To: Hal Maring
From: Hank Revercomb (PI), Dave Tobin (CoI), Bob Knuteson (CoI), Fred Best (CoI),
Chris Moeller (CoI), Dan Laporte (CoI), and Larrabee Strow (Collaborator)
Date: 9 May 2012
Re: **Year-1 NPP Science Team Grant (NNXAK21G) Progress Report**

This is the year-1 progress report for our grant entitled "***Assessment and Optimization of IR Radiance Measurements and Products for Climate, Assimilation, and Remote Sensing Applications: Continued NPP Science Team Participation***". This report is organized around the milestone called out in our proposal (dated May 2010).

The original proposal milestones were broken down by years 1-3 with year 1 being prelaunch activities. Because the start of the grant was delayed and launch of Suomi NPP occurred on 28 October 2012, our first year's effort included some significant Post-launch activities. Also, our efforts have leveraged other operational activities at University of Wisconsin-Madison, Space Science and Engineering Center (UW-SSEC) to accomplish a great deal in this first year of the grant. Support from the NPP Atmosphere PEATE has been especially important for our CrIS SDR work.

As a brief summary of our early assessments, we are extremely pleased with the excellent performance of the CrIS instrument. It is proving to be a very stable, low noise (substantially better than both AIRS and IASI), and highly accurate (better than 0.2 K 3-σ brightness temperature for all wavelengths and scene temperatures) replacement for the EOS Aqua AIRS sounder. It seems certain that CrIS will be capable of continuing the AIRS climate record with equal or better accuracy and spectral resolution, while requiring significantly fewer spacecraft resources.

Also, the CrIS full spectral resolution mode, which offers a constant 0.625 cm^{-1} unapodized resolution from 3.7 to 16 microns (normal resolution for the longwave band that results in a resolving power as high as 4300 at 3.7 microns compared to the AIRS resolving power of 1200-1400), has been successfully demonstrated on orbit. We should lobby for routinely bringing this new higher spectral resolution data to the ground, instead of allowing it to be discarded on the spacecraft to minimize data volume (a 1991 design decision).

Year 1: Pre-launch Assessment and Preparation Milestones

1. *Pre-NPP launch estimate of on-orbit performance*

CrIS

Figure 1 shows the expected accuracy of CrIS for each of its nine footprints (color coded) based on pre-launch tests and analyses of thermal vacuum data. The differences between footprints for the LW and MW bands are due to detector non-linearity differences. These estimates were derived by RSSing uncertainty estimates for all of the independent parameters of the calibration equations. Note that the expected performance for all three spectral bands substantially exceeds the requirements (stated as a per cent of 287 K radiance as illustrated in the top row of plots). In terms of not-to-exceed (3-σ) brightness temperature shown in the lower row of plots, the accuracy is expected to be less that 0.2 K everywhere, when non-linearity coefficient refined on orbit are used. Therefore, we expect the accuracy of CrIS to be excellent, and to exceed that of the EOS AIRS sounder for many spectral regions. Initial results support this expectation.

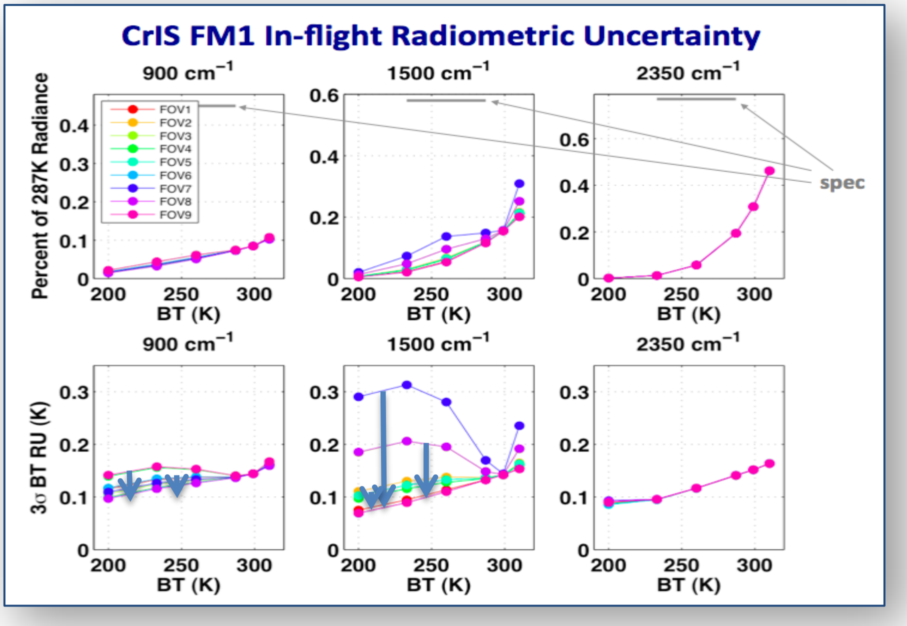

Figure 1: Pre-launch expected calibration accuracy.

The inherent spectral stability and accuracy of CrIS are also expected to be excellent. The Instrument Line Shape (ILS) is well known from fundamental Fourier Transform Spectrometer (FTS) design principles (proven with CO_2 laser measurements in T/V testing), and the onboard sample control laser and Neon calibration subsystem are expected to be stable to better than 1 ppm. This far exceeds the stability of the AIRS that varies several ppm during each orbit.

Also, the effective spectral resolution of CrIS is generally higher than that of the EOS sounder, not lower as is sometimes stated. While over the years comparing grating and FTS performance has been a controversial point, Figure 2 presents an explanation of our statement above using the 15 micron CO_2 region in the LW band as an example. While differences of ILS make it difficult to make apples-to-apples comparisons of CO_2 information content in the spectral domain, reasonably direct comparisons are possible in the interferogram domain. The figure compares the CO_2 signal captured by the FTS boxcar to that of the Fourier transform of a grating ILS. Clearly, the amount of CO_2 signal in the 1st and 2nd resonance regions captured by a grating is about equal to the FTS when its resolution is approximately equal to the UNapodized

FTS resolution--not the FTS apodized resolution. Detailed comparisons of this type for CrIS and AIRS make it clear that the high spectral resolution content of CrIS is comparable to, but somewhat better than, that of AIRS.

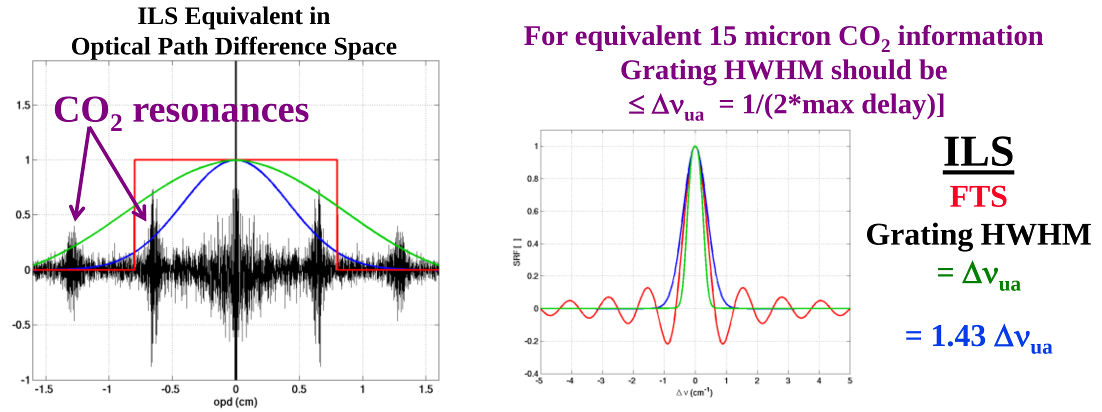

Figure 2. Effective resolution comparison of a typical grating compared to that of an unapodized FTS instrument for the 15 micron CO_2 band. In the interferogram represented on the left, the larger signals near 0.65 and 1.3 cm optical path difference (OPD) are the CO_2 resonance regions corresponding to its equally spaced absorption lines. Note that an FTS covering out to 0.8 cm OPD like CrIS captures all of the first and largest resonance region, while a grating with resolution equal to the apodized FTS resolution misses a large fraction of that resonance and only picks up a very small fraction of the second resonance region. From an information content point of view, a grating needs to have a resolution on the order of the FTS unapodized resolution to have comparable information content.

Finally, the noise performance of CrIS is presented in Figure 3. The performance shown is actually for flight data, since it is so close to the pre-launch expectation. The Cris NEdN is four times better than that for AIRS in the critical CO_2 region of the LW; comparable, but smaller in the MW (except for FOV 7 that is anomalously high by about 2-3 times); and comparable in the photon limited SW where the grating has a theoretical advantage (shown for 290 K—at 250 K AIRS NEdN is slightly smaller than CrIS).

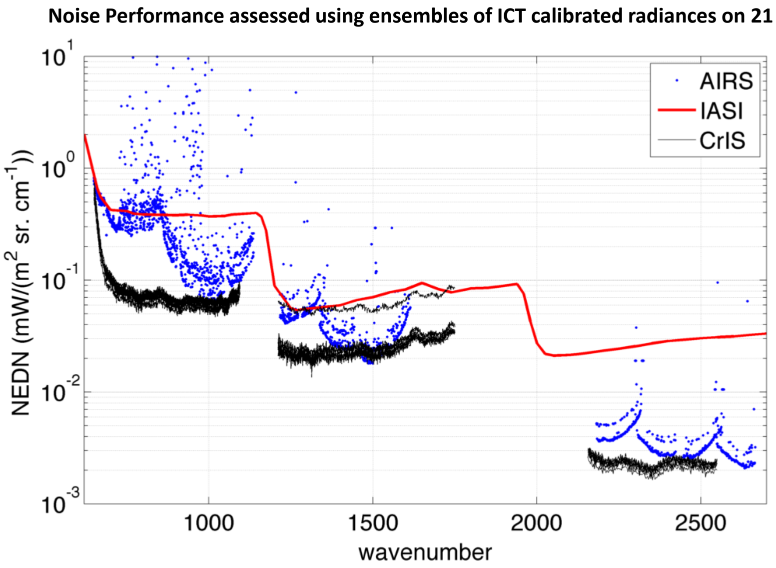

Figure 3. CrIS inflight Noise Equivalent Radiance, compared to AIRS and IASI.

VIIRS

In the final months leading up to the launch of NPP in October 2011, Wisconsin, as the spectral lead on the govt team, played an active role in reviewing and finalizing the VIIRS at-launch spectral calibration to demonstrate launch readiness. This effort included the following:

- VIIRS instrument level and spacecraft level govt team "Best" relative spectral response (RSR) combined to form govt team "Fused" RSR estimate for VisNIR bands.
- Worked alongside industry to facilitate high quality VIIRS RSR at-launch characterization, transferring knowledge between govt team and industry.
- Reviewed industry RSR releases of March 2010, December 2010, and Sept 2011. Industry RSR found satisfactory for VIIRS at-launch use.
- Radiometric impact of differences between govt team and industry RSR products evaluated and found to be small.
- RSR elements of at-launch VIIRS SDR LUT reviewed; found satisfactory.
- Assessment of spectral impact on radiometry evaluated and found to be small and similar to that of MODIS heritage bands (Figure 4).

These activities contributed to readiness of the VIIRS spectral characterization for launch and laid the groundwork for anticipating on-orbit adjustments to the VIIRS spectral characterization. Further, the spectral characterization was made available to the NASA science community for their application, supporting performance evaluations at the EDR level.

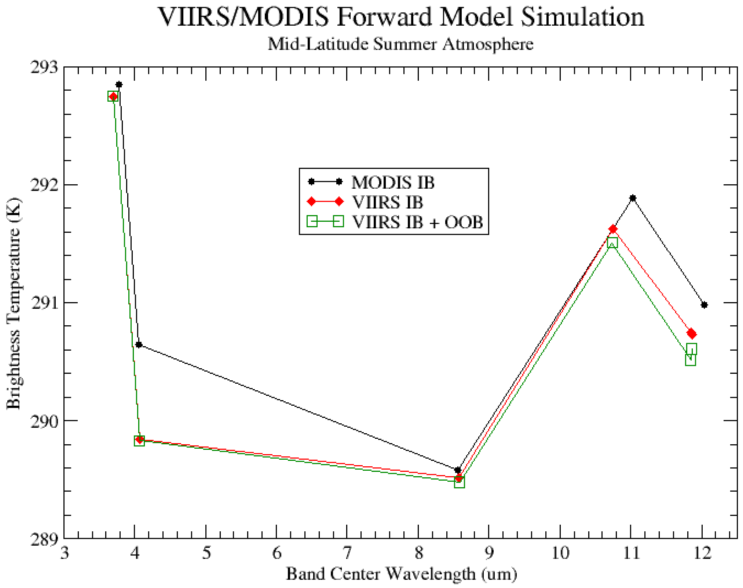

Figure 4. Radiometric model demonstrating spectral influence on VIIRS brightness temperature. Calculations for VIIRS in-band and in-band + out-of-band show only minor out-of-band influence. MODIS in-band brightness temperatures provided for reference.

2. CrIS SDR algorithm assessment using pre-launch T/V data

At UW-SSEC, our approach to CrIS SDR algorithm assessment has been two pronged: (1) Develop a UW-SSEC/UMBC Matlab version of the SDR algorithm, known as CCAST (CrIS Calibration Algorithm Sensor and Testbed), based on our software developments and T/V data analyses, and (2) Develop CSPP (Community Science Processing Package) a Direct Broadcast version based on ADL, the Linux version of the operations code distributed by Raytheon. The first is especially important for NPP, because it allows us to very quickly implement changes for evaluating the effects of algorithm refinements and changes. In fact, it also allowed us to prove that many initial problems were software related, not instrument performance issues, and to process all of the CrIS 1st light data shown at the AMS annual meeting in January. We are now capable of running both versions on the NPP Atmosphere PEATE.

3. Preliminary PEATE processing of CrIS SDR algorithms on test datasets

On the Atmosphere PEATE, we are routinely running CSPP SDR processing on CrIS Data, and are also ingesting IDPS results. This allows us to make comparisons to identify remaining problems with IDPS data and to help identify fixes.

4. Preliminary PEATE processing of VIIRS SDR algorithms on test datasets

For VIIRS, the Atmosphere PEATE is concentrating on EDR software and analyses. However, through the new CSPP Direct Broadcast software it is capable of processing raw VIIRS data to SDRs. Evaluations of thermal infrared data quality using CrIS are being used to investigate the need for any SDR algorithm changes.

Post-launch Validation and Optimization Milestones (originally a year-2 activity)

1. CrIS radiometric performance evaluation using Principle Component Analysis (Fig 5.)

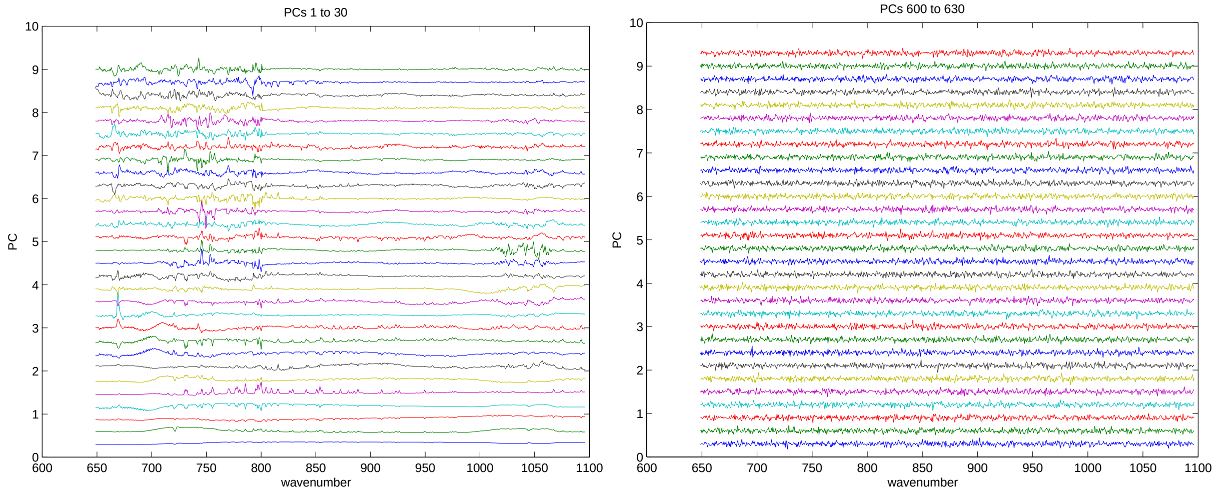

Figure 5: Preliminary LW Principal Components of CrIS data do not identify any major concerns.

Figure 5 is a sample of the preliminary PCA results performed on CrIS LW data. The first 30 Principal Components (or eigenfunctions) shown on the left display physically reasonable features of atmospheric spectral variations. In contrast, PCs 600-630 shown to the right look like random noise, as expected for a normally functioning instrument. No noticeably unphysical artifacts were apparent in these early analyses, so further more detailed evaluation were postponed for a later date.

2.   Preliminary on-orbit inter-comparisons of CrIS radiances with AIRS and IASI

AIRS compared to CrIS with SNOs

A mapping of the SNOs for our preliminary comparison of CrIS with AIRS is shown in Figure 6. Note that good comparisons can be made at a wide range of latitudes every 2-3 days, because of the tandem nature of their orbits (both at 1330 local time, with altitudes of 710 km for AIRS and 824 km for Suomi NPP).

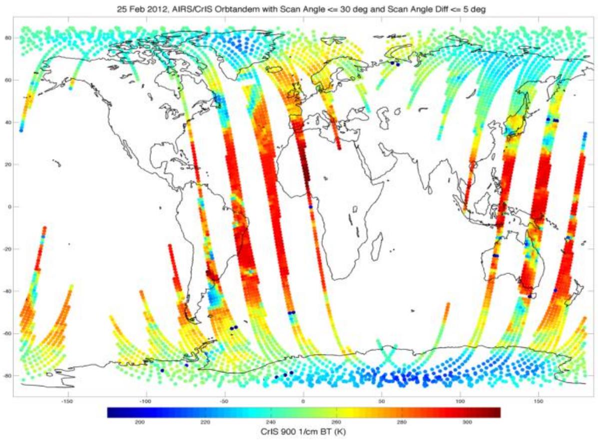

Figure 6. CrIS/AIRS simultaneous nadir overpasses on 25 February 2012 with view angles ≤30° and difference angles ≤5°.

The results of the SNO comparison are shown in Figure 7. The histograms compare the mean (blue) and median (purple) differences for each of the CrIS LW (left) and MW (right) detectors. The probability distribution functions of the differences are also show for the nine detectors arranged in the 3x3 arrays used by CrIS. Note that the median differences for all detectors in a band, as well as the peak differences between detectors are well under 0.2 K. While these differences are indicative of a good calibration for both instruments, this is the level of difference that we will be working to understand better for the NPP climate applications of CrIS and AIRS.

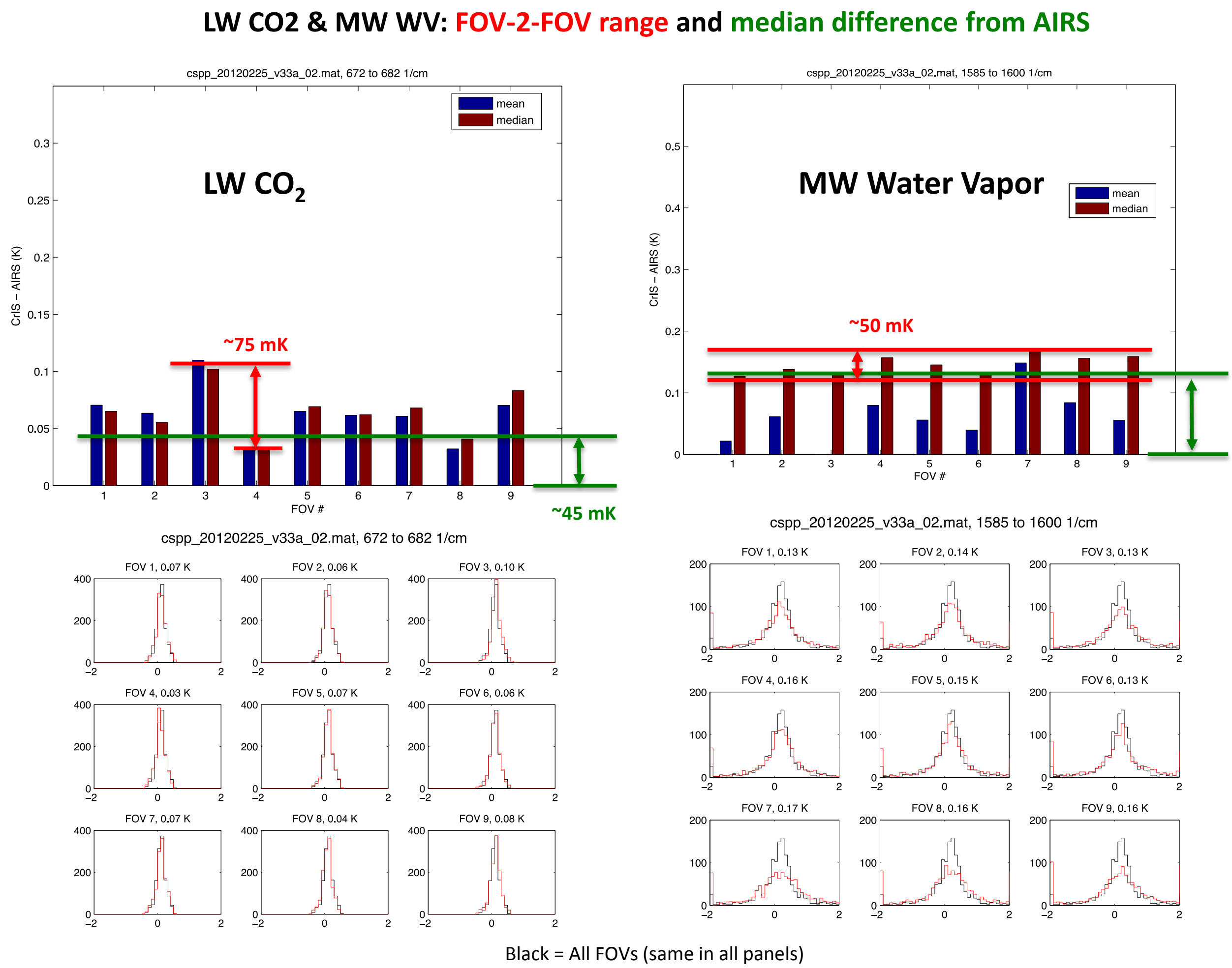

Figure 7. Histograms and PDFs of CrIS-AIRS for all nine CrIS field-of-views for an opaque CO_2 region (672-682 cm^{-1}) on the left and for the center of the water vapor band (1585-1600 cm^{-1}) on the right.

IASI compared to CrIS with SNOs

Initial comparisons to IASI have not progressed as far as the AIRS comparisons; our status is summarized in Figures 8 and 9. Figure 8 shows that the number of useable SNOs available on 24 and 25 February 2012 is very limited, as expected. Clearly a much larger sample set is required to do a careful comparison. However, this figure also illustrates our capability to locate the desired SNOs, which prepares us up to perform this comparison early in year 2. Figure 9 shows the brightness temperature spectra corresponding to the SNOs of Figure 8. While the range of brightness temperatures represented in this limited sample does not show anything above about 270K, previous SNO work with AIRS and IASI has shown that temperatures up to 295 K will be covered by a more extended sample. This wide range of temperatures for such high latitude samples was one of the pleasant surprises from our early work with SNOs.

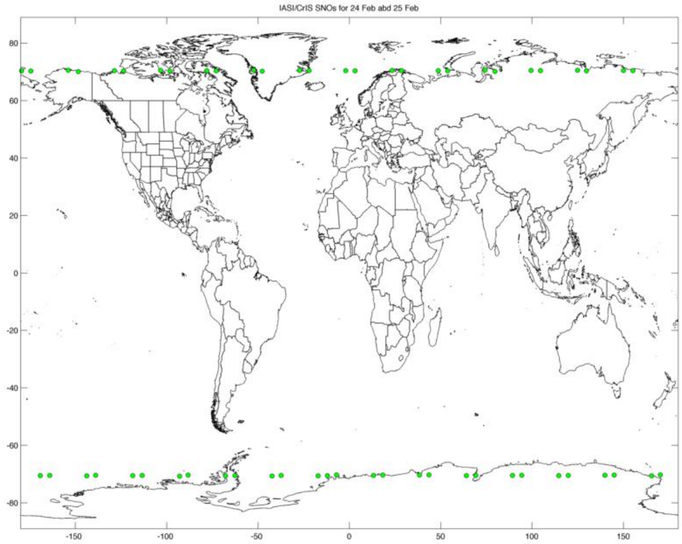

Figure 8. Locations of CrIS and IASI SNOs on 24 and 25 February 2012 (green circles). Note that because of the different local times of their orbits (930 for IASI and 1330 for CrIS), only infrequent comparisons near 73° north and south latitude are possible.

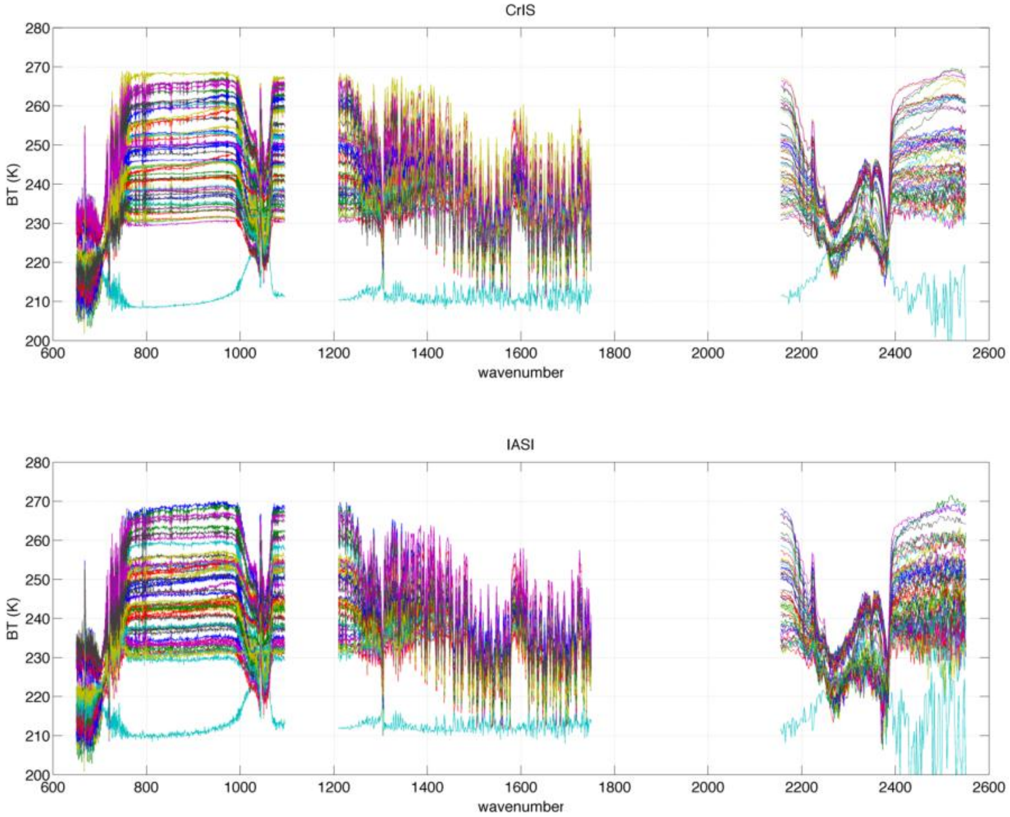

Figure 9. SNO Brightness temperature spectra from CrIS and from IASI converted to CrIS spectral resolution and sampling. Note the distinct similarities and the lower noise for CrIS.

3. Preliminary on-orbit inter-comparison of CrIS and VIIRS radiances

Because they are deployed together as payload on the Suomi NPP spacecraft, the CrIS and VIIRS instruments present a daily opportunity for global comparison of their common spectral bands. In a given 24 hour period, over 2 million potential matchups between CrIS and VIIRS are obtained, providing a robust data set for understanding the relative performance of these instruments and their evolution on-orbit. CrIS instrument spectra overlap VIIRS spectral coverage of bands M13, M15, M16, and I5. Early in the lifetime of Suomi NPP, preliminary (pre-Beta) calibrated VIIRS and CrIS SDR products have been compared using Jan 21, 2012 global data in an early on-orbit review of radiometric performance. To simulate VIIRS observations the CrIS high spectral resolution radiances were convolved to the VIIRS band average relative spectral response (RSR). The VIIRS observed radiances were averaged over the CrIS 13 km footprint to simulate CrIS observations. After converting the simulated CrIS and VIIRS radiances to brightness temperature using a Planck function in the wavenumber (CrIS) and the wavelength (VIIRS) domain, the matchups are differenced and plotted (Figure 10). Aggressive filtering on VIIRS uniformity over the CrIS footprint reduces the influence of any mis-registration between the two sensors by removing highly structured scenes from the comparison data set. The early results of Figure 10 suggest that both instruments are achieving their expected performance. Biases between the instruments are below 0.25 K with minimal scene temperature dependence evident in the plots. Plots as a function of scan angle further indicate that the VIIRS HAM mirror response vs scan (RVS) is well characterized. This early case presents a snapshot example of the daily performance monitoring that will be applied under Beta, provisional, and validated SDR status. These comparisons will further provide insight into the evolution of the CrIS and VIIRS SDR performance over the lifetime of the mission.

4. CrIS SDR algorithm refinement using checkout phase radiance observations

Our specific CrIS SDR algorithm efforts to date have concentrated on (1) refining Non-linearity Coefficients by evaluating the message from out-of-band harmonic analyses for each of the 27 detectors and by performing FOV-to-FOV radiance level comparisons for each band, and (2) refining spectral calibration coefficients by performing spectral shift tests on a FOV-to-FOV basis for all three spectral bands. These analyses have been very successful, as indicated by the good FOV-to-FOV consistency for the data shown in Figure 7.

Early analyses of the need for algorithm refinement have been conducted. Areas for expected future concentration include (1) refinement of the radiometric model of radiance reflected from the Internal Calibration Target (ICT), and (2) evaluation of small SW FOV-to-FOV differences observed for uniform scenes (about 0.06 K effects for opaque CO_2 channel data).

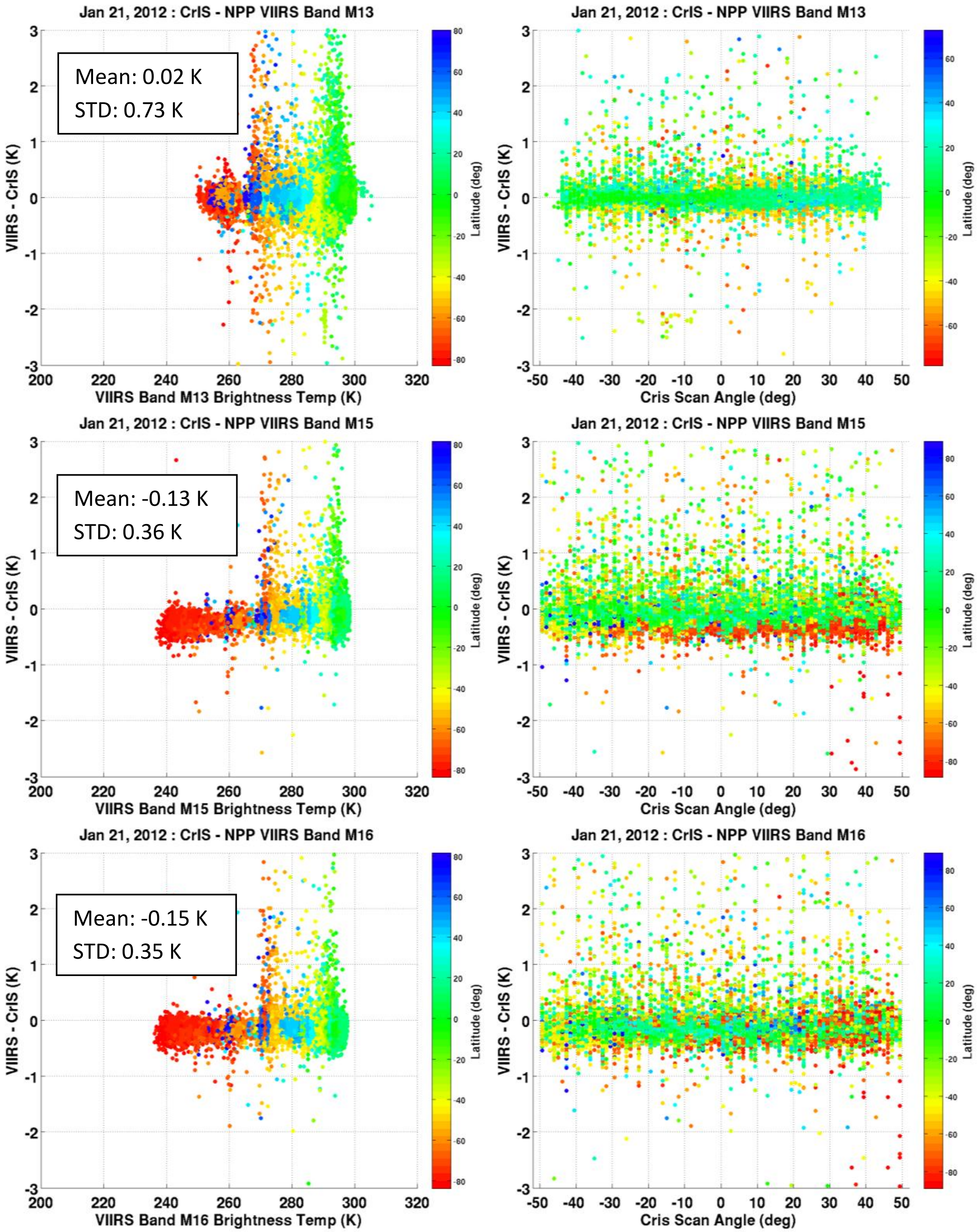

Figure 10. Preliminary VIIRS-CrIS comparisons for Jan 21, 2012 global data set. Both VIIRS and CrIS SDR are pre-Beta in this first example of comparisons. Nevertheless, the comparisons show very good agreement for these bands with minimal dependence on scene temperature (left) or on scan angle (right).

Future Plans

In our proposal we categorized our activities in three phases, (1) assessment, (2) optimization, and (3) Test. This year dealt with assessment of CrIS and VIIRS performance, both pre-launch and on orbit, and next year will refine the on-orbit assessment and begin the performance optimization activity. We are looking forward to an even more active Year 2 now that the CrIS and VIIRS on the Suomi NPP satellite are successfully in orbit and past the very intensive initial operational preparation stages that have brought both instruments data streams successfully to Beta classification.

Finally, a plug for planning a follow-on advanced sounder--now that CrIS is successfully in orbit and performing up to expectations, it is not too early to start thinking seriously about a post JPSS CrIS that includes both (1) fully contiguous spectral coverage and (2) substantially increased spatial resolution. Because the CrIS instrument design is modular, this can be accomplished by incorporating larger imaging arrays (with active cooling if needed) behind the same high throughput interferometer, all-reflective telescope, and calibration/scene viewing subsystem. By leveraging the current design in this way, the next major step in advanced sounding can be accomplished quite cost effectively.