Analysis of the CrIS Flight Model 1 Radiometric Linearity

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Abstract: The CrIS Flight Model 1 has recently completed thermal vacuum testing. Here we present the independent UW-SSEC analyses of various test data to assess the radiometric linearity of the sensor.

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1 Introduction

The Cross-track Infrared Sounder (CrIS) is an interferometer sounder that will measure upwelling spectrally resolved infrared earth radiances which will be used to construct vertical profiles of atmospheric temperature, moisture and pressure for the NPOESS program. Like its predecessors AIRS and IASI, CrIS is an advanced temperature and moisture profile sounder.

CrIS utilizes three 3x3 arrays of discrete photovoltaic (PV) HgCdTe detectors. While the nonlinearity of the PV detectors was expected to be negligible, TVAC testing of Flight Model 1 (FM1) revealed a significant level of FM1 detector nonlinearity for the longwave (LW) and midwave (MW) arrays. This paper presents the independent UW-SSEC analyses of various test data to assess the radiometric linearity of the sensor and a nonlinearity correction algorithm that has been demonstrated to correct much of the nonlinear response, significantly reducing the total radiometric uncertainty.

2 Radiometric Linearity

A nonlinearity correction (NLC) method for Fourier Transform Spectrometers (FTS), developed at the UW-SSEC has been successfully applied to the AERI, S-HIS, and NAST-I sensors [1-5]. This NLC approach is based directly on photoconductive (PC) HgCdTe detector theory. While the CrIS detectors are photovoltaic (PV) HgCdTe, the nature of the CrIS nonlinear detector response is similar to that associated with the PC HgCdTe detectors of the aforementioned sensors. This suggests that the CrIS PV HgCdTe detector nonlinearity can be accurately represented by the same third order polynomial relationship previously used for the AERI, NAST-I and S-HIS,

$$I_c = I_m + a_2(I_m)^2 + a_3(I_m)^3 \qquad [1]$$

Where I_c is the corrected signal, I_m is the measured signal, and a_n are the nonlinearity coefficients. Separating I_m into an AC interferogram f and a DC offset, V,

$$\begin{aligned} I_c &= (f+V) + a_2(f+V)^2 + a_3(f+V)^3 \\ &= (1+2a_2V+3a_3V^2)f + (a_2+3a_3V)f^2 + a_3f^3 + (V+a_2V^2+a_3V^3) \\ &= (1+2a_2V)f + a_2f^2 + (V+a_2V^2) \quad if \ a_{>2}=0 \end{aligned} \qquad [2]$$

Fourier transform to wavenumber space

$$\begin{aligned} C_c &= F\{I_c\} \\ &= (1+2a_2V)F\{f\} + a_2F\{f^2\} \\ &= (1+2a_2V)C + a_2C \otimes C \end{aligned} \qquad [3]$$

The in-band correction is composed of a dominant term proportional to the uncalibrated spectrum, C, and a smaller squared correction to the band edges. For CrIS, the squared dependence is negligible in-band, due to of the location of the in-band cut-offs. In the absence of an instrument double pass, the squared dependence for CrIS would be identically zero in-band. To successfully apply the nonlinearity correction, the nonlinearity coefficients and DC level need to be accurately determined.

2.1 Derivation of the nonlinearity coefficients using Diagnostic Mode (DM) data

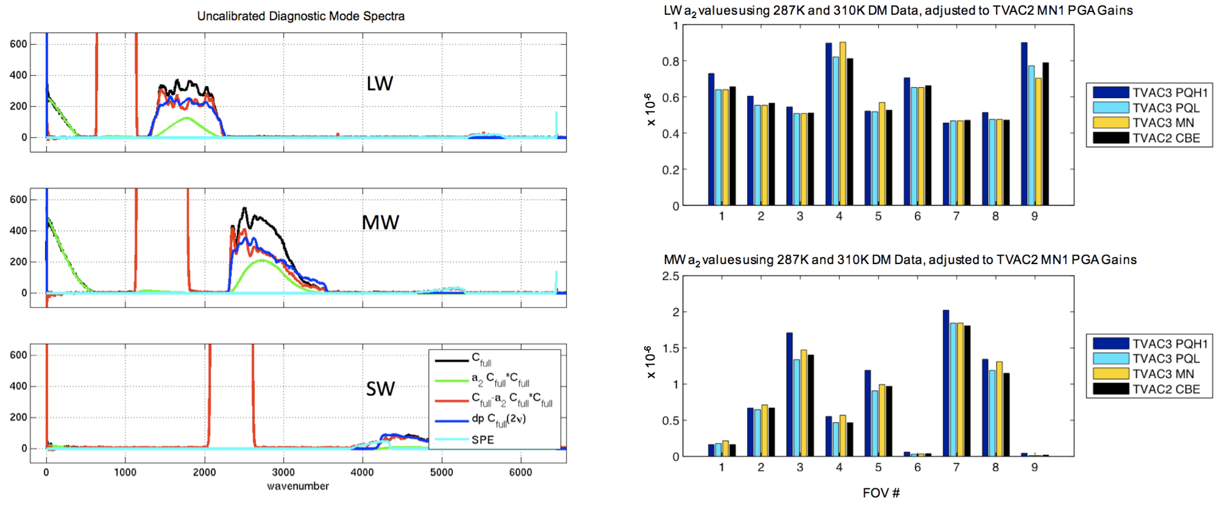
The a_2 coefficients are derived using the out of band regions for diagnostic mode (no DSP filter or decimation applied) data and may be refined from fit to TVAC External Calibration Target (ECT) views with the assumptions that CrIS SW band is linear. Recall, if $a_{>2} = 0$

$$I_c = I_m + a_2 I_m^{\;2} \qquad [4]$$

In the low wavenumber out of band region, the nonlinearity corrected signal should approach zero. Differencing equation [4] for two different signal intensities (blackbody target temperatures, T_1 and T_2, with corresponding uncalibrated spectra C_{T_1} and C_{T_2} respectively), and I_c equal to zero,

$$a_2 = \mathrm{Re}\left\{ \frac{C_{T_1} - C_{T_2}}{C_{T_1}^{\;*} C_{T_1} - C_{T_2}^{\;*} C_{T_{21}}} \right\} \qquad [5]$$

This differential signal method removes any signal independent artifacts in the out of band region that would affect accurate determination of the nonlinearity coefficients from the out of band data. It is also very important to account for any double pass or sample position error induced signals that may be present in the out of band region.



(a) (b)

Figure 1: (a) An example of diagnostic mode uncalibrated spectra for the CrIS sensor, along with the corresponding simulated double pass and fractional sample position error (SPE) spectra. Note that the low wavenumber, out of band signal for the SW is near zero, as expected for a detector with negligible nonlinear response. (b) Summary of a_2 values from TVAC-3, compared to the TVAC-2 "CBE" values. All of these are from the "differential signal method" using ECT2287K and ECT@310K data.

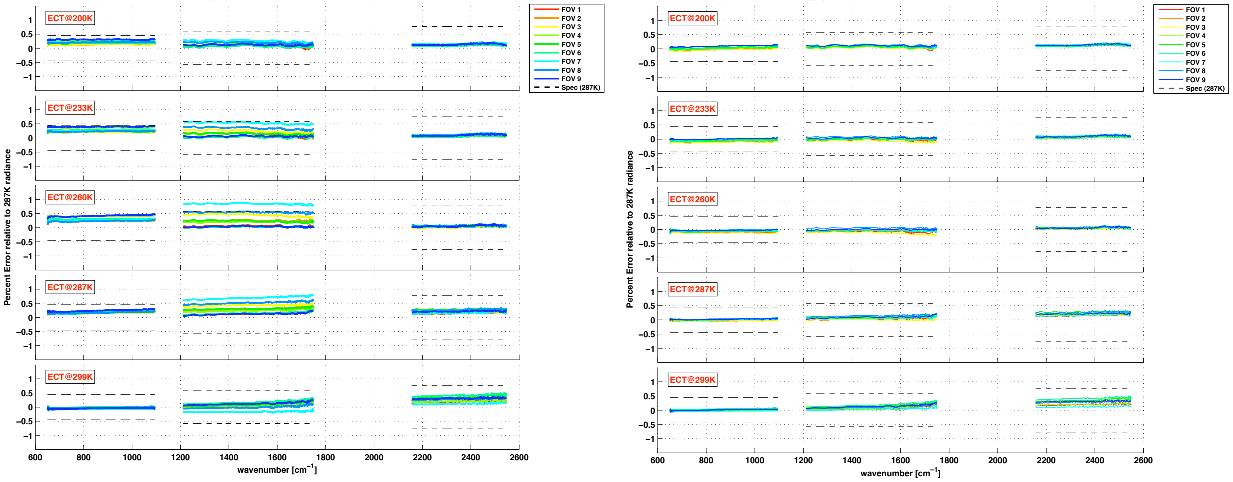
Data was collected at three thermal operating environments during TVAC: Mission Nominal (MN), representative of the nominal thermal environment for the mission orbit; and Proto-Qual Low (PQL) and Proto-Qual High (PQH) representing low and high temperature extremes respectively, and associated with other orbits. When detector chain PGA gains are properly accounted for, results to date also show that there is no significant change in the diagnostic mode responsivity for MN1, PQH, and PQL, suggesting no “radiometric” gain adjustment is required in comparing a_2 from MN1, PQH, and PQL. Secondly, the derived values of a_2 do not exhibit an obvious dependence on the combination of scene radiance levels and/or targets used in the derivation when the differential signal method is used. In general, there is ~10% or better agreement between all of the TVAC-3 and TVAC-2 values derived using this method. Additionally, the differences between the results using this method and the refined nonlinearity coefficient values resulting from fit to TVAC ECT views also agree within ~10%. From these results, it is reasonable to conclude there is ~10% uncertainty in the current determination of the a_2 values.

2.2 UW-SSEC Detector Based DC Level Model

For the CrIS the measured DC level signal is not available for each Earth view interferogram. Accordingly, the interpretation (and correction) of the nonlinearity requires a theoretical model for the DC level on each CrIS detector. The basic assumption for the UW DC level model is that the observed CrIS nonlinear response is driven by photon flux levels on the detectors (similar to mechanism for PC detectors). We use a representation of the DC level that accurately accounts for photon flux changes between scene views (electrical offset contributions to measured DC levels need to be excluded). The DC level offset for a space view is also modeled, but the correction is relatively insensitive to this DC level offset, because of the differences with respect to the space view that appear in the calibration equation. MN, PQL, and PQH data has been used to empirically validate the UW DC level model. Details of the model and validation are not included in this 3-page summary, but will be presented in a future paper.

3 Results and Conclusion

Figure 2 illustrates the radiometric uncertainty as a percent error relative to the radiance from a 287K blackbody target, with and without the nonlinearity correction applied. Note that there is no nonlinearity correction applied to the shortwave (SW) band.



(a) (b)

Figure 2: Radiometric uncertainty, specified as percent error relative to the radiance from a 287K blackbody target; (a) no nonlinearity correction applied (b) nonlinearity correction applied. The radiometric uncertainty requirement for 287K is indicated by dashed lines.

Thermal vacuum testing of the CrIS FM1 sensor revealed an unexpected level of detector nonlinearity. An independent UW-SSEC analyses of various test data to assess the radiometric linearity of the sensor was completed and the corresponding UW-SSEC developed nonlinearity correction has been demonstrated to correct much of the observed nonlinearity in the FM1 TVAC radiance measurements, reducing the total radiometric uncertainty significantly. The correction uses a DC level model based upon reasonable estimates of photon flux along with a quadratic “cross-term” correction and nonlinearity coefficient values derived using the out of band regions for diagnostic mode data and refined from fit to TVAC External Calibration Target (ECT) views. The nonlinearity coefficients, as derived from out-of-band DM interferogram data, are very consistent over all bench and TVAC conditions.

4 References

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