Early Checkout of the Cross-track Infrared Sounder (CrIS) on Suomi-NPP

The Cross-track Infrared Sounder (CrIS), a high spectral resolution infrared sounder on the Suomi-NPP satellite, will complement and extend similar data records begun by the Atmospheric Infrared Sounder (AIRS) on EOS-Aqua and by the Infrared Atmospheric Sounding Interferometer (IASI) on METOP. As part of NOAA and NASA efforts, over the past several months CIMSS/SSEC researchers have played a key role in the early checkout of the sensor including fine tuning of various calibration coefficients and characterization of the sensor's performance.

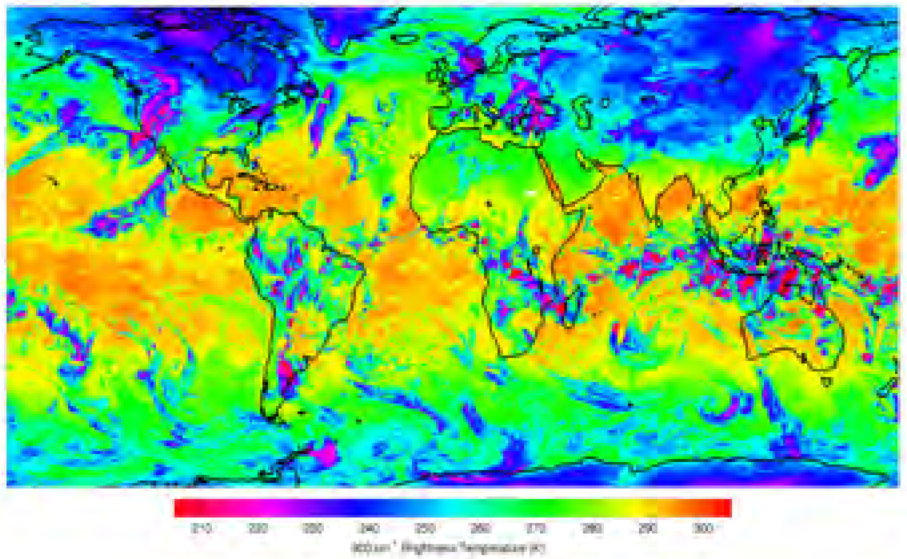

Figure 1. Data is flowing in from the Cross-track Infrared Sounder (CrIS) instrument aboard NASA's newest Earth-observing satellite, the Suomi National Polar-orbiting Partnership (NPP). This image is a composite of 900 cm-1 brightness temperatures from three days of CrIS data from January 21, 23 and 25, 2012. The orange colors represent very warm sea surface temperatures, while magenta represents both very cold temperatures as well as high-altitude cloud tops.

Following the Suomi-NPP launch on 28 October 2011, the CrIS was powered up on 20 January 2012. The CrIS sensor is a Fourier transform spectrometer, with an 8 cm clear aperture utilizing plane mirror interferometer technology. CrIS scans a 2200km swath width (+/- 50 degrees), with 30 Earth-scene fields-of-regard. Each field-of-regard consists of 9 fields-of-view (FOVs), arrayed as 3x3 array of 14km diameter spots (nadir spatial resolution). Each swath (with an 8-second repeat interval) also includes views of the internal calibration target (warm calibration point), and a deep space view (cold calibration point). For each FOV, longwave (9.14 - 15.38um), midwave (5.71 - 8.26um) and shortwave (3.92 - 4.64 um) interferograms are collected with a maximum optical path difference of 0.8 cm corresponding to a spectral resolution of 0.625 cm-1. Due to historical limits on the download data rate, however, the midwave and shortwave interferograms transmitted to the ground are currently truncated at 0.4 cm and 0.2 cm optical path difference, respectively. The overall instrument data rate is <1.5Mbps. Only photovoltaic detectors are used in the CrIS instrument. The detectors are cooled to approximately 81K using a 4-stage passive cooler with no moving parts. Primary uses of CrIS include assimilation of the radiance data into NWP models for medium range weather forecasting, retrievals of vertical profiles and temperature and water vapor, and various climate studies.

CIMSS/SSEC has been integrally involved in the CrIS project over the past decade, including design of the sensor and algorithms, participation in the Thermal Vacuum testing of the sensors, and most recently in the post-launch Early Checkout activities. Goals of the Early Checkout phase of CrIS included fine-tuning of various sensors parameters and calibration coefficients, evaluation of the software algorithms and processing system responsible for producing Sensor Data Records (SDRs) (aka calibrated radiance spectra) from the Raw Data Records (RDRs) (aka interferograms), and declaration of the CrIS SDRs as "beta" status and subsequent dissemination of the radiance data via CLASS, NWP data assimilation, and Environmental Data Record (EDR) (aka temperature and water vapor soundings) evaluation efforts. Some examples of the Early Checkout activities performed at CIMSS/SSEC include analysis of the interferometer operation, radiometric noise performance assessment, spectral calibration, radiometric nonlinearity corrections and radiometric calibration, and evaluation of the on-board numerical filter. Highlights of these findings are described below.

Interferometer Fringe Counting and Imaginary Parts of the Calibrated Radiance Spectra

A requirement for proper calibration of the CrIS radiance spectra is the ability of the interferometer to maintain fringe counts of the metrology laser signals and/or a robust algorithm to account for fringe count errors. Due to various issues, the fringe count error detection and correction algorithm in the operational CrIS SDR algorithm has been disabled. However, analyses shows that the interferometer has not experienced any fringe count errors to date. This result is very important in terms of confirmation of the design and operation of the interferometer and also in the high quality of the resulting radiance spectra. An important diagnostic on this aspect of the radiometric calibration is obtained by using the imaginary part of the calibrated radiances, which is included in the SDR product files. If the fringe counting and basic radiometric calibration has been performed correctly, the imaginary part of the calibrated spectra will have zero mean and characteristics of random noise across the spectrum. Figure 2 shows a sample of these imaginary parts for ascending node data on 18 April. The lack of structure and non-zero imaginary parts confirms the proper fringe counting of the CrIS interferometer and resulting radiometric calibration.

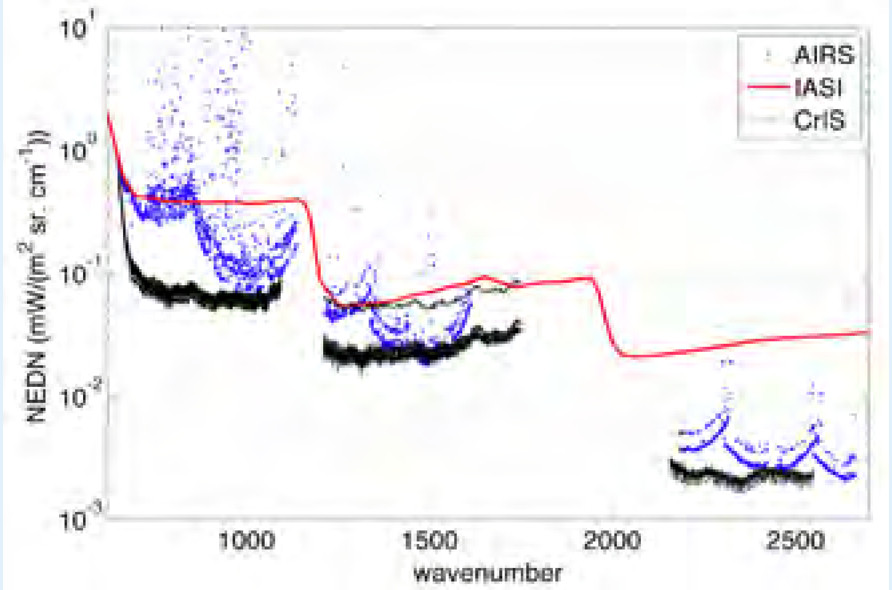

Figure 3. CrIS radiometric noise performance compared to AIRS and IASI.

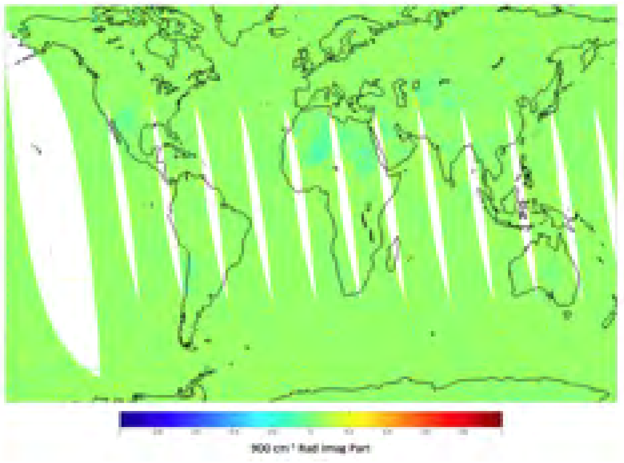

Figure 2. Imaginary parts of calibrated radiance spectra on 18 April 2012. The lack of structure and non-zero imaginary parts confirms the proper fringe counting of the CrIS interferometer and resulting radiometric calibration.

Radiometric Noise Performance Assessment

As expected, the noise performance of CrIS is excellent. Figure 3 shows an estimate of the CrIS radiometric noise performance compared to the noise performance of both AIRS and IASI. This CrIS noise estimate was derived from an ensemble of ICT and space view data and represents the random component of the noise. As shown, the random noise performance of CrIS in the longwave spectral region is approximately four times better than AIRS and IASI, and comparable to AIRS in the midwave and shortwave spectral regions. In contrast to AIRS, other analyses performed to date have shown that non-random components of the CrIS noise are very small, and most likely negligible for most science and climate applications.

Spectral Calibration

One of the main advantages of high spectral resolution, and interferometers in particular, is the ability to obtain high accuracy in terms of spectral calibration. The spectral calibration of CrIS is proving to be excellent, with spectral accuracy of approximately 1 ppm (parts per million). CrIS utilizes the novel concept of including a neon lamp, and periodic views of the neon lamp are used to assess and/or adjust the spectral calibration of the sensor. More traditionally, clear sky Earth view observations and calculations can also be used to assess the spectral calibration. To date, these analyses have shown the spectral calibration knowledge and stability to be significantly better than 1 ppm (the CrIS spec at 10 ppm). As part of the CIMSS/SSEC efforts, we also used

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an analysis method to assess inter-FOV spectral calibration that was developed previously for IASI data. Spectral consistency among FOVs is very important, and this method which assesses the spectral calibration of FOVs with respect to the center FOV (FOV5) observations has some significant advantages over approaches which use clear sky calculations as the reference. This type of analysis was used to make refinements in the FOV positions of the detectors which impacts the spectral characteristics of the data. Figure 4 shows an example result from this type of analysis for data collected on 27 March (after the refinements) showing spectral consistency among the nine longwave FOVs on the order of a few tenths of ppm.

Radiometric Nonlinearity Correction and Radiometric Calibration

During the thermal vacuum testing of CrIS, the longwave and midwave photovoltaic detectors were found to exhibit significant nonlinearity.

This behavior was characterized and found to be very similar to quadratic nonlinear behavior previously experienced and characterized in other sensors such as our aircraft sensor, the Scanning-HIS. For CrIS we developed nonlinearity characterization tests and correction algorithms that were adopted by the program. The nonlinearity behavior of some of the CrIS detectors was also found to change during shut-down/warm-up cycles of the sensor, and so post-launch characterization and refinement strategies were also developed for the Early Checkout phase. These efforts included collection and analysis of "diagnostic mode" data which provides out-of-band harmonic signals useful for characterization of the nonlinearity and an analysis technique used to refine the nonlinearity correction coefficients which draws upon the differential behavior of the nonlinearity among FOVs. Figure 5 shows an example of the magnitude of the radiometric nonlinearity correction for FOV7, which exhibits large nonlinearity in both the longwave and midwave bands. As shown, the nonlinearity correction approaches ~1K and has significant spectral shape, and so an accurate correction algorithm is very important. Following our post-launch nonlinearity refinements, Figure 6 shows differences between clear sky observed and calculated spectra (c/o L. Strow at UMBC) using the at-launch and refined nonlinearity correction coefficients. After the nonlinearity refinements, the agreement between FOVs (and the overall agreement with calculated spectra) is very good, less than ~0.1K in the longwave spectral region and less than ~0.2K in the midwave region.

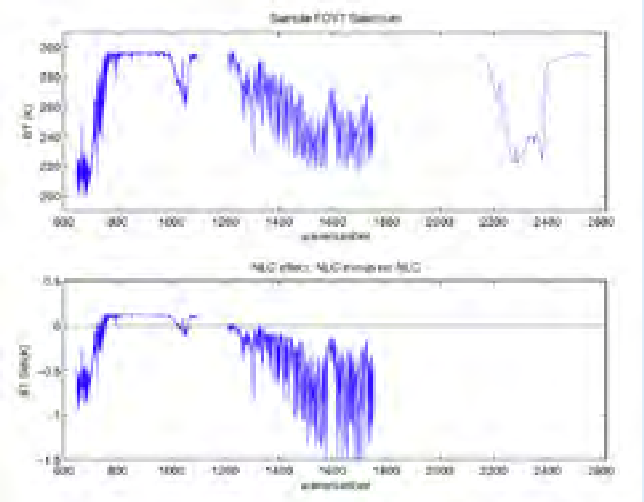

Figure 5. An example of the magnitude of the radiometric nonlinearity correction for FOV7. The spectral shape and magnitude of the nonlinearity corrections can vary significantly from one Earth view to another.

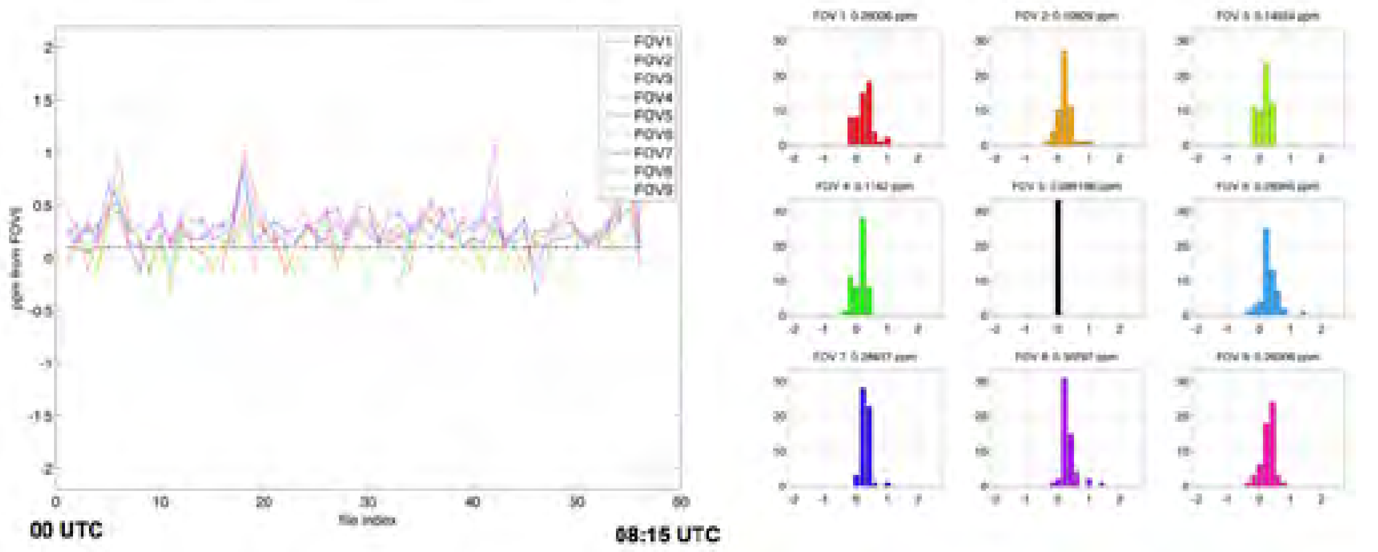

Figure 4. An example result of inter-FOV spectral calibration for 27 March 2012, following a sensor shut-down/warm-up event on 24/25 March. The left hand panel shows the spectral calibration determined with respect to FOV5 for each 8 minute segment of data, and the right hand panels show the distributions (ppm) of spectral shifts for each FOV.

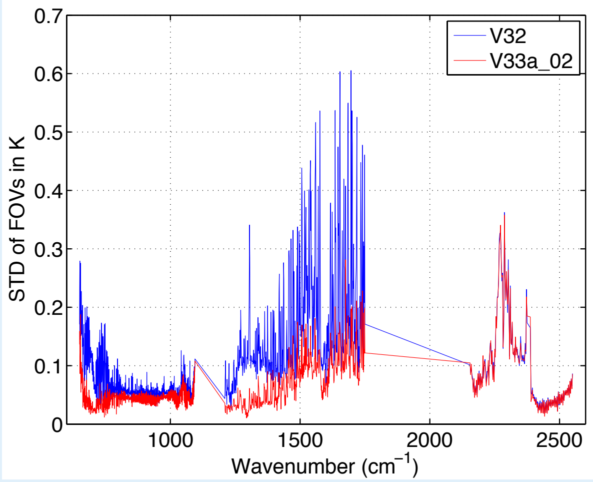

Figure 6 (c/o L. Strow at UMBC). Standard deviation among FOVs of clear sky obs-calcs using the at-launch (blue) nonlinearity correction coefficients and using refined coefficients determined with post-launch out-of-band harmonic and Earth view consistency analysis (red).

In terms of the overall radiometric uncertainty of the CrIS data which incorporates nonlinearity facts and all other calibration contributions, analyses are still on-going, but we expect the in-flight CrIS radiometric uncertainty estimates to be less than 0.2K 3-sigma for all scene temperatures and wavelengths.

Interferometer Sweep Direction Biases and Adjustments to the On-board Numerical Filter

As part of our analyses of the CrIS data, a small bias in the calibration of the data from one interferometer sweep direction versus the other was discovered. This bias was as large as ~0.4 K in the longwave end of the longwave spectral band, relatively small throughout the rest of the longwave band and midwave band, and also significant in some regions of the shortwave spectral band. After various analyses, we diagnosed this issue to be due to the performance of the on-board numerical filter. Simulations of the effect were performed, and a new numerical filter was designed and uploaded to the sensor. Figure 7 shows data collected on the day the new filter was uploaded, showing the sweep direction bias prior to the upload (which looks like along track "striping" of the data) and afterwards, where this source of striping is significantly reduced.

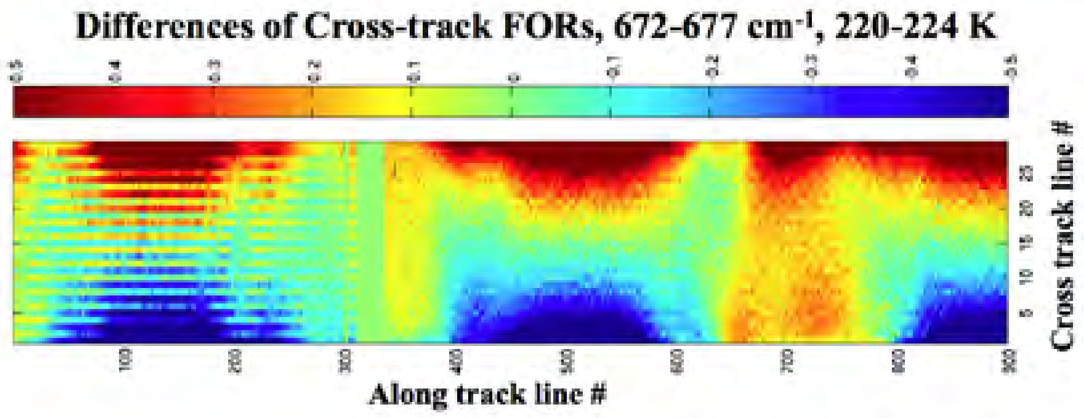

Figure 7. Longwave spectral region sweep direction biases on 18 April, with the at-launch numerical filter (prior to along track line # 300) and after upload of the new numerical filter.

Summary

CIMSS/SSEC is an integral participant in the post-launch evaluation of CrIS. The Early Checkout phases of these efforts have been very successful, with upload of refined "v33" calibration coefficients and on-board numerical filter coefficients in April, and subsequent declaration of the CrIS radiance prodcuts as "beta" quality. Going forward, the radiance cal/val efforts will continue, with further analyses to investigate remaining issues in the CrIS data and processing. CrIS radiance data will also start being disseminated to NWP centers for data assimilation efforts, and used by researchers to evaluate and refine the EDR (retrievals) from CrIS.

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