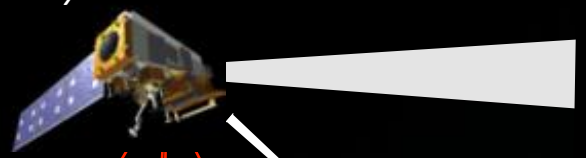
Suomi-NPP Cross-Track Infrared Sounder (CrIS) Radiometric Calibration Uncertainty

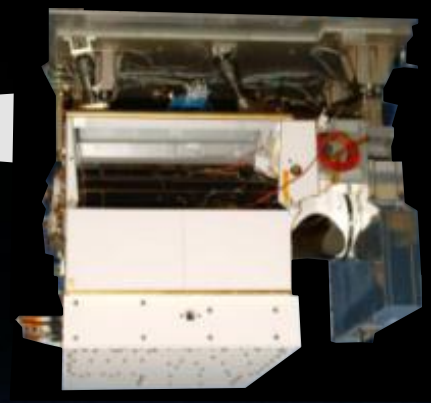
David Tobin, Henry Revercomb, Robert Knuteson, Joe Taylor, Lori Borg, Dan DeSlover, Graeme Martin

Thurs, 11:30AM, rm C213, talk 10.3
Suomi NPP/JPSS Cal/Val and Product Development
Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems
94th American Meteorological Society Annual Meeting
2-6 February 2014, Atlanta, GA

CrIS Operational Concept

CrIS on Suomi-NPP, built by ITT Exelis





Key Sensor Features

Large 8 cm Clear Aperture
Three Spectral Bands
3x3 FOVs at 14 km Diameter
Photovoltaic detectors in all 3 bands
4-Stage Passive Detector Cooler
Plane-Mirror Interferometer With DA
Internal Spectral Calibration
Ambient Internal Calibration Target
Modular Construction

±50° Cross track Scans + Space and ICT views

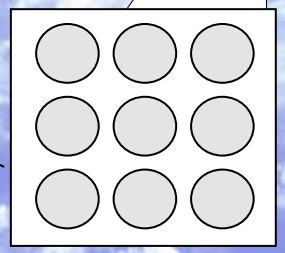
Downlink

Ground Station

30 Earth FORs

2,200 km Swath

3x3 Array of CrIS FOVs (Each at 14-km Diameter)

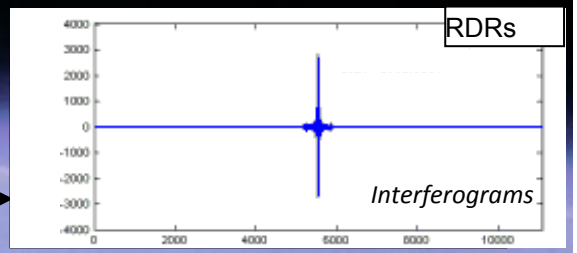


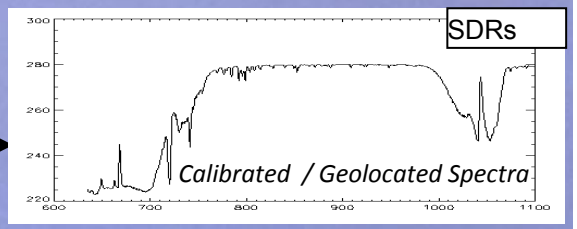
Decode Spacecraft Data

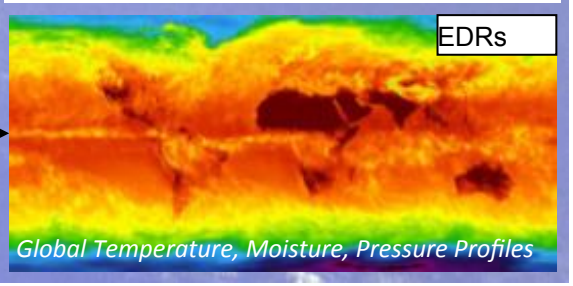
CrIS SDR Algorithm

Co-Located ATMS SDRs

EDR Algorithm







Band	Wavelength Range (cm-1)	(μm)	Sampling (cm-1)	No. Chan.
SWIR	2155-2550	4.64-3.92	2.5	159
MWIR	1210-1750	8.26-5.71	1.25	433
LWIR	650-1095	15.38-9.14	0.625	713

EXELIS CrIS

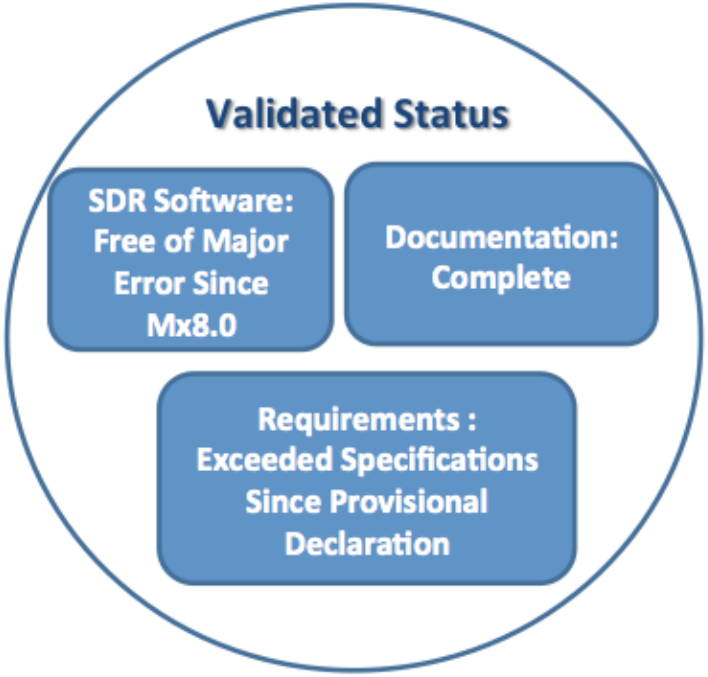
Suomi-NPP SDR Validated Status Review Meeting
(ATMS, CrIS, VIIRS, OMPS)
18-20 December 2013

JPSS Project CrIS SDR Team PIs:

Yong Han, NOAA STAR
Larrabee Strow, UMBC
Dan Mooney, MIT/LL
Mike Cromp, Exelis
Wael Ibrahim, Raytheon
Hank Revercomb, UW
Deron Scott, SDL
Degui Gu, NGAS
Dave Johnson, NASA
Carrie Root, JPSS/DPA

CrIS SDR Reached Validated Maturity Level

- Requirements
  - Instrument & SDR performances exceeded requirements since Provisional status declaration 1/31/2013
- SDR software
  - Stable & free of errors that can impact data quality since 11/14/2013 (Mx8.0)
- Documentation
  - 5 presentations in this meeting
  - 6 Journal papers
  - SDR User's Guide & Revised ATBD
  - Error Budget table



CrIS SDR uncertainties (**blue**) vs. specifications (black)

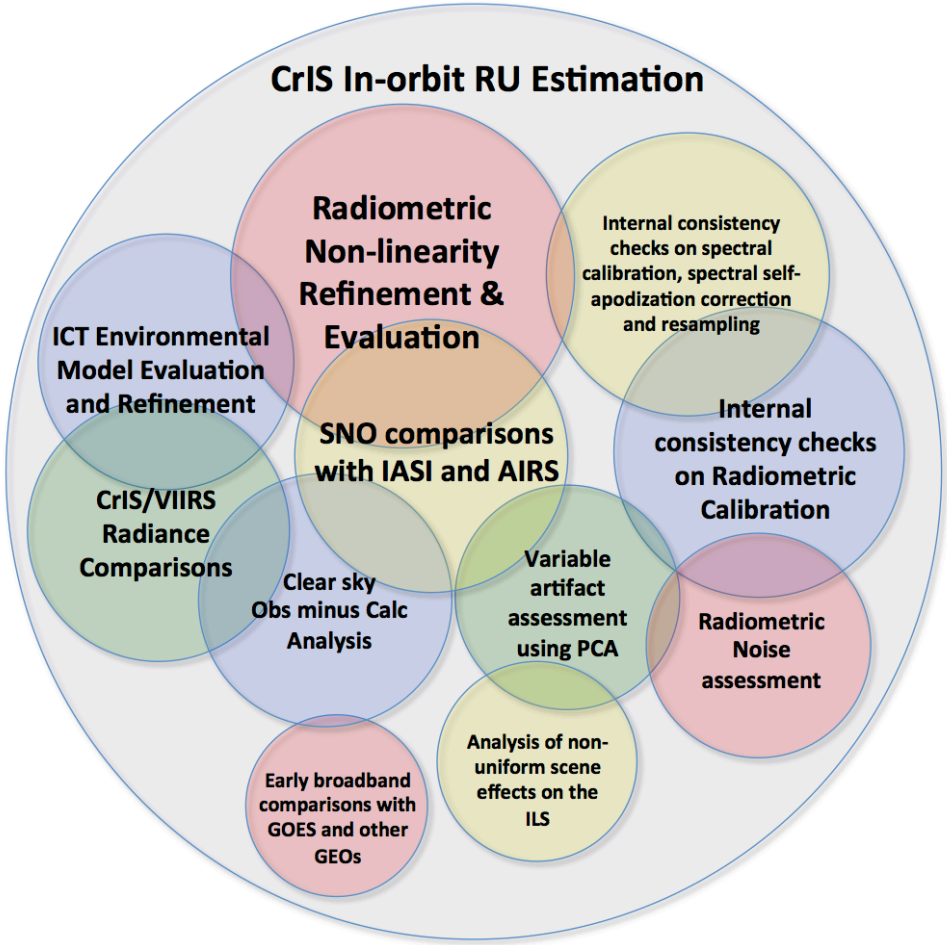
Band	NEdN @287K BB mW/m²/sr/cm⁻¹	Radiometric Uncertainty @287K BB (%)	Frequency Uncertainty (ppm)	Geolocation Uncertainty (km) *
LW	**0.098** (0.14)	**0.12** (0.45)	**3** (10)	**1.2** (1.5)
MW	**0.036** (0.06)	**0.15**(0.58)	**3** (10)	**1.2** (1.5)
SW	**0.003** (0.007)	**0.2** (0.77)	**3** (10)	**1.2** (1.5)

* Within 30° scan angles

Radiometric Uncertainty (RU) Estimates

- Required in order to understand the size and dependencies of the primary contributors to the CrIS SDR uncertainties, for calibration improvements, weather, process, trend, and inter-calibration applications.

"Meteorology + Metrology"



Radiometric Uncertainty Estimates

Simplified On-Orbit Radiometric Calibration Equation:

$$R_{scene} = \mathcal{R}e\{(C'_{scene} - C'_{SP}) / (C'_{ICT} - C'_{SP})\} R_{ICT}$$ with:

Nonlinearity Correction: $C' = C \cdot (1 + 2\, a_2\, V_{DC})$

ICT Predicted Radiance: $R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, [\, 0.5\, B(T_{ICT,\, Refl,\, Measured}) + 0.5\, B(T_{ICT,\, Refl,\, Modeled})]$

Parameter Uncertainties:

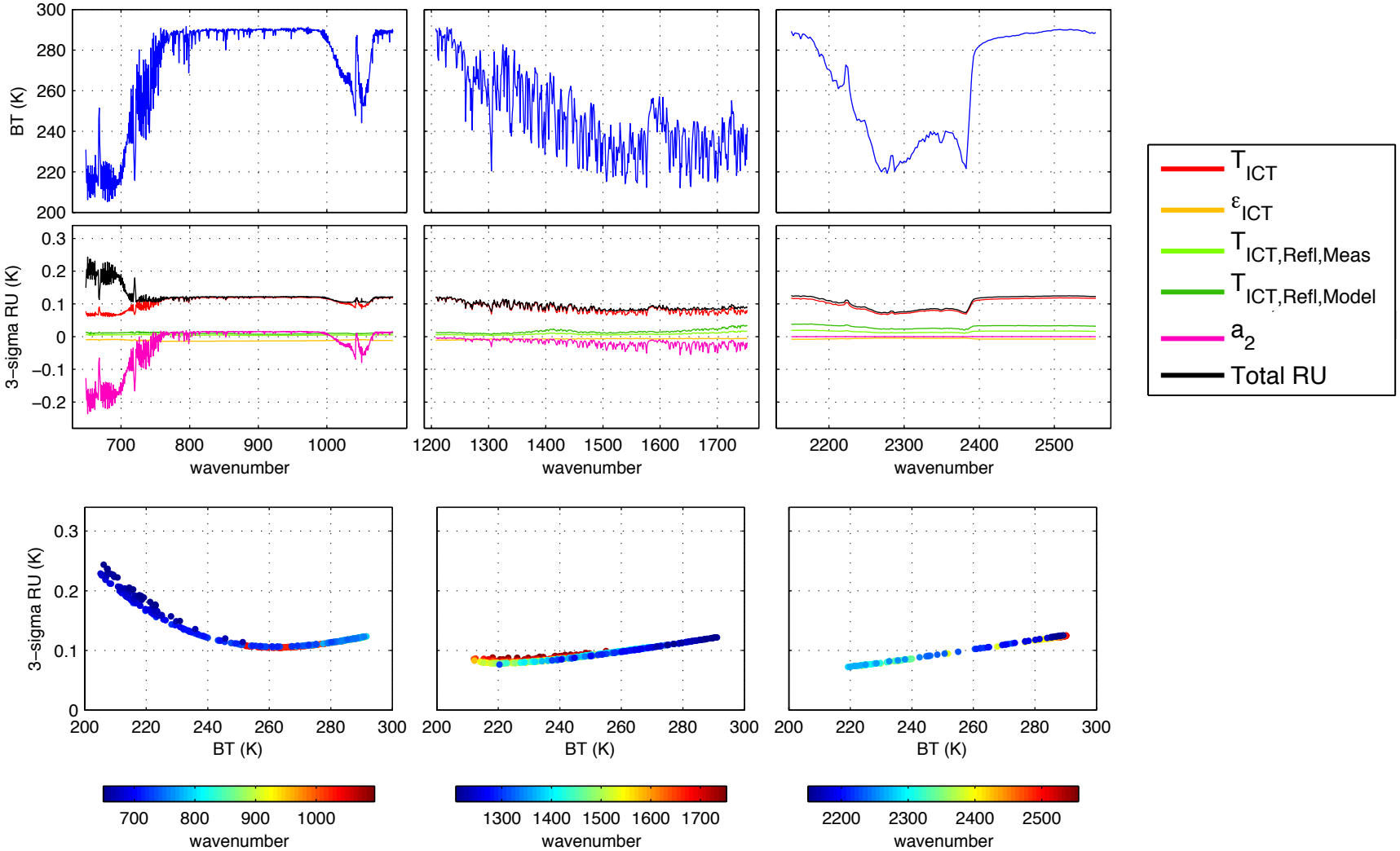
Parameter	Nominal Values	3-σ Uncertainty
T_{ICT}	280K	112.5 mK*
ε_{ICT}	0.974-0.996	0.03
$T_{ICT,\, Refl,\, Measured}$	280K	1.5 K
$T_{ICT,\, Refl,\, Modeled}$	280K	3 K
a_2 LW band	0.01 – 0.03 V^{-1}	0.00403 V^{-1}
a_2 MW band	0.001 – 0.12 V^{-1}	0.00128 – 0.00168 V^{-1}

**Exelis at-launch estimate*

Following *Tobin et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, J. Geophys. Res. Atmos., 118, 10,589–10,600, doi:10.1002/jgrd.50809.*

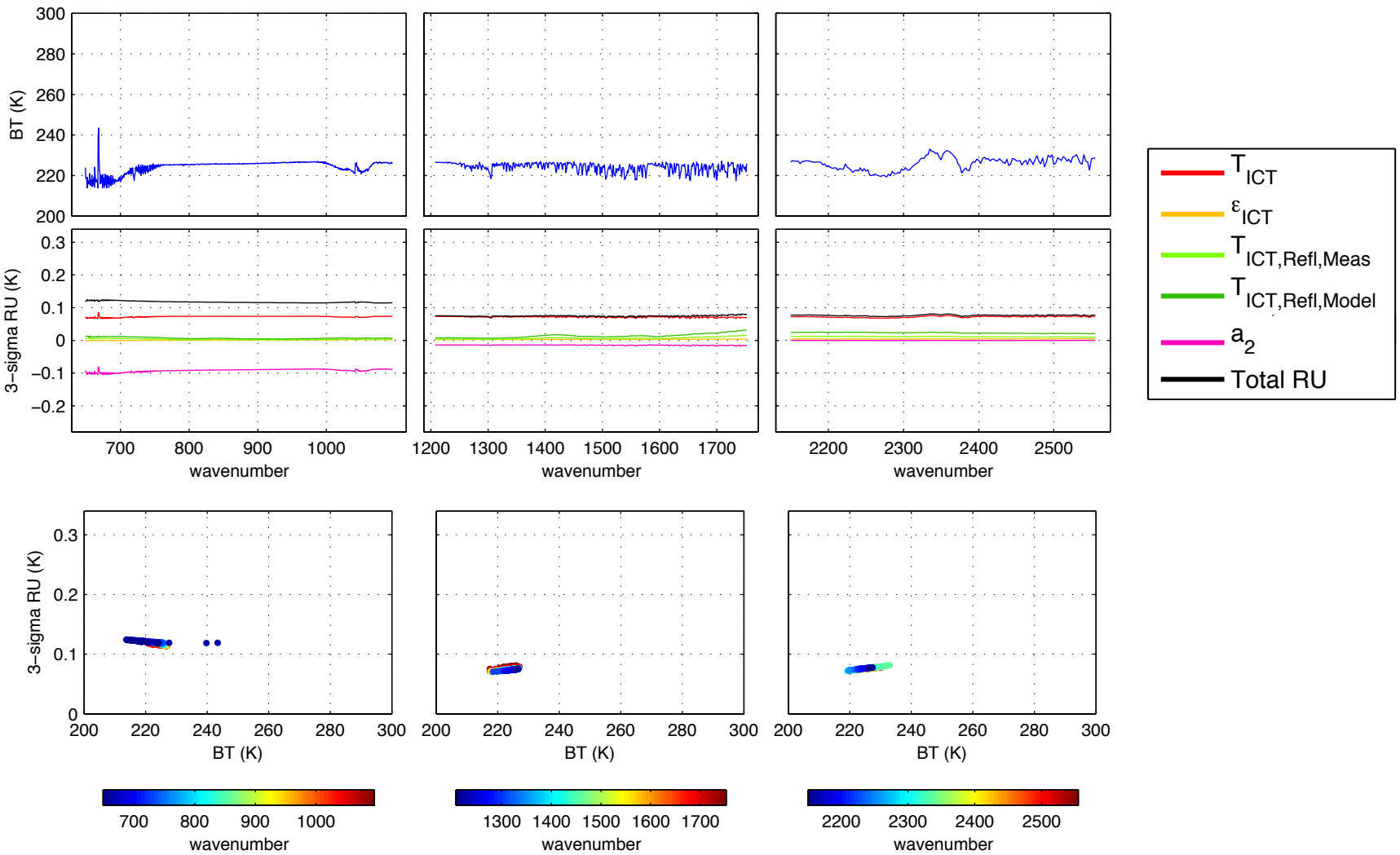
Example 3-sigma RU estimates

For a typical warm, ~clear sky spectrum



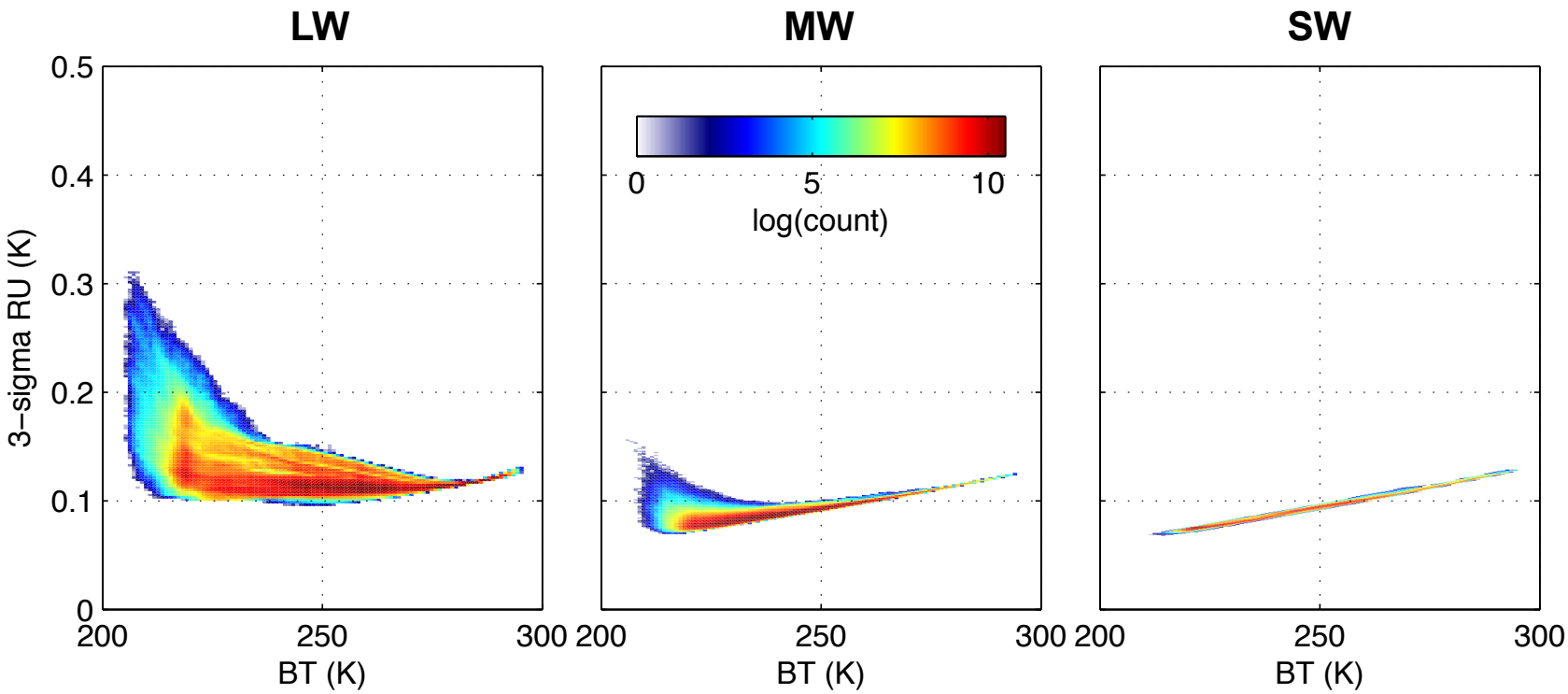
Example 3-sigma RU estimates

For a cold, high cloud spectrum



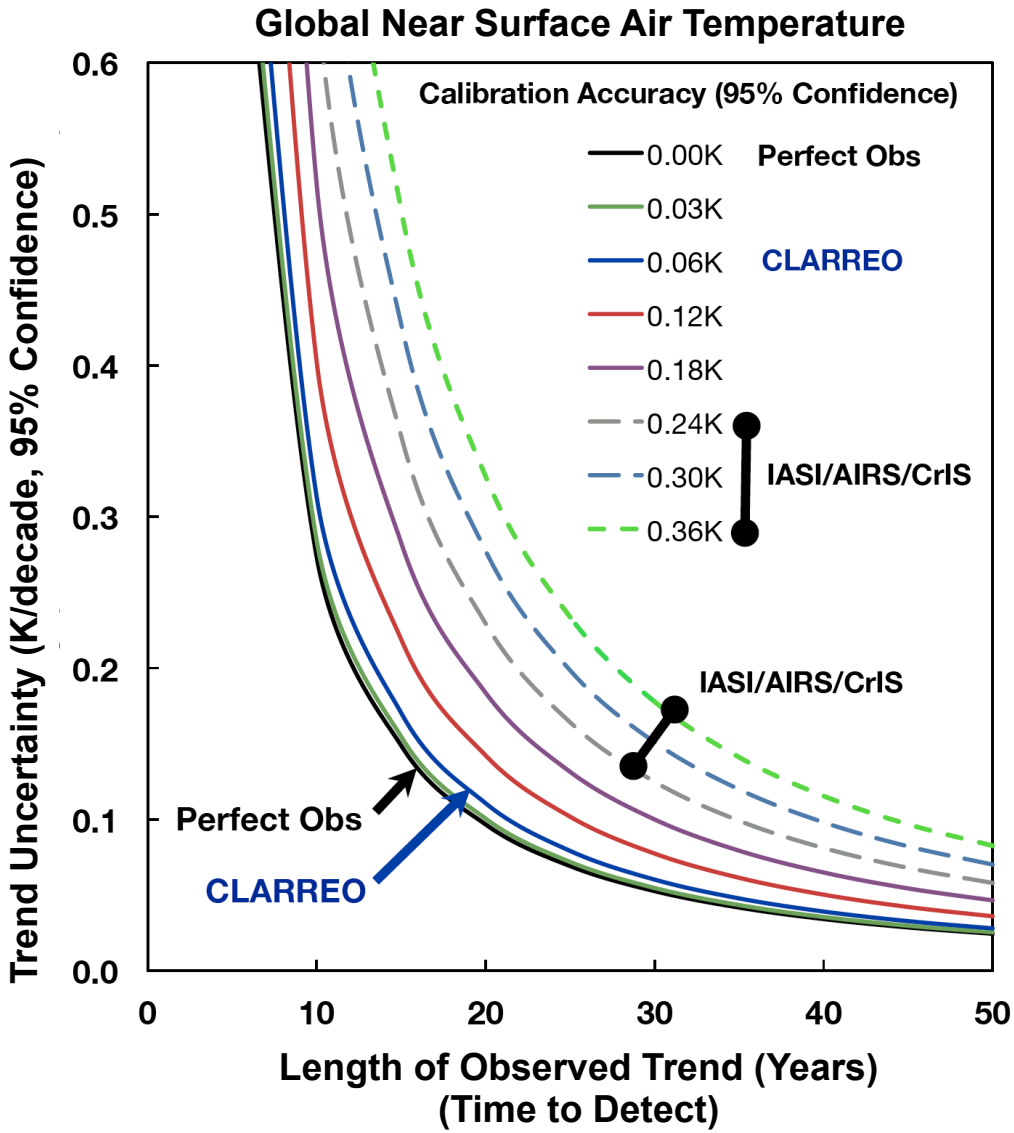
Example 3-sigma RU estimates

Log scale RU distributions for one orbit of CrIS Earth view data, including all FOVs and spectral channels within the band:



- **Overall, RU is <0.3K (LW), <0.15K (MW), <0.15K (SW): Better than spec by approximately a factor of 4.**

Achieving Climate Change Absolute Accuracy in Orbit,
Wielicki et al., BAMS, 2013



Other Terms

Smaller contributors not currently accounted for in the calibration algorithm or included in current RU estimates:

- Other smaller/negligible terms:
  - Detector temperature changes, Changes in DA Bias tilt over 4 minutes, Changes in optical flatness, OPD sample rate drift over 4 minutes, Electronic gain drift over 4 minutes, Electronic delay drift over 4 minutes, FOV to FOV crosstalk in same band, FOV to FOV crosstalk between bands, Stray light, Optics temperature change during cal, Changes in channel spectra

- Spectral Ringing
- Polarization
- Possible SW Nonlinearity

Evaluations of RU estimates
("Cal/Val")

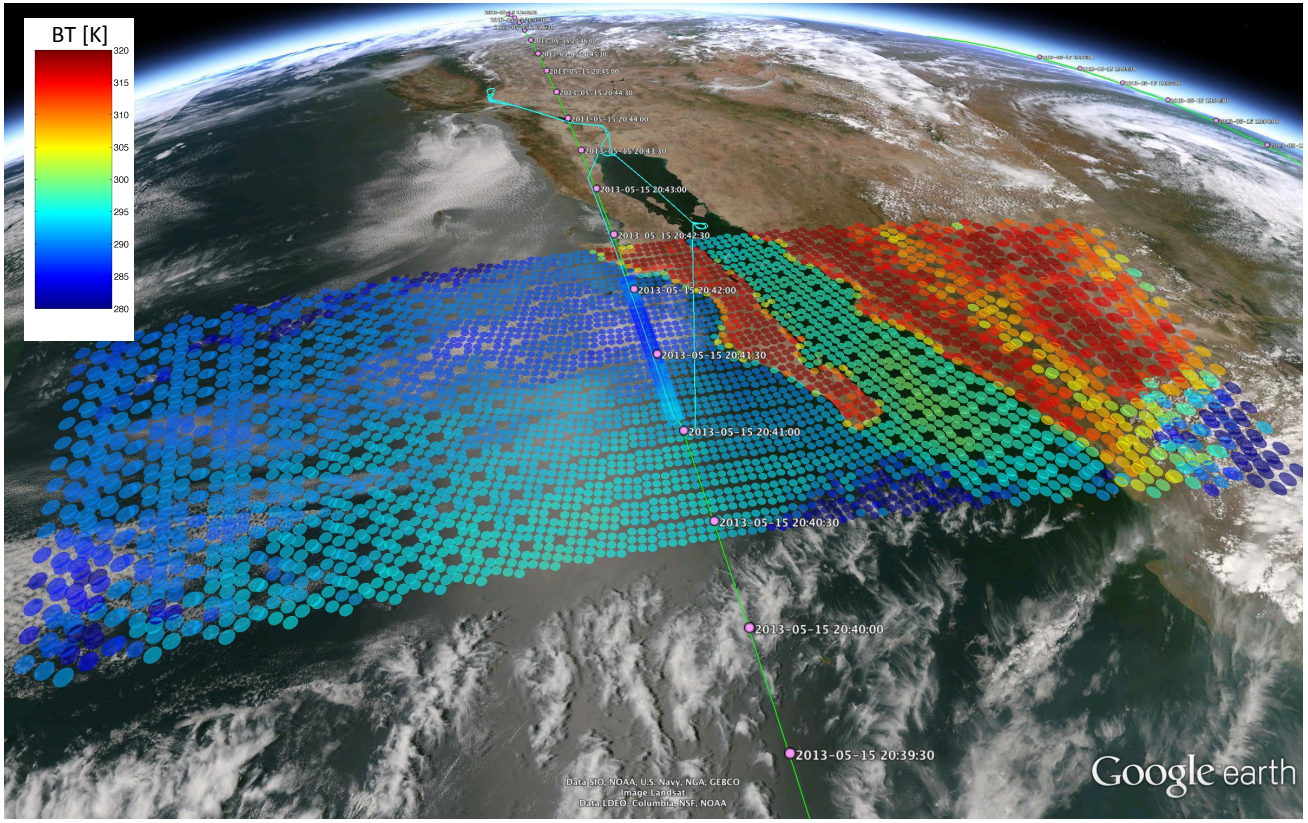
- Aircraft underflights
- CrIS/VIIRS comparisons
- CrIS/IASI comparisons
- CrIS/AIRS comparisons
- Clear sky Obs-Calc

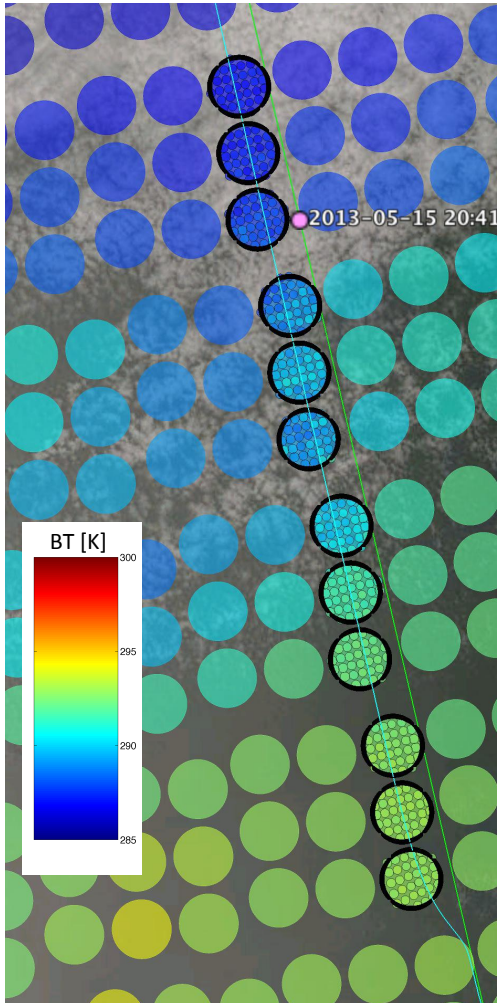
➢ A range of techniques, with various levels of uncertainty/statistics/traceability, to assess the CrIS SDRs and associated RU estimates.

May 2013 Suomi-NPP JPSS Aircraft Campaign

Scanning-HIS evaluations of CrIS Calibration

See Joe Taylor poster # 690.



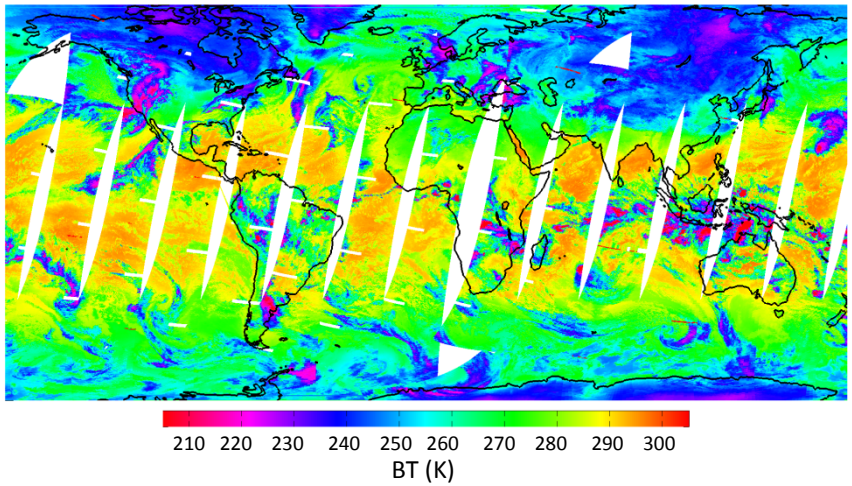


May 15 Underflight example:
S-HIS and CrIS 895–900 cm^{-1} BTs overlaid on VIIRS true color image

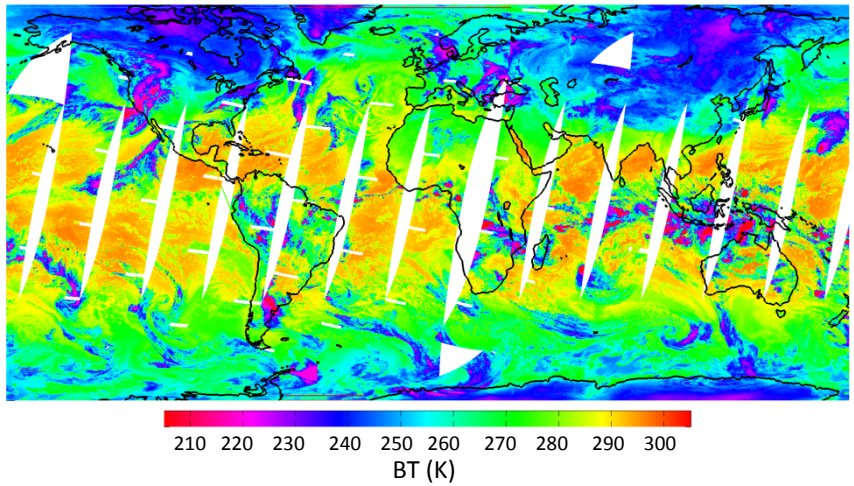
CrIS/VIIRS comparisons

Example Daily Comparisons, M15 band @ 10.8μm, Descending

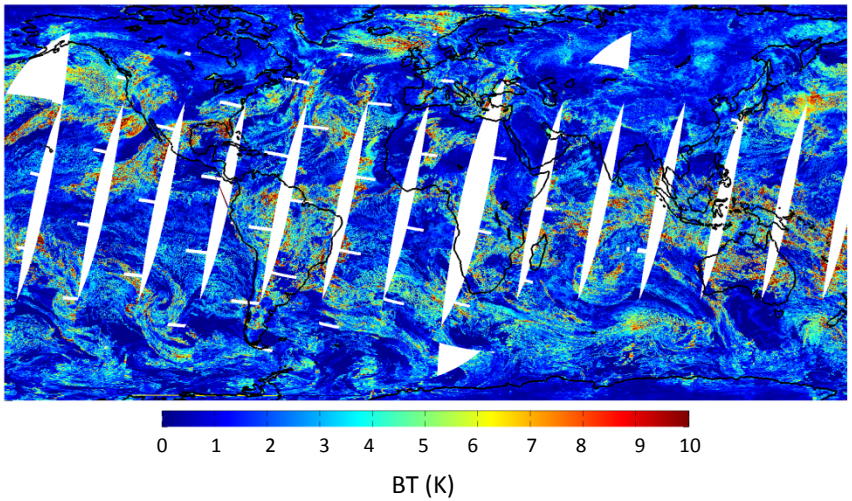
CrIS convolved with VIIRS SRF



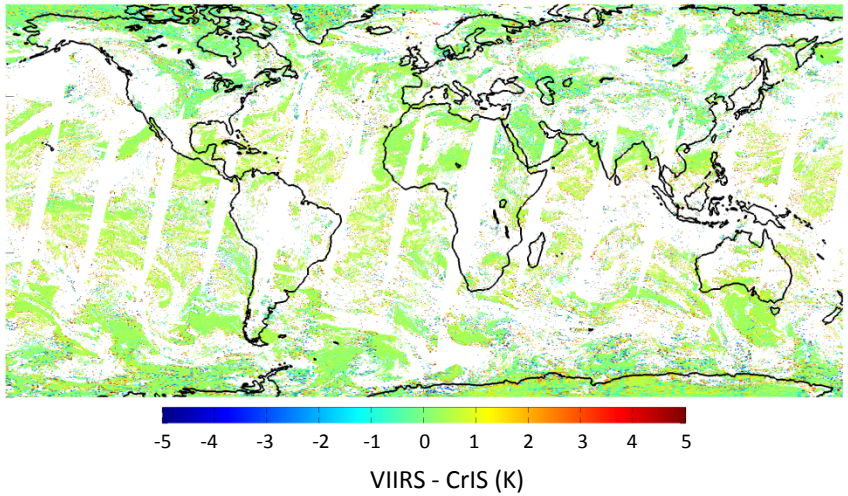
VIIRS mean within CrIS FOVs



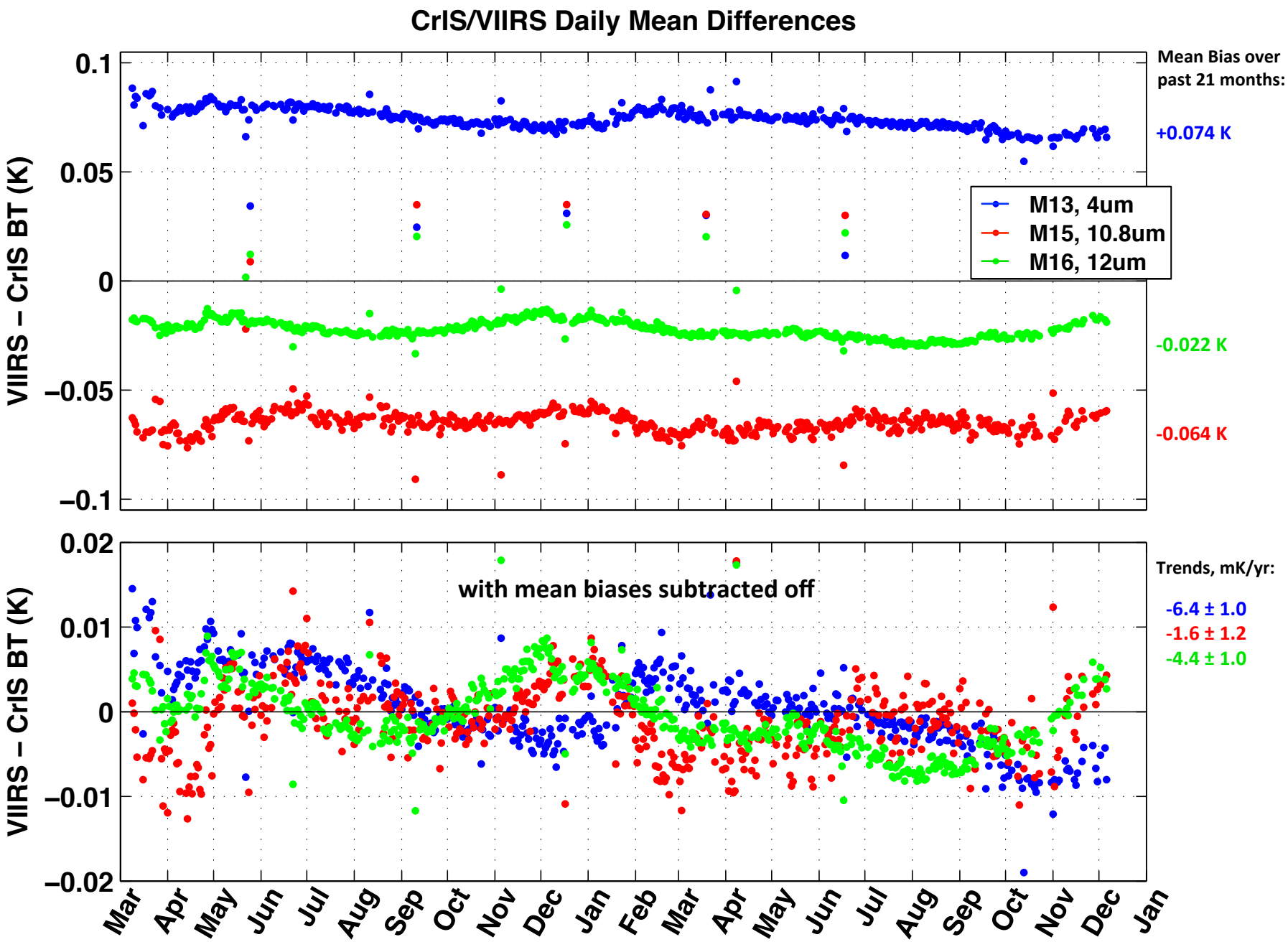
VIIRS standard deviation within CrIS FOVs



Differences for uniform scenes



- Each day includes ~500,000 colocations which pass a spatial uniformity test

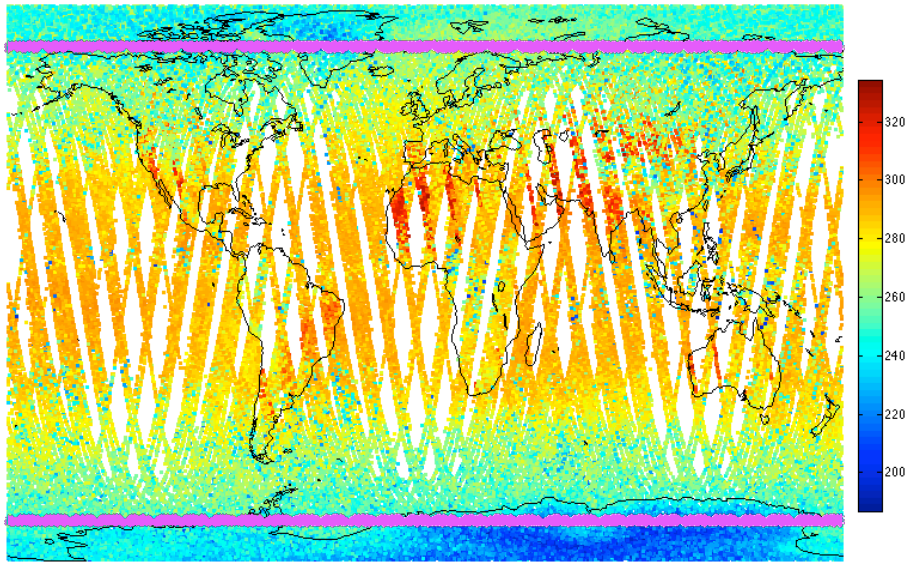


- CrIS/VIIRS daily mean differences are < 0.1K and trends are < 10 mK/yr

SNO Datasets

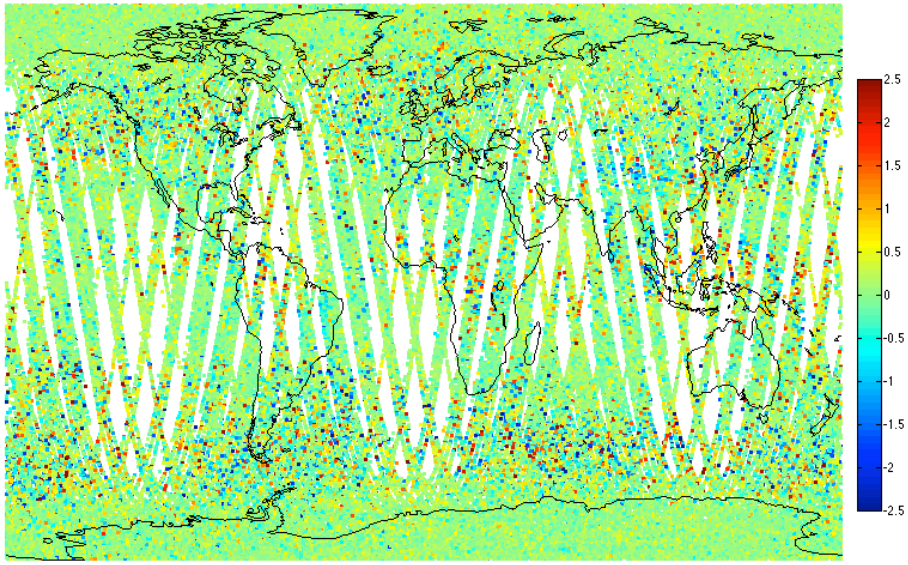
CrIS/AIRS: 1.2M "Big Circle" SNOs collected to date (March 2012 to Nov 2013);
20 minute window; -30 to 30 deg scan angle, <=2 deg scan angle diff.
AIRS V5 L1B; CrIS ADL/CSPP SDR_1.4b_NLC_ILS

2510 cm^{-1} CrIS/AIRS SNO BTs



CrIS/IASI SNO locations

835 cm^{-1} CrIS/AIRS SNO BT Diffs

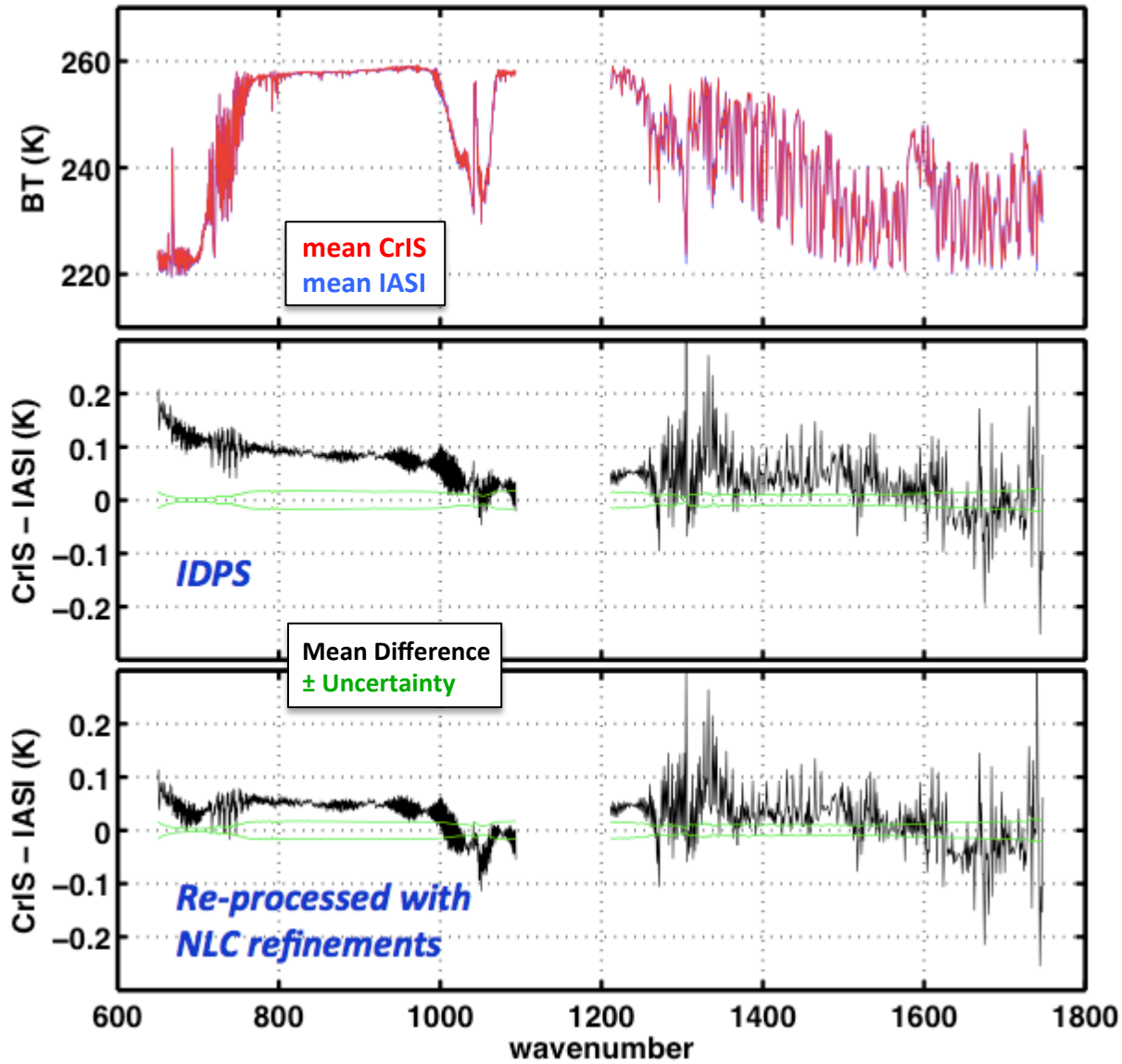


CrIS/IASI-A: 5270 "Big Circle" SNOs collected to date (March 2012 to Nov 2013);
20 minute window; nadir. ~20 days of coincidences, ~30 day gaps,
~half at +72.4 deg, ~half at -72.4 deg.
IASI_xxx_1C_M02; CrIS ADL/CSPP SDR_1.4b_NLC_ILS

CrIS/IASI Northern SNOs

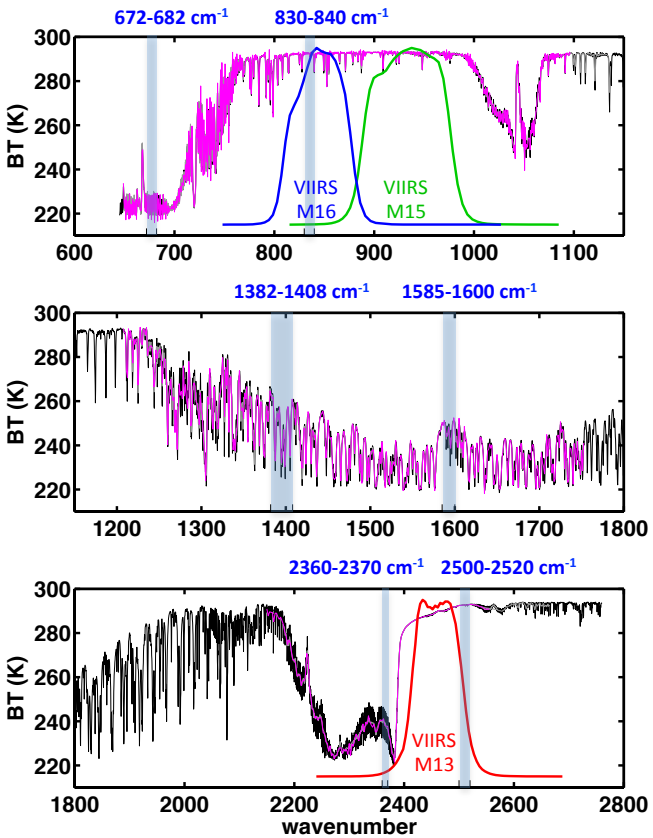
Hamming apodization

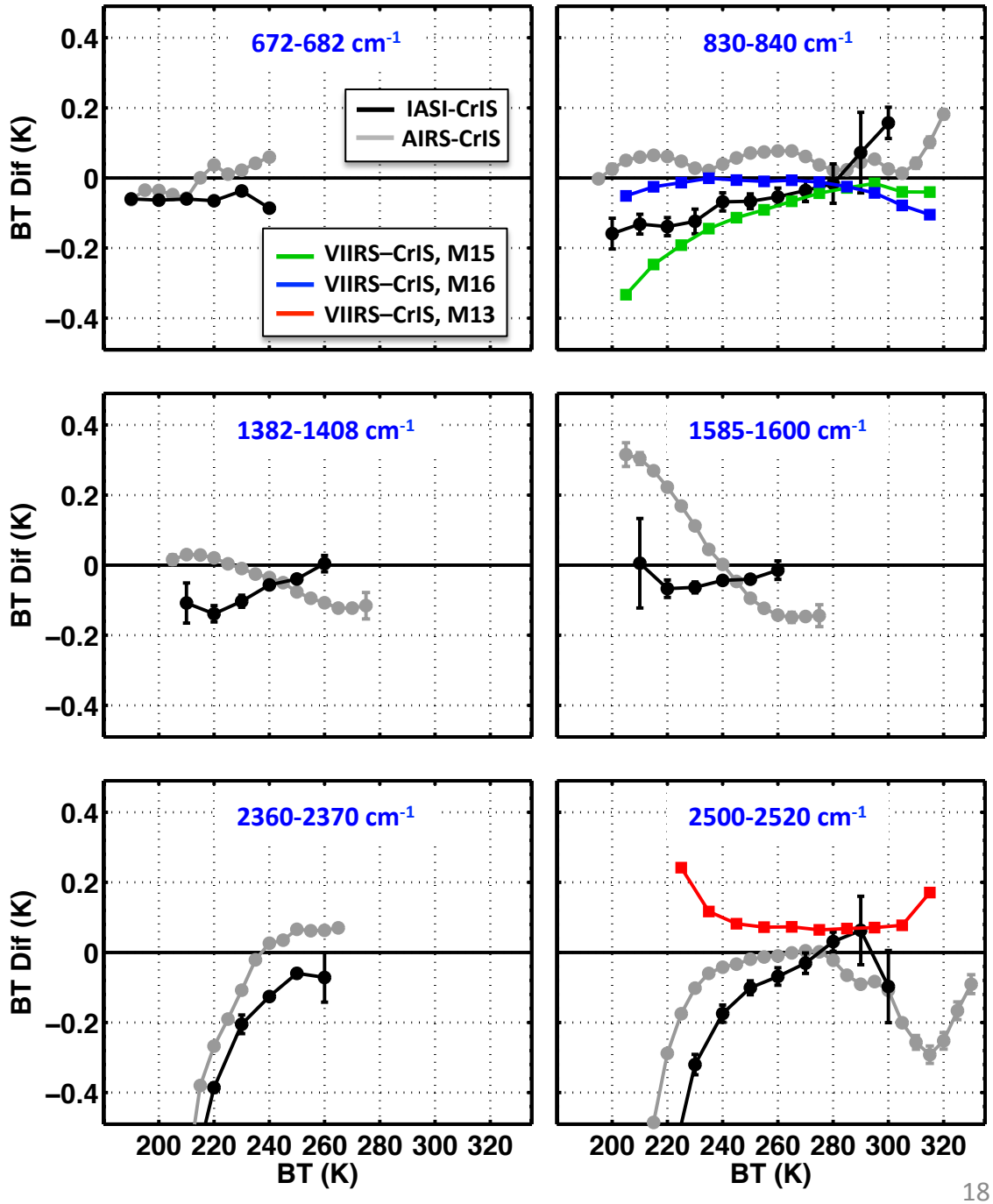
- Results shown for current IDPS processing and with a reprocessed dataset including Nonlinearity and Spectral algorithm/ coefficient refinements to be implemented in IDPS processing this month.
- Differences of ~0.2K or less
- NLC refinements:
  - Improved agreement in the LW band.
  - Negligible changes in the the MW band, as expected.



Summary of SNO results

for 6 representative spectral regions, and VIIRS/CrIS comparisons:



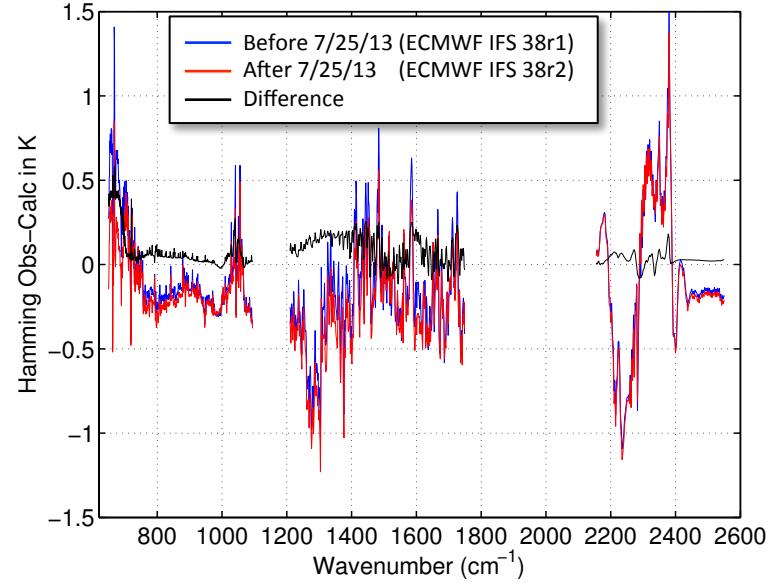


- LW differences display only small dependence on scene BT for both IASI and AIRS SNOs.
- MW differences are relatively independent of scene BT for IASI and for AIRS at 1382-1408 cm^{-1}; Differences for AIRS at 1585-1600 cm^{-1} range from ~+0.3K at 200K to -0.1K at 265K.
- SW differences are relatively flat above ~240K; Below ~230K larger differences between all three sensors are observed.
- Consistent with SNO results reported by L. Strow (UMBC) and L. Wang (NOAA STAR).

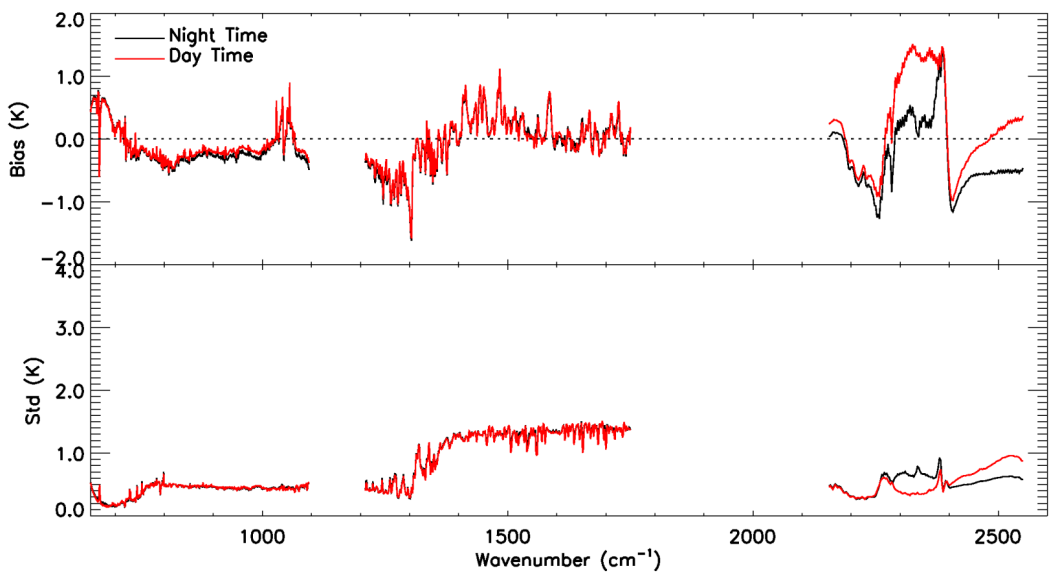
Clear Sky Obs-Calc Analyses

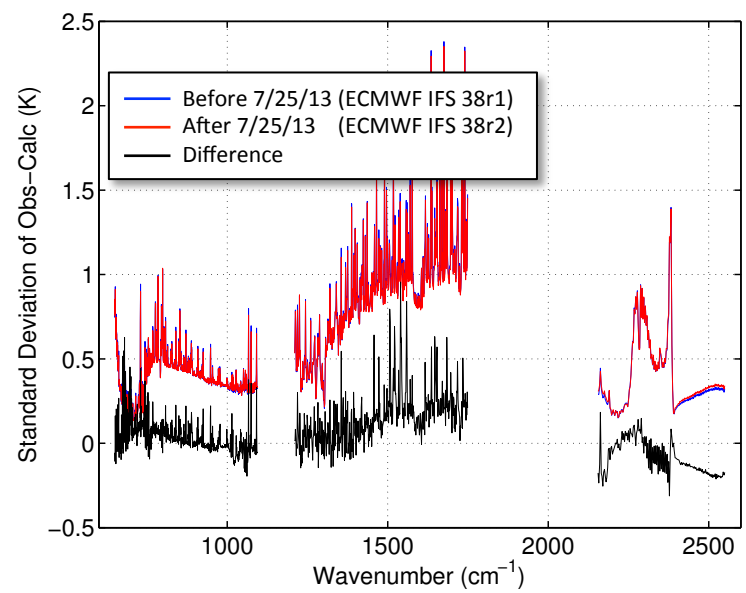
- Behavior of mean biases and standard deviation of obs-calcs are consistent with forward model and atmospheric state uncertainties and imply very good radiometric performance for CrIS.

c/o Larrabee Strow, UMBC:



c/o Yong Chen and Yong Han, NOAA STAR:





Summary, Conclusions

- On-orbit Radiometric Uncertainty (RU) characterized:
  - Based on careful estimation of 3-sigma uncertainties of the primary calibration parameters and perturbation of the radiometric calibration equation
  - Overall RU estimates are < 0.3K (LW), < 0.15K (MW), < 0.15 K (SW)

- CrIS SDRs and RU estimates have undergone extensive verification/evaluation over a range of representative conditions
  - Periodic aircraft underflights provide high quality, SI traceable verification of the CrIS RU
  - CrIS/VIIRS comparisons imply excellent stability of both sensors, and scene BT dependence further characterized and diagnosed
  - SNOs of CrIS/AIRS and CrIS/IASI show excellent mean agreement and behavior with scene temperature
  - Clear sky obs-calcs imply very good CrIS radiometric performance

- Areas of further refinement have been identified and are under investigation
  - Spectral Ringing
  - Polarization
  - Possible low level SW band nonlinearity

➢ **CrIS on Suomi-NPP is providing daily, global high spectral resolution radiance spectra for NWP, Atmospheric State Retrieval, Regional Forecasting, Climate Process and Trend studies, and Intercalibration.**

➢ **Users can refer to these recent efforts to understand the size and dependencies of CrIS RU contributions and the relevance to their particular applications.**