poster 1p.05

CrIS Radiometric Calibration: Uncertainty Estimates and Evaluations

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Introduction

Radiometric Uncertainty (RU) characterization of a sensor dataset describes the various sources of calibration uncertainty and their relevant dependencies. For infrared spectrometers, common examples include the uncertainty in the knowledge of the calibration blackbody temperature and resulting radiance uncertainty as a function of scene temperature, or, the uncertainties in the degree of polarization of a scan mirror and resulting radiance uncertainties as a function of wavelength, scan angle, and scene temperature. RU characterization is required for various applications and is particularly important for climate and intercalibration studies, for sensors being intercalibrated as well as sensors serving as a reference. For high spectral resolution infrared sounders, RU estimates have been provided recently for the Atmospheric Infrared Sounder (AIRS) (Pagano, 2013) and for the Cross-track Infrared Sounder (CrIS) on Suomi-NPP (Tobin, 2013). Here, the CrIS RU results are summarized, and post-launch cal/val efforts to validate the CrIS radiances and RU estimates are presented.

Pagano, T. S., H. H. Aumann, M. Weiler; Lessons learned from the AIRS pre-flight radiometric calibration. Proc. SPIE 8866, Earth Observing Systems XVIII, 88660U (September 23, 2013); doi:10.1117/12.2023810.
Tobin, D., et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, J. Geophys. Res. Atmos., 118, 10,589–10,600, doi:10.1002/jgrd.50809.

Summary and 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)
- Nonlinearity correction algorithm and coefficients refined
  - Provides improved traceability of the nonlinearity coefficients to the TVAC External Calibration Target
  - Refinements reduce overall RU in LW band and reduce FOV dependence in LW and MW bands
  - SDRs reprocessed using NLC (and ILS) refinements and distributed
- 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

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Radiometric Uncertainty Estimates

Simplified On-Orbit Radiometric Calibration Equation:

$$R_{scene} = Re\{(C'_{scene} - C'_{SP}) / (C'_{ICT} - C'_{SP})\}\, R_{ICT} \quad \text{with:}$$

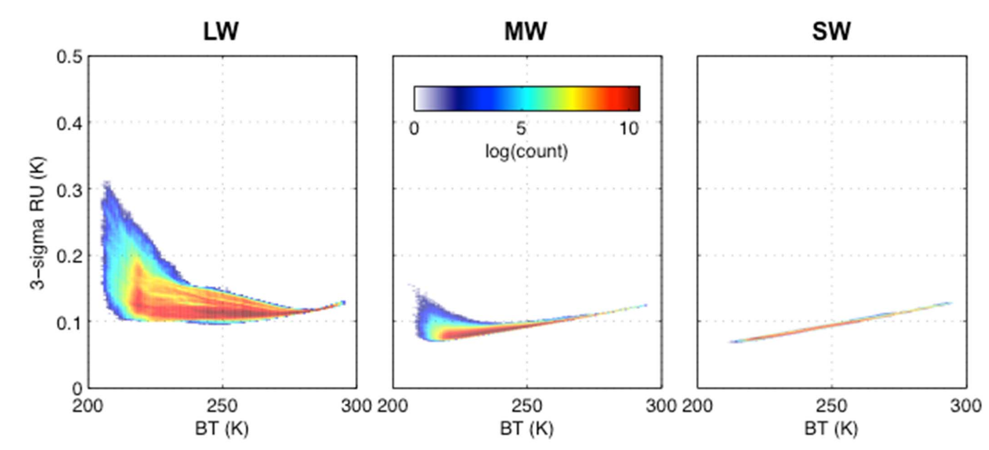
Nonlinearity Correction: $C' = C \cdot (1 + 2\, a_2 V_{DC})$

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

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}

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



- Uncertainties are greatly reduced due to re-analysis of the TVAC data and on-orbit FOV-2-FOV analysis. In particular, MW band uncertainties are greatly reduced due to the high degree of linearity of MW reference FOV9.
- Overall, RU is <0.3K (LW), <0.15K (MW), <0.15K (SW): Better than spec by approximately a factor of 4.

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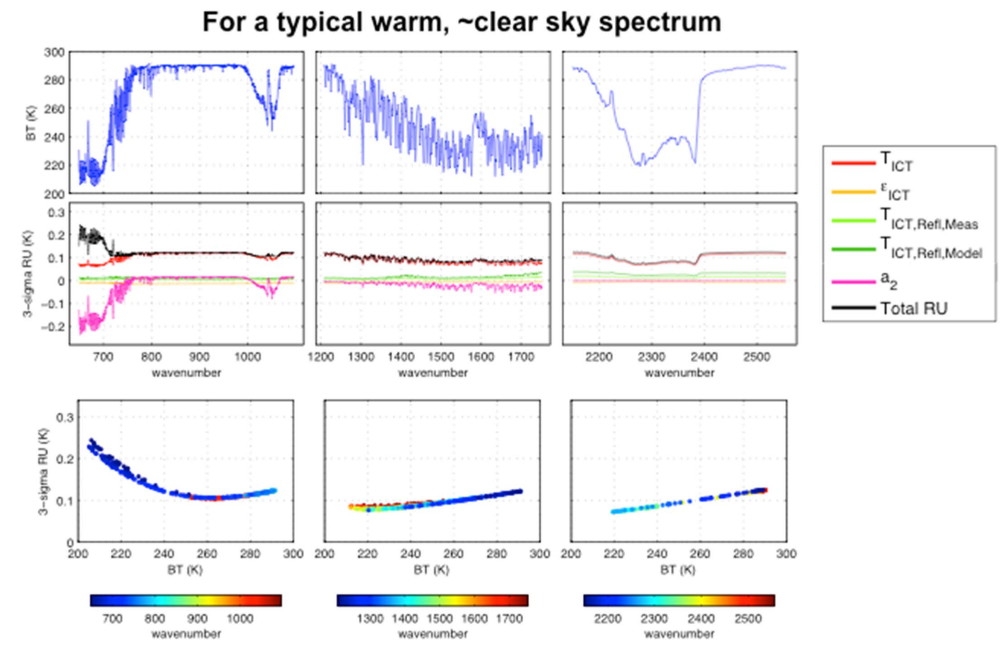
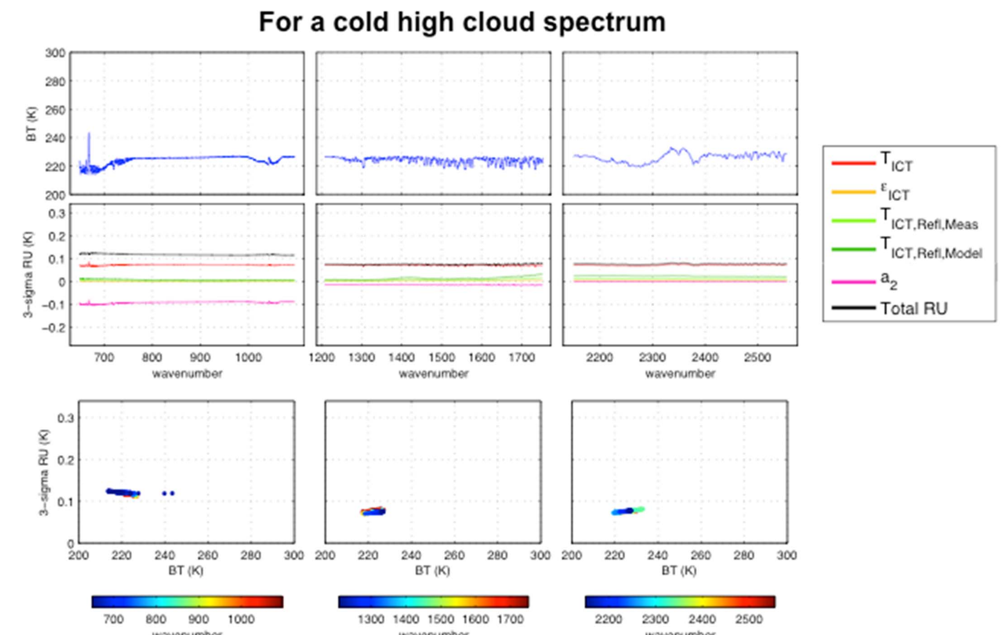
Example 3-sigma RU estimates

For a typical warm, ~clear sky spectrum



For a cold high cloud spectrum



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Other Terms

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

- Spectral Ringing
- Polarization
- Possible SW Nonlinearity

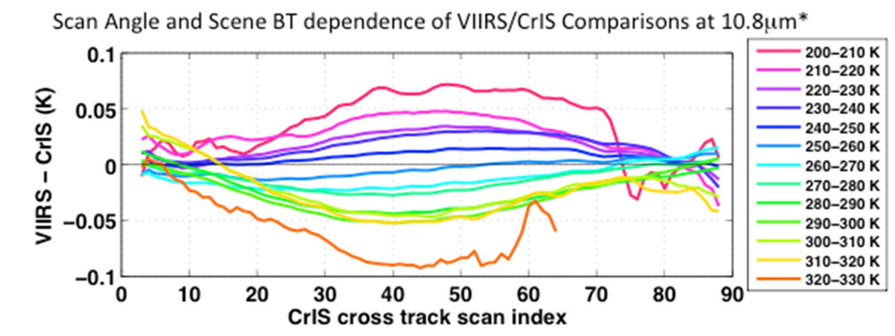
(Discussed below)

- Other smaller/negligible terms:
  - Detector temperature changes, Changes in DA Bias tilt over 4 minut 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

Error from Scene Mirror Induced Polarization

- CrIS uses a 45° gold scene mirror that provides low sensitivity to polarization; no correction is included in the SDR algorithm/processing.
- However, it seems almost certain that CrIS should have polarization effects of ~0.1 K for especially warm and cold brightness temperatures in some spectral regions.
- A correction should be developed based on CrIS characterization tests yet to be conducted (measurements of scene mirror degree of polarization, p_r, and interferometer polarization sensitivity, p_t)
- Radiance error dependence ~$2 p_r p_t\, (N - B_{ICT})$
- Suggestions of this type of behavior in CrIS/VIIRS comparisons vs. scan angle:

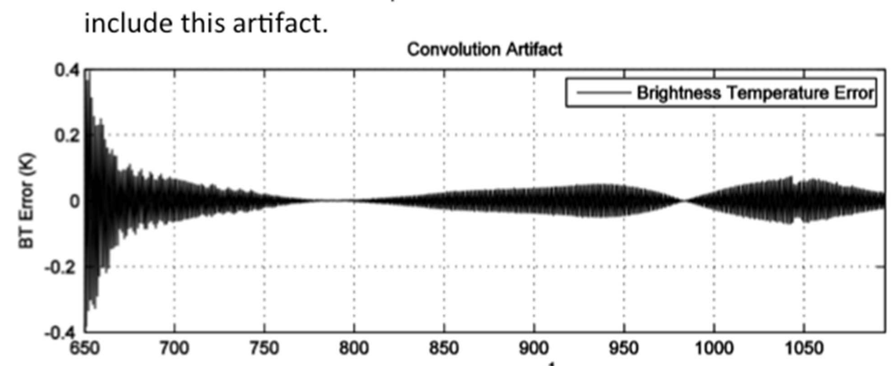
Scan Angle and Scene BT dependence of VIIRS/CrIS Comparisons at 10.8μm*



* Biases removed for mean of INDICES 1-10 & 80-90

Spectral Ringing

- For the large majority of spectral channels, the associated artifacts are very small, and with apodization are negligible everywhere.
- Root Cause was recently determined: on-board application of the FIR filter to the raw interferograms is done in a non-cyclical fashion violating the Convolution Theorem.
- An accurate software fix is possible and has been demonstrated with a small sample of data. Modifications to the calibration software is under development and future CrIS data will not include this artifact.



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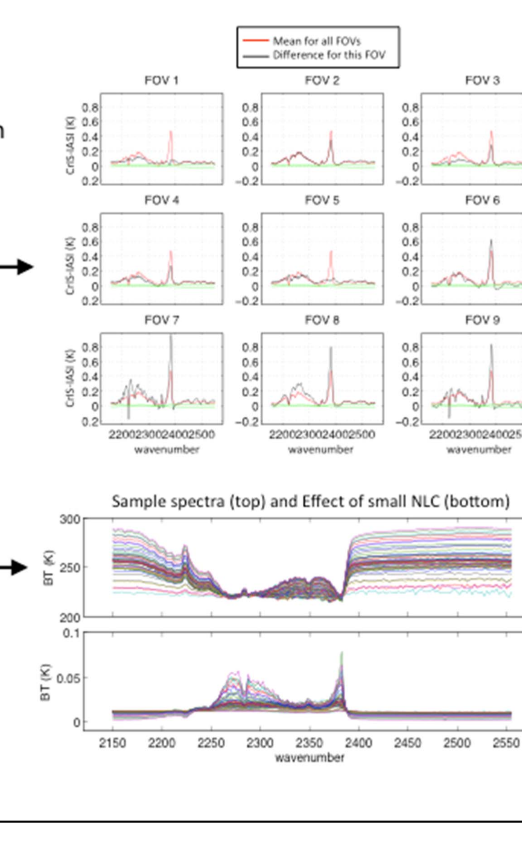
SW Band Biases

FOV-2-FOV analyses and differences with respect to other sensors suggest small artifacts in the SW band, both in Mean biases and FOV-2-FOV differences.

E.g. Differences with respect to IASI →

Mechanisms investigated to date:

- Spectral shift
- Thermal SP view contamination
- Solar SP view contamination
- Noise
- Polarization
- Low level Nonlinearity →
  - Displays FOV dependent behavior
  - Has plausible spectral and scene level dependencies



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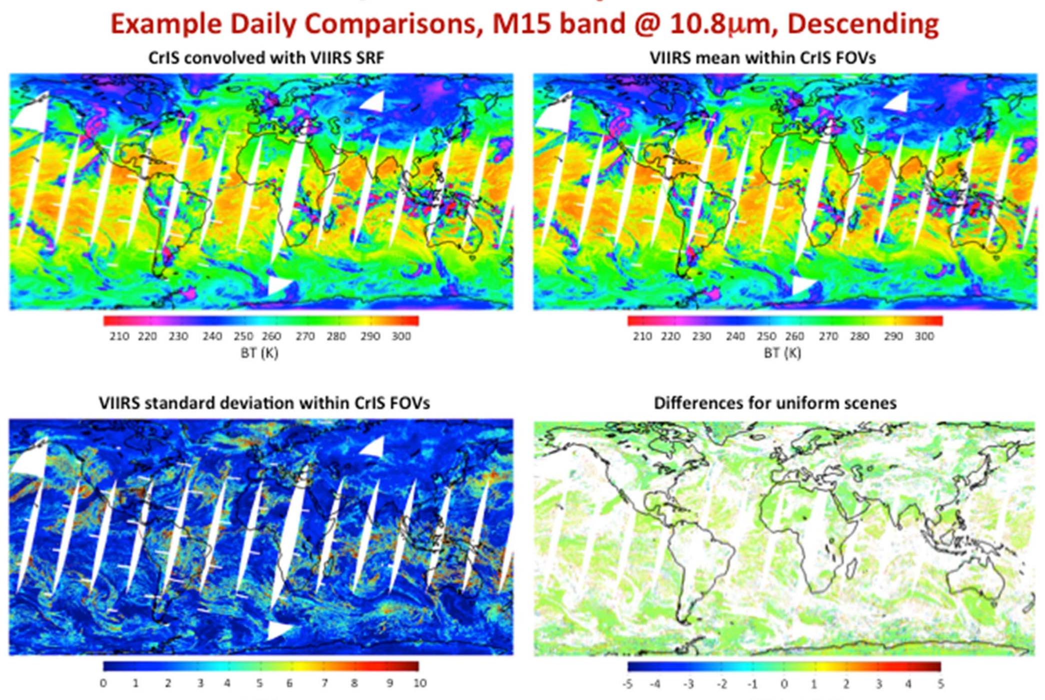
CrIS/VIIRS comparisons

Example Daily Comparisons, M15 band @ 10.8μm, Descending



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

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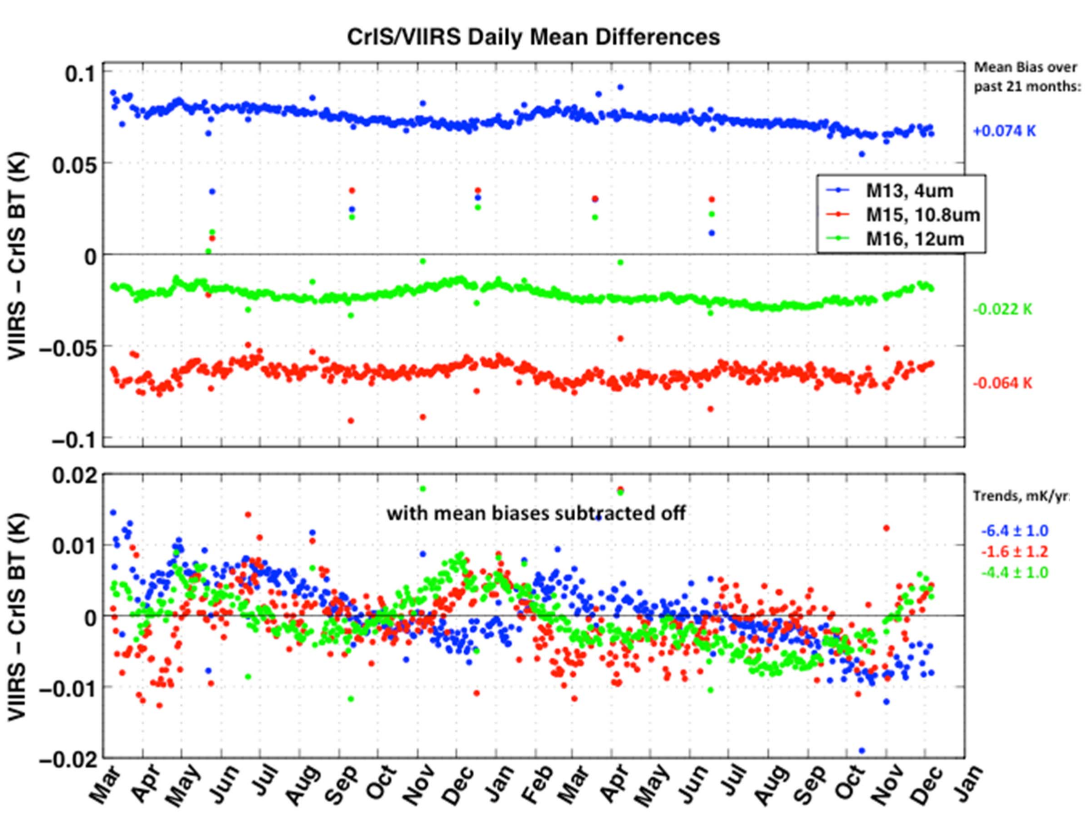
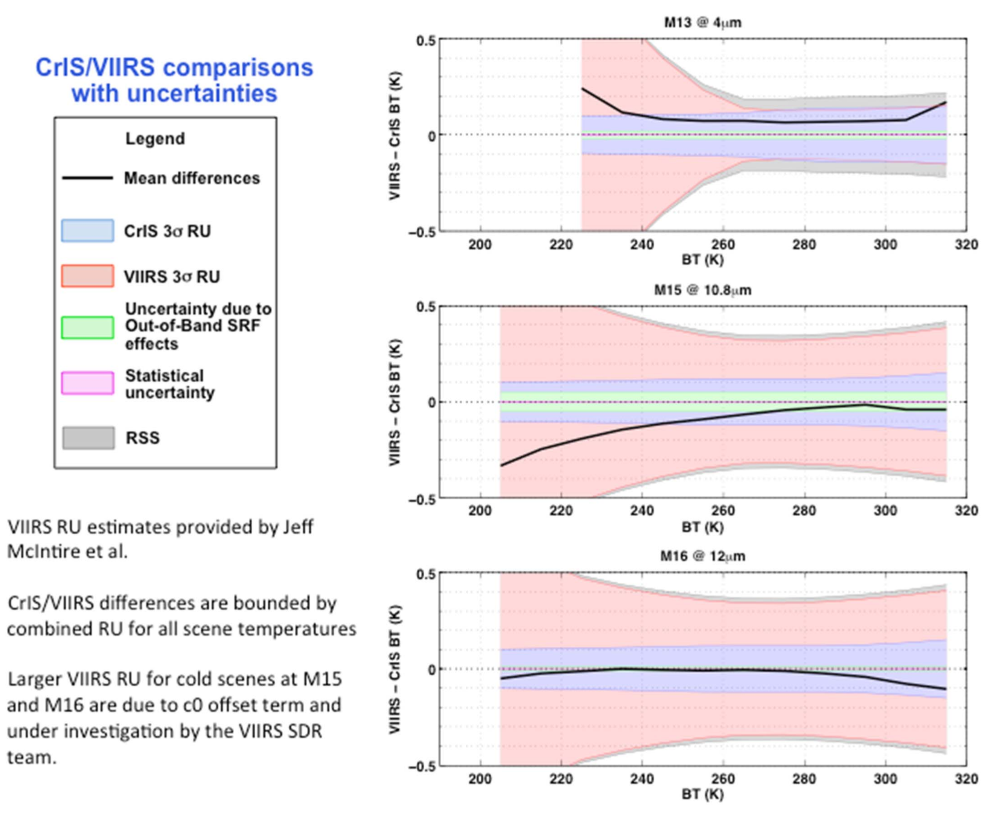
CrIS/VIIRS Daily Mean Differences



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

CrIS/VIIRS comparisons with uncertainties



- VIIRS RU estimates provided by Jeff McIntire et al.
- CrIS/VIIRS differences are bounded by combined RU for all scene temperatures
- Larger VIIRS RU for cold scenes at M15 and M16 are due to c0 offset term and under investigation by the VIIRS SDR team.

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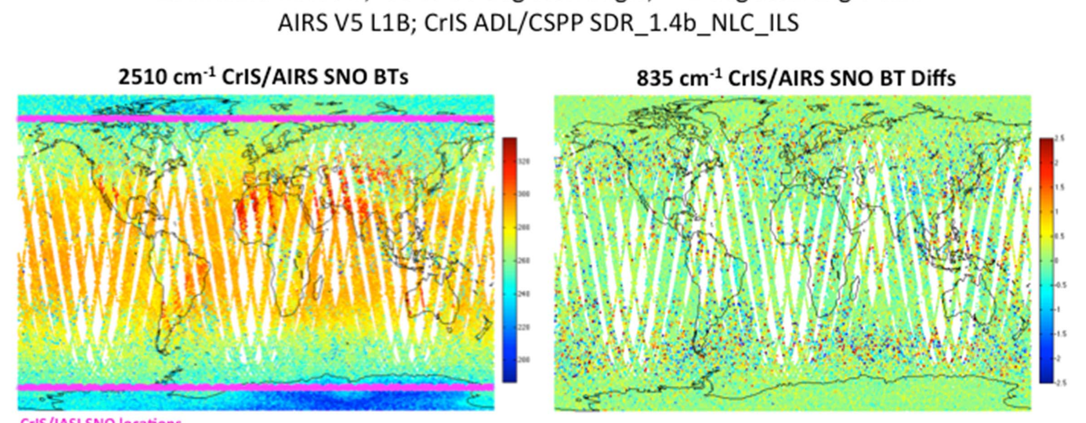
SNO Datasets

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



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

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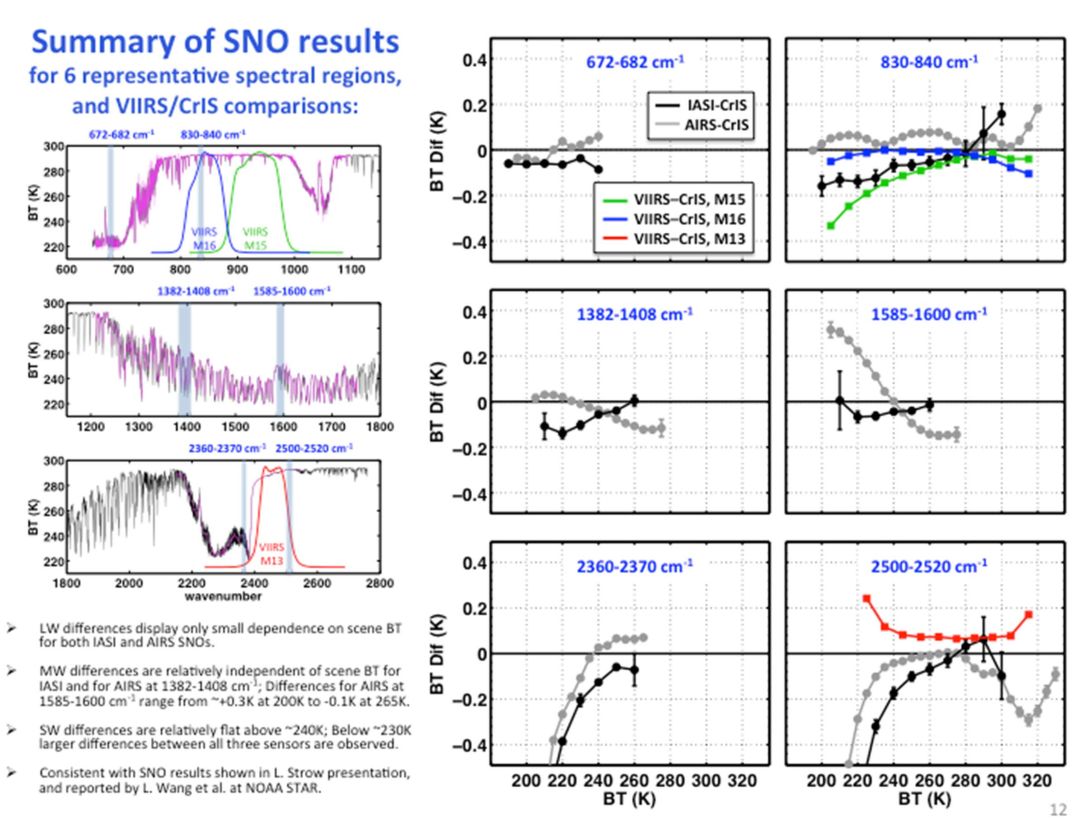
Summary of SNO results

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 shown in L. Strow presentation, and reported by L. Wang et al. at NOAA STAR.

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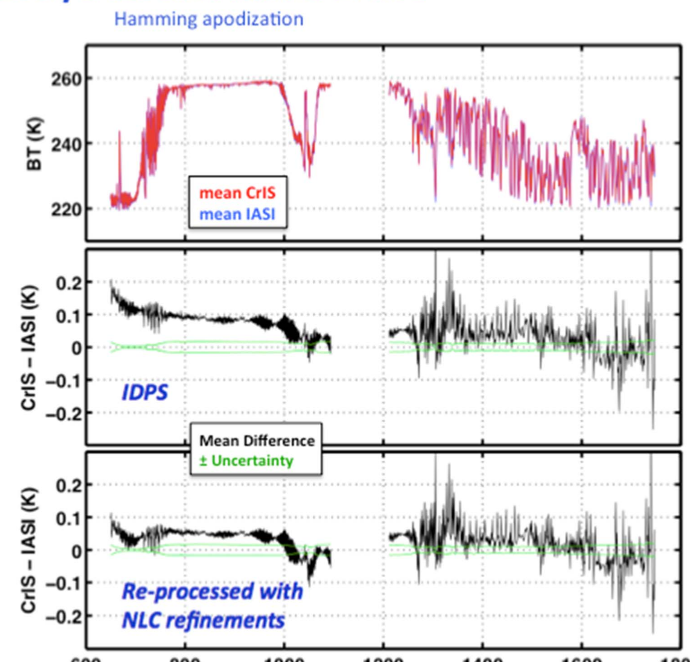
CrIS/IASI Northern SNOs

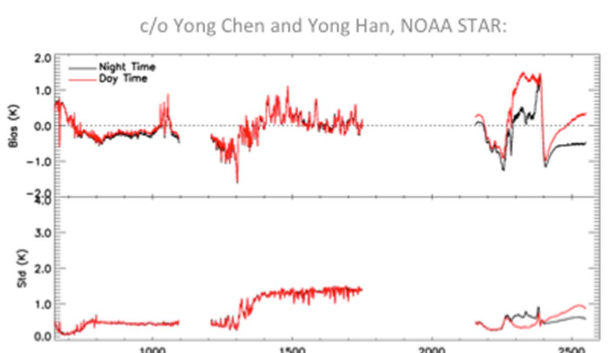
- Results shown for IDPS processing and with the reprocessed dataset including the NLC refinements presented earlier.
- Differences of ~0.2K or less
- NLC refinements:
  - Improved agreement in the LW band.
  - Negligible changes in the MW band (as expected).



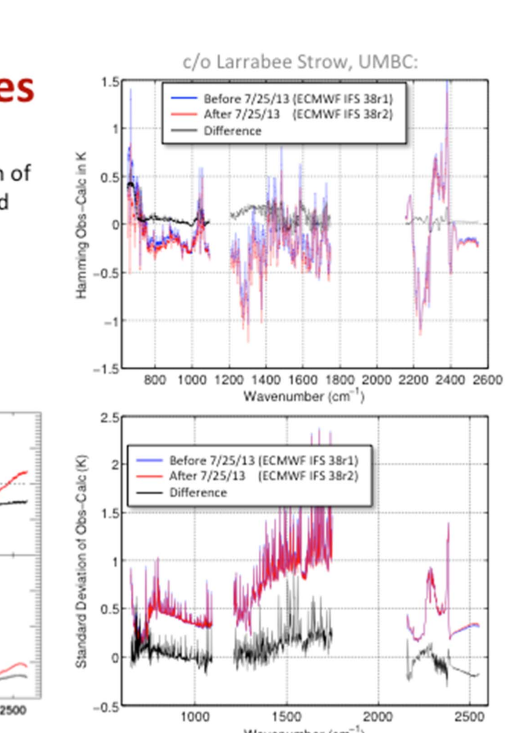
Clear Sky Obs-Calc Analyses

- 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 Yong Chen and Yong Han, NOAA STAR:



c/o Larrabee Strow, UMBC:



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