Rigorous and Traceable Assessment of the CrIS Radiometric Calibration Uncertainty

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Summary and Outline

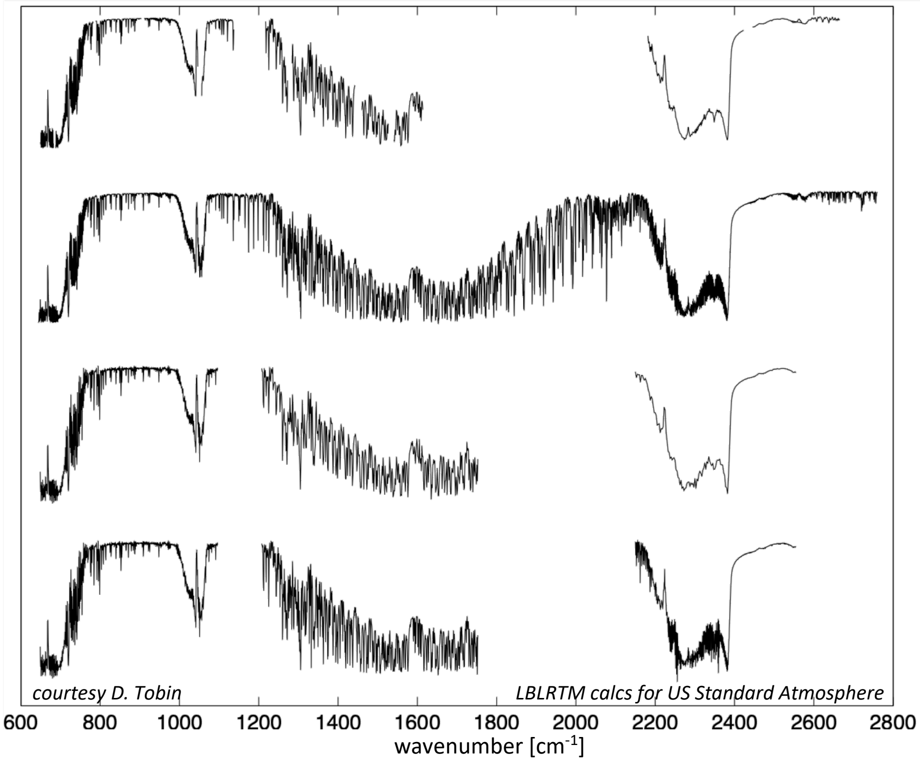
We have developed a new capability/tool for determining a rigorous estimate of the CrIS measurement Radiometric Uncertainty (RU) for any CrIS L1b calibrated radiance, which utilizes a methodology that is consistent with the accepted metrology approach to uncertainty analysis. The Radiometric Uncertainty Tool documentation, sample code, and static RU parameters are now available via the NASA GES DISC L1b landing pages

- Introduction
  - The CrIS sensors and the NASA L1B project
  - Radiometric uncertainty
- CrIS Radiometric Uncertainty
- Summary

Intro: The Cross-track Infrared Sounder (CrIS) Sensors

- CrIS is an infrared Fourier Transform Spectrometer (FTS)
- An FTS measures an interferogram as a function of optical path difference
- The spectrum and the interferogram are simply related via the Fourier Transform
- CrIS spectral coverage is split into 3 spectral bands (LW, MW, and SW)
- Each spectral band uses a 3 x 3 detector array to provide ~14 km fields of view at nadir from an 833 km orbit
- 27 detectors, 2223 spectral channels at 0.625cm^{-1} sampling, 14 km footprint at nadir

- Compact, large aperture, athermalized design
- Fully wedged / tilted with excellent image quality
- Pupil imaging system
- PV MCT detectors
- 4-stage passive cooler

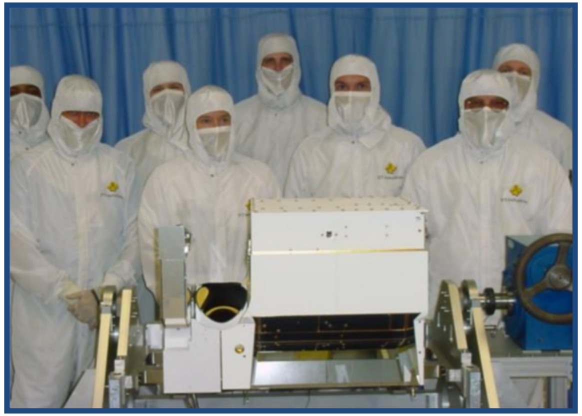


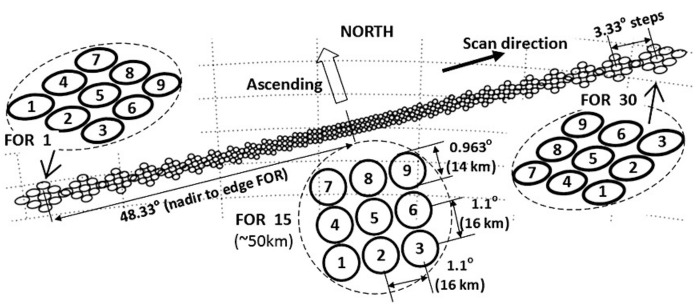
AIRS
L1B: > 1200
Resolving Power
9 FOV/50km square

IASI
L1C: ±2 cm OPD
Gausian apodized
4 FOV/50km square

CrIS NSR
±0.8, 0.4, 0.2 cm
OPD unapodized
9 FOV/50km square

CrIS FSR
±0.8 cm OPD
unapodized
9 FOV/50 km square





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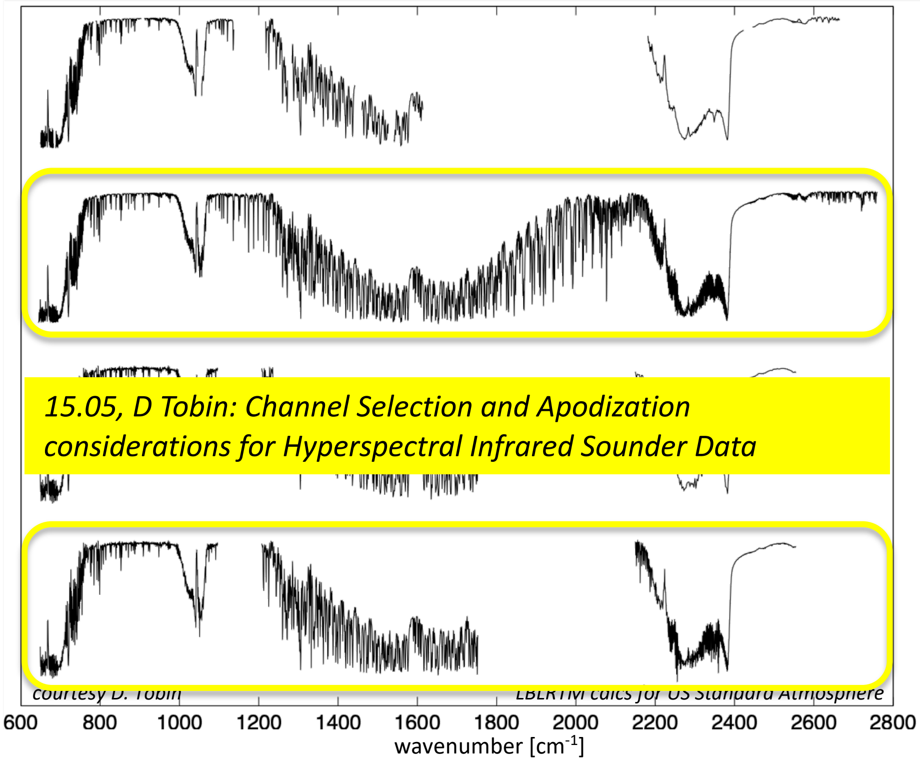

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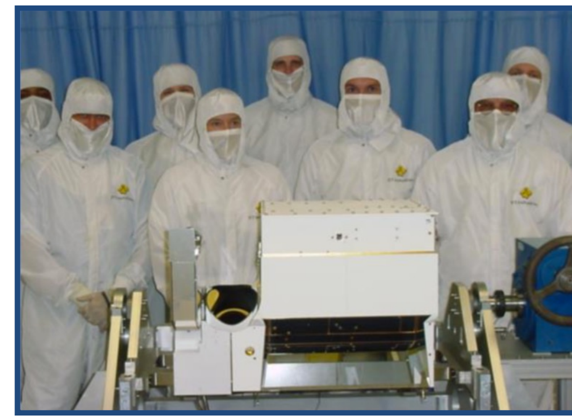
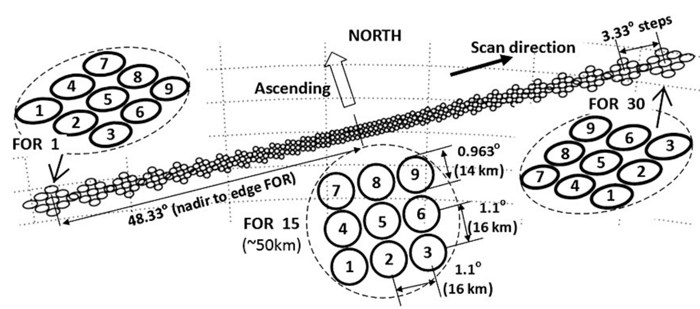




Intro: The CrIS NASA L1B Project and Product

- A low-cost, small team, PI led effort, tasked with efficiently producing extremely accurate, transparent, and traceable multi-sensor continuity radiance products needed for long-term trending of key climate variables
- Joint effort at University of Wisconsin – Madison and University of Maryland Baltimore County (PIs: Joe Taylor and Larrabee Strow)
- Funded by NASA to generate a climate quality CrIS L1B mission data record (SNPP, JPSS-1/NOAA-20 through JPSS-4/NOAA-23) to continue or improve on EOS-like data records
- CrIS L1B product (UW), CrIS/VIIRS co-located IMG product (UW), Climate Hyperspectral Infrared Product (CHIRP) for AIRS and CrIS (UMBC), CrIS RTA (UMBC)
- The CrIS L1B team continues to support efforts relating to creating climate quality products from five CrIS sensors: three in orbit, one just completed ground testing, and one to undergo ground testing this upcoming year.

5.05, G Martin: Status of the NASA CrIS Level 1B Product for Climate Applications

Intro: Radiometric Uncertainty

- A measurement can never be made to be perfectly exact and is complete only when accompanied by a quantitative statement of its uncertainty.
- The documentation of and ability to calculate the uncertainty in the sensor measurements is a critical aspect of a reference sensor and a climate quality measurement record.
- Radiometric Uncertainty (RU) characterizes the accuracy of the observed radiance and is an upper bound (coverage factor k=3 or 3-σ) of the bias with respect to the true radiance and is scene and instrument environment dependent.
- RU does not include effects such as detector noise which vary randomly from one spectrum to another.
- RU addresses the inherent accuracy of the CrIS observations, and do not include processing and quality control parameter related artifacts, which can be removed with future reprocessing efforts.

Intro: Radiometric Uncertainty and Metrology

- Use the terminology and methodology for evaluation of measurement uncertainty recommended by the national and international institutions that govern traceability to the Système international d'unités (SI).
- The Bureau International des Poids et Mesures (BIPM) Joint Committee for Guides in Metrology (JCGM) has responsibility for the following two documents:
  1. The Guide to the Expression of Uncertainty in Measurement (known as the GUM)
  2. The International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (known as the VIM)
- Two important concepts:
  1. Combined standard uncertainty of the measurement $u_c(y)$
  2. Expanded uncertainty $\mathrm{U} = \mathrm{k} \cdot u_c(y)$; When the normal distribution applies, a coverage factor of k = 2 defines an interval having a level of confidence of approximately 95 percent, and k = 3 defines an interval having a level of confidence greater than 99 percent.

Intro: Radiometric Uncertainty and Metrology

The combined standard uncertainty of measurement y is $u_c(y)$

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + \sum_{i=1}^{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j).$$

f is the functional relationship between the measurement y and the input estimates x_i
$u(x_i)$ is the standard uncertainty associated with each x_i
$u(x_i, x_j)$ is the estimated covariance associated with x_i and x_j
$\partial f / \partial x_i$ are referred to as the sensitivity coefficients

If the individual uncertainties are independent, then $u(x_i, y_i) = 0$ and

known as the law of propagation of uncertainty or the RSS method

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$$
$$= \sum_{i=1}^{N} u^2\left(f(x_i)\right)$$

valid only if the input quantities x_i are not significantly correlated

CrIS Radiometric Uncertainty

- The radiometric uncertainty (RU) in the calibrated radiance can be determined via a perturbation analysis of the calibration equation.
  - This is equivalent to the differential error analysis described in the GUM
- Our new tool builds on the radiometric uncertainty assessment and methodology described by Tobin et al. (2013) for the SNPP CrIS sensor (*Suomi-NPP CrIS radiometric calibration uncertainty*, J. Geophys. Res. Atmos., 118, 10,589–10,600, doi: 10.1002/jgrd.50809).
- CrIS uses a physical calibration with clearly defined traceability and uncertainty assessment for all calibration parameters *(No nonphysical correction parameters)*

CrIS Radiometric Uncertainty: Primary Contributors

- Analyses have shown that the primary contributors to the CrIS radiometric uncertainty are the individual uncertainties in
  1) The Internal Calibration Target (ICT) temperature, effective ICT cavity emissivity, and the temperatures of the reflected terms in the ICT environmental model;
  2) The nonlinearity correction quadratic coefficient (LW and MW bands only); and
  3) The polarization correction parameters (combined scene mirror and sensor polarization and the sensor polarization angle).
- Polarization was not expected to be a significant contributor to radiometric uncertainty and was not included in the original SNPP RU assessment and paper. All the primary contributors listed above are included in the current RU estimates.

Taylor, Joe K., et al. "Assessment and Correction of View Angle Dependent Radiometric Modulation due to Polarization for the Cross-track Infrared Sounder (CrIS)." *Remote Sens.* **2023**, *15*, 718. https://doi.org/10.3390/rs15030718

CrIS Radiometric Uncertainty: Key Calibration Parameters and Traceability

Traceability is critical for a climate data record

Detector Nonlinearity: quadratic nonlinearity coefficient and DC Level

a_2 and V_{DC}

- Pre-launch Out-of-band harmonic analyses
- Pre-launch ECT views at six temperatures
- Post-launch Out-of-band harmonic analyses
- Post-launch FOV-to-FOV analyses

ICT (Internal Calibration Target): ICT temperature and emissivity

T_{ICT} and e_{ICT}

- Pre-launch PRT calibrations
- Pre-launch emissivity characterization
- Pre-launch L_{ICT} verification using TVAC External Calibration Target (ECT) with $T_{ECT} = T_{ICT}$

Polarization: combined scene mirror and sensor polarization and sensor polarization angle

- Optical design analyses and component level measurements
- Post-launch pitch maneuver data

$p_r p_t$ and α

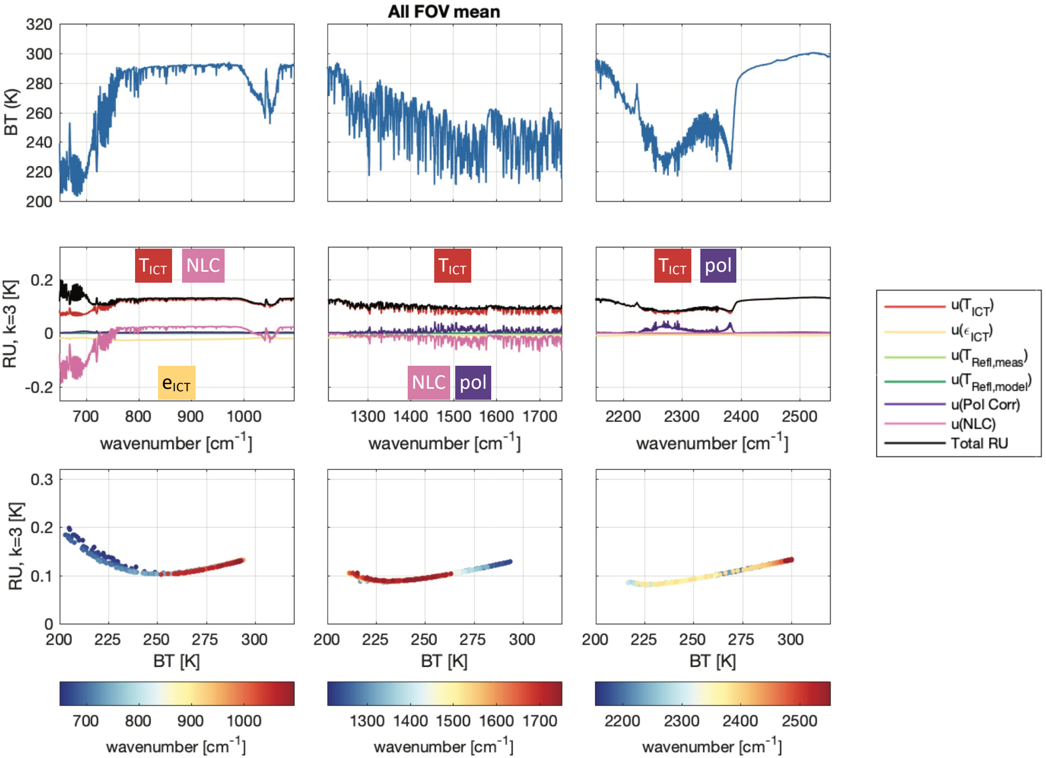
External Calibration Target (ECT) view TVAC data used to characterize the sensor radiometric nonlinearity and provide end-to-end calibration traceability to NIST via temperature sensor calibrations and NIST TXR measurements

CrIS Radiometric Uncertainty: A New Capability for RU Calculation

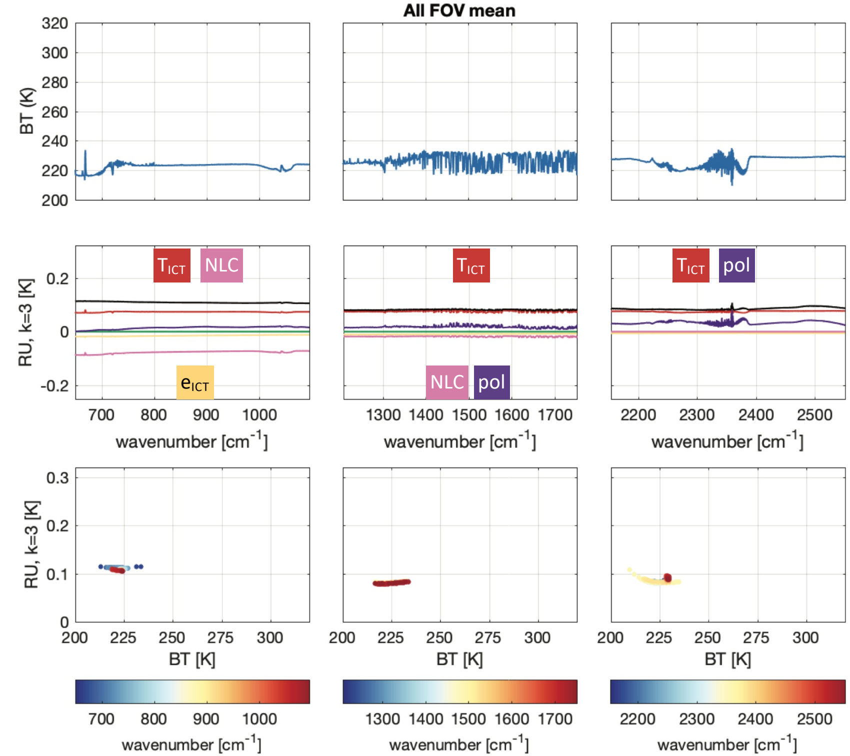
- The CrIS NASA L1b V3 product, along with a small static parameter file, contain all information needed to accurately calculate the radiometric uncertainty for any CrIS NASA L1b calibrated radiance (*no static parameter file will be needed in Version 4)*.
- This allows the end-user to determine the radiometric uncertainty for any radiance without the explicit calculation of the combined uncertainty for the CrIS radiometric calibration which would require the corresponding L1a data, any context granules used in the calibration, and the calibration package.
- Radiometric Uncertainty Tool documentation, sample code, and static RU parameters are now available via the GES DISC L1b landing pages ('NASA Cross-track Infrared Sounder (CrIS) Level 1B Radiometric Uncertainty Description Document, v3')

CrIS Radiometric Uncertainty Examples
6-minute Granule Mean (all FOV, FOR, Scan)

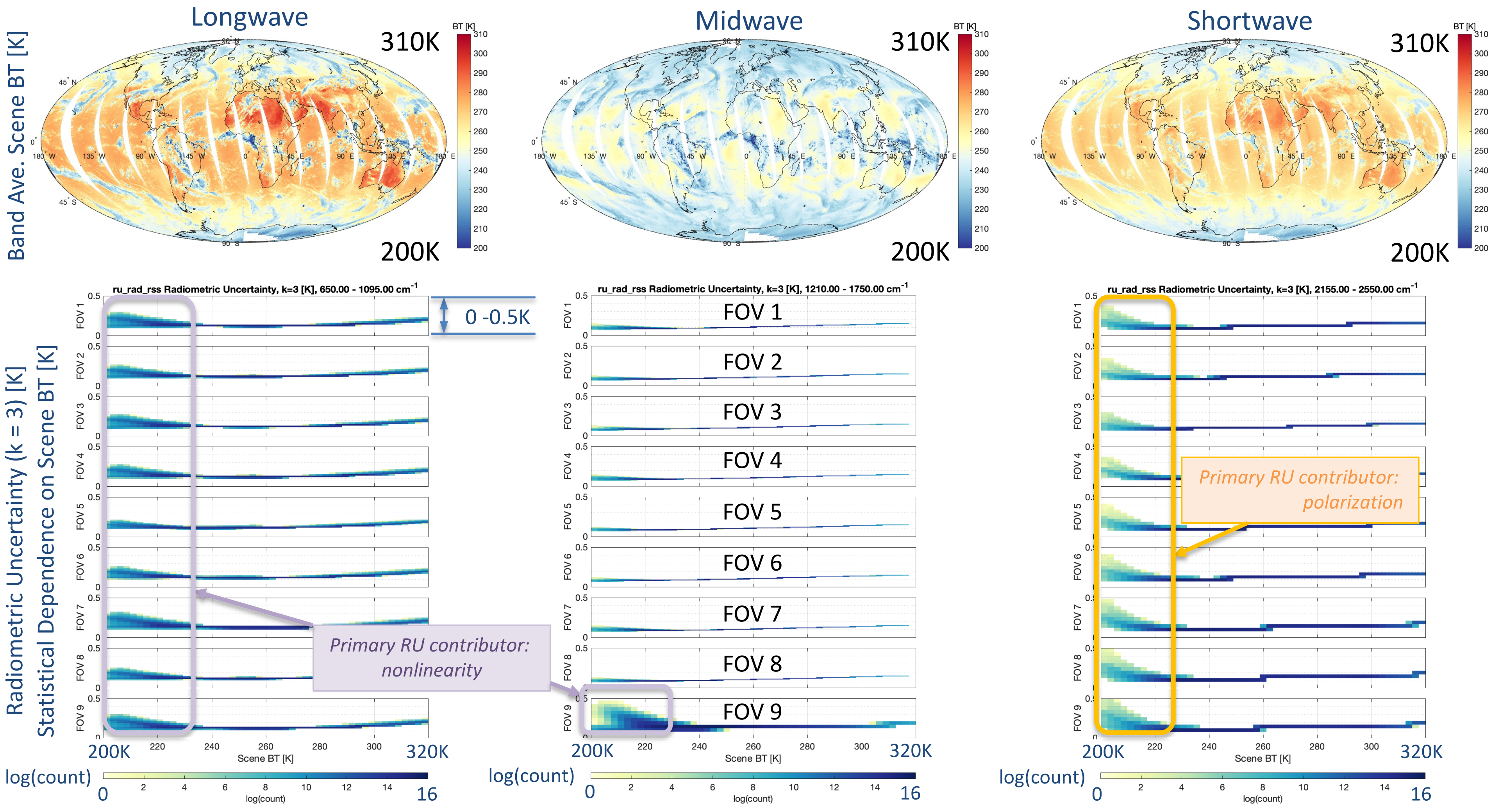
Example Tropical Ocean Scene: NOAA-20



Example Antarctic Scene: NOAA-20



CrIS Radiometric Uncertainty Examples
~12 hours of data (NOAA-20 Ascending, 2018-04-01), RSS RU



Summary

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- The Radiometric Uncertainty Tool documentation, sample code, and static RU parameters are now available via the NASA GES DISC L1b landing pages ('NASA Cross-track Infrared Sounder (CrIS) Level 1B Radiometric Uncertainty Description Document, v3'); all information will be included in the Version 4 product, and the static file will no longer be needed.
- Spectral ringing is unrelated to the inherent accuracy of the CrIS observations and is not included in the RU estimate; only significant (larger than 0.1 K) in small spectral regions, correction in development. *[2.10, H. Revercomb, Correction for Ringing in the Calibrated Spectra of the Cross-track Infrared Sounder]*
- Spectral calibration is not currently rolled into the radiometric uncertainty estimate. CrIS demonstrated spectral calibration accuracy is currently better than 2-3ppm (can be improved to ~1ppm in future L1b processing versions).