Validation of MTG observed spectra by comparison to LEO hyperspectral sounders

"Can we Validate GEO observed spectra by comparison to LEO hyper-spectral sounders?"

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Workshop on Assimilation of Hyper-spectral Geostationary Satellite Observations
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ECMWF

Outline

1. **Hyperspectral LEO accuracy for intercalibration (mainly CrIS) and Leo/Leo Intercal examples**

2. **GSICS GEO/LEO methodology and products**

3. **Example AHI/CrIS comparisons**

4. **The Absolute Radiance Interferometer (ARI) and CLARREO**

5. **Other Thoughts**

Suomi-NPP CrIS Radiometric Uncertainty Estimate

(Differential error analysis of the calibration equation, aimed at providing a useful estimate of the absolute accuracy of the mean of a large ensemble of observations. Input parameter uncertainties are based on the design of the sensor and engineering estimates of the calibration parameters; i.e. no external information via external "Cal/Val" used.)

Simplified On-Orbit Radiometric Calibration Equation:

$$R_{Earth} = \mathit{Re}\{(C'_{Earth} - C'_{Space}) / (C'_{ICT} - C'_{Space})\} R_{ICT} \quad \text{with:}$$

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

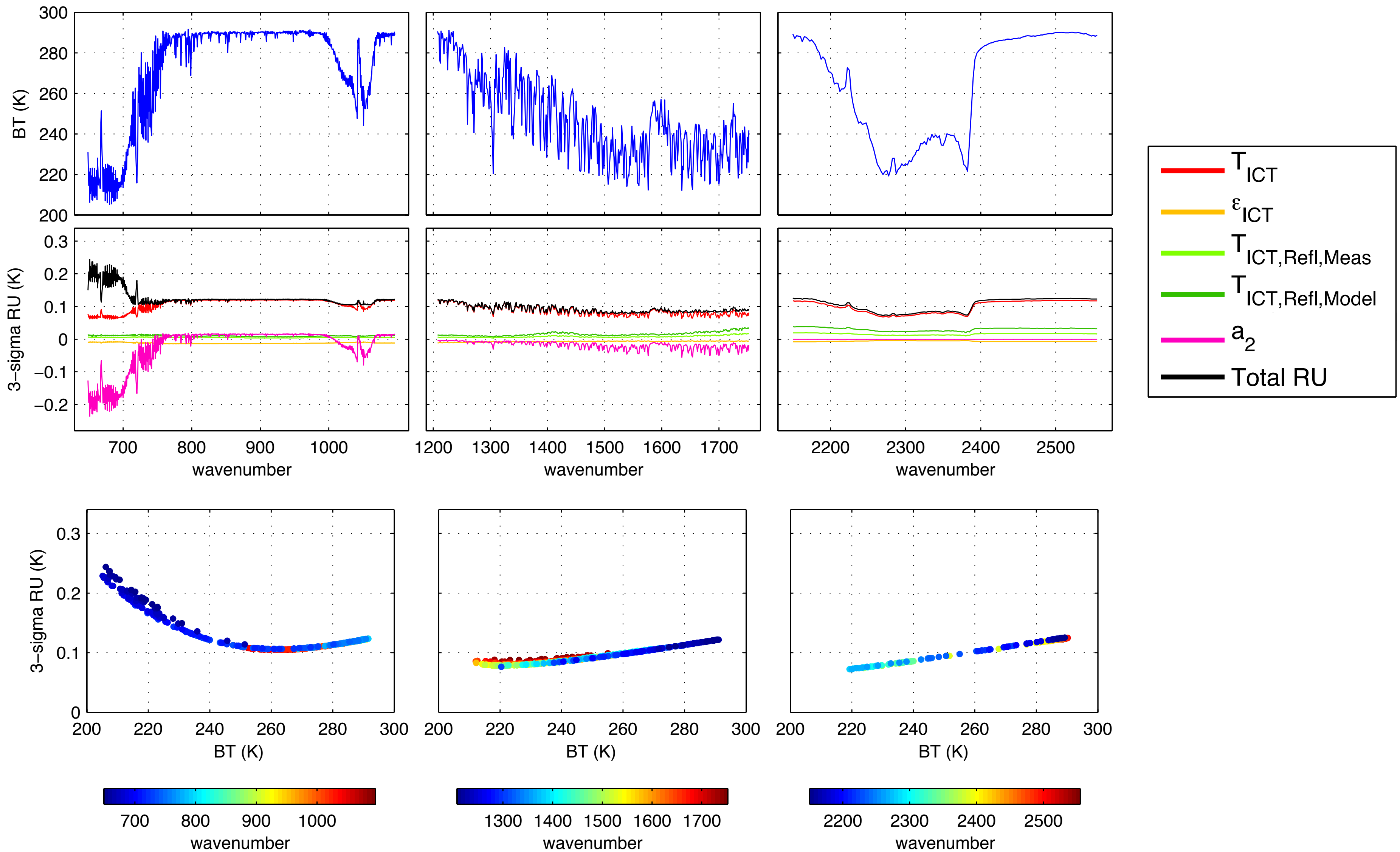
ICT Predicted Radiance: $R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, [\, 0.5\, B(T_{ICT,\ Refl,\ Measured}) + 0.5\, B(T_{ICT,\ Refl,\ Modeled})]$

Parameter Uncertainties:

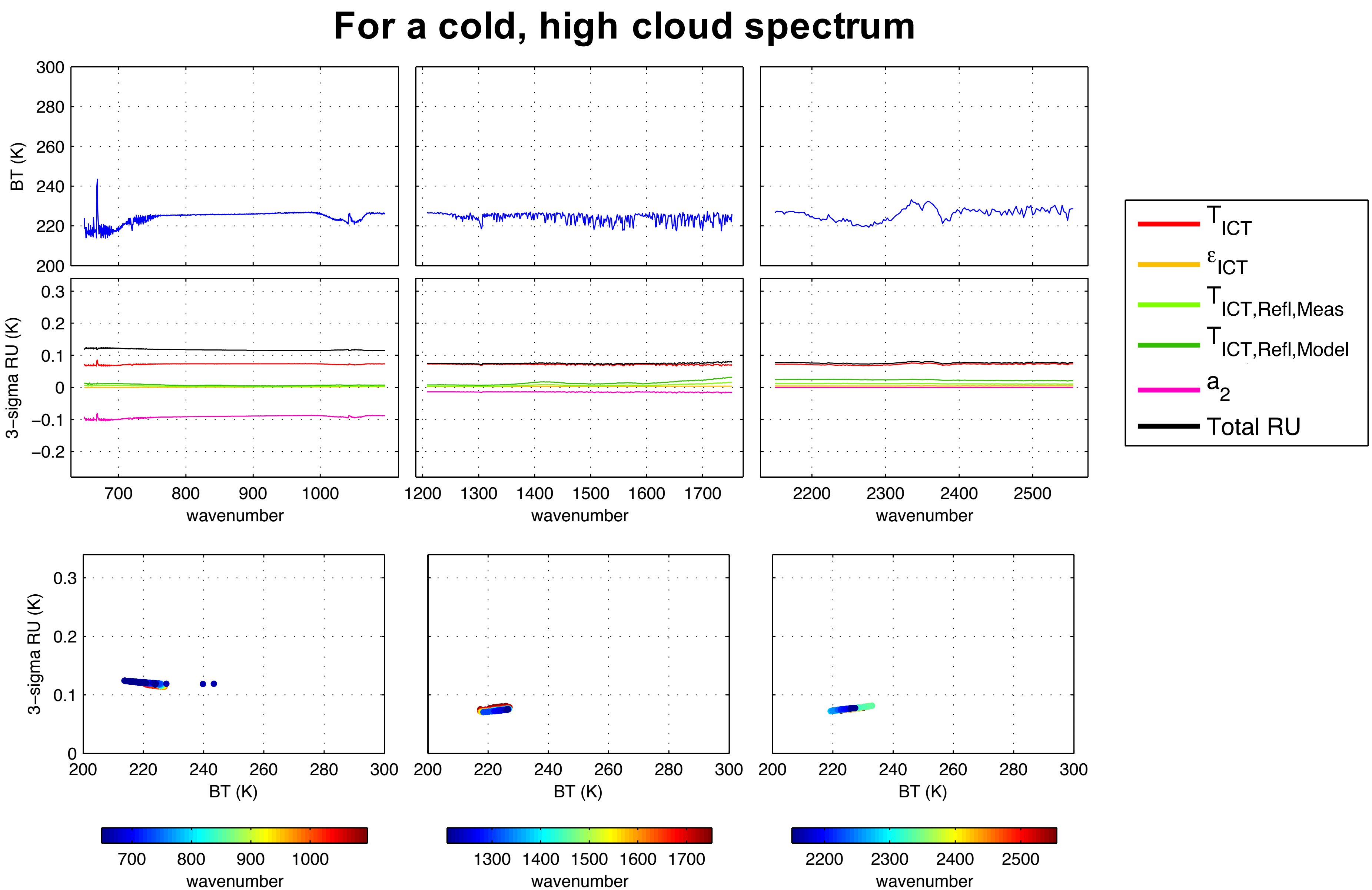
Parameter	Nominal Values	3-σ Uncertainty
T_{ICT}	280K	112.5 mK
ε_{ICT}	0.974-0.996	0.03
$T_{ICT,\ Refl,\ Measured}$	280K	1.5 K
$T_{ICT,\ Refl,\ Modeled}$	280K	3 K
a_2 LW band	0.01 – 0.03 V^{-1}	0.00403 V^{-1}
a_2 MW band	0.001 – 0.12 V^{-1}	0.00128 – 0.00168 V^{-1}

Example 3-sigma RU estimates

For a typical warm, ~clear sky spectrum



Example 3-sigma RU estimates

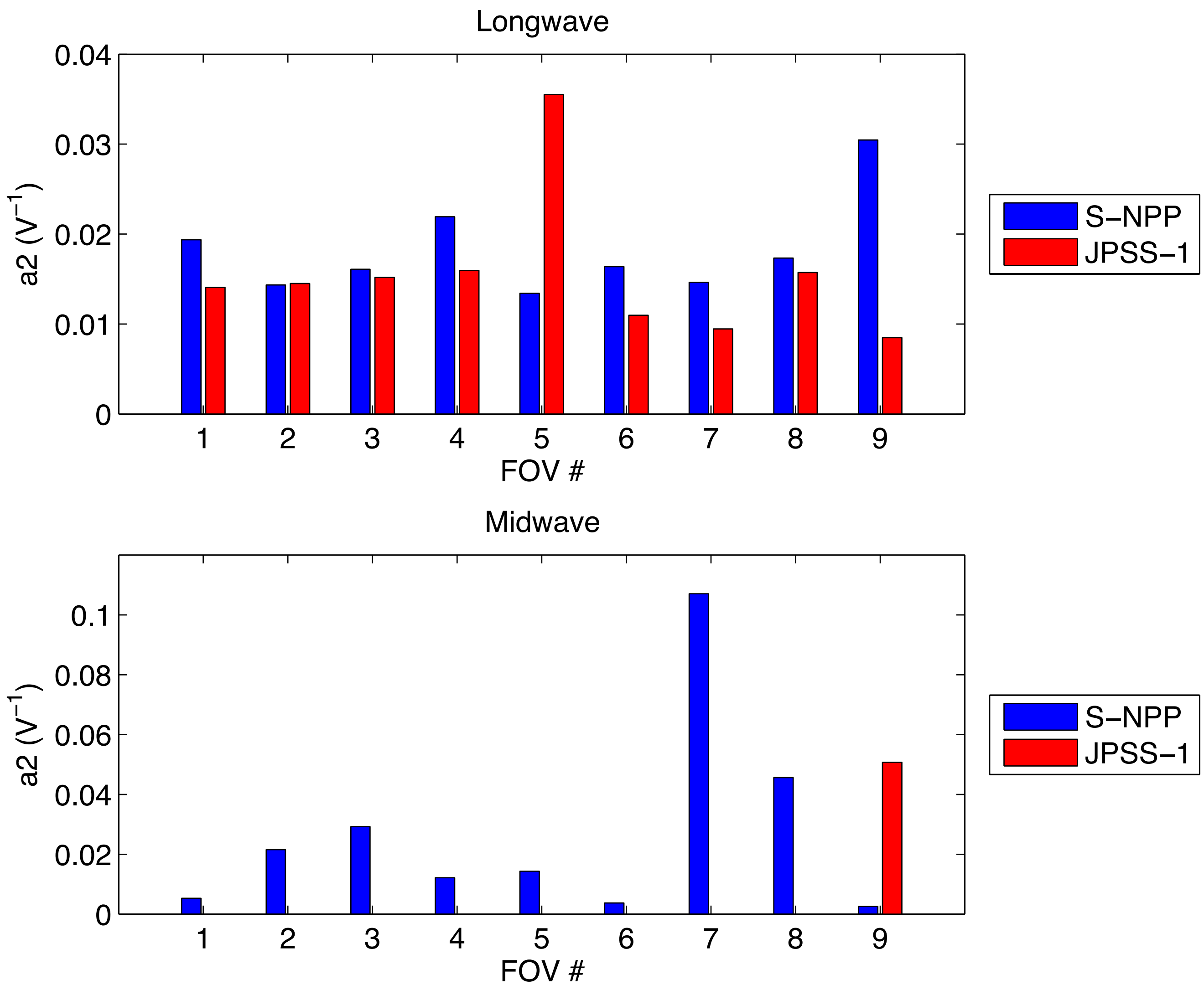


Recent CrIS calibration algorithm/parameter investigations

- MW FOV7 nonlinearity
- Scene mirror induced polarization
- “Spectral Ringing” for unapodized spectra
  - “True” ringing
  - On-board FIR filtering
  - Self-apodization corrections
  - Spectral/Radiometric order of calibration operations
- T_{ICT} uncertainty
  - Current values are too large because axial gradients are overestimated in current analyses. Results in change from 112 mK to ~88 mK 3-sigma.

JPSS-1 Calibration Accuracy is very similar to Suomi-NPP CrIS

Main differences are: 1) Improved ICT emissivity, and 2) Different Nonlinearity magnitudes:

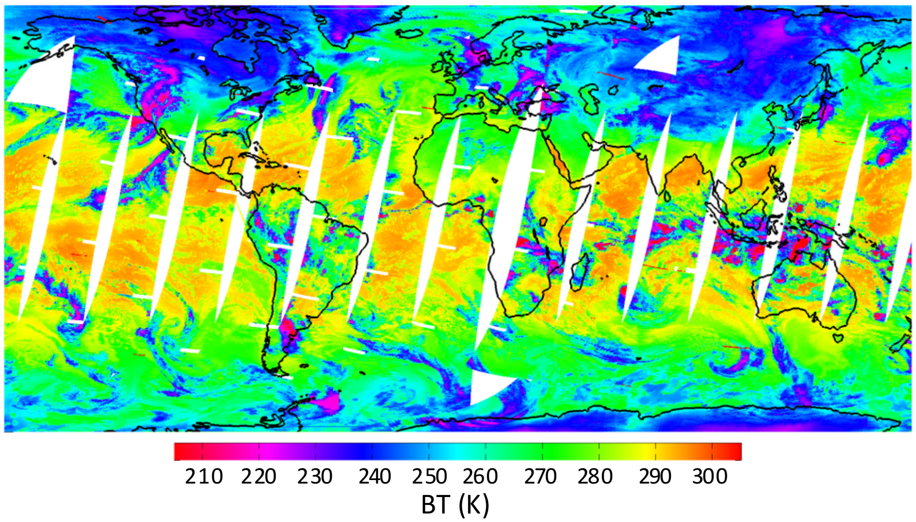


Leo/Leo Intercal examples

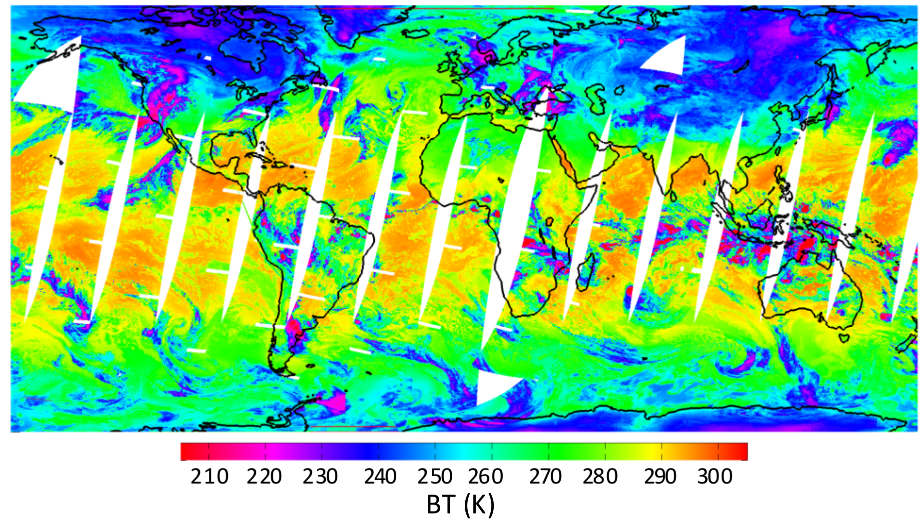
CrIS/VIIRS comparisons

Example Daily Comparisons, M15 band @ 10.8μm, Descending

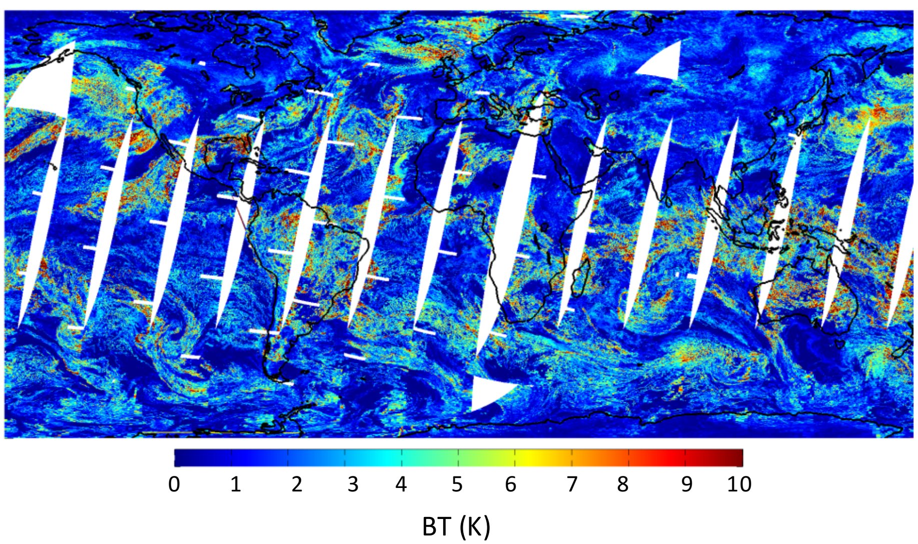
CrIS convolved with VIIRS SRF



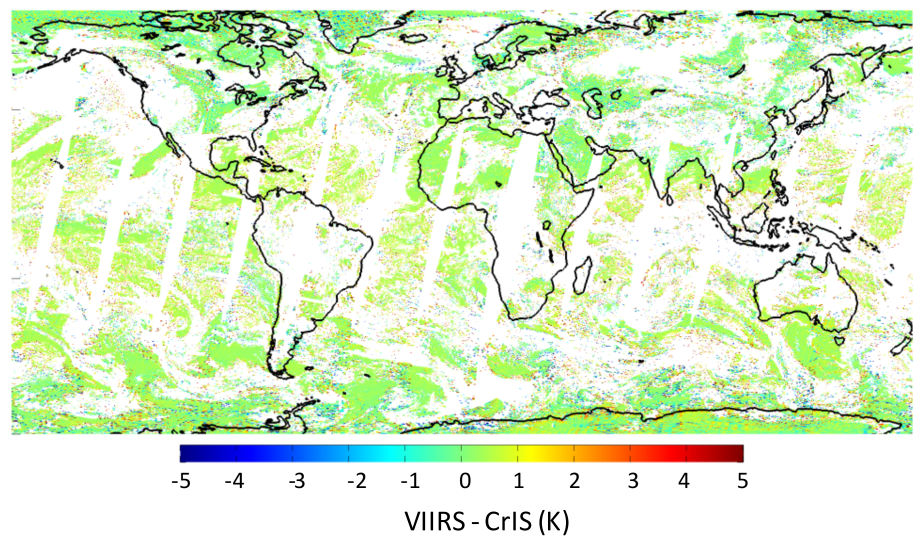
VIIRS mean within CrIS FOVs



VIIRS standard deviation within CrIS FOVs

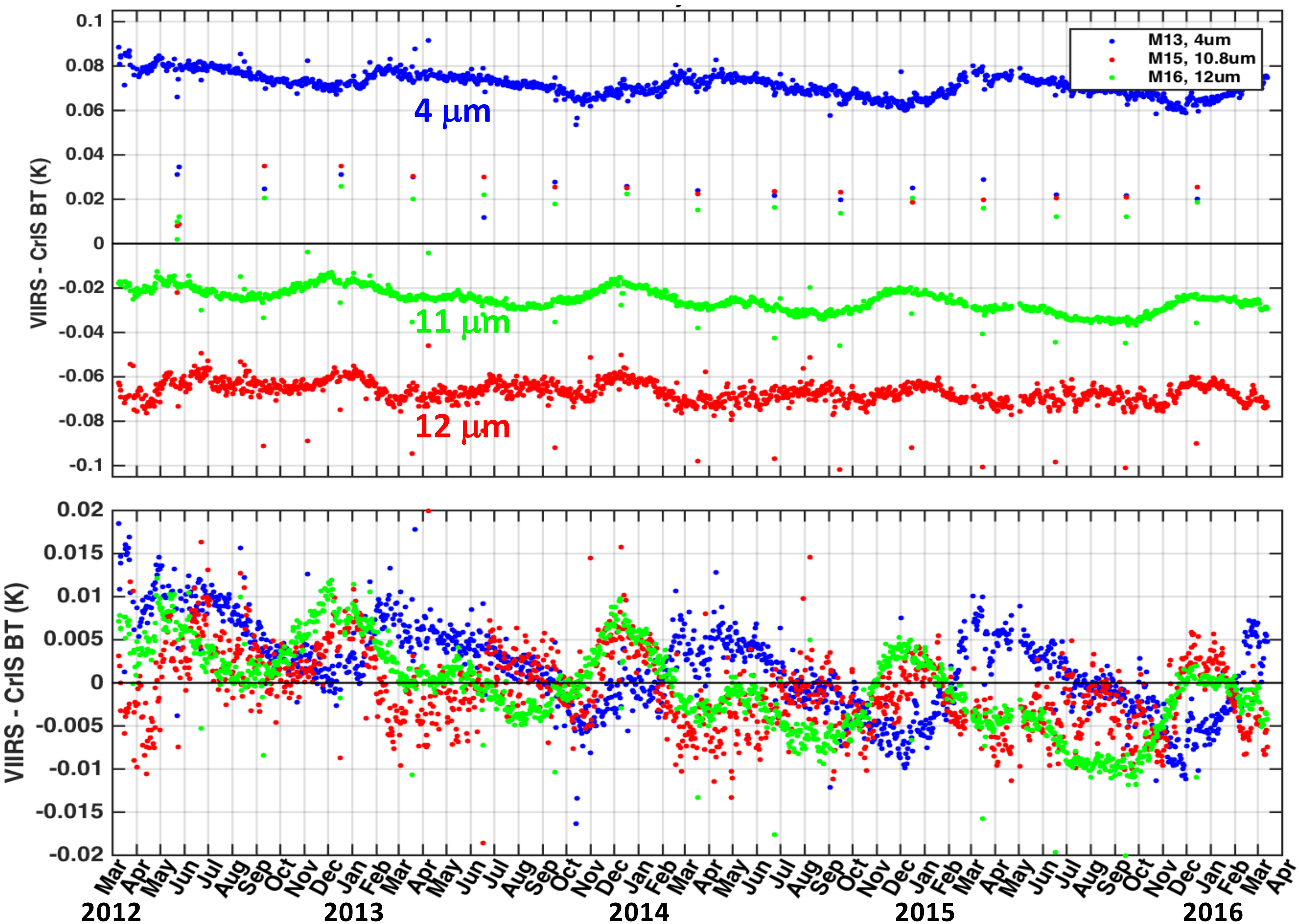


Differences for uniform scenes



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

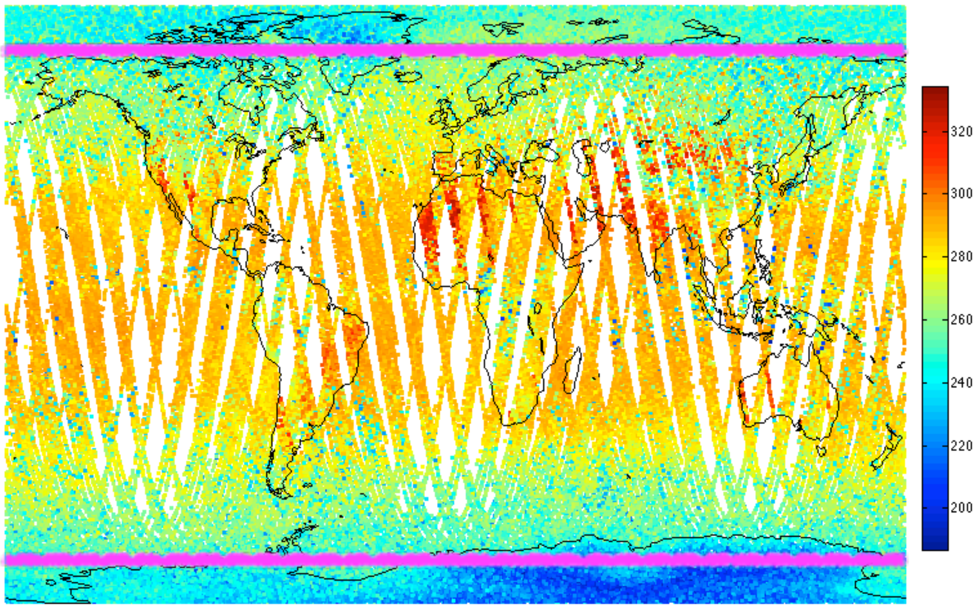
CrIS/VIIRS BT differences show trends of less than 2 mK/yr



SNO Datasets

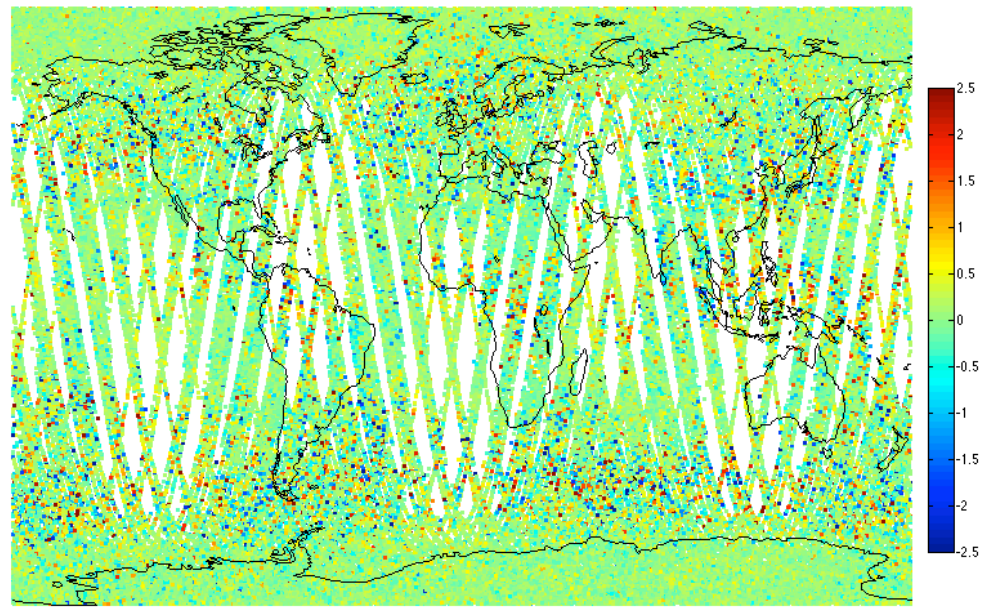
CrIS/AIRS: ~12M "Big Circle" SNOs collected to date;
20 minute window; -30 to 30 deg scan angle, <=2 deg scan angle diff.

2510 cm⁻¹ CrIS/AIRS SNO BTs



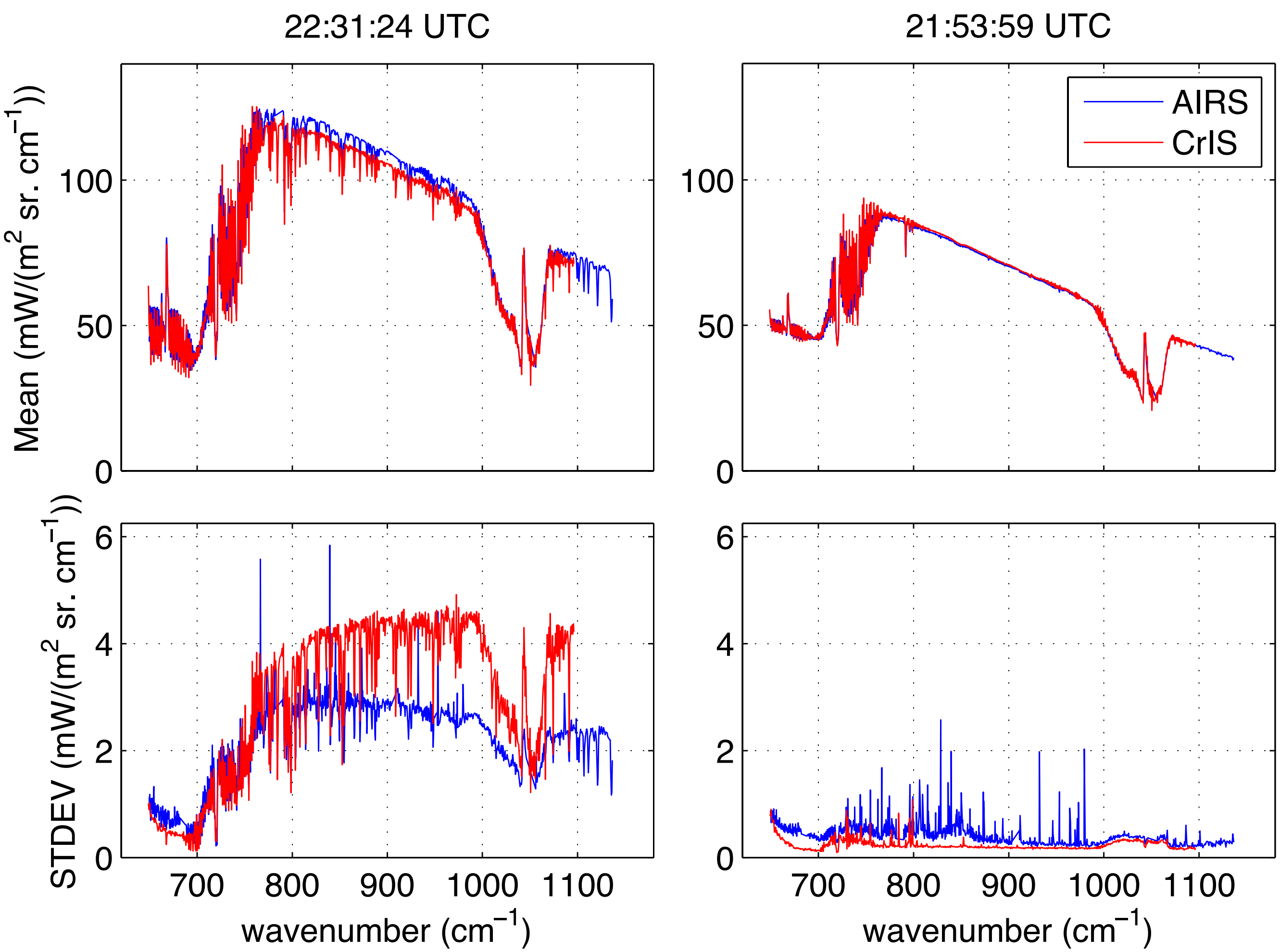
CrIS/IASI SNO locations

835 cm⁻¹ CrIS/AIRS SNO BT Diffs



CrIS/IASI-A: ~50,000 "Big Circle" SNOs collected to date;
20 minute window; nadir. ~20 days of coincidences, ~30 day gaps,
~half at +72.4 deg, ~half at -72.4 deg.

AIRS/CrIS SNOs, 2 examples

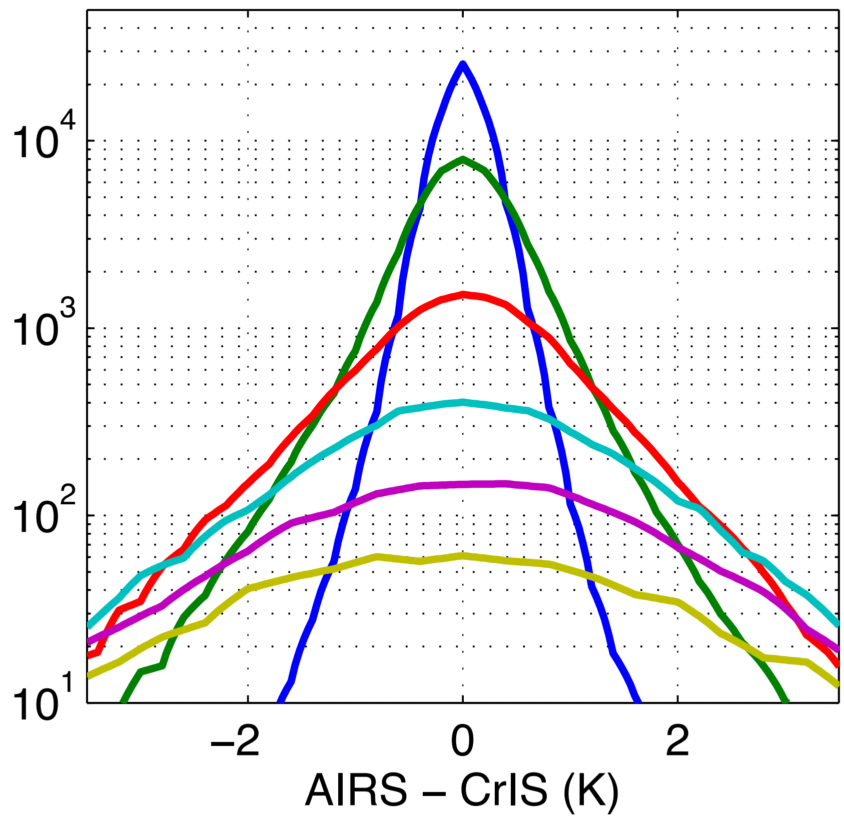


50 km radius "big circle" SNOs

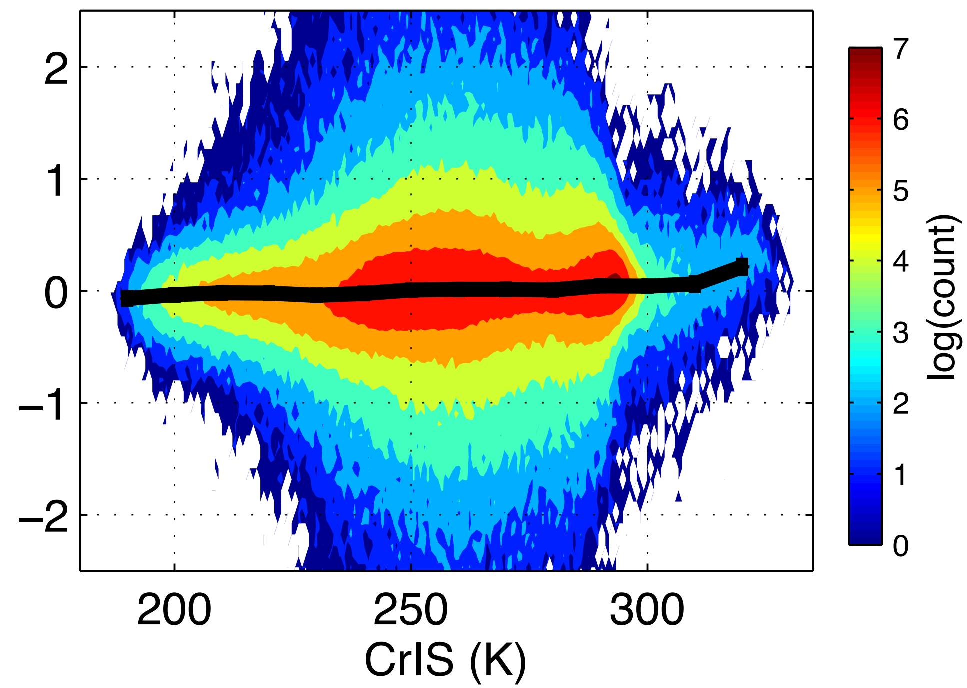
Observed spatial variability is a very good indicator of the quality of the SNO

AIRS/CrIS SNOs @ 900 cm^{-1}

SNO differences (AIRS-CrIS) for 6 spatial variability bins

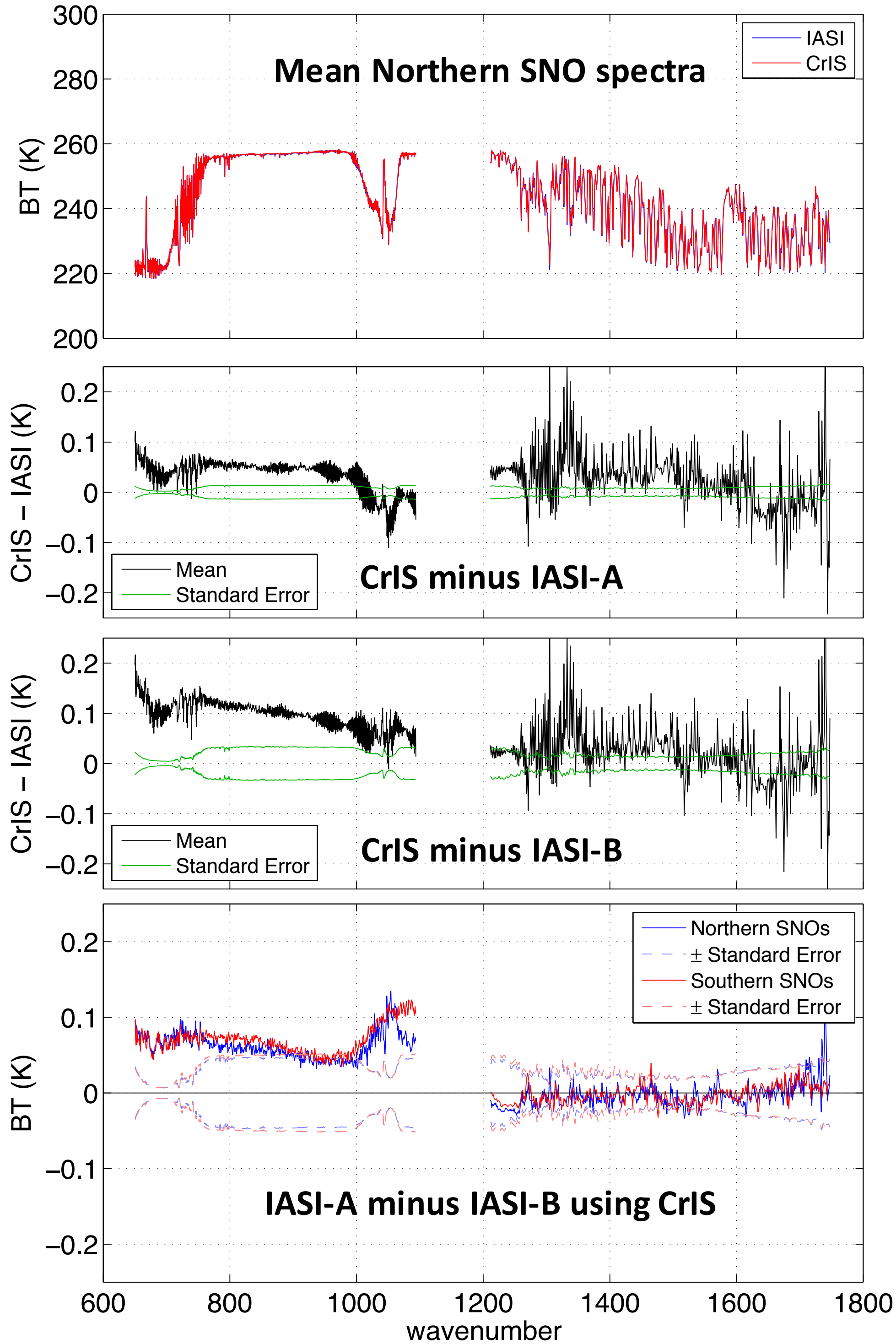


AIRS-CrIS (K) differences as a function of scene temperature



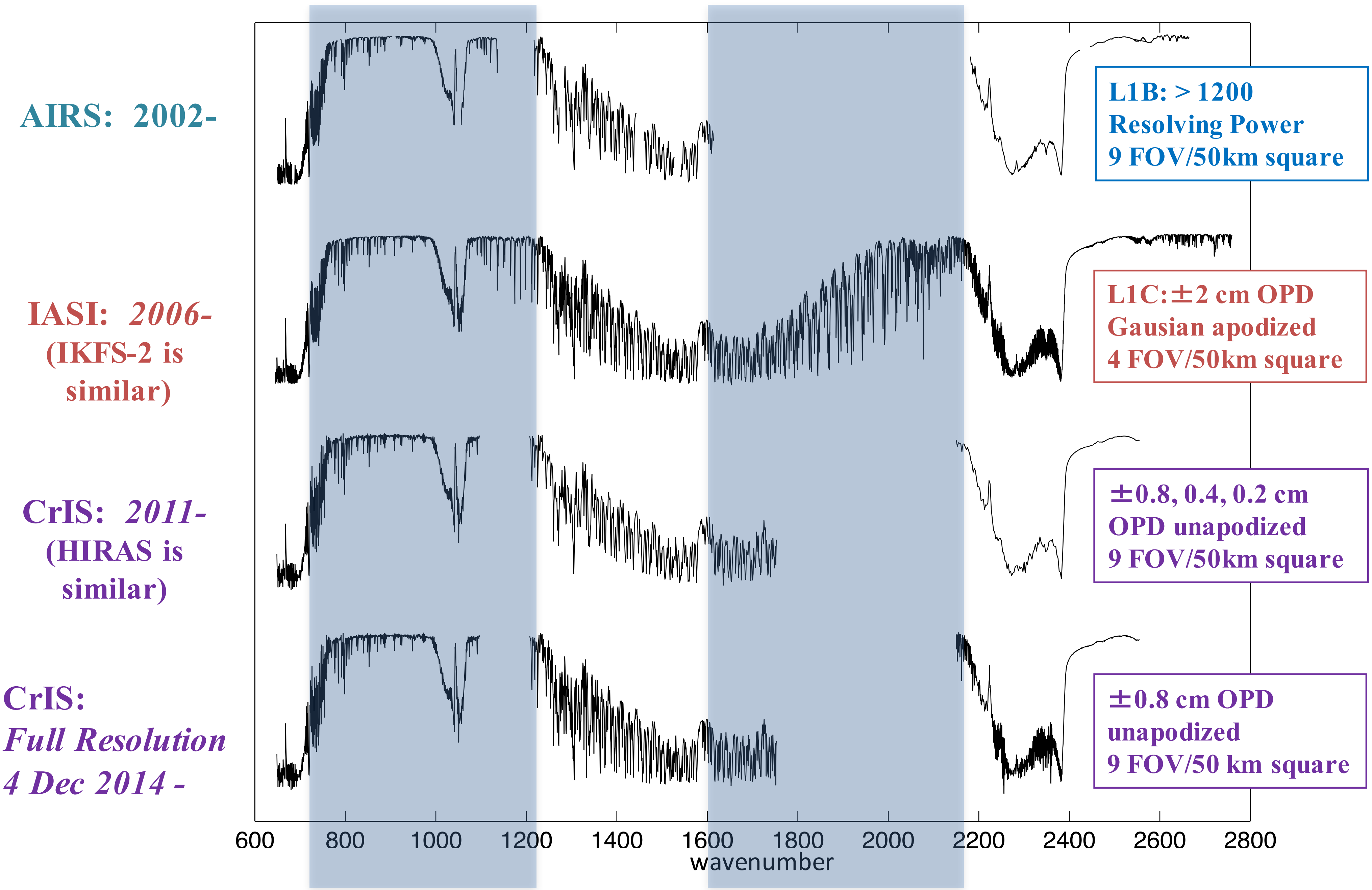
IASI-A, CrIS, IASI-B Comparisons

(on CrIS spectral scale and resolution with Hamming apodization)

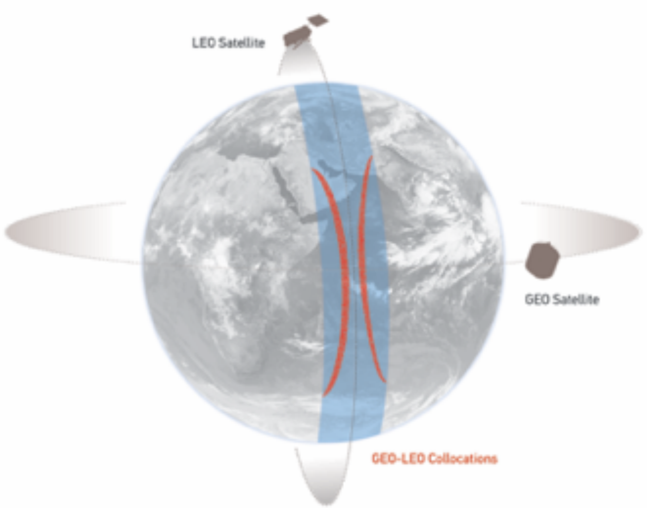


Geo/Leo Intercal examples

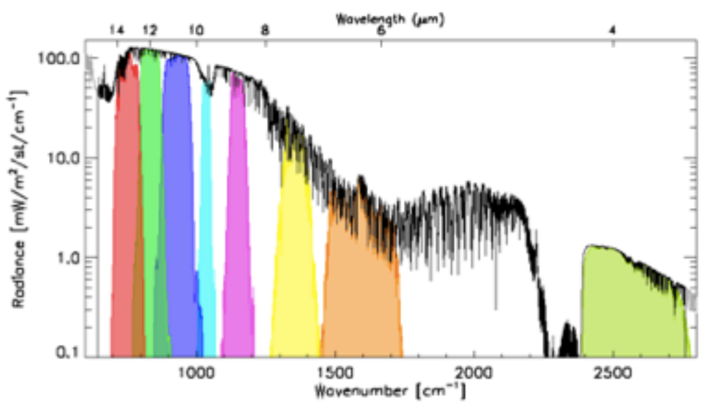
LEO coverage of MTG-IRS spectral bands



GEO-LEO IR - Hyperspectral SNO



Schematic illustration of the geostationary orbit (GEO) and polar low Earth orbit (LEO) satellites and distribution of their collocated observations.



Example radiance spectra measured by IASI (black), convolved with the Spectral Response Functions of SEVIRI channels 3-11 from right to left (colored shaded areas).

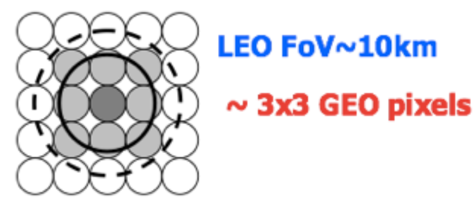
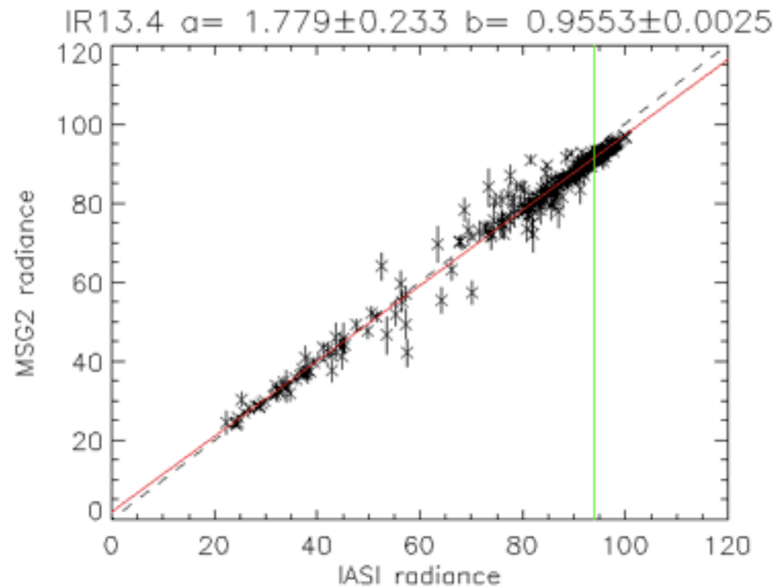


Illustration of spatial transformation.
Small circles represent the GEO FoVs and the two large circles represent the LEO FoV for the extreme cases of FY2-IASI, where nxm=3x3 and SEVIRI-IASI, where nxm=5x5.

GSICS Global Space-based Inter-Calibration System

GEO-LEO IR - Hyperspectral SNO

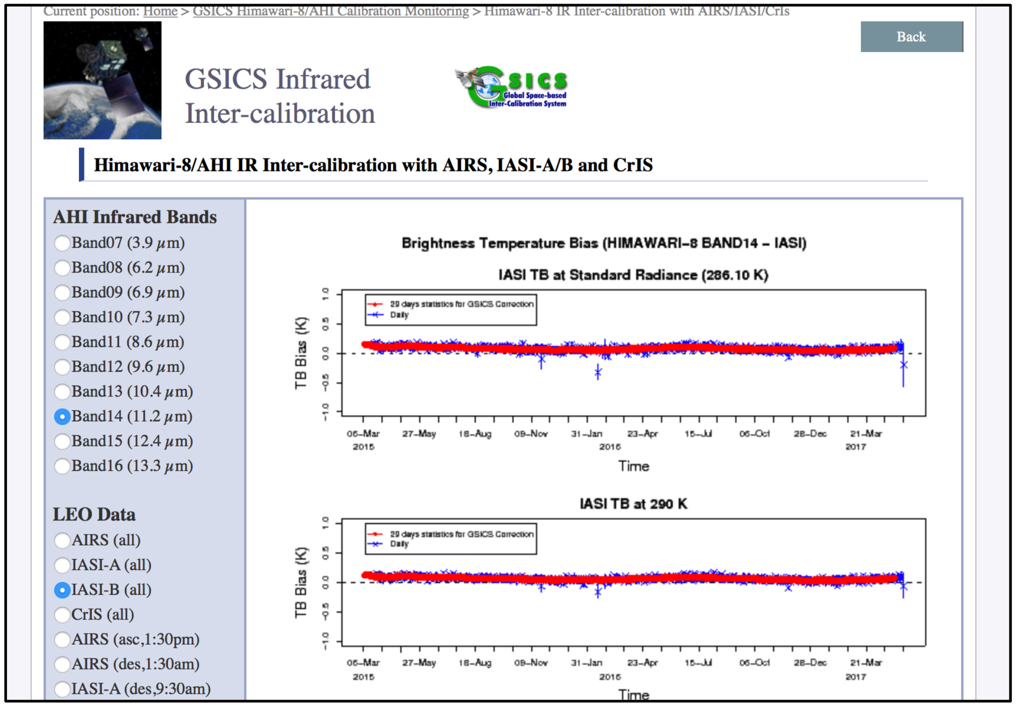
- Simultaneous near-Nadir Overpasses
  - of GEO imager and LEO sounder
- Select Collocations
  - Spatial, temporal and geometric thresholds
- Spectral Convolution:
  - Convolve LEO Radiance Spectra with GEO Spectral Response Functions
  - to synthesise radiance in GEO channels
- Spatial Averaging
  - Average GEO pixels in each LEO FoV
  - Standard Deviation of GEO pixels as weight
- Weighted Regression of LEO v GEO rads
  - Evaluate Bias for Standard Radiance Scene

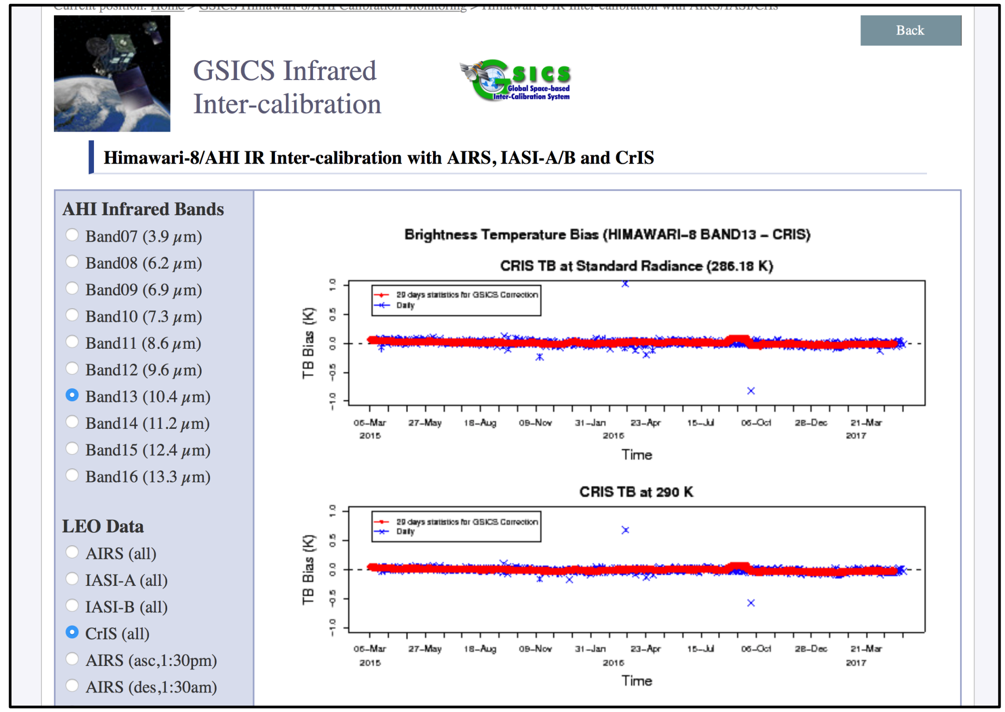


Weighted linear regression of $L_{GEO|REF}$ and <L_{GEO}> for Meteosat-9 13.4µm channel based on single overpass of IASI

Example GSICS related products/documents

- **Himawari-8/AHI IR Inter-calibration with AIRS, IASI-A/B and CrIS**
- http://www.data.jma.go.jp/mscweb/data/monitoring/gsics/ir/monit_geoleoir.html

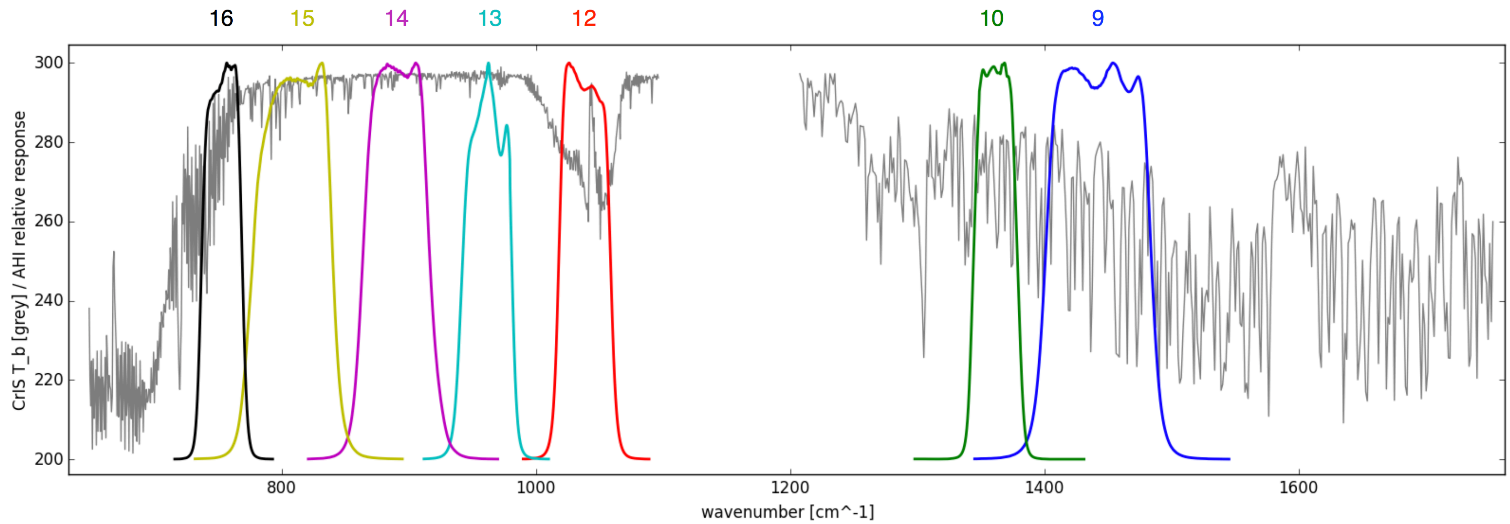


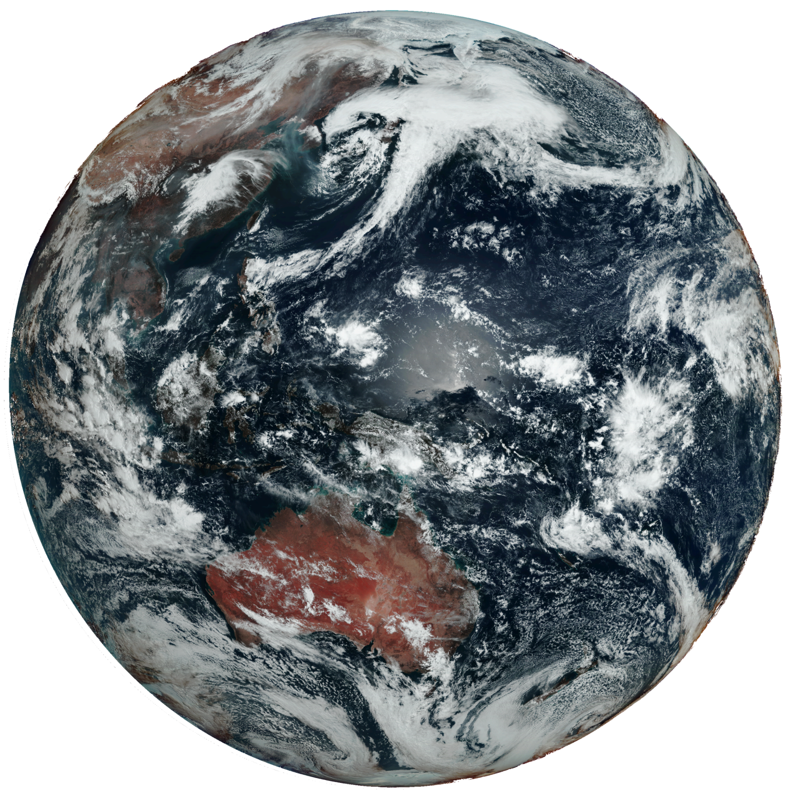


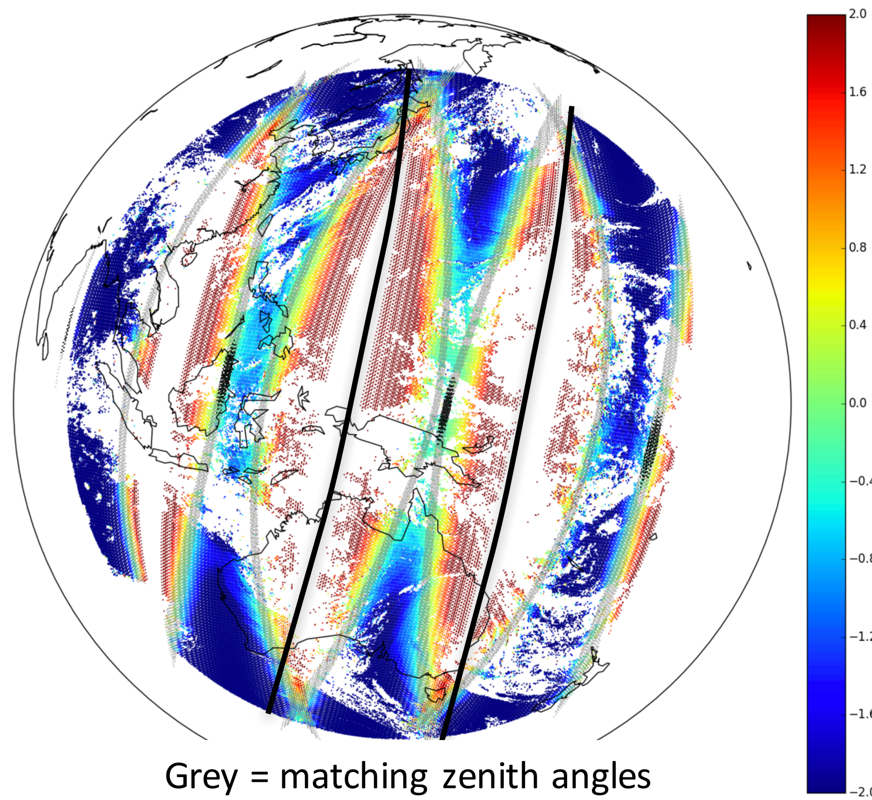
- ***ATBD for Prototype GSICS SEVIRI- IASI Inter-Calibration***

  EUMETSAT Doc.No. : Issue : Date : WBS : EUM/MET/TEN/09/0774 v2A Draft, 16 March 2011
- T. J. Hewison, "An Evaluation of the Uncertainty of the GSICS SEVIRI-IASI Intercalibration Products," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 51, no. 3, pp. 1171-1181, March 2013.doi: 10.1109/TGRS.2012.223633

Example CrIS / AHI comparisons for June 2015





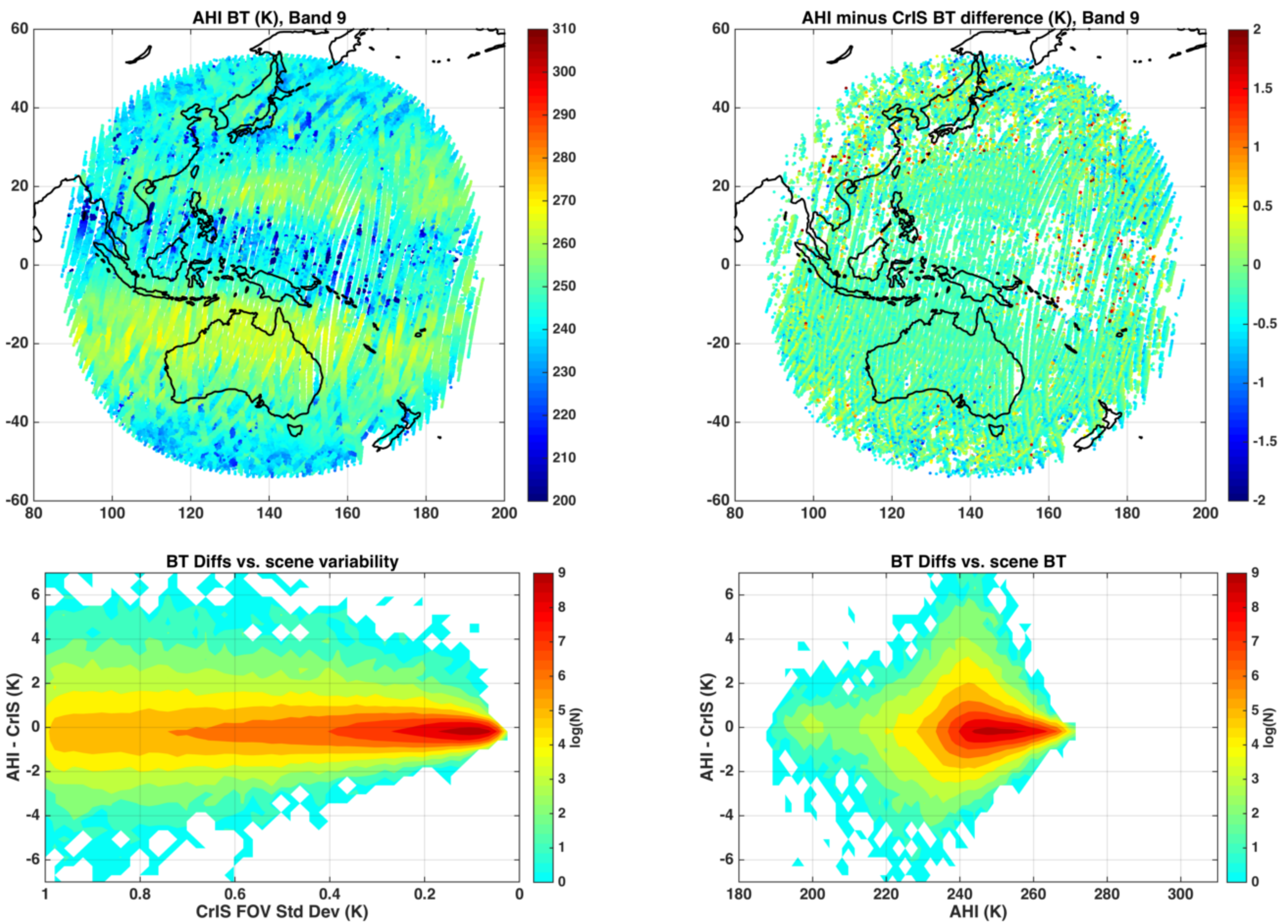


Grey = matching zenith angles
Black = matching zenith and azimuth angles

Band 9 @ ~7 μm

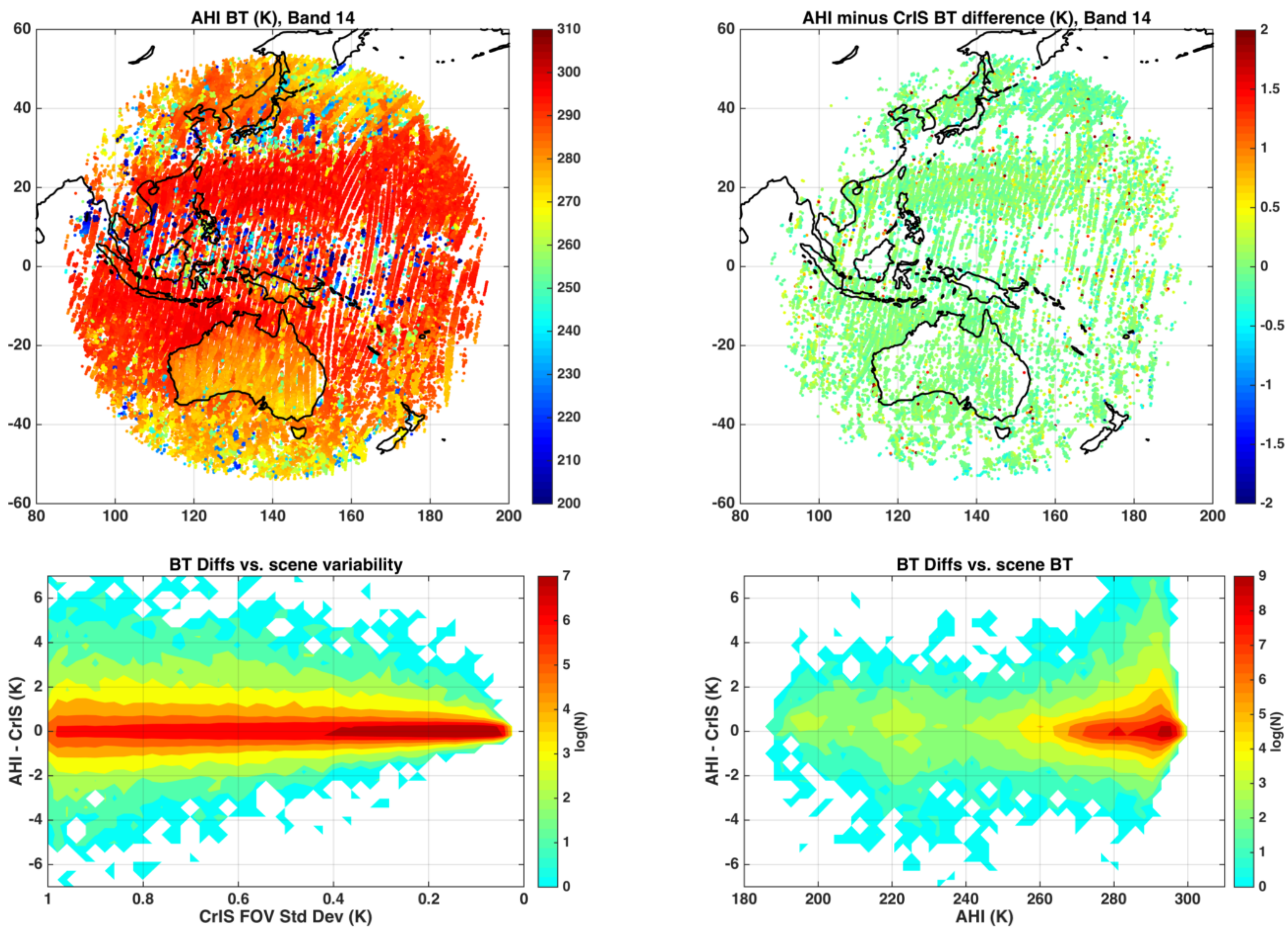
June 2015 Night-time, AHI Zenith angle < 62.5 deg, CrIS/AHI Zenith Angle Difference < 2 deg, Time difference < 10 min

N= 263,118 (132,051) for CrIS FOV Stdev < 1K (0.2K)



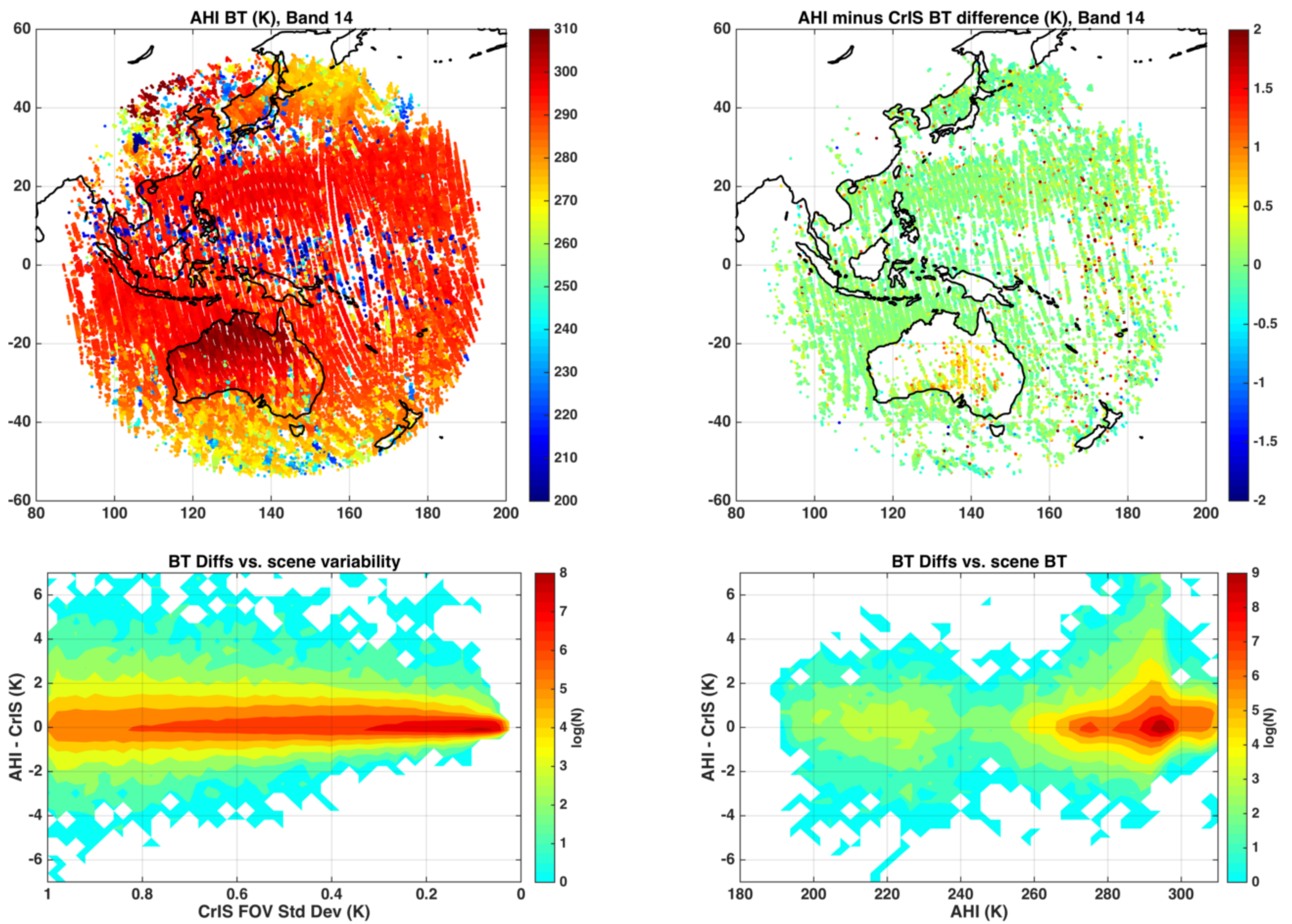
Band 14 @ ~11 µm

June 2015 Night-time, AHI Zenith angle < 62.5 deg, CrIS/AHI Zenith Angle Difference < 2 deg, Time difference < 10 min
N= 127,555 (34,198) for CrIS FOV Stdev < 1K (0.2K)



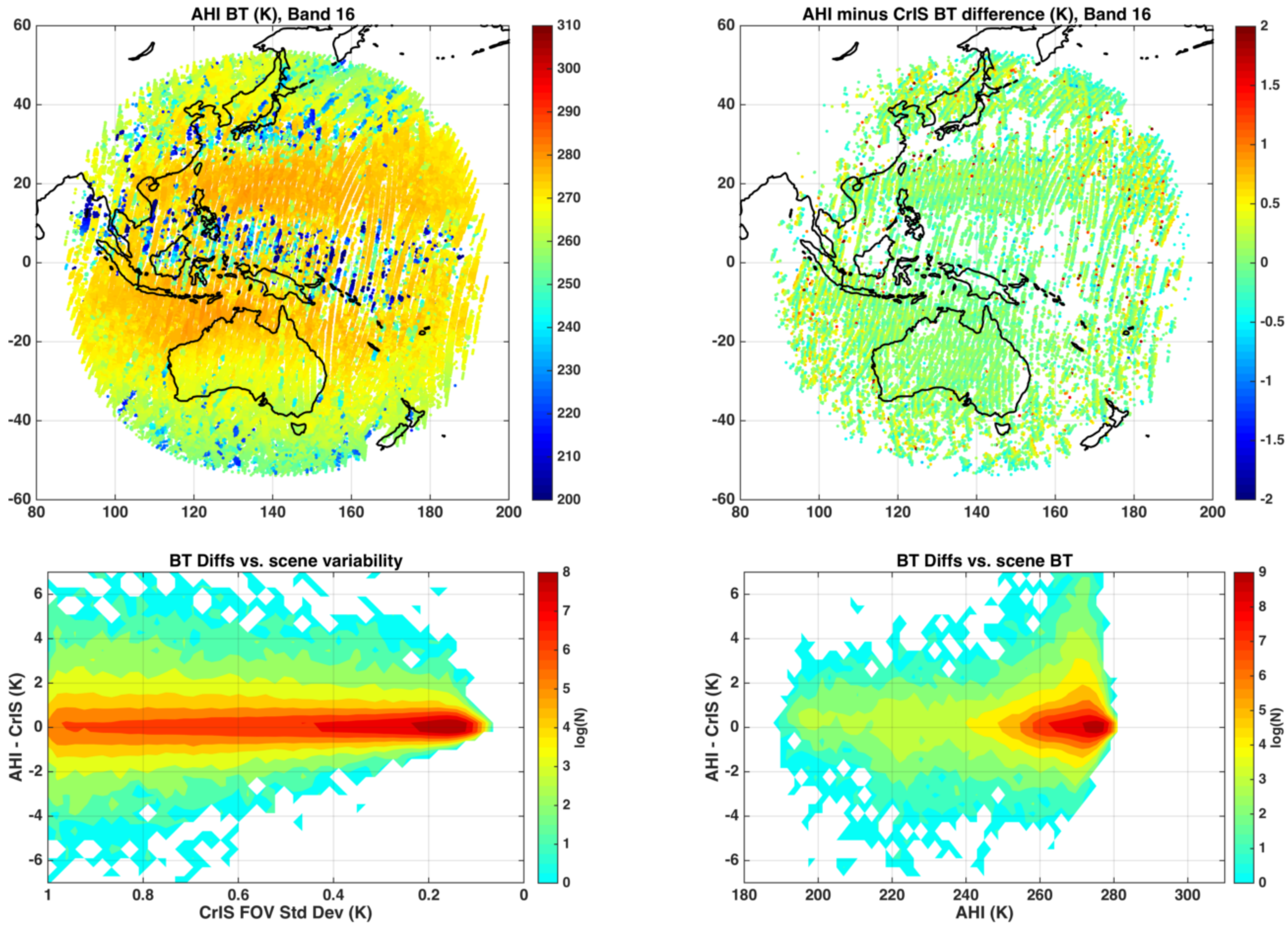
Band 14 @ ~11 μm

June 2015 Day-time, AHI Zenith angle < 62.5 deg, CrIS/AHI Zenith Angle Difference < 2 deg, Time difference < 10 min
N= 119,837 (36,998) for CrIS FOV Stdev < 1K (0.2K)



Band 16 @ ~13 μm

June 2015 Night-time, AHI Zenith angle < 62.5 deg, CrIS/AHI Zenith Angle Difference < 2 deg, Time difference < 10 min
N= 174,797 (53,185) for CrIS FOV Stdev < 1K (0.2K)



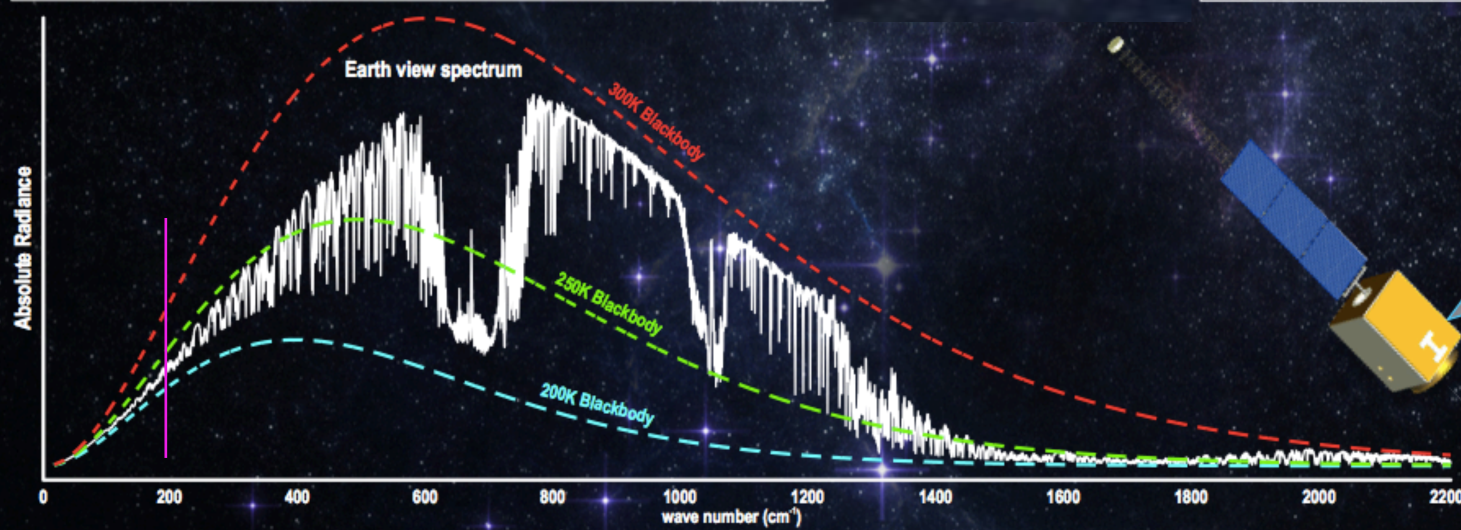
CLARREO: IR Climate Benchmarking & Intercalibration

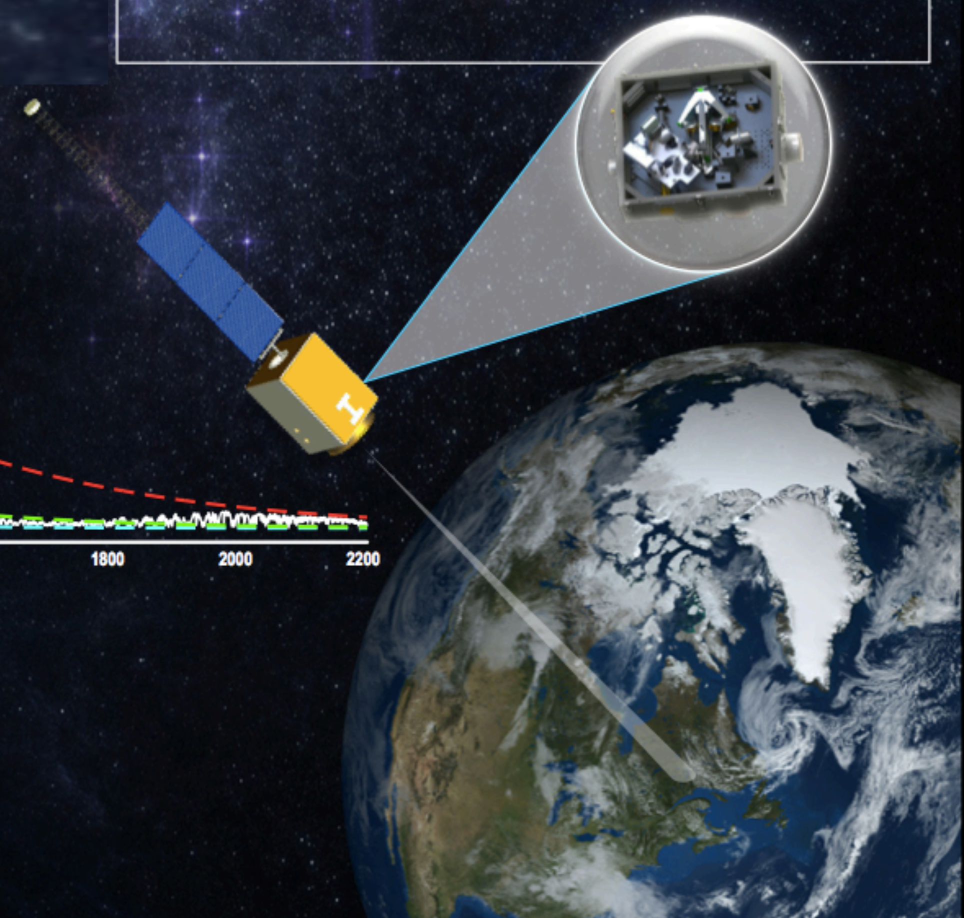
Benchmarking Radiance for Climate Change:

With the rapid increase in climate forcing through the addition of infrared active molecules to the atmosphere by fossil fuel combustion and the probability of carbon release from expanding melt zones in the Arctic, the need for irrefutable observations to define the current state of the atmosphere is becoming increasingly critical. The first goal of the Zeus mission is to provide a global benchmark climate record for this and future generations that, by virtue of its high accuracy determined against international standards on-orbit, establishes a new foundation for quantitatively defining the rate of climate change. Achieving this goal will provide decision support for a range of societal issues including water resources, human health, natural resources, energy management, insurance infrastructure, and others that are linked to our understanding of how climate is changing. *The first science objective of Zeus is to provide a benchmark of the thermal infrared radiance spectrum against which similar future observations can be compared to establish atmospheric change with credibility.*

Benchmarking Radiance for Climate Forecast Testing:

Significant uncertainties exist in forecasts of our future climate. For example, the differences between the IPCC Fourth Assessment models is significant indeed, ranging from virtually no predicted change to a change of 0.6 K/decade between the Japanese medium resolution model and the GISS-EH model for the North American region. Central to the climate sensitivity discrepancy among different IPCC models, is their different climate feedback strengths. To narrow down the uncertainty of climate projection given by the ensemble of these models, it is imperative to measure and confront these models with the feedback strengths measured from observations. *To address this issue, the second science objective of Zeus is to provide a benchmark of the thermal infrared radiance spectrum to determine longwave forcings and longwave feedbacks for testing climate models.*





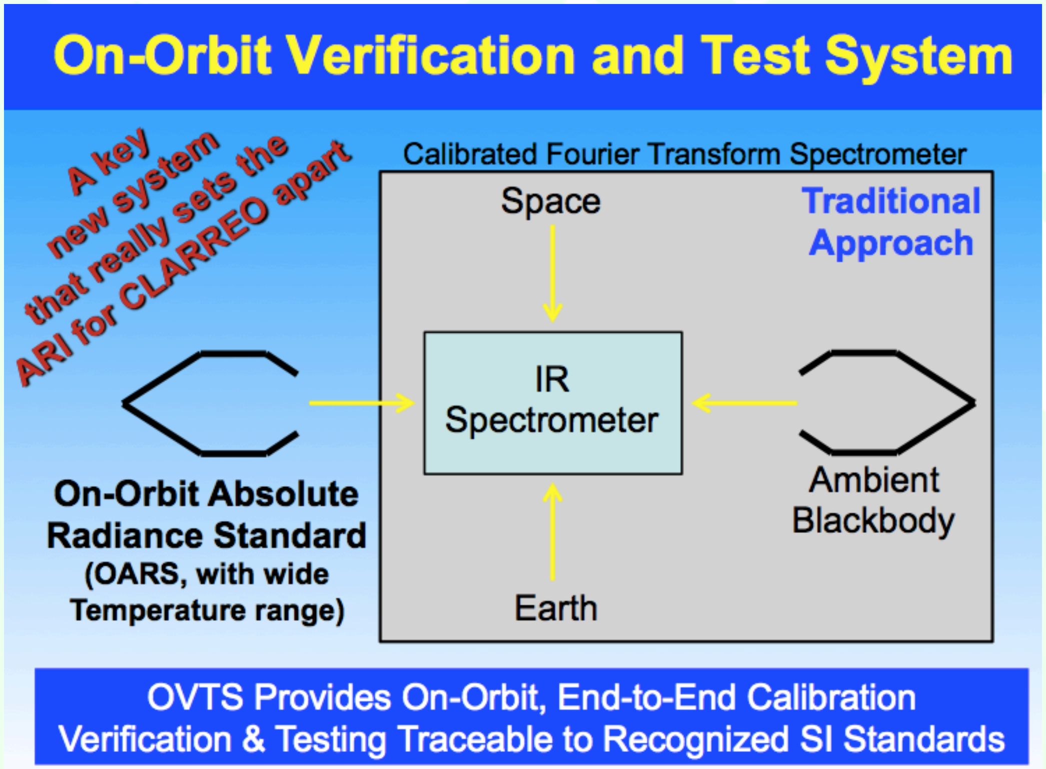
Benchmarking Radiance for Reanalysis and Intercalibration:

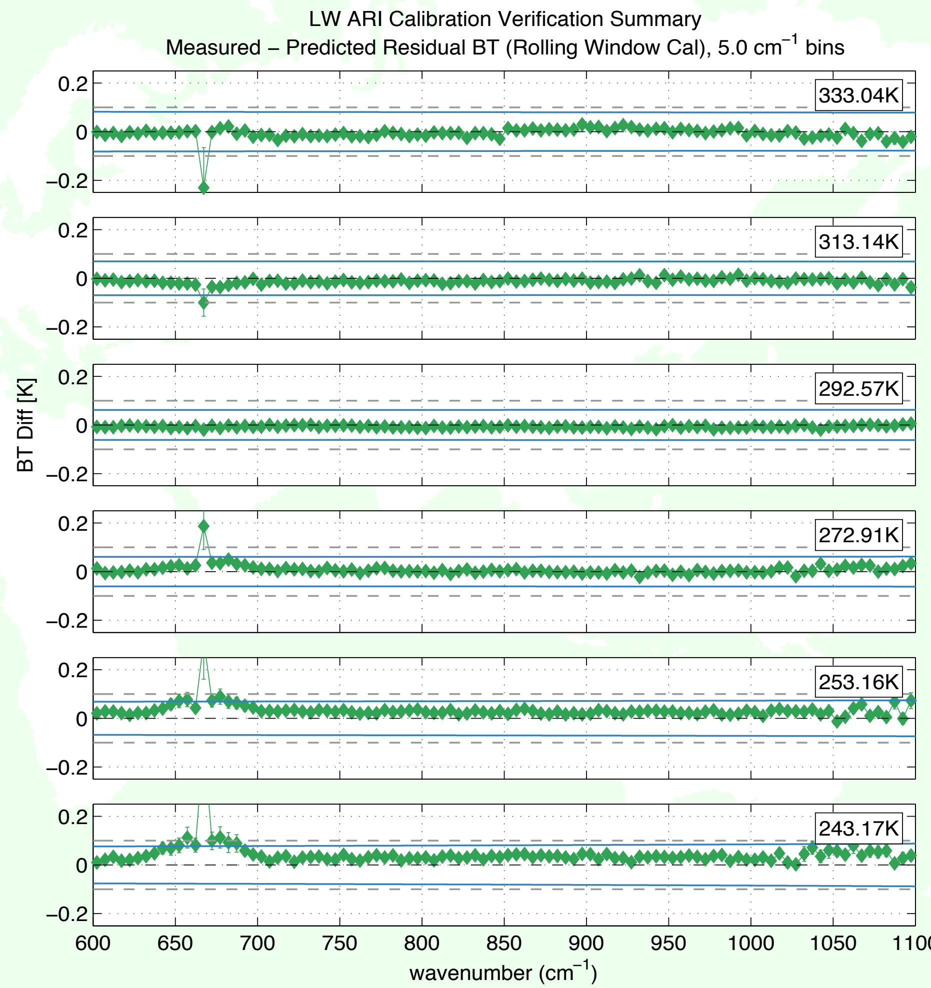
Weather forecast systems utilize data from a wide range of satellite systems and sensors that are primarily designed for operational weather forecast requirements. Eliminating biases between the various sensors is important for making optimal use of the data, and is a primary goal of the Global Space-based Intercalibration System (GSICS) and data assimilation centers. A spectral radiance dataset with high accuracy and on-orbit traceability is required for both Reanalysis methods employing data assimilation techniques and direct intercalibration techniques such as Simultaneous Nadir Overpass analyses to anchor the calibration of the operational weather sensors. *Addressing this issue, the third science objective of Zeus is to provide a benchmark of the thermal infrared spectrum that can provide reference intercalibration for other sensors and for anchoring reanalysis.*

Foldout from CLARREO (Climate Absolute Radiance & Refractivity Observatory) related 2011 proposal to the NASA Earth Venture program

Climate Benchmarking & Intercalibration

- **High Accuracy, verified on-orbit**

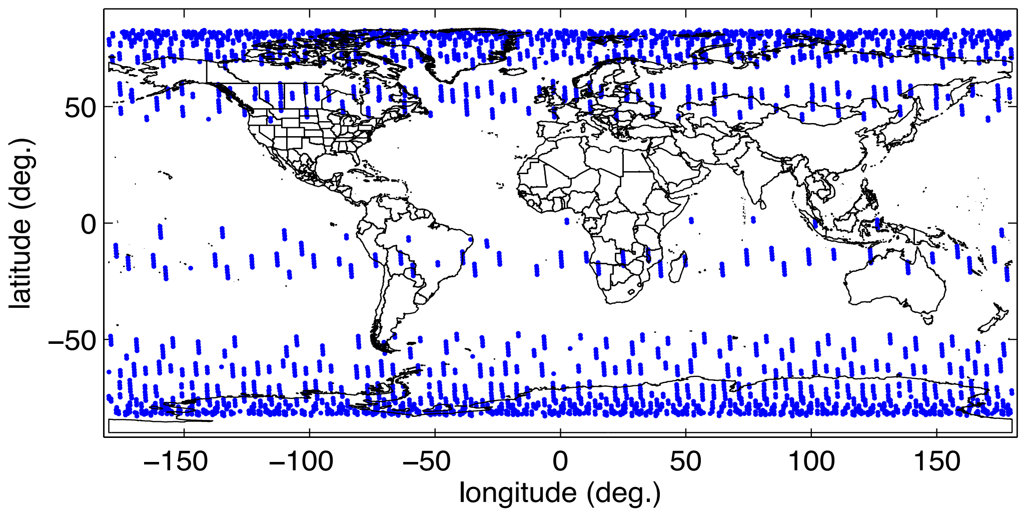




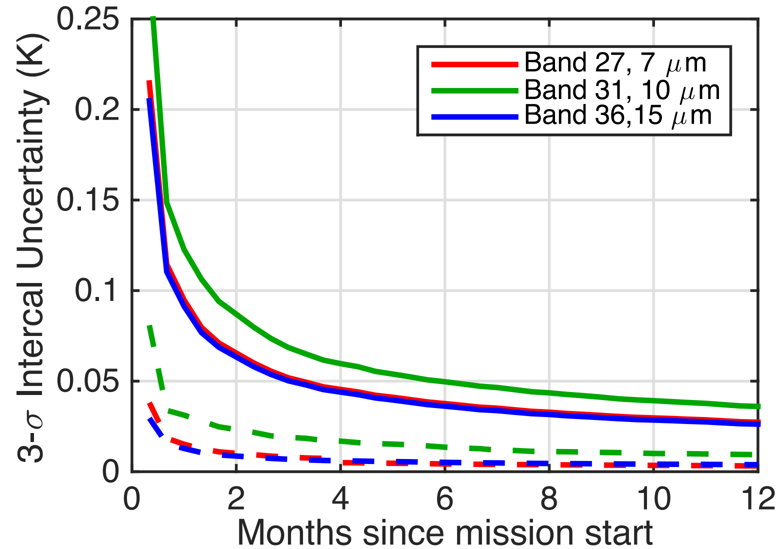
Differences between Absolute Radiance Interferometer (ARI) calibrated brightness temperatures and predicted from the On-Orbit Absolute Radiance Standard (OARS).

CLARREO Intercalibration

- **Transferring the CLARREO ARI accuracy and calibration traceability to concurrent IR sensors**



Characteristics of CLARREO/sounder (sun sync) SNOs for one year and 1 polar orbit CLARREO.

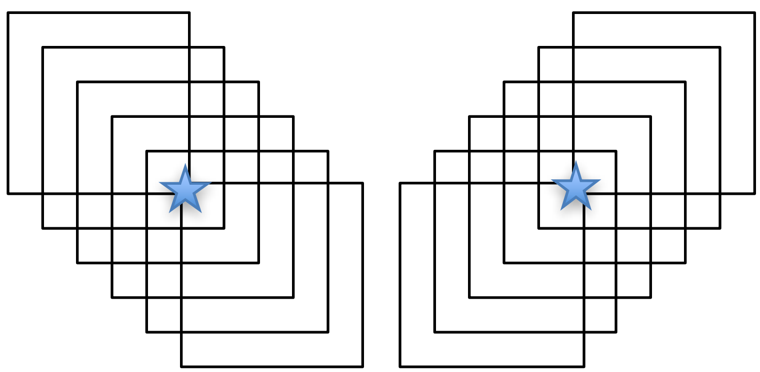


Intercalibration uncertainty as a function of mission length for single spectral channels in the 7, 10, and 15 μm regions for CLARREO/CrIS SNOs.

Tobin, D., R. Holz, F. Nagle, and H. Revercomb (2016), Characterization of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) ability to serve as an infrared satellite intercalibration reference, J. Geophys. Res. Atmos., 121, doi:10.1002/2016JD024770.

Other Thoughts

- **Spectral calibration asssesment using IASI and CrIS**
- **Leo hypsectral calibrations are full aperture calibration**
- **By 2023: 2 IASIes, 2 CrISes, plus IKFS and HIRAS**
- **MTG-IRS dedicated obs to assess inter-pixel consistency, e.g:**



Thank You