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SUOMI NPP/JPSS CROSS-TRACK INFRARED SOUNDER (CRIS): NON-LINEARITY ASSESSMENT AND ON-ORBIT MONITORING

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1. INTRODUCTION

The Cross-track Infrared Sounder (CrIS) on the Suomi NPP satellite is the first in a series of U.S. advanced operational sounders that will provide more accurate, detailed atmospheric temperature and moisture observations for weather and climate applications. A primary motivation for the CrIS measurements is for the improvement of medium range numerical weather prediction (NWP). An important secondary objective is to continue the record of accurate high spectral resolution infrared measurements with large daily spatial coverage begun by the NASA Atmospheric InfraRed Sounder (AIRS) on the EOS Aqua platform. These data have demonstrated the high information content of the spectrally resolved thermal infrared emission spectra. Both the NWP and climate applications of the IR sounder data require good long-term calibration stability in individual sensor records and well characterized radiometric and spectral calibration to facilitate the creation of consistent product records over multiple sensor platforms.

Initial assessment of CrIS radiometric and spectral calibration, described in Revercomb et al. 2013, demonstrate excellent performance and meet or exceed pre-launch expectations. Preliminary evaluation of CrIS radiometric performance shows agreement with the EOS AIRS heritage sensor to within about 0.2 K for most spectral channels (Tobin et al. 2013).

This paper describes the refinement of the Cross-track Infrared Sounder (CrIS) pre-launch non-linearity coefficients based on on-orbit data. This paper also presents a non-linearity coefficient monitoring methodology which can track the change in FOV-to-FOV radiometric differences in spectral regions sensitive to changes in non-linearity. This approach provides the JPSS CrIS Cal/Val team an approach to monitor changes in the sensor non-linearity across future instrument warm-up/cool-down event and assess any possible long term trends.

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2. DATA

The CrIS sensor on Suomi NPP measures upwelling infrared radiance at 1,305 spectral channels in three spectral bands; LWIR: 9.14-15.38 µm, MWIR: 5.71-8.26 µm, and SWIR: 3.92-4.64 µm. A Fourier Transform Spectrometer (FTS) designed and fabricated by ABB-Bomem of Quebec, Canada and integrated by ITT/Exelis of Fort Wayne, Indiana provides infrared spectra with a resolving power of approximately 1200 or better. The CrIS obtains large daily spatial coverage using a cross-track scan mirror to obtain 30 cross-track fields of regard (FOR) of the Earth every 8 seconds. Calibration data is collected once every cross-track scan line with a view of the internal calibration target (ICT) and deep space (DS) using the same 45 degree mirror used to view the Earth. The Suomi NPP satellite is maintained in a sun-synchronous orbit that provides the nominal local overpass times of approximately 1:30 pm (day) and 1:30 am (night).

Each CrIS FOR is composed of nine fields of view (FOVs) arranged in a 3x3 pattern. The FOR diameter of 50 km was a design requirement to provide compatibility with time and space coincident microwave measurements from the Advanced Temperature and Moisture Sounder (ATMS). Each CrIS FOV in the 3x3 pattern is sampled using three spatially co-aligned detectors. Photovoltaic MCT detectors are used for the LWIR and MWIR spectral bands while InSb detectors are used for the SWIR band. The nine InSb detectors used in the SWIR band coverage have demonstrated a high degree of linearity both pre-launch and post-launch. However, despite an expectation of linearity by the sensor vendor prior to fabrication, the PV MCT detectors selected for the CrIS FM1 flight model exhibited a small but significant non-linear response to radiance input during thermal vacuum testing. Moreover, each of the individual nine LWIR and nine MWIR detectors has a slightly different non-linear response. This effect if uncorrected would lead to relative calibration errors among the 3x3 pattern of FOVS which would greatly complicate the use of the data for NWP and climate applications. For this reason a nonlinearity correction algorithm was proposed by the Uni. of Wisconsin and ultimately implemented as part of the CrIS SDR algorithm.

3. METHODOLOGY

The Uni. of Wisconsin has extensive experience in the calibration of FTS observations using a two point calibration method to transform the measured interferograms of Earth, ICT, and DS views into a real calibrated spectrum (Revercomb et al., 1988). This method was also adopted for the CrIS SDR algorithm. However, for this method to be successful any non-linearity of the sensor response to input radiance must first be corrected either in the interferogram space where the effect occurs or equivalently in the space of complex spectra obtained through a complex Fourier transform of the interferograms. For these detectors, a non-linearity correction algorithm developed by the Uni. of Wisconsin for use in aircraft and ground-based sensors was applied to CrIS data (Knuteson et al 1994). These corrected raw spectra were shown to meet the radiometric requirement tests in thermal vacuum testing and the algorithm to apply these corrections was built into the operational CrIS SDR algorithm. Details of the JPSS project implementation of the non-linearity correction for CrIS can be found in the most recent version of the CrIS SDR ATBD.

For the purposes of this paper, it is sufficient to note that only two free parameters are required to characterize the correction model over all scene temperatures. The two model parameters physically represent the voltage on the detector corresponding to "zero" input radiance (Vinst) and the quadratic coefficient of the expansion of the true interferogram in terms of a power series in the measured interferogram (a2). The Vinst parameter is obtained from an extrapolation of ICT and deep space target views while accounting for instrument self-emission. The a2 parameter was determined pre-launch as a "best fit" using as truth the thermal vacuum (T/V) external target operated over a wide range of scene temperatures (220 – 320 K).

4. RESULTS

Since each of the nine LWIR and nine MWIR could potentially exhibit non-linear response, a total of 36 parameters must be determined to provide a complete set. The pre-launch thermal vacuum testing resulted in an initial estimate of these 36 parameters. The pre-launch a2 values from this determination are shown in Figure 1 with the label "v32". The uncertainty in each pre-launch a2 value is shown as an error bar. Note that the determination of the pre-launch a2 values is between 10 and 20 % as determined from the thermal vacuum data (calibrated external target brightness temperature minus blackbody truth) shown in Figure 2. Hence both the pre-launch non-linearity parameter values and the uncertainty in these values was obtained pre-launch during thermal vacuum testing. The accuracy of these estimates is directly related to the knowledge of the T/V external target temperature and emissivity. Since the external target was calibrated against SI standards, this provides a traceability path for the pre-launch determination of CrIS non-linearity parameters.

However, many of the CrIS FM1 PV MCT detectors, particularly MWIR FOV 7, have exhibited changes in both the detector response (NESR) and detector non-linearity upon warm-up and subsequent cool-down. This was known pre-launch with the implication that the pre-launch non-linearity values may not be optimal for on-orbit use. For this reason, a priority in the short sensor checkout phase (about 6 weeks) was the re-establishment of the 36 nonlinearity parameters using on-orbit data.

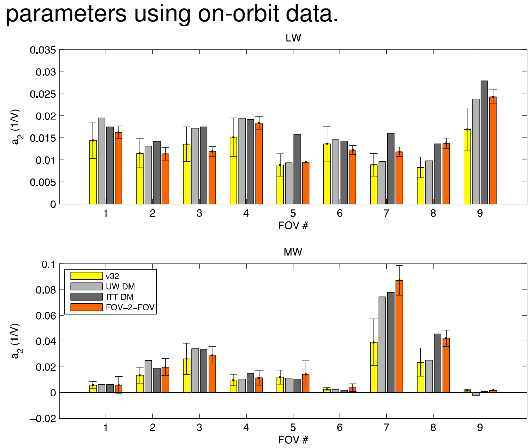

Figure 1. Comparison of a2 estimates pre- (v32) and post-launch (UW DM, ITT DM, FOV-2-FOV) for CrIS longwave (upper) and mid-wave (lower) spectra bands by field of view.

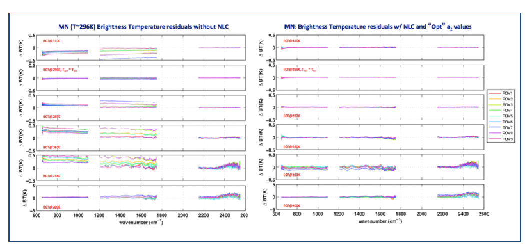

Figure 2. Pre-launch characterization of CrIS a2 parameters before (left) and after (right) nonlinearity correction relative to the T/V external calibration target.

Prior to launch, two methods were devised for the assessment of the nonlinearity parameters on-orbit which involve the use of only CrIS data. The first method takes advantage of the unique signature of detector nonlinearity in an FTS instrument. As has been described in the literature (e.g. Knuteson et al. 1994), the effect of a quadratic nonlinearity in the interferogram domain is to produce a low-resolution artifact which peaks outside the optical pass band. This method requires data which has not been numerically filtered, since the intent of the numerical filter is to remove any out-of-band data in order to reduce the overall rate of data transmission to the ground. In the CrIS program these raw unfiltered measurements are known as diagnostic mode (DM) interferograms. The sensor must be put into a special data collection mode to obtain these DM data and only one FOV can be obtained at a time. In anticipation of using the out-of-band non-linearity signal, DM data were collected during T/V testing for each blackbody target, ECT, ICT, and space target (ST). The estimation of a2 parameters was performed by two groups (ITT/Excelis) and the Univ. of Wisconsin (UW). This same data collection was obtained post-launch using the Earth, ICT, and deep space as targets. The post-launch out-of-band a2 estimates shown in Figure 1 (without error bars) are labeled "ITT DM" and "UW DM". Since the ITT and UW a2 determination algorithms are slightly different, the difference between the two DM derived a2 values is a measure of the uncertainty in this method. Note that the DM data determination suggests that some detectors, e.g. LWIR FOV 9 and MWIR FOV 7, changed between pre- and post-launch while most stayed within the combined uncertainty of the estimates.

Fortunately one of the MWIR detectors (FOV 9) in CrIS FM1 requires essentially zero correction, i.e. it exhibits highly linear response to input radiance. Since in a statistical sense FOV 9 observes the same Earth scene types as FOVs 1 to 8 (ignoring the small angular spread among the FOVs), a methodology was devised using on-orbit calibrated data to take advantage of the linearity of FOV 9 to further reduce the uncertainty of the MWIR detectors to less than 5%. The approach is to compute radiance differences of each FOV relative to a reference FOV over a large set of observations, e.g. 10 or more orbits restricted to FORs within 30 degrees of nadir. The result is shown in Figure 1 in the MWIR band labeled FOV-2-FOV. The error bars on the FOV-2-FOV estimate represent a statistical uncertainty from the dataset used during the brief sensor checkout period and are not our final estimated systematic error. Ultimately we believe the systematic error in the MWIR nonlinearity a2 values for each detector can be reduced to <2% but that is in progress.

Unfortunately the LWIR band does not have any detectors that are highly linear; in fact all the detectors appear to exhibit a similar non-linear response. Without an obvious choice, LW FOV 5 was selected as the reference FOV for the same FOV-2-FOV analysis applied to the LWIR band. Note that there is no statistical error bar shown in Figure 1 for the LW FOV 5 since it was held fixed in the FOV-2-FOV analysis. However a small scale factor was applied to the on-orbit LW FOV 5 a2 value to account for a possible pre- and post-launch change. This scaling was obtained from the ratio of DM a2 estimates by UW pre- and post-launch. An estimate of the uncertainty in that scale factor used for LW FOV 5 (only) is currently in progress. Note that the LWIR FOV-2-FOV analysis using LW FOV 5 as a reference verifies the large change in LW FOV 9 seen in the DM data analysis; however the consistency in the other FOVs with smaller non-linearity is less apparent. The FOV-2-FOV approach provides a relatively simple method for the near-real time monitoring of a2 parameters relative to the reference FOVs for the duration of the mission.

A preliminary inter-calibration assessment of CrIS brightness temperatures using METOP-A IASI data are shown in Figure 3 for simultaneous nadir overpasses (SNOs) during 2012. The improvement of the post-launch estimates relative to the pre-launch values is very apparent. These results are still preliminary since an update to the nonlinearity parameter set is anticipated following completion of an uncertainty analysis.

5. CONCLUSIONS

CrIS LW and MW PV detectors exhibit a quadratic nonlinearity while CrIS SW are highly linear. The quadratic nonlinearity coefficients determined in thermal vacuum testing (V32) were adjusted post-launch to minimize the inter-FOV radiometric error (V33) and to take advantage of on-orbit diagnostic mode data collection. The primary method for determining a2 values for V33 was the FOV-2-FOV method using a reference FOV in the LWIR and MWIR. The analysis used for pre- to post-launch was conducted on a limited set of data in the brief instrument checkout period. Further refinement of these estimates are anticipated based on more subsequent analysis. In particular, the uncertatinty in the MWIR non-linearity can in principle be made negligible by tying FOV 1-8 to the highly linear FOV 9. The LWIR FOVs may have an overall systematic uncertainty. Independent validation using METOP IASI inter-calibration demonstrates the importance of the post-launch on-orbit update of the nonlinearity parameters and provides confidence in the methodology used. Future work includes monitoring the relative FOV-to-FOV radiometric stability in order to assess the magnitude of trends in the nonlinearity parameters over time.

Acknowledgments

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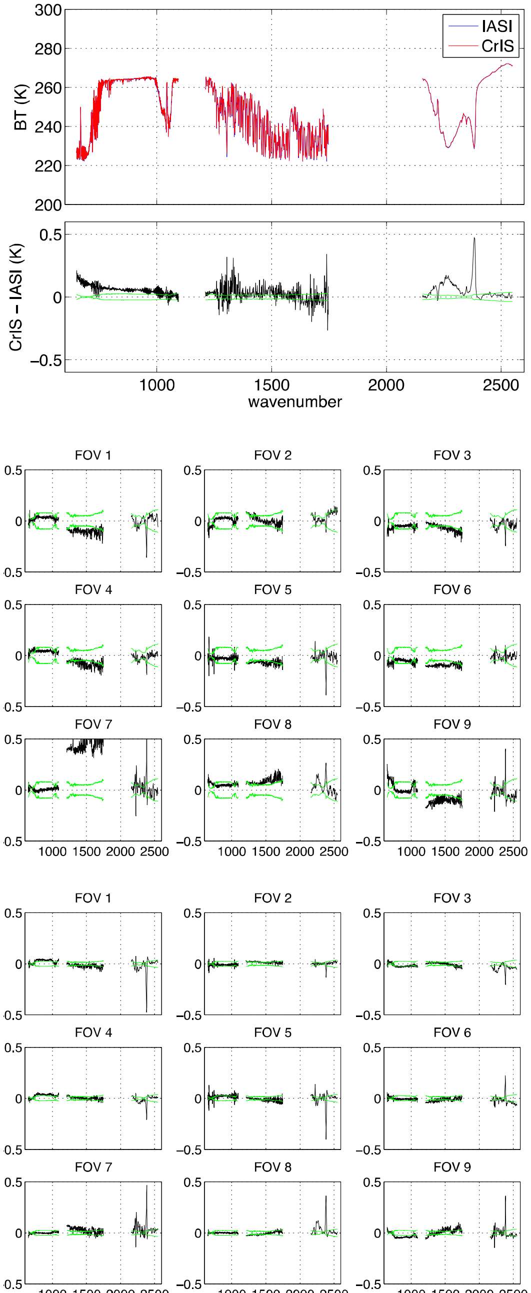

Figure X. Northern CrIS/IASI SNOs for mean over all FOVs (top), using pre-launch non-linearity parameters by FOV (middle), using post-launch non-linearity parameters by FOV (lower).

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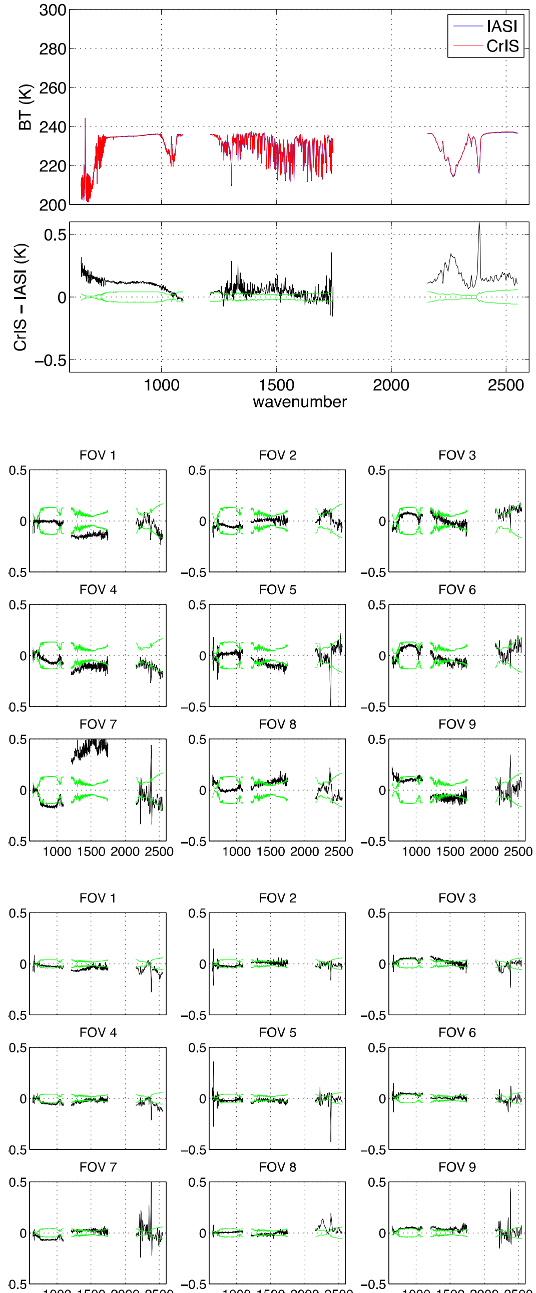

Figure Y. Southern CrIS/IASI SNOs for mean over all FOVs (top), using pre-launch non-linearity parameters by FOV (middle), using post-launch non-linearity parameters by FOV (lower).

Revercomb et al., 2013, Suomi NPP/JPSS Cross-track Infrared Sounder (CRIS): Radiometric and Spectral Performance, AMS Annual Meeting, Austin, TX, January 2013.

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