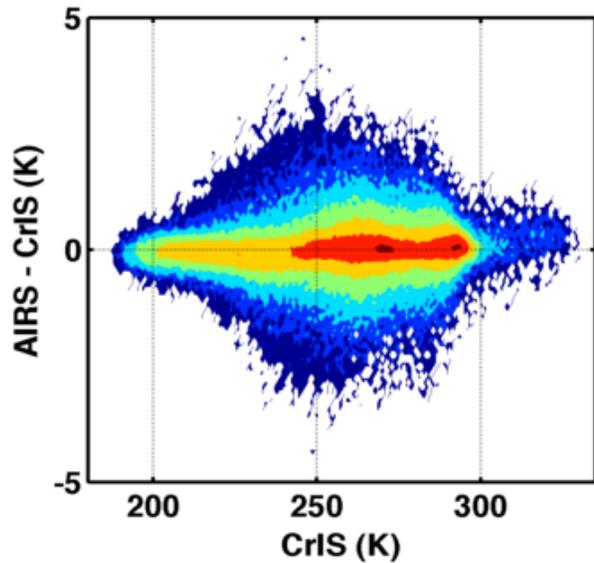
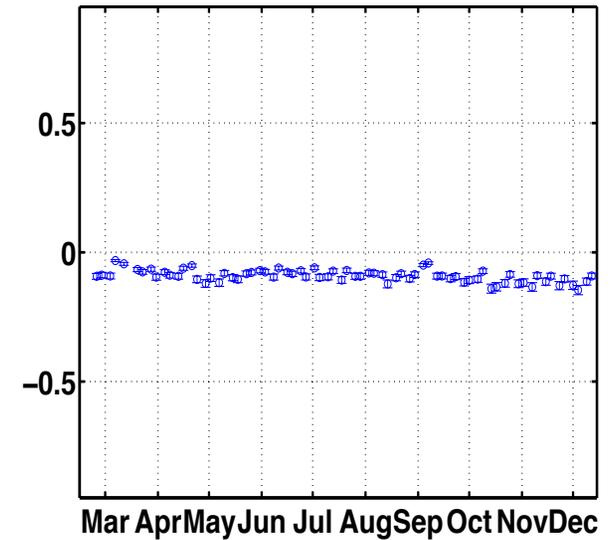
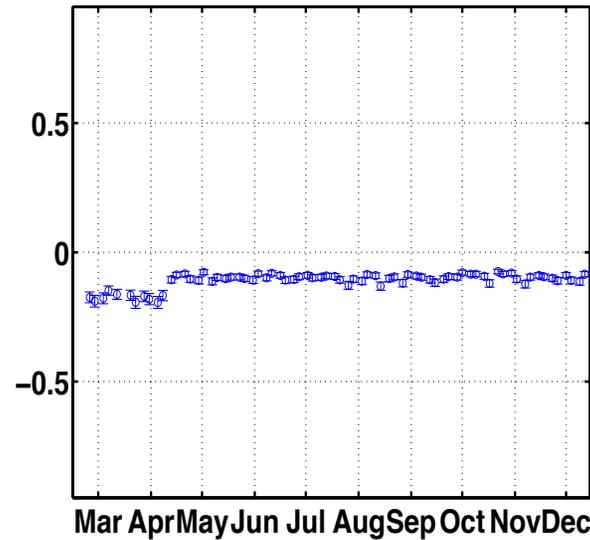
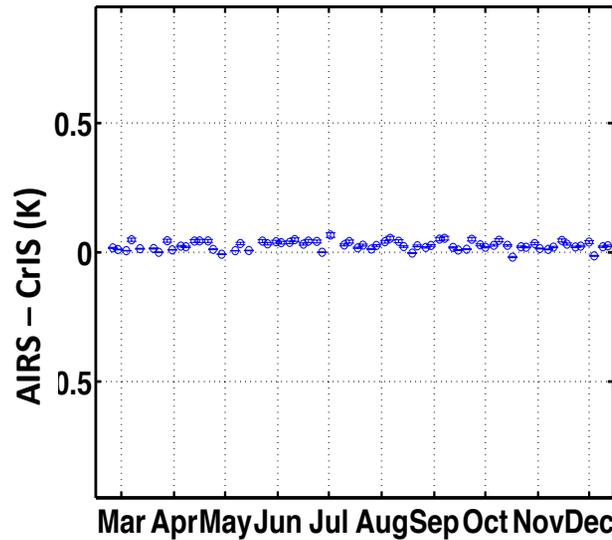


CrIS/AIRS comparisons for Sample Wavenumber Regions

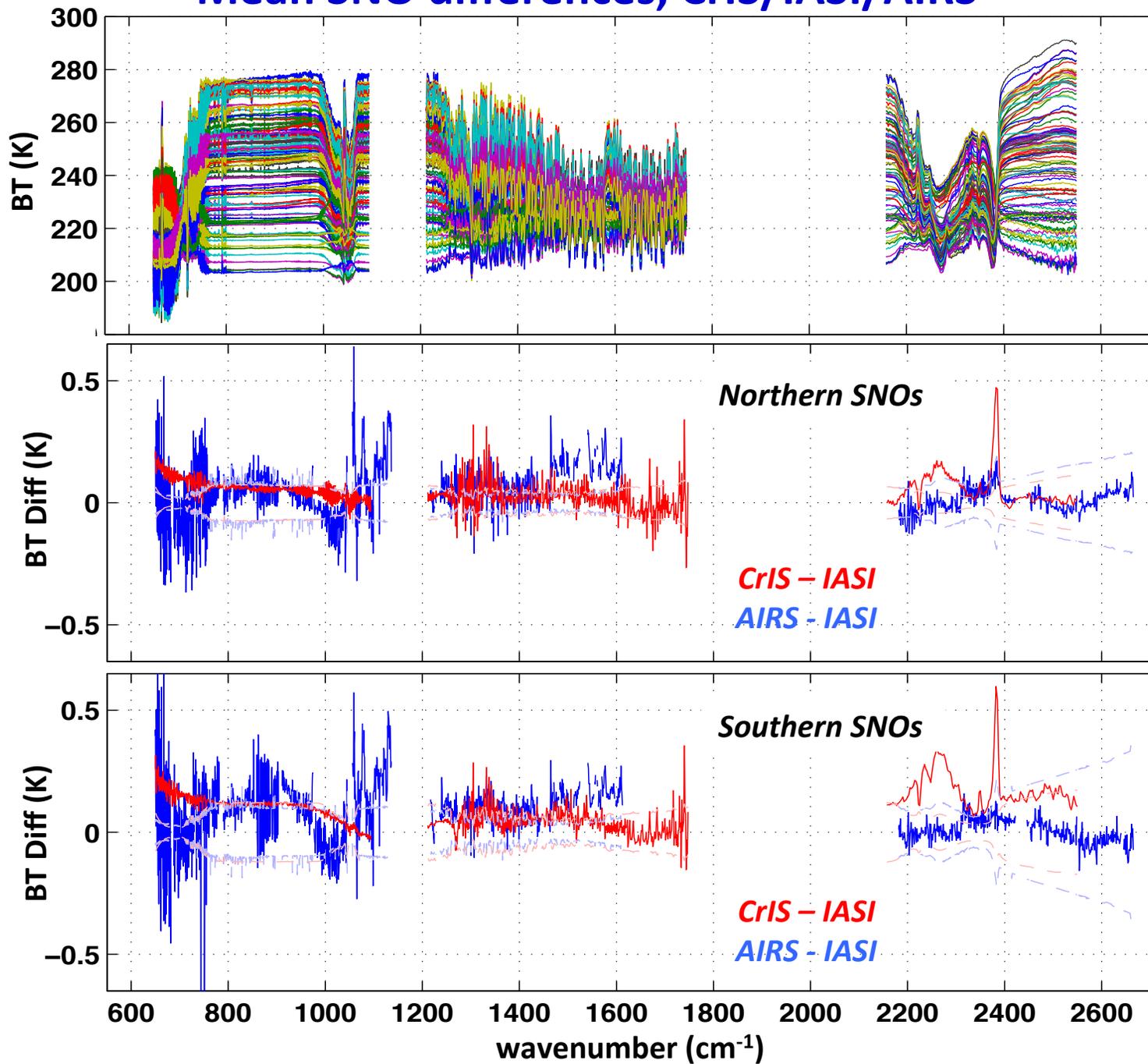
LW window
835 cm^{-1}

Upper Trop H₂O
1592 cm^{-1}

SW window
2510 cm^{-1}



Mean SNO differences, CrIS/IASI/AIRS

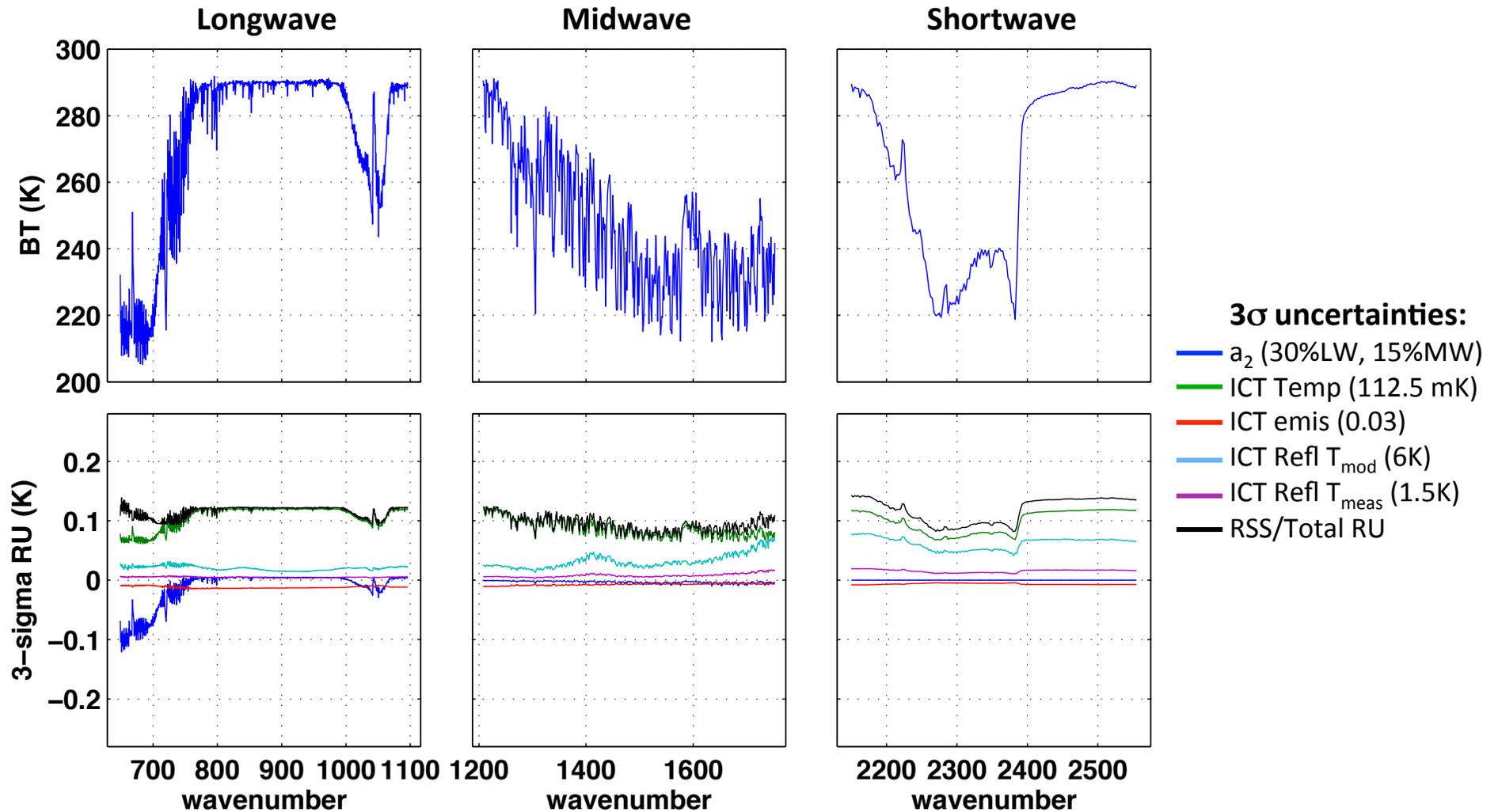


Other On-orbit Performance Notes:

(what did not happen)

- Interferometric noise (spectrally correlated) is exceptionally small— therefore, the vibration isolation stage was not deployed
- Radiation/particle induced Spikes are essentially non-existent – only 2 detected since launch
- No interferometer fringe count errors to date
- No signs of transmittance reduction from Ice buildup
- ILS effects on climate mean spectra from non-uniform scenes are very small (demonstrated by difference of corner and center FOV means)

In-Flight Radiometric Uncertainty (RU) Estimates for a typical ~clear sky scene

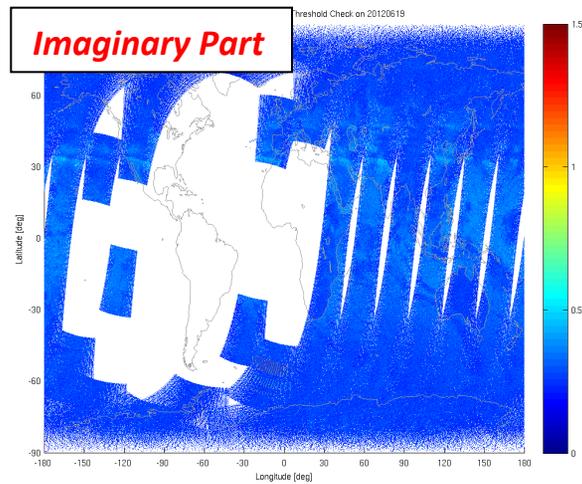
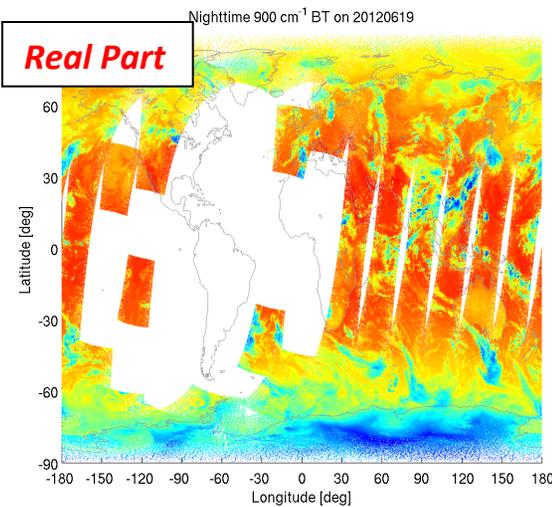
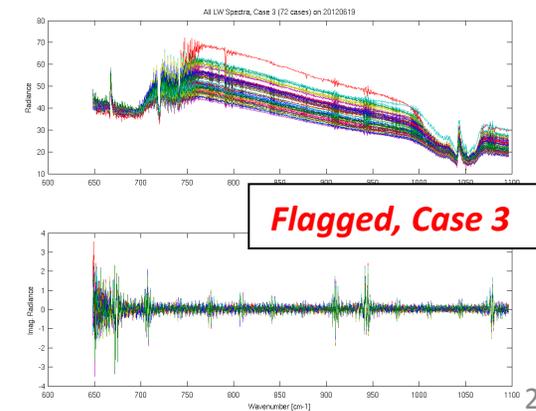
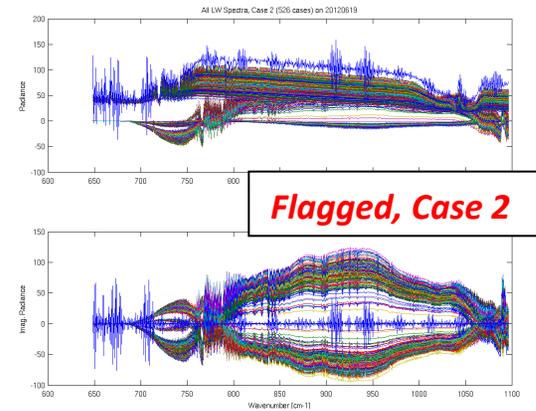
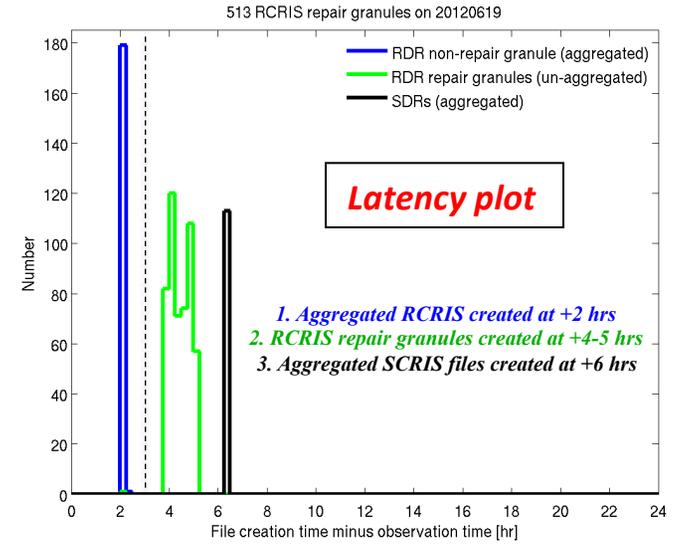
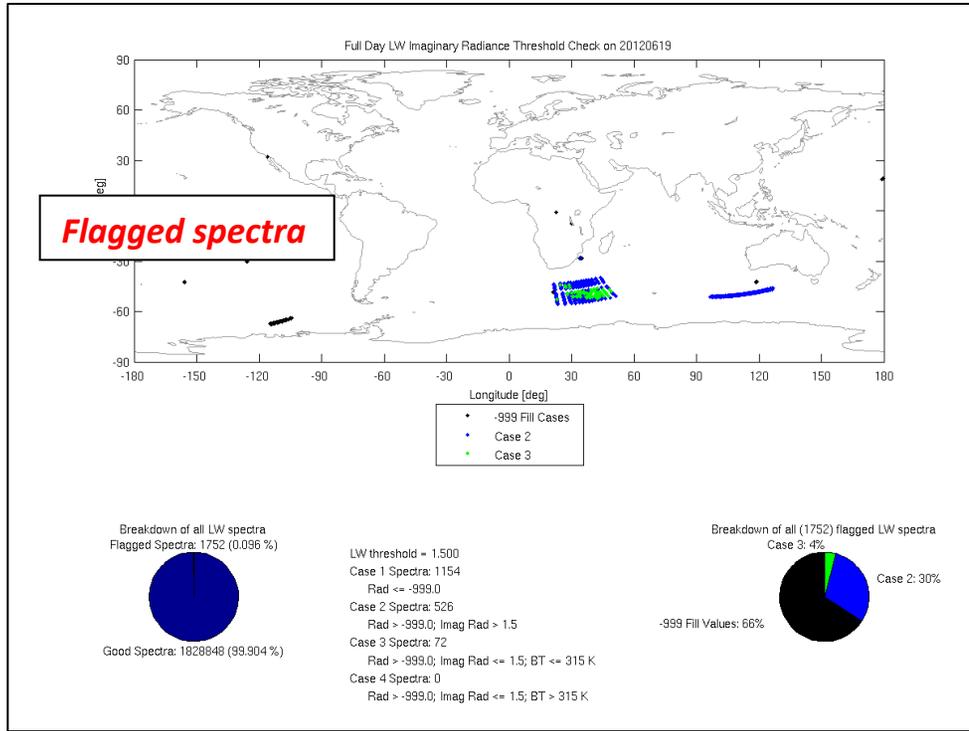


* Not including Shortwave cold scene and Gibbs ringing artifacts

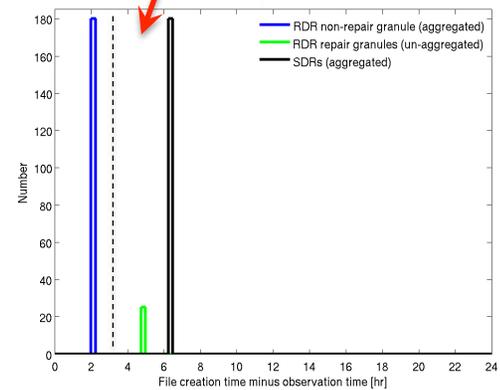
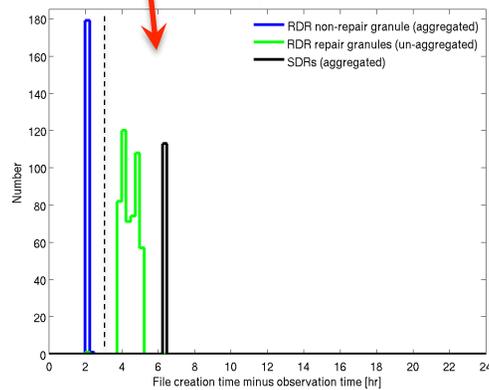
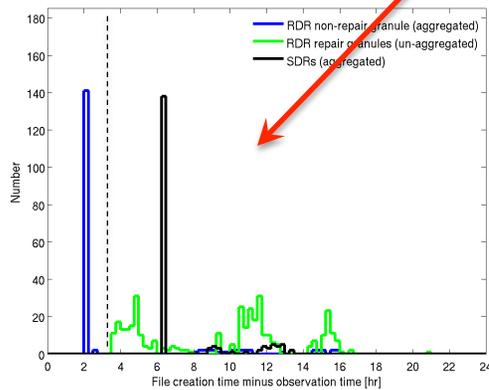
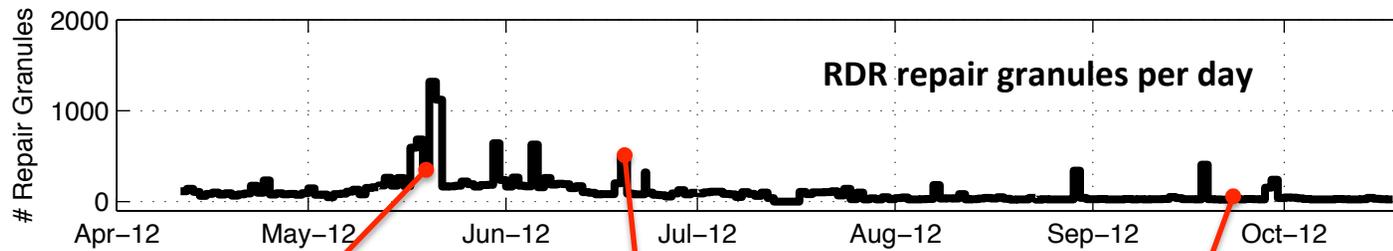
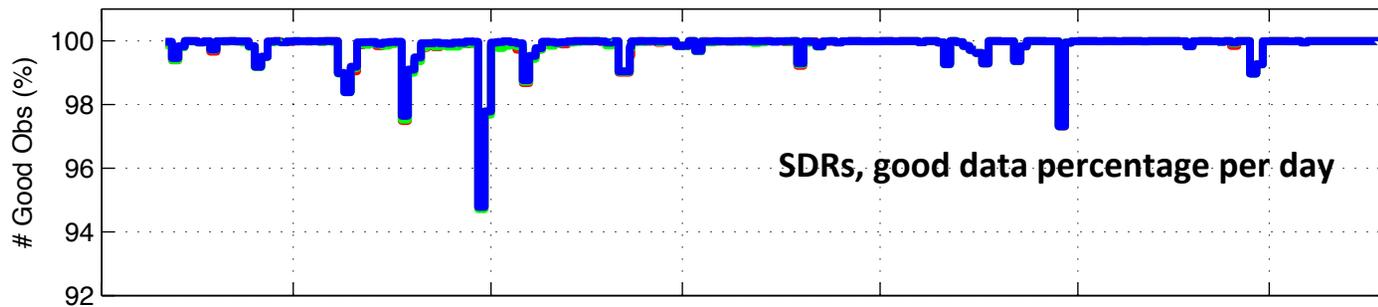
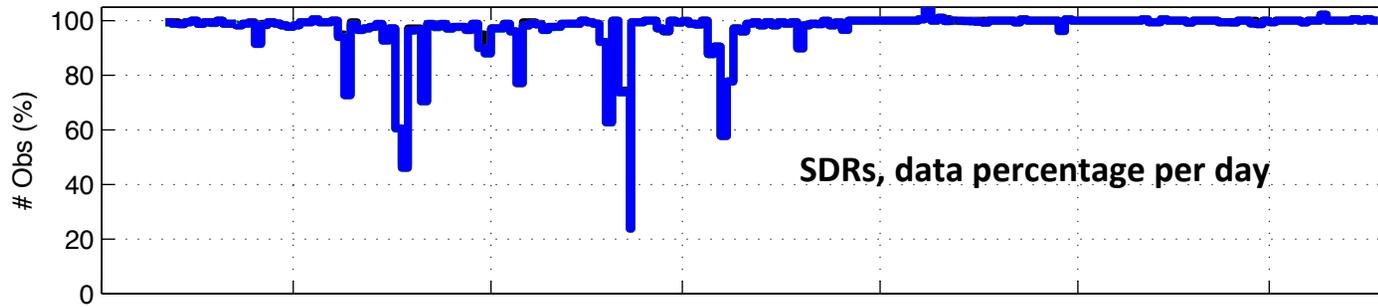
Current Leins, Areas of Investigation

- ◆ **Shortwave band, cold BT artifacts**
 - As seen in comparisons with AIRS, IASI, and Obs/Calcs
 - Well below spec, but still needs to be addressed
- ◆ **Gibbs effect, Spectral ringing**
 - Largest at band edges
 - Investigating source and possible fixes
- ◆ **Refinements to ILS and NLC coefficients**
 - Considering sub-tenth ppm adjustments to FOV positions and adjustments to LW NLC a2 coefficients, in June time frame.
- ◆ **“Repair Granules” in operational processing**
 - See next slides; users should use QA flags

Example QC plots for 2012.06.19, IDPS/CLASS products:



Operational QC time series



What's Next?

◆ Suomi-NPP CrIS

- “Validated” status expected mid 2013, including small refinements to ILS and NLC calibration coefficients
- Plan to go into full resolution mode (0.625 cm⁻¹ unapodized resolution in all 3 bands) in June 2013. Full interferograms will be downloaded; operational SDR product will remain at truncated resolution.
- NOAA/NASA currently determining plans/organization for reprocessing to produce a climate quality radiance dataset.

◆ JPSS-1 CrIS

- Very similar to NPP CrIS but with a re-designed and higher emissivity ICT
- Bench level and Thermal Vac testing to begin May/June of this year
- Launch now scheduled for early 2017

◆ JPSS-2 CrIS

- Smaller footprints; 3x3 FOVs (14km) replaced with effective 12x12 (~3.5km)
- Spectral gaps removed
- Launch in 2020/1

A world map with a light beige background and dark brown outlines of continents. The map is centered on the Atlantic Ocean, showing North and South America on the left, Europe and Africa in the center, and Asia and Australia on the right. The text "Thank You" is overlaid in the center of the map.

Thank You