Tropical simultaneous nadir observations for IR sounder evaluation and comparison

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ABSTRACT

Simultaneous Nadir Observations (SNOs) contain thousands of pairs of observations taken within 8 km and 10 minutes. SNOs have been very useful for comparisons in polar conditions. But classic SNO pairing criteria have very low yield in the tropics, making these SNOs less useful for investigating instrument performance for hotter scenes or scenes with high contrast. We introduce a modified methodology, which finds pairs of matched spectra in a wider angular range but is restricted to the tropics. We illustrate this with AIRS and CrIS data. Insight into instrument differences is gained from statistical distributions of the residual differences between the matched pairs. A sample analysis compares AIRS and CrIS brightness temperature at 900 cm-1 as function of scene brightness temperature. The proposed method may be applicable to matchups of other sensors on different spacecraft.

Keywords: Simultaneous Nadir Observations, SNO, AIRS, CrIS, hyperspectral sounding, infrared, climate

1. INTRODUCTION

The Atmospheric Infrared Sounder[1] (AIRS) is a hyperspectral IR sounder launched on the EOS Aqua into a 1:30 PM sun-synchronous polar orbit in May 2002. It observes 2378-channel thermal IR spectra for each scene, covering a spectral range from 3.7 µm to 15.4 µm. AIRS spectra are used by Level-2 processes to measure many atmospheric and surface properties including temperature and water vapor profiles; abundance of trace gases (including ozone, methane carbon monoxide, carbon dioxide); cloud properties; dust; and surface temperature and IR emissivity. AIRS now provides an unprecedented record of over 12 years of high-quality data.

The Cross-track Infrared Sounder[2] (CrIS) on Suomi NPP was launched in October 2011, also in a 1:30 PM sun-synchronous polar orbit. It is an operational hyperspectral sounder with a primary mission to support forecasting. It covers roughly the same spectral range as AIRS. CrIS spectra can be used to retrieve the same geophysical parameters as AIRS using similar algorithms. The Suomi NPP spacecraft orbit is similar to EOS Aqua but not identical. Further CrIS instruments are to be launched into similar orbits every 5 years on the JPSS series of spacecraft, eventually providing a climate record spanning decades.

While the spectra from each hyperspectral sounder can be used to retrieve the same geophysical quantities with conceptually similar algorithms, subtle differences in the orbits, footprint sizes and spectral resolution make it likely that the results will be slightly different. For weather and for climate process studies this is not critical, but long-term climate studies will require combining the records from individual instruments to make a continuous time series. To track expected climate signals on the order of 0.1 K/decade, differences must also be understood within ~0.01 K. This extremely demanding level can not be achieved by comparing the retrieved geophysical products, but requires a direct comparisons of calibrated radiances while two instruments are flying in similar orbits at the same time.

Table 1 gives some key parameters for AIRS and the first CrIS.

Table 1. Comparison of key parameters of AIRS and CrIS

Platform	Instrument	Instrument Type	Scan Rate (s)	Scan Range (°)	Scan Pattern	Nadir FOR Diameter (km)	Spectral Channels
Suomi NPP	CrIS	IR (FTS)	8	±50	30 x 3 x 3	14	1305
EOS Aqua	AIRS	IR (Grating)	8/3	±50	90	14	2378

Comparisons of AIRS and CrIS can use many types of data. Some comparisons are based on global statistics, with the assumption that since both instruments are observing the same planet, over time they should see the same sorts of things. Or statistics can be local, separately comparing observations from each instrument to "ground truth". Because of differences in the retrieval algorithms there are no exactly corresponding domain subsets and these types of comparisons are not very helpful at tracking down the causes when differences are found.

The most direct comparison of two instruments is the comparison of calibrated radiances where AIRS and CrIS observe nearly the same scene at the same scan angle at the same time. Unfortunately the FOVs can never match exactly in time and space, however, the mean radiance difference should approach zero for a sufficiently large data set. The key is to create sufficiently large sets of pairs of observations. As the number of pairs increases, the probable error in the mean decreases and, at some point may the mean may be statistically significantly different from zero, i.e. instrument differences emerge. There is a tradeoff between very tight spatial and temporal coincidence requirements, which yields almost no data, and looser coincidence requirements that yield a large amount of data with a large scatter.

The most common type of simultaneous observations is the Simultaneous Nadir Observation[3] (SNO). Sounder SIPS at JPL for example collects AIRS/CrIS SNOs where:

1) FOV centers are within 8 km
2) observations are within 10 minutes
3) both instruments observe within +/- 1 FOR (1 AMSU FOV; 3.3 degrees) of nadir

The different 1:30 PM orbits sun-synchronous orbits of the two platforms give a 2.667 day repeating pattern in how close together the satellite tracks are and how close observations of the same location are in time. Many matches are seen near the poles and excellent agreement has been shown between AIRS and CrIS under the uniform cold dry conditions which dominate these sets. However, these sets represent less than 6% of the area of the globe and the results are not globally representative. There are instrumental differences that make the calibration for different seasons (sun angle) and under warmer and less homogeneous conditions challenging. Agreement in the polar zone is a necessary but not sufficient condition to expect agreement in the tropical zone, which covers 50% of the globe, and is key to weather and climate. The classic SNOs are of limited help. As example the entire month of April 2014 produces only 40,000 SNO observation pairs in the tropical zone. In order to make the analysis with the desired 100 mK accuracy for a wide range of conditions, about 1 million spectra are required. Unfortunately combining several years of data blurs the analysis of trends. The task is to find a data set with 1 million samples in one month.

Table 2. Comparison of key parameters of EOS Aqua and Suomi NPP

	EOS Aqua Orbit	Suomi NPP Orbit
Period	99 minutes	101 minutes
Altitude	710 km	835 km
Inclination	98.12 degrees	98.63 degrees
Repeat cycle	233 orbits per 16-days	228 orbits per 16 days

2. APPROACH

For TSNOs (Tropical SNOs) we collect spectra where:

1) FOV centers are within 8 km
2) observations are within 10 minutes
3) both instruments observe within +/- 3 FOR (3 AMSU FOV; 9.9 degrees) of nadir
4) latitude is within 30 degrees of the equator

The first two conditions are identical to the older SNO methodology. The difference is that TSNOs allow each instrument to look farther from nadir, and that we now collect only tropical spectra.

First we must review the implications of including spectra further from nadir. The higher angle allows for more atmospheric absorption, and this could influence the data. Figure 1 shows the impact to a calculated spectrum for a clear tropical case when it is observed at nadir vs 9 degrees from nadir. Differences are very small, comparable to instrument noise.

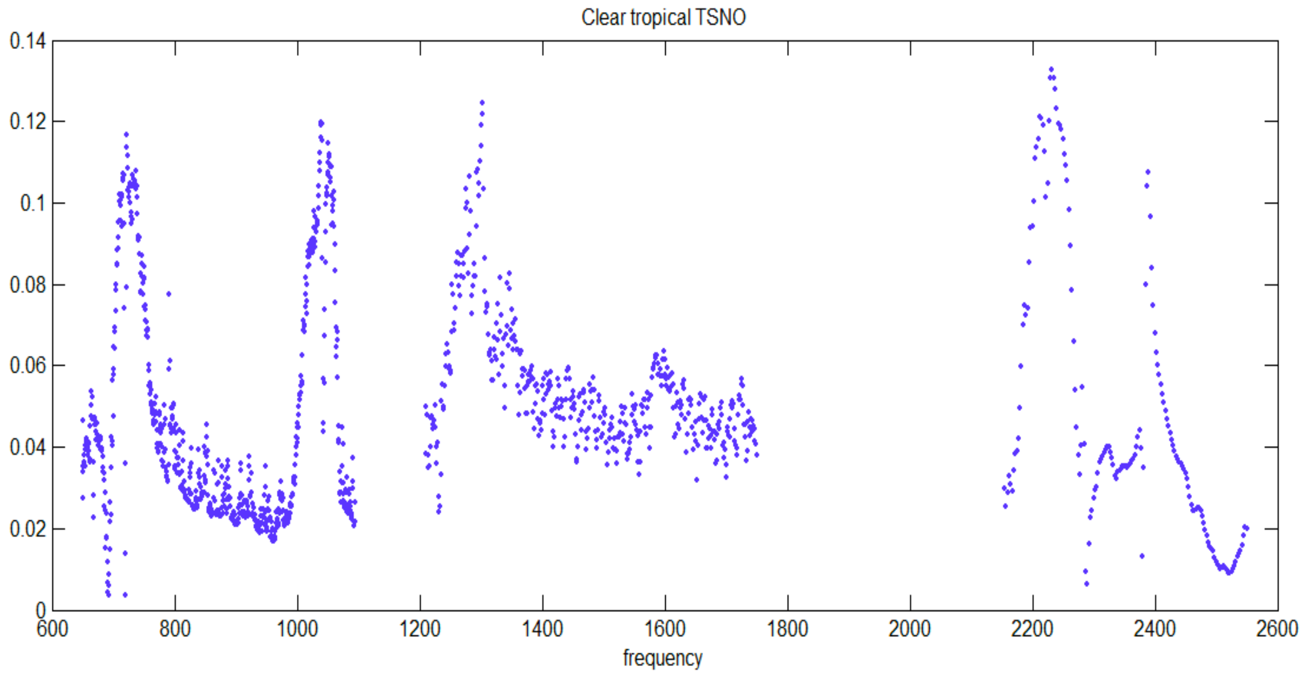

Figure 1. Radiometric impact from use of wider nadir swath (K)

Also note that we expect even this small difference to cancel to first order since the final data set will contain approximately the same number of spectra at each angle from each instrument.

3. SAMPLE RESULTS

The test set is April 1-29, 2014. The AIRS data uses Level-1C[4] with a 2645-channel continuous spectrum with outliers removed, while the CrIS data is the CCAST calibration from UMBC with Hamming apodization applied.

There are over 300,000 pairs of spectra in the set, including land and ocean cases and day and night, but all from the tropics.

A first look at a daily mean of the matched spectra shows obvious differences. The instruments have somewhat different spectral ranges, but the main difference is in spectral resolution. AIRS has higher spectral resolution so its spectral lines are deeper.

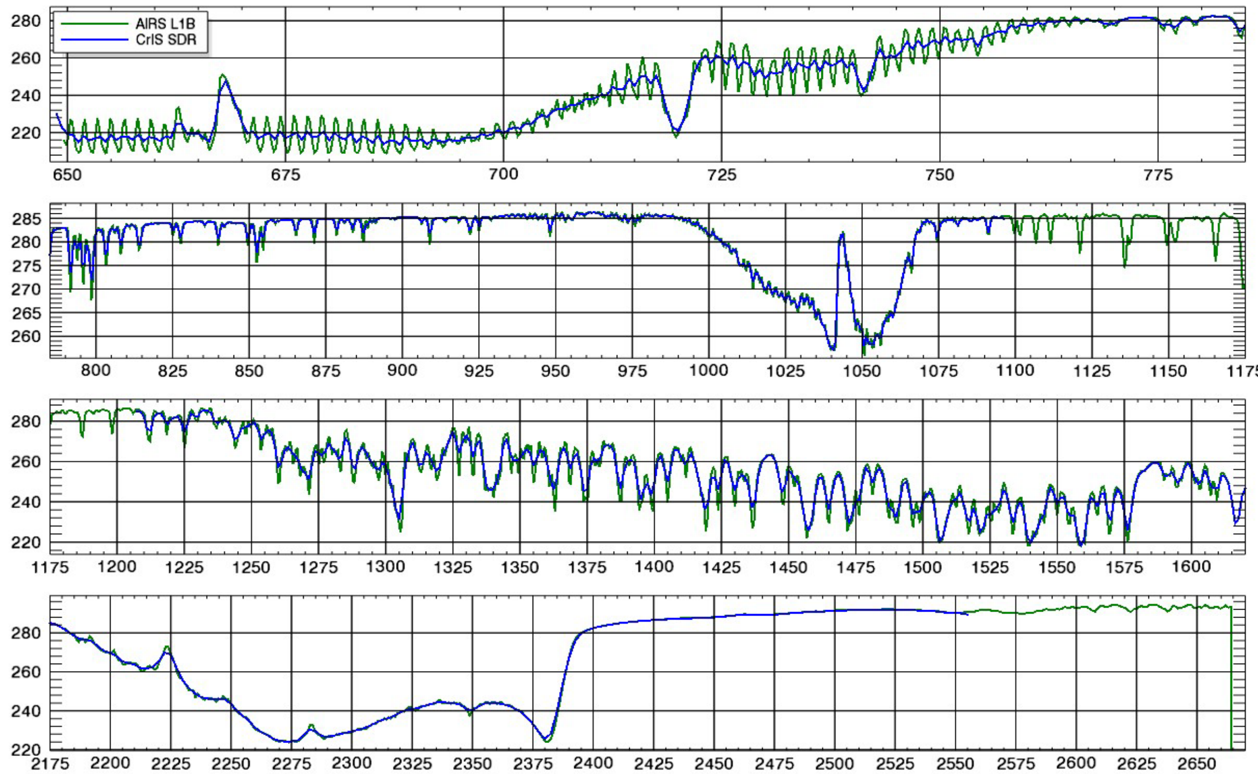

Figure 2. AIRS and CrIS mean tropical spectra (K)

A difference plot shows just how large the differences resulting from spectral resolution are. Work is currently in process to resample the two instruments to a common spectral grid, but for now we can get insight into more subtle instrument effects by concentrating on a few spectral windows where the lack of spectral structure in the observations makes the different sampling unimportant. One of these regions is the atmospheric window near 900 cm^{-1}.

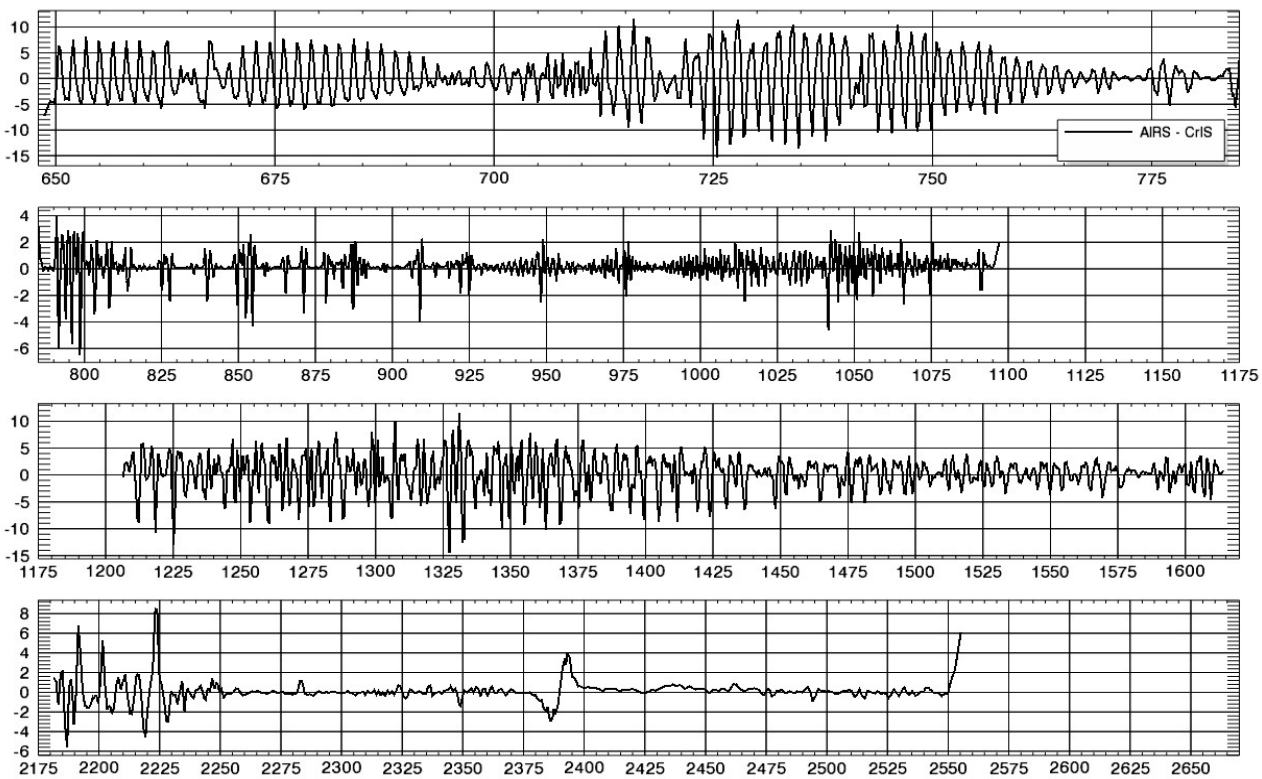

Figure 3. Difference between AIRS and CrIS mean tropical spectra (K)

Comparing the median brightness temperature (BT) of the AIRS channel at 900.3 cm^{-1} (BT900AIRS) to the CrIS channel at 900.0 cm^{-1} (BT900CrIS) as a function of scene BT gives Figure 3. Each point here represents the median of 6000-7000 observations after the observations are sorted by the mean of BT900AIRS and BT900CrIS.

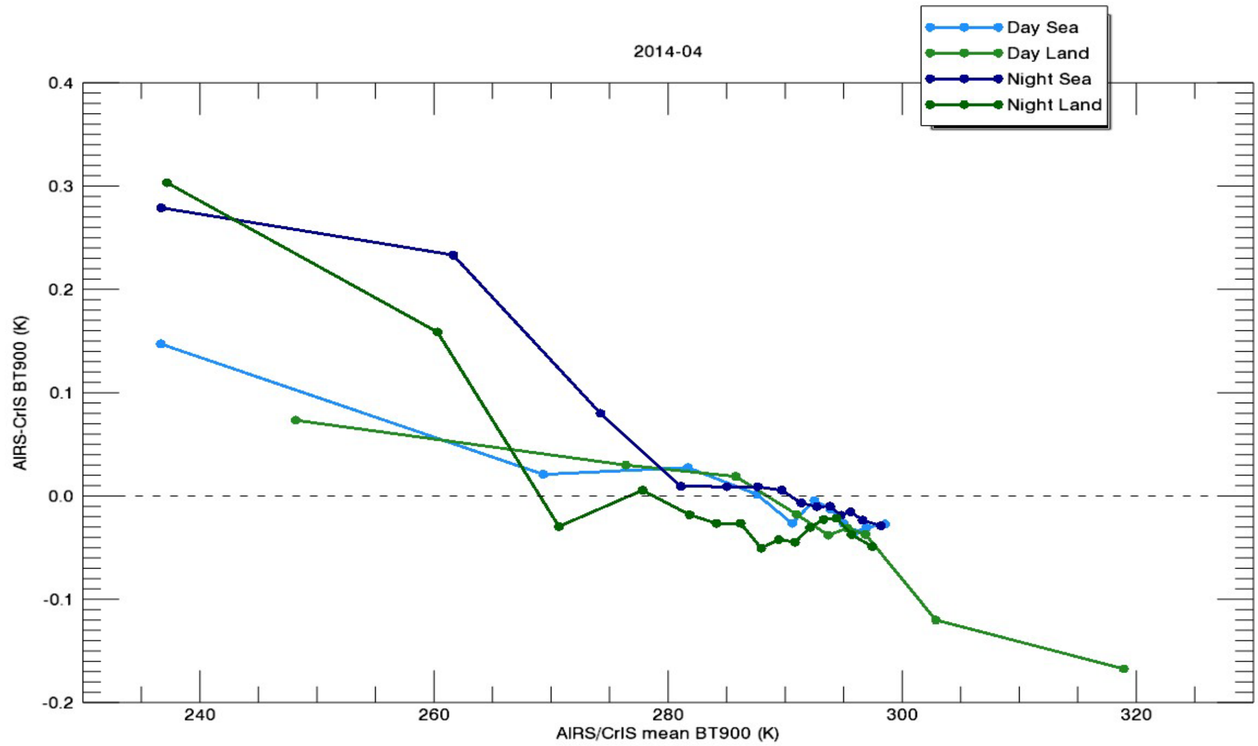

Figure 4. AIRS minus CrIS median BT by scene temperature

Most of the data is concentrated at scene temperatures between 280 and 300 K, and here the instruments consistently agree within 0.05 K. But there seems to be a clear slope in the differences, with AIRS warmer for cold scenes and CrIS warmer for hot scenes. There's also an apparent day/night difference in this difference for cold scenes only. Analysis of the causes of the AIRS/CrIS differences is out of scope of this paper.

4. DISCUSSION

4.1 Geophysical sampling

There are approximately 29,000 pairs of spectra per orbital repeat, spanning ~8 orbits, but concentrated where the platforms are at closest approach. In that case we can collect 18 spectra per scan for each instrument, spanning +/- 9.9 degrees from nadir. Near the ends of the aligned period, we are collecting 1 spectrum per scan from each instrument where AIRS is near +9 degrees and CrIS is near -9 degrees or vice versa. So even though we have a large number of observations each orbital repeat, they are too concentrated in a few orbital passes to form a representative sample.

For effects where each observation is essentially independent, like instrument noise and small-scale scene variability, the 29,000 observation pairs in one day of overlap will reduce the impact of the effects by a factor of sqrt(29,000) ~= 170.

But there are also larger-scale scene differences like desert vs. vegetated, dust clouds, or high vs. low-pressure systems. These may be present for ~ ½ of an orbital pass through the tropical zone of +/-30 degrees latitude. Thus one day of observations may only reduce the impact of these scene effects by a factor of ~sqrt(16) = 4 per day, or even less when land and sea and/or day and night are analyzed separately. Accumulating data over more than one day is essential to get a representative set, as in the 1-month set used in the analysis above. A month of data with the current algorithm gives >300,000 spectra, so the million-spectra target is attainable with various combinations of months of data, while still providing a strong statistical basis to observe seasonal effects and trends.

5. CONCLUSIONS

TSNO is a powerful tool for comparing AIRS and CrIS in the 50% of the area of the globe that is most critical for weather and climate. TSNO needs to be paired with a tool that resamples AIRS data to match CrIS channels before it can be used for direct comparisons of AIRS vs. CrIS over the full range of frequencies. This will be presented in future work.

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