Hyperspectral Sounder Radiance Comparisons of SNPP/NOAA-20 CrIS, METOP-A/B/C IASI, and Aqua AIRS: Refined Analysis Techniques and Updated Results

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Summary

This work presents an updated approach and current results from an inter-comparison of SNPP/NOAA-20 CrIS, Aqua AIRS, and METOP-A/B/C IASI using simultaneous nadir overpasses (SNOs). Comparisons include a spatial sampling error and the CrIS radiometric uncertainty.

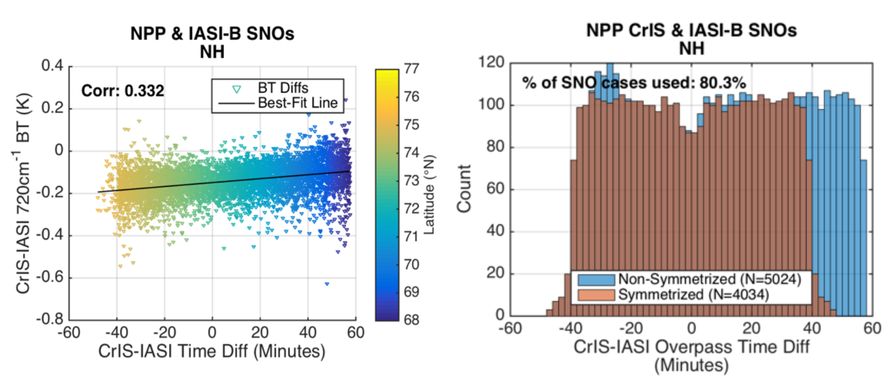
Comparisons of CrIS and IASI show very good agreement, with radiometric biases that are mostly spectrally flat and mostly within the CrIS radiometric uncertainty. Comparisons of CrIS and AIRS also show good general agreement but have larger biases than seen between CrIS and IASI with spectral features that are indicative of AIRS calibration artifacts as seen in previous studies. A double difference comparison of NOAA-20 CrIS minus SNPP CrIS using either AIRS or IASI show agreement within about 0.1 K for each of the LW, MW, and SW spectral bands with some isolated exceptions that are discussed.

A detailed analysis of CrIS/AIRS collocation matchups along the CrIS orbit has been performed for both SNPP and NOAA-20 (N20) CrIS. The differences between CrIS and AIRS are relatively small (< 300 mK) along the orbit for each CrIS sensor for LW and SW window regions. However, the double difference (SNPP CrIS – AIRS) minus (NOAA20 CrIS – AIRS) is even smaller (< 100 mK) with a small orbit phase dependence in the LW 900 cm^{-1} channel but no dependence in the SW 2500 cm^{-1} channel.

Methods:

Time Difference Histogram Symmetrization

For certain wavenumbers, namely the CO_2 absorption region, the CrIS/IASI and AIRS/IASI SNO BT differences are slightly correlated with the difference between the satellite overpass times. To remove any potential bias from this effect, a random selection of an equal number of samples from each side of the time difference histogram is made. This is facilitated using 2 minute time difference bins. The figure below shows an example of this correlation, as well as the NPP CrIS and IASI-B overpass time difference histogram before and after symmetrization.



For all platform combinations between CrIS/IASI and AIRS/IASI between 70% to 82% of SNO samples are kept. Figure 1 shows the non-symmetrized time difference histogram is indeed skewed to one side so that if a mean was taken over the full dataset, it could be expected to be affected by temporal sampling mismatch effects. This method is more important to use on the CrIS/IASI and AIRS/IASI datasets than the CrIS/AIRS datasets due to the fact that a much tighter time mismatch criterion can be applied to the CrIS/AIRS datasets due to the higher yield of SNO samples.

Spatial Sampling Uncertainty

One challenge of comparing measurements from two instruments is ensuring the spatial and temporal mismatch is minimized and accounted for in an uncertainty estimate. Tobin et al. (2016) and Taylor et al. (2020) discuss theoretical sampling uncertainties due to sampling differences between two satellite-based sounding instruments and provide a rigorous approach to computing weighted ensemble means of Gaussianly distributed measurement differences. In the approach, comparisons of lesser quality due to increased sampling differences are down-weighted. An uncertainty for the weighted bias is included. The equations below are based off the theory of these papers but are tailored to the big circle SNO method (two sounders with about equal sized footprints). The following equation defines a spatial variance, used as the SNO spatial sampling uncertainty:

$$\sigma_{space}^2 = (1 - {}^{O_1}/_{M_1})\sigma_1^2/M_1 + (1 - {}^{O_2}/_{M_2})\sigma_2^2/M_2$$

Here, M is the number of footprints of each sounder within the big circle and σ is the standard deviation of the sounder measurements within the big circle. O is the effective number of footprints within the big circle that overlap each other and is defined for each instrument as $O = A_{overlap}/A_{footprint}$, where $A_{overlap}$ is the total area of overlap between the two sounders' footprints and $A_{footprint}$ is the area of a single sounder footprint. The table below lists average areas of overlap, O values, and M values for various instrument combinations. Here, the area of the instruments' footprints and overlaps are computed assuming that the footprints are perfect circles so that $A_{footprint} = \pi * R^2$, where R is the radius of the footprint. Since the big circle SNO method inherently restricts the sounder footprints to be close to nadir, the radii chosen are reflective of the radii values when the instruments are pointing at nadir. For CrIS this value is chosen to be 7 km, for IASI it's 6 km, and for AIRS it's 6.75 km.

	CrIS/IASI	CrIS/AIRS	AIRS/IASI
$Area_{Overlap}$ (km^2)	2,714.2	5,621.2	2,998.4
O_{CrIS}	17.6	36.5	--
O_{AIRS}	--	39.3	20.9
O_{IASI}	24.0	--	26.5
M_{CrIS}	111.9	66.0	--
M_{AIRS}	--	74.0	125.0
M_{IASI}	49.5	--	49.5

Once the spatial sampling uncertainties are computed, and if all other sources of uncertainty are ignored or assumed negligible (e.g. temporal sampling or instrument noise), then the individual weights, w, are computed as:

$$w = 1/\sigma_{space}^2,$$

and the uncertainty for the ensemble weighted mean as (where N is the total number of SNOs included in the ensemble mean):

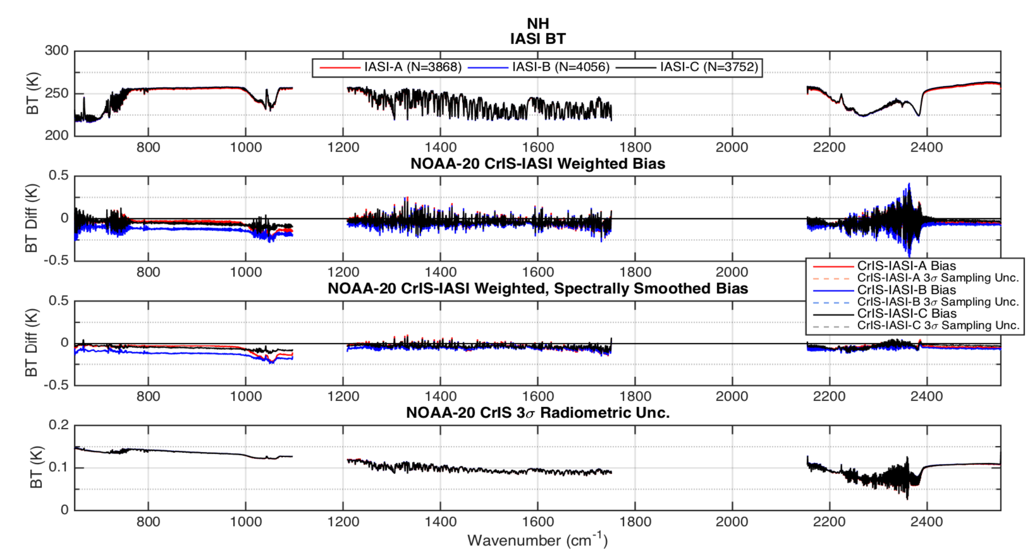
$$u = \sqrt{1/\Sigma_{i=1:N} w_i}$$

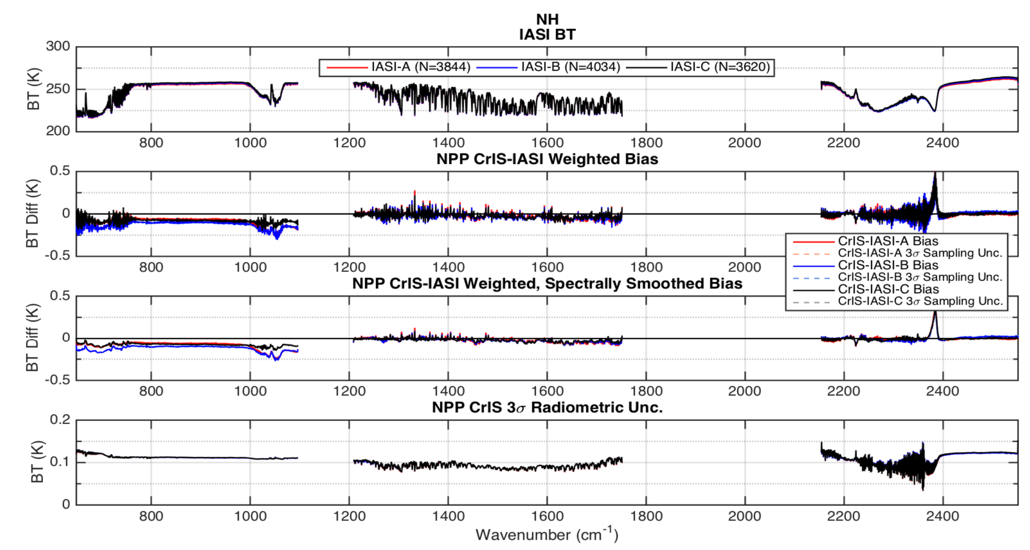
In these analyses, the temporal sampling is assumed negligible due to the use of tight time difference criteria and time difference histogram symmetrization.

High Latitude SNO Comparison

CrIS/IASI

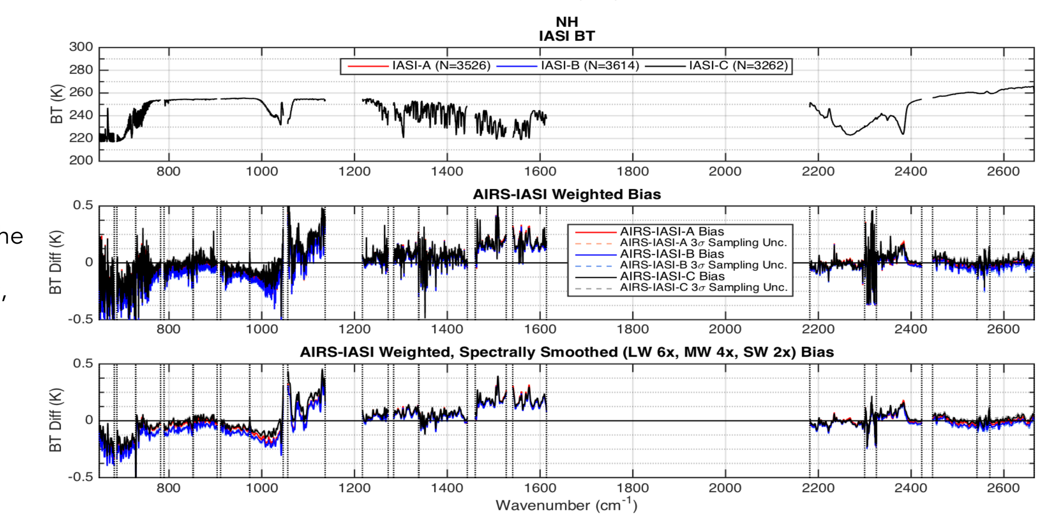
- IASI is converted to CrIS (FSR) spectral resolution
- Biases have 3σ sampling unc. overlaid, which is <0.03K for each NOAA-20 – IASI-A/B/C and NPP – IASI-A/B/C
- NPP and NOAA-20 radiometric unc.** is <0.15 K (bottom panels of below figures)
- NPP CrIS-IASI and NOAA-20 CrIS-IASI spectrally smoothed biases are generally well under <0.2 K (except SW 2380 cm^{-1} for NPP)
- NPP CrIS & IASI (spectrally smoothed) are in agreement with primary exceptions of 2380cm^{-1} SW region, LW O_3 region, and for IASI-B in the LW CO_2 region
- NOAA-20 CrIS & IASI (smoothed) are w/in agreement with primary exceptions of the LW O_3 and SW 2350 cm^{-1} region
- On scale shown, the biases are well behaved and spectrally 'flat'. The un-smoothed biases suggest a small absolute spectral calibration bias between IASI and CrIS, TBR.

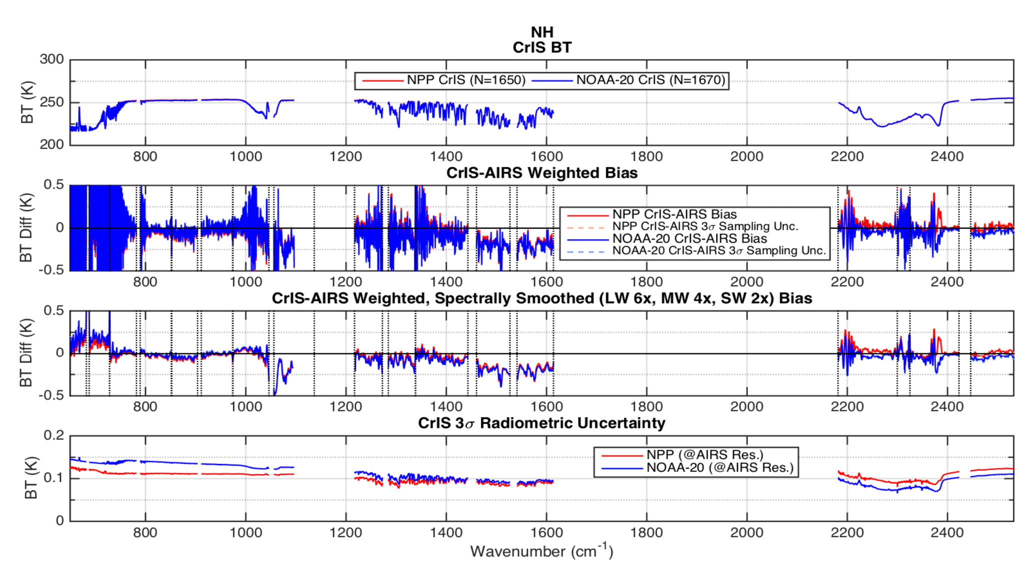




AIRS/IASI

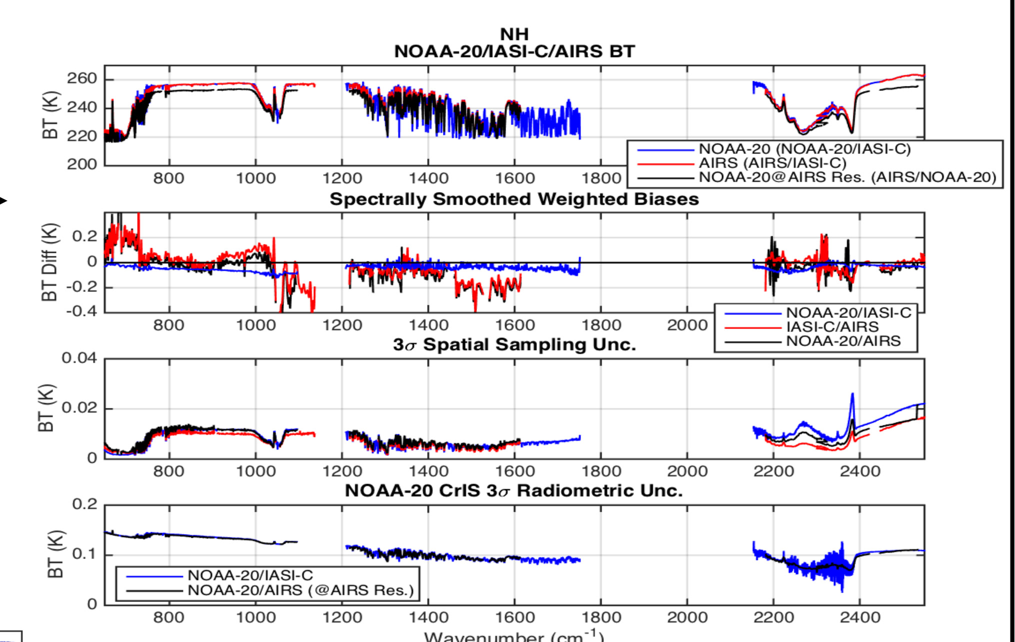
- IASI is converted to AIRS spectral resolution
- AIRS-IASI smoothed biases are generally under 0.3 K (LW), 0.25 K (MW), and 0.15 K (SW)
- Sampling unc. Is under ~0.02 K across the full spectrum
- AIRS and IASI have larger areas of disagreement around LW 700 cm^{-1} and 1050 cm^{-1} and the MW 1500-1600 cm^{-1} region
- AIRS and IASI biases on this scale are flat in certain regions, e.g. SW & LW window regions, however regions with slightly larger spectral features imply AIRS calibration issues there





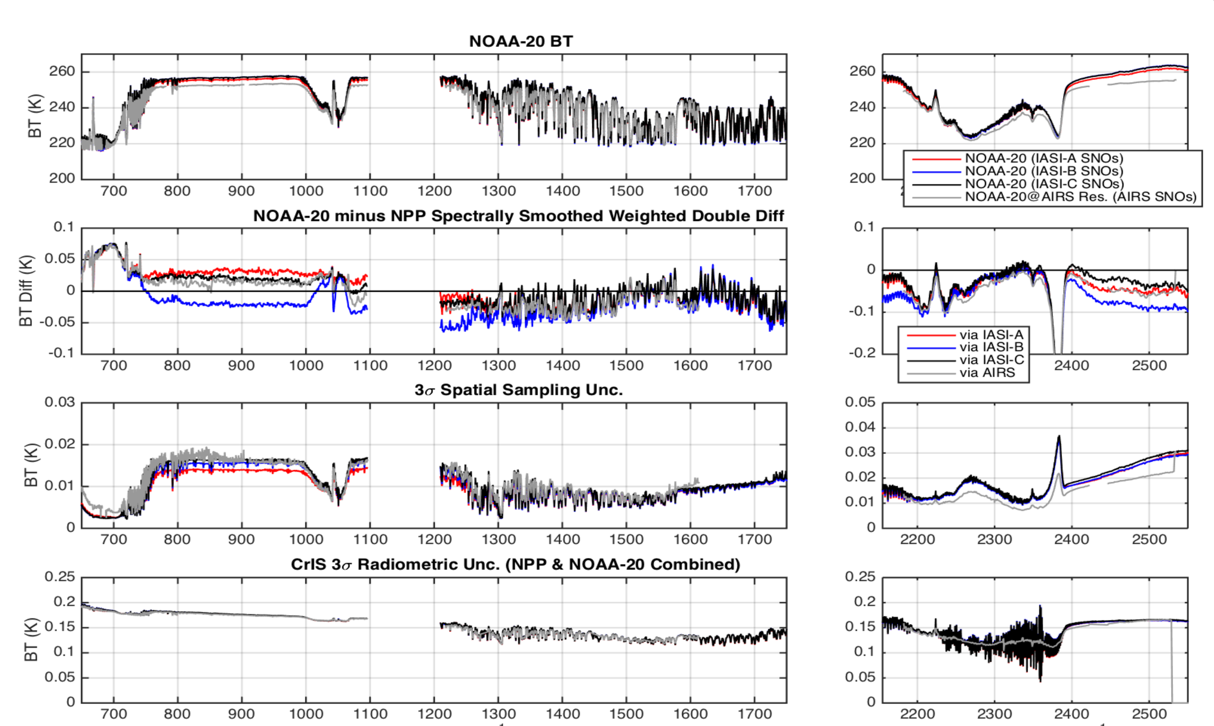
CrIS/AIRS

- CrIS is converted AIRS spectral resolution
- CrIS-AIRS smoothed biases are generally under 0.3 K (LW), 0.25 K (MW), and 0.25 K (SW)
- Sampling unc. Is under ~0.02 K across the full spectrum
- CrIS radiometric uncertainties** again under 0.15 K
- CrIS and AIRS have larger areas of disagreement around LW 700 cm^{-1} and 1050 cm^{-1} and the MW 1500-1600 cm^{-1} region → similar to the AIRS-IASI biases, implying calibration issues in AIRS in these regions



IASI/AIRS/CrIS 3-Way Comparison

- 3 way comparison of NOAA-20 CrIS, IASI-C and AIRS smoothed biases for the NH is shown to left
- IASI-C - AIRS and NOAA-20 CrIS - AIRS biases have qualitatively similar spectral features, while NOAA-20 CrIS – IASI-C is much spectrally 'flatter' → This implies AIRS has calibration issues in specific regions, e.g. around 700 cm^{-1} and 1500 cm^{-1}
- Sampling uncertainties are under 15 mK in LW/MW and 25 mK in SW
- NOAA-20 radiometric unc.** (for each IASI-C and AIRS comparisons) is under 150 mK
- When accounting for NOAA-20 CrIS radiometric unc., NOAA-20 CrIS and IASI-C are in good general agreement when spectrally smoothed, and NOAA-20 CrIS and AIRS are often in disagreement



CrIS Double Differences

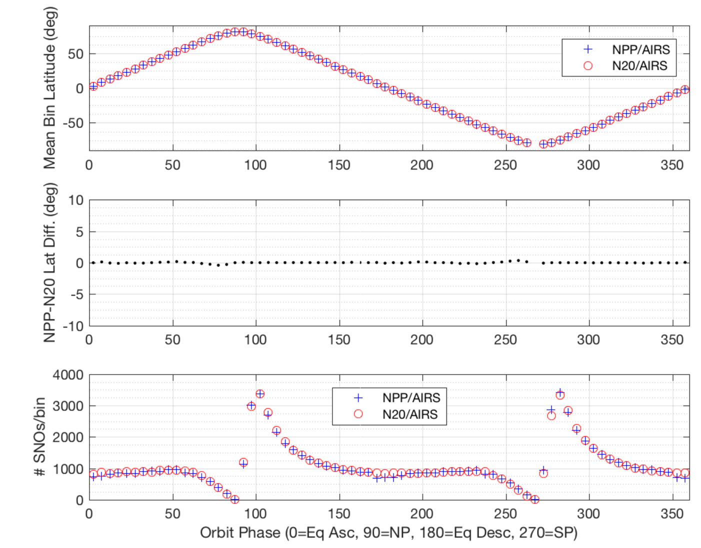
- NOAA-20 minus NPP spectrally smoothed bias double difference for the NH is shown to the right and is computed using AIRS and each IASI as a reference
- NOAA-20 minus NPP difference is under 75 mK in LW/MW, 100 mK in SW (except for 2380cm^{-1} region)
- Spatial sampling unc. is <20 mK in LW/MW, <35 mK in SW → Even with the CrIS double differences being exceedingly small, the SNO methodology used here enables us to make claims about agreement between instruments (e.g. at 700cm^{-1})
- NOAA-20 and NPP combined radiometric uncertainties** are ~200 mK in LW, ~150 mK in MW/SW → NOAA-20 and NPP agree well w/in the current radiometric uncertainty estimates (ignoring 2380cm^{-1} region which is prone to BT conversion issues)

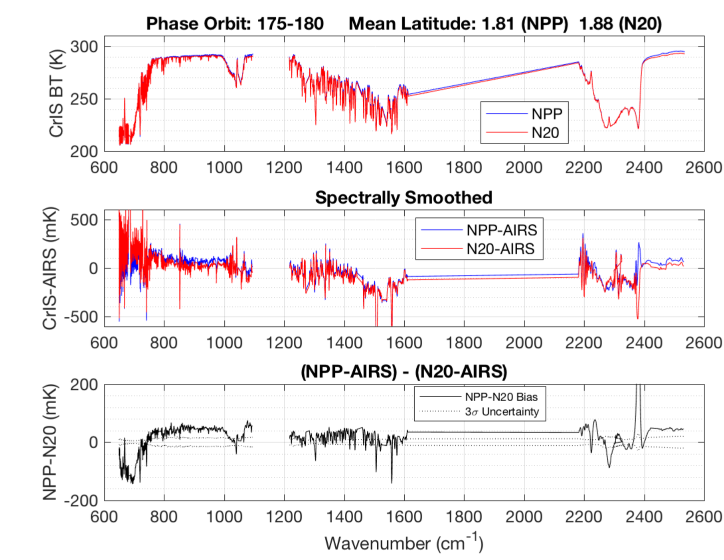
**NPP and NOAA-20 radiometric uncertainties are combined via RSS; radiometric unc. for NOAA-20 currently being refined

CrIS/AIRS Orbit Phase Dependence

- Orbit phase analyses are useful for diagnosing any issues in the SNPP ICT environmental model which has an orbital phase dependent component, while the N20 ICT emissivity is higher and also does not require the orbit phase modeling.

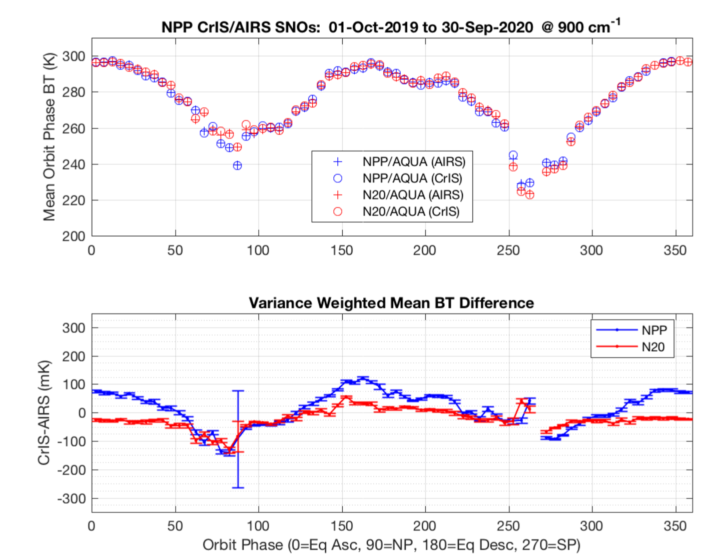
Orbit Phase Sample Numbers



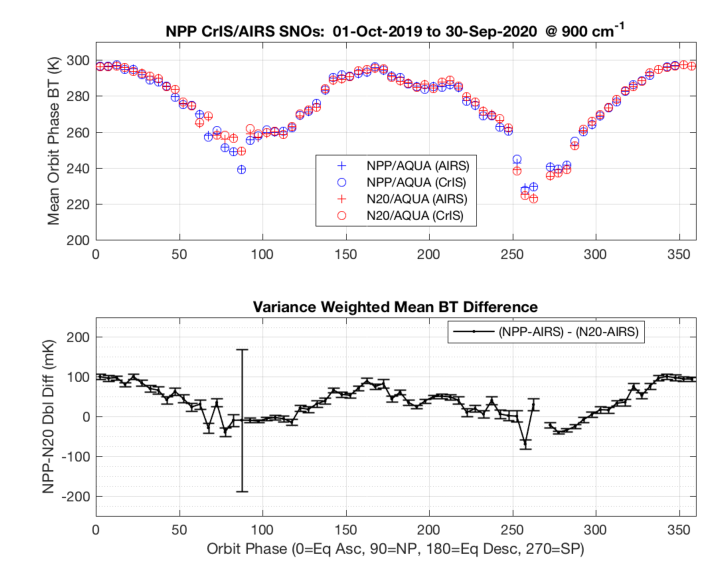


Example for 5 deg latitude bin

LW Window 900 cm^{-1}

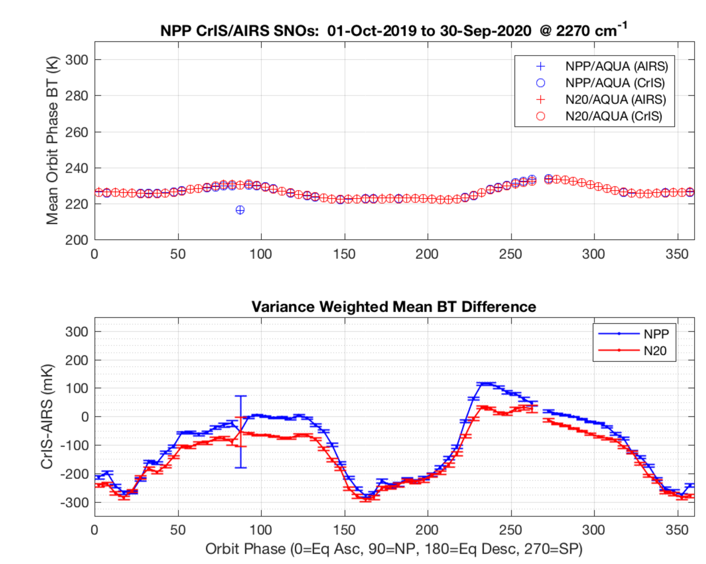


NPP – AIRS
N20 – AIRS

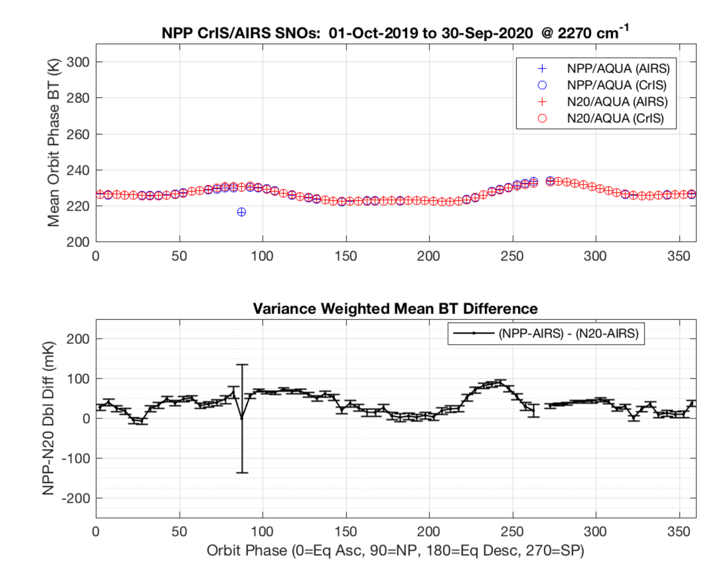


NPP – N20

SW N_2O 2270 cm^{-1}

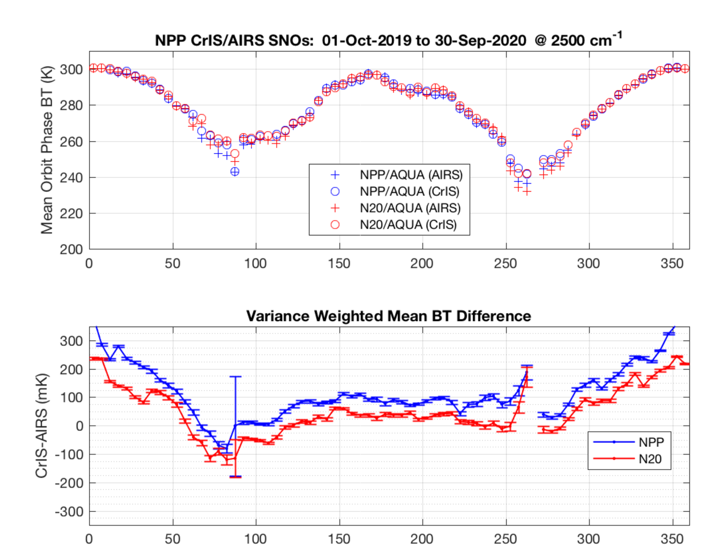


NPP – AIRS
N20 – AIRS

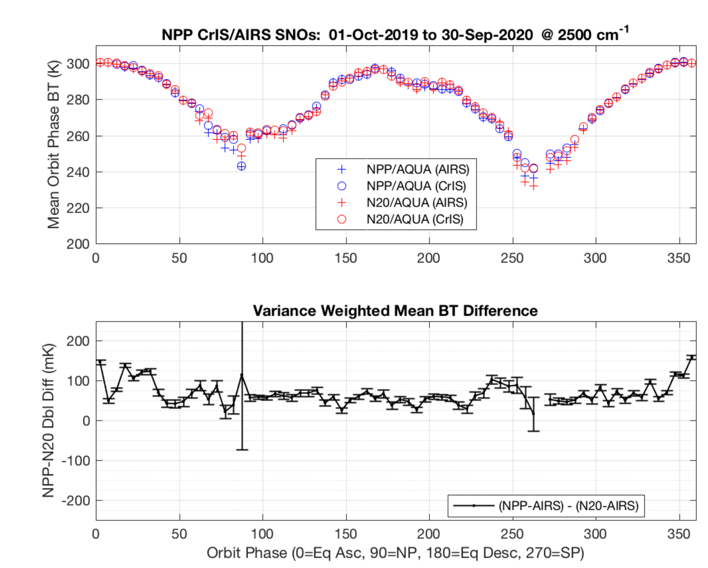


NPP – N20

SW Window 2500 cm^{-1}



NPP – AIRS
N20 – AIRS



NPP – N20

References

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NOAA-20 CrIS FSR L1b V3 Data Ref: UW-Madison Space Science and Engineering Center: Hank Revercomb; UMBC Atmospheric Spectroscopy Laboratory: Larrabee Strow (2020), JPSS-1 CrIS Level 1B Full Spectral Resolution V3, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: [Data Access Date], 10.5067/LVEKYTNSRNKP

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AIRS L1C v6.7 Data Ref: AIRS Science Team/Larrabee Strow (2019), AIRS/Aqua L1C Infrared (IR) resampled and corrected radiances V6.7, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: [Data Access Date], 10.5067/VWD3DRC07UEN

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