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CC: Dr. Dave Johnson, NASA LaRC

Date: 26 February 2015

Re: **Year 2 (1 May 2014 – 30 April 2015) Progress Report for NASA Award Number NNX13AI99G, UW-SSEC Participation in the Ground Test Characterization of CrIS and VIIRS**

This is the year 2 progress report for NASA Award Number NNX13AI99G, “UW-SSEC Participation in the Ground Test Characterization of CrIS and VIIRS”. The report is separated into two main sections for the CrIS and VIIRS related work.

1. CrIS

Thermal Vacuum testing of JPSS-1 CrIS is now complete and over the past year we have contributed to the testing process and data analyses with focus on the radiometric calibration and spectral calibration of the sensor and performance of the calibration algorithms. The data analysis effort is ongoing, with algorithm and calibration coefficient determinations still taking place. Current efforts and results are summarized here.

1.1. TVAC data archive and processing

We have downloaded and archived all of the TVAC data relevant to the radiometric and spectral calibration tests, and also processed these data using our Matlab reader to produce data files ready for processing. This has involved daily monitoring of the testing status and participation in the weekly Wednesday afternoon and Thursday TVAC/Tech telecons.

1.2. Radiometric Calibration and Nonlinearity

One of our main focuses of the J1 TVAC testing is to characterize the radiometric calibration uncertainty and in particular the nonlinearity behavior. Overall, J1 CrIS has nonlinearity behavior very similar to S-NPP CrIS. With the TVAC testing, we use analysis of the out-of-band harmonics produced by the nonlinearity and ECT (External Calibration Target) view data over a range of ECT temperatures to determine the nonlinearity characteristics and coefficients.

Nonlinearity analyses using Diagnostic Mode data collections

Diagnostic Mode (DM) data (by-passing the FIR filter, and retaining the out-of-band signals) is collected for J1 bench testing and for each plateau of TVAC testing. From the low-wavenumber out-of-band region, we derive quadratic nonlinearity coefficients, a_2, from the DM data as a preliminary estimate of the nonlinearity magnitude. DM a_2 values from these analyses are shown below in Figure 1. These values also agree very well with similar analyses performed by Exelis, with the exception of small differences for some of the very linear MW FOVs and the very linear SW FOVs; these differences are under investigation. For example, we observe MW FOV2 to have very small but consistently positive values. These DM a2 values are particularly useful in trending of the nonlinearity behavior, as the detector nonlinearity has the potential to change with warm-up/cool-down which occurs between bench testing, TVAC testing, spacecraft level testing, and on-orbit.

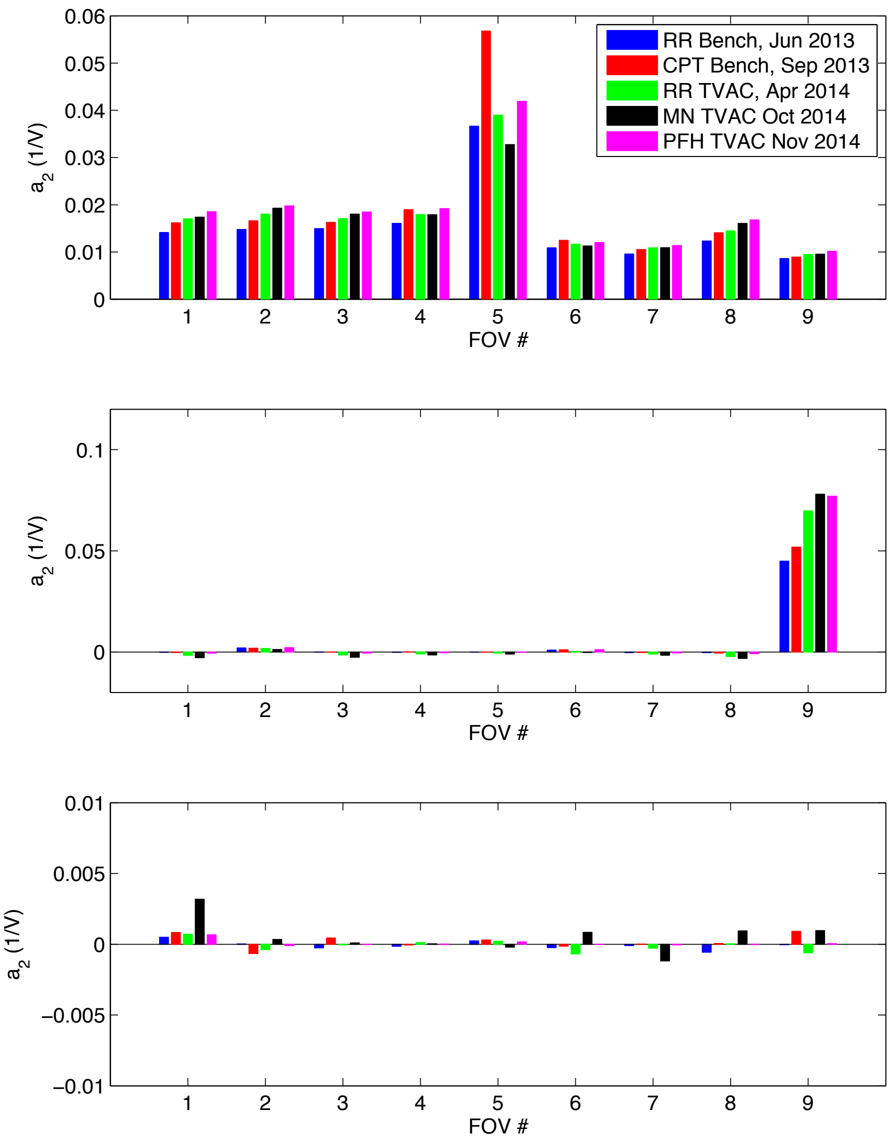

Figure 1. Quadratic nonlinearity coefficients, a_2, derived from J1 CrIS Diagnostic Mode data.

Imaginary Radiance analysis

With the J1 TVAC ECT view data, we have observed small imaginary part residuals of the calibrated radiances, which are correlated with the magnitude of the nonlinearity. We have investigated this in detail recently, with hypotheses that this is due to subtle imperfections in the quadratic nonlinearity correction and/or higher order nonlinearity contributions. Our analyses do not support these hypotheses, but rather suggest that there could be small phase shifts due to time delays associated with different time constants/delays which are correlated with nonlinearity behavior. Very small linear phase shifts can explain the observed imaginary parts, and if this is the root cause, then the resulting impact on the real part of the calibrated radiances is very small. These results have been summarized and presented to the NASA/NOAA SDR team members.

Nonlinearity Analysis using stepped ECT view data

A primary goal of the TVAC testing is to determine the nonlinearity behavior and correction coefficients from "stepped ECT view data". This is ECT view data collected over a range of ECT temperatures which can be used to measure nonlinearity. ECT view residuals (calibrated ECT view spectra minus predicted ECT view spectra) are shown below in Figure 2 after tuning of the quadratic nonlinearity coefficients using the Mission Nominal data. ECT view data at 310K, 299K and 260K is used in this analysis but ECT residuals are shown for all temperatures. The lower temperature ECT view data is not currently used in the analysis due to large uncertainties in the predicted ECT views and in the Space Target views due to reflections. Overall, the ECT residuals are very small and very well behaved, providing evidence that the nonlinearity for J1 is very well characterized.

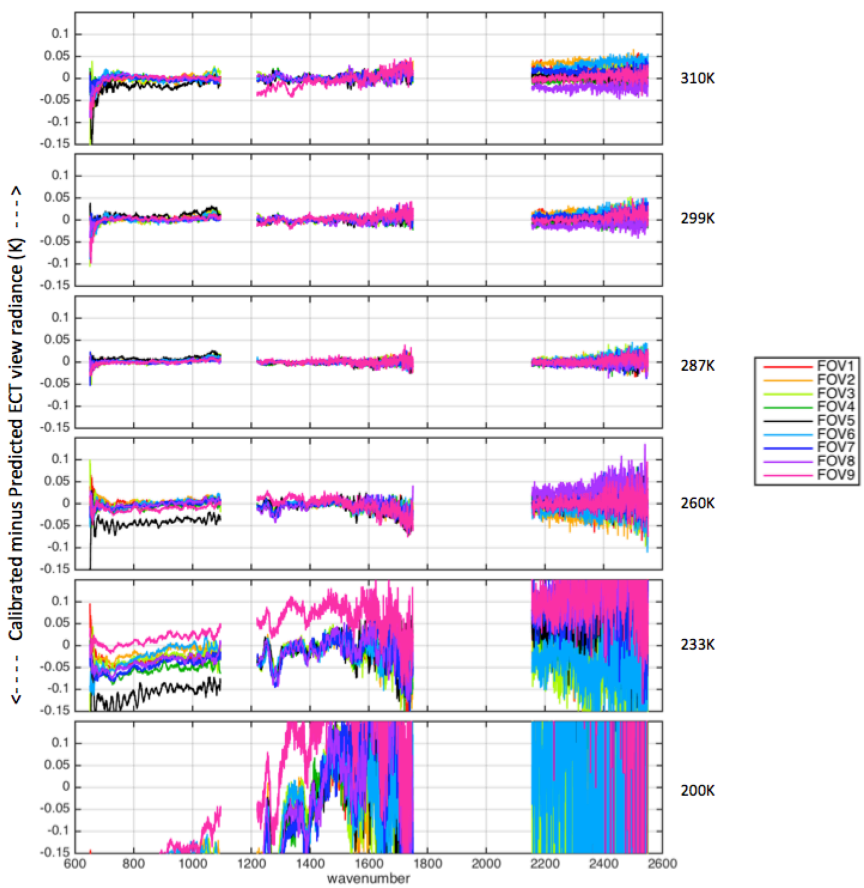

Figure 2. Mission Nominal ECT view residuals using UW a2 values and with ECT view temperature derived from linear CrIS MW and SW band FOVs.

The ECT view analysis and nonlinearity determinations are on-going. Currently, the a2 values to be loaded into the J1 engineering packet are from the UW analysis:

lw: [0.0141 0.0145 0.0152 0.0159 0.0355 0.0110 0.0095 0.0157 0.0085]

mw: [0 0 0 0 0 0 0 0 0.0507]

sw: [0 0 0 0 0 0 0 0 0]

These values are derived using linear CrIS FOVs to determine the FOV dependent ECT view temperatures which are used to predict the ECT view spectra, and using Vinst and modulation efficiency values derived by Exelis. Similar analyses have been performed using the R1 and R2 temperature sensors on the back plate of the ECT, along with various candidate correction terms, to predict the ECT view spectra, which provide slightly different a2 values. These analyses will continue and will also take into account NIST measurements of the ECT which took place this month.

1.3. Gas cell spectral interfov analysis

To compliment TVAC spectral calibration analyses, we have performed a "spectral inter-FOV" analysis of the J1 TVAC gas cell data. This analysis method is similar to other approaches but instead of using a calculated transmission spectrum as the reference, it uses the center FOV 5 as the reference for the other off-axis FOVs. Since the center FOV5 is relatively insensitive to FOV diameter and position, it provides a robust reference for the other FOVs which require large spectral corrections. And, opposed to calculated spectra, the use of FOV5 as reference avoids all issues associated with the calculation of the gas transmission. Also in our analyses, we use the ICT and ST view spectra along with the gas cell view data to calibrate the data with nonlinearity and FIR convolution corrections included to produce observed transmission spectra. Results of this type of analysis are shown below in Figures 3 and 4. These analyses provide information on 1) the quality of the TVAC gas cell data, 2) the spectral characteristics of J1 CrIS, 3) the performance of the self-apodization corrections, and 4) estimate the J1 off-axis FOV angles. The observed spectral inter-FOV residuals are, in general, very well behaved.

In addition to these MN results, we have also performed the spectral inter-FOV analysis on all of the J1 TVAC gas cell data. These results show small differences between interferometer sweep directions and small differences for the two instrument "sides" but some significant differences (not unexpected) between the three mission plateaus (MN, PFH, PFL). Also, we have processed the data and performed the spectral inter-FOV analysis using the draft ILS parameters provided by Exelis on 17 December. This analysis shows spectral inter-FOV differences which are very small, providing confirmation of the draft parameters. A sample result is shown in Figure 5. A recommendation from this work, however, is that the Exelis/draft J1 ILS parameters should be the result of testing results at MN only, rather than an average over all three mission plateaus.

Finally, a small set of Diagnostic Mode gas cell data was collected as part of the TVAC testing, and we are currently analyzing the data. We are investigating the spectral ringing characteristics of the data.

1.4. Miscellaneous

1.4.1. RDR reader and xml databases

During J1 TVAC, a number of different XML databases were released. We analyzed the differences in the various releases and created and provided new versions of the RDR reader to be consistent with the new data.

1.4.2. Meetings/Presentations

Tobin, David, Hank Revercomb, Fred Best, Robert Knuteson, Joe Taylor, Dan DeSlover, Lori Borg, Graeme Martin, Infrared Hyperspectral Calibration and Intercalibration: Recent experience with Satellite and Aircraft Sensors, EUMETSAT Meteorological Satellite Conference, Geneva, Switzerland, 22-26 September 2014.

Merrelli, Aronne; Tobin, David; Knuteson, Robert; Greenwald, Thomas; Revercomb, Hank; (2014), Comparing Cross-track Infrared Sounder Observations with Forward Model Calculations, Abstract IN13C-3656 Presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec.

DeSlover, D. H., R. Knuteson, D. C. Tobin and H. E. Revercomb (2015): Monitoring climate signatures with high spectral resolution infrared satellite measurements. *Proceedings from the 95th American Meteorological Society Annual Meeting, 27th Conference on Climate Variability and Change*, Phoenix, AZ, January 2015.

Tobin, D. C., H. Revercomb, R. Knuteson, J. Taylor, L. Borg, D. H. DeSlover, G. Martin, A. Merrelli, and T. Greenwald Suomi-NPP Cross-track Infrared Sounder (CrIS): Radiometric Calibration and Validation, *Proceedings from the 95th American Meteorological Society Annual Meeting, Joint session of the 11th Annual Symposium on New Generation Operational Environmental Satellite Systems and the 20th Conference on Satellite Meteorology and Oceanography,* Phoenix, AZ, January 2015.

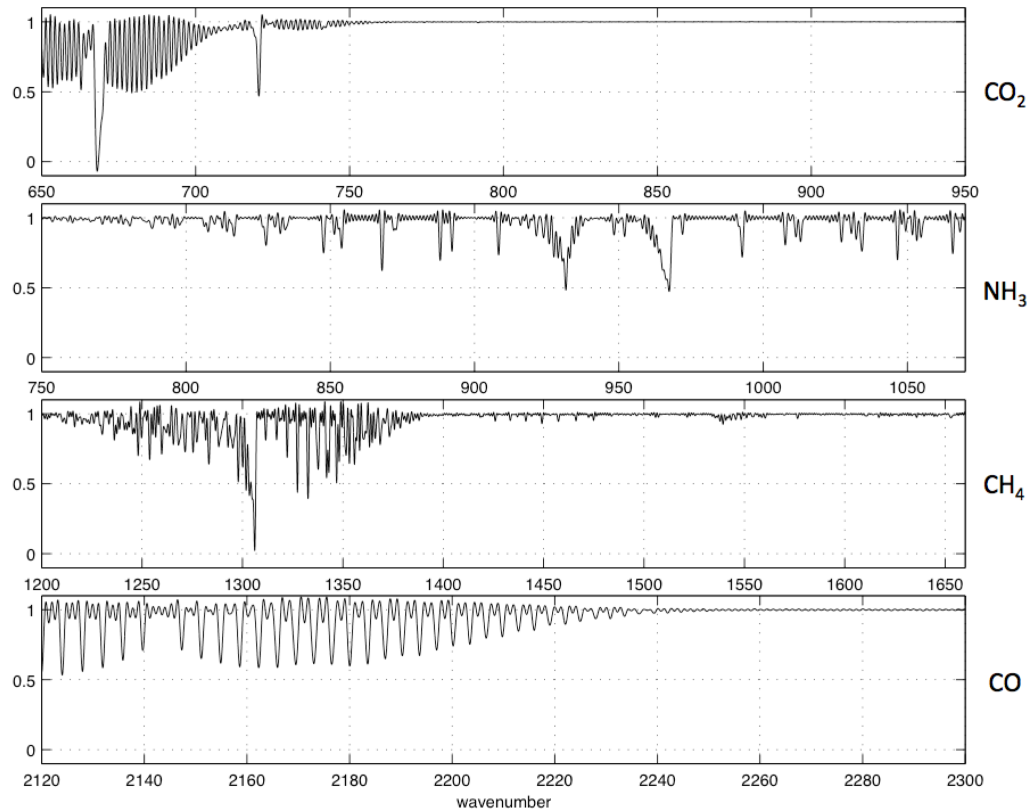

Figure 3. Example J1 gas cell spectra.

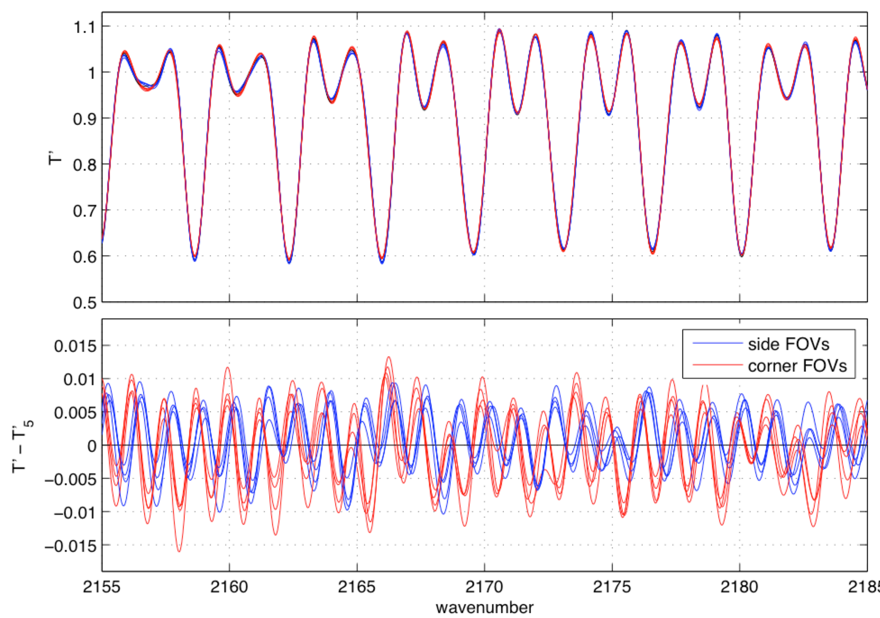

Figure 4. Spectral Inter-FOV differences for Mission Nominal Side 2 Carbon Monoxide spectra.

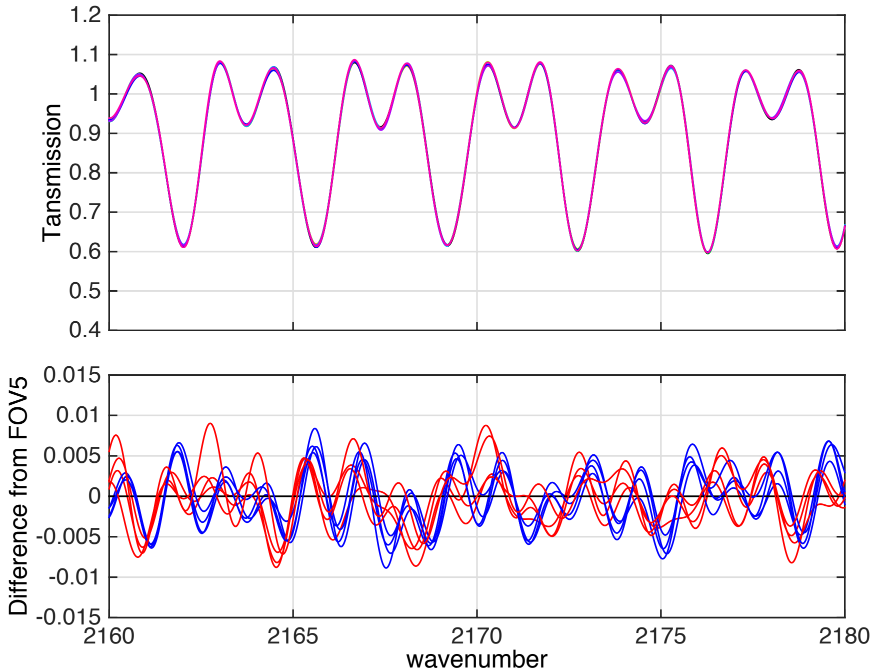

Figure 5. CO gas cell spectral and inter-FOV differences using spectral corrections performed using the draft J1 ILS parameters provided by Exelis on 17 December. In the bottom panel, blue curves re side FOVs and red are corner FOVs.

2. VIIRS

2.1. Summary

The JPSS-1 VIIRS sensor level pre-launch test program was completed in Year 2 of this award. A high quality test data set has been collected for characterizing VIIRS relative spectral response (RSR) and an initial analysis through a combined VIIRS DAWG and Raytheon effort has been achieved. The JPSS-1 VIIRS Version 0 (Beta) detector level RSR has been readied for release to the VIIRS user community. This funding also supports participation in all aspects of the VIIRS Data Analysis Working Group (DAWG).

Year 2 included the Pre-TVAC, TVAC and Post-TVAC phases of the JPSS-1 VIIRS pre-launch sensor test program. This award supported on-site (Raytheon El Segundo facility) participation during the TVAC and post-TVAC phases of the pre-launch test program as well as collaboration with Raytheon engineers and analysts to ensure a high quality test data collection for spectral characterization of JPSS-1 VIIRS. The effort includes subject matter expert (SME) oversight and contribution to the Raytheon analysis of a relative spectral response (RSR) product from the sensor test program data including an RTE model-based water vapor correction applicable to M9 RSR measurements. A VIIRS version 0 (Beta) detector level RSR release has been assembled for use by the VIIRS community in their early testing of VIIRS SDR and EDR performance.

2.2. Spectral Measurements

Spectral measurements during the sensor level pre-launch test program consist of FP-15/16 and NIST T-SIRCUS measurements. During FP-15/16 the Spectral Measurement Assembly (SpMA) source was used to measure in-band and out-of-band components of all VIIRS spectral bands. T-SIRCUS measurements, which were limited to VIIRS warm focal plane bands due to the ambient measurement environment, complement the FP-15/16 measurements with a “flight-like” full focal plane illumination measurement designed to integrate all influences of an on-orbit observation (filter performance, electrical and optical crosstalks). Highlights and items of interest of the spectral measurement effort include:

- In-band and out-of-band (OOB) spectral regions of all bands/detectors were successfully measured using the SpMA yielding a high quality data set. Appropriate repeat measurements were collected where needed (see additional items below). This effort was supported by on-site participation at Raytheon El Segundo.

- Flood illumination spectral measurements using NIST T-SIRCUS system were collected in December 2014 for all warm focal plane bands. Minor wavelength gaps exist in the data record but the measurement objectives were achieved, yielding an integrated measurement of filter, electrical and optical effects of the focal plane. Additional measurements were collected using different operation modes of the T-SIRCUS system to seek SNR improvements at those wavelengths where measurement quality was lower. This effort was supported by on-site participation at Raytheon El Segundo.

- Relative source output (RSO) characterization during measurement of some warm focal plane bands was influenced by a spectral position offset. These bands were examined carefully with a recommendation of repeating the measurements for M5, I1, and M4. Repeat measurements confirmed the impact of the spectral offset.

- During M9 measurements, SpMA slit settings that govern the spectral bandpass of the light exiting the SpMA source were altered from nominal to accommodate signal uniformity on the VIIRS focal plane. RTE-based modeling however confirmed an impact on the retrieved spectral shape of the M9 RSR. A recommendation was made and implemented to repeat the M9 measurements using nominal slit settings.

- A discovery was made that the 1000-1200nm spectral range out-of-band measurements for SWIR and MWIR bands were invalid due to the use of a light blocking order sorting filter in that spectral range. An alternative order filter was identified and applied for repeat measurements of SWIR bands. MWIR bands were not repeated due to low expectation of OOB features in that spectral range (based upon F1 experience and VIIRS optical design). Repeat measurements of SWIR bands confirmed no OOB contamination in this wavelength range.

- Due to roll-off in transmission, the silicon neutral density filter applied to M11 OOB measurements was not ideal. An alternate Germanium neutral density filter was used in a repeat measurement and provided high quality data.

- A mismatch of SpMA slit widths between different portions of the OOB measurements was identified for M8 and a portion of M10 measurements. Upon close examination the impact of the mismatch, while not ideal, was assessed to be well below uncertainty requirements and thus repeated measurements were not requested.

- During Pre-TVAC and TVAC spectral measurements, temperature and humidity monitors were operated in the ambient portion of the measurement environment to provide water vapor concentration data. The quality of these measurements was verified. These measurements were tantamount to the successful water vapor correction of M9 in-band spectral measurements. In addition to the water vapor monitoring, it is recommended to operate one or more CO2 monitors in the ambient environment to assist in mitigating CO2 attenuation at wavelengths in the longwave wing portion of M13.

2.3. Spectral Measurements Analysis

All spectral bands being successfully measured during the spectral portion of the pre-launch measurement program, the Raytheon analysts undertook an analysis to generate the in-band plus out-of-band RSR. Oversight and review, including approval and recommendations at key points of the analysis were provided by Wisconsin, both through on-site and telecon meetings. The JPSS-1 RSR are shown in Figure 6. Some elements of the RSR analysis include:

• Relative source output correction (RSO) was based upon source lamp characterization that was closest in terms of source lamp usage hours to the RSR measurements.

• RSO of some bands contained a spectral offset. Root cause of this offset was found to be a combination of GSE hardware performance coupled with source characterization practices. A spectral adjustment to the source characterization was approved for bands that were less sensitive to the offset, while other bands were recommended for repeat measurement (as documented in Spectral Measurements section).

• SpMA spectral smile measurements were reviewed. These measurements, while informational, lack consistency and so could not be confidently applied to the RSR. The amplitude of the SpMA spectral smile however appears to be small and well within spectral wavelength uncertainty requirements for all gratings used in the FP-15 measurements, mitigating concerns about not applying this correction to the RSR.

• M9 RSR were corrected for water vapor attenuation influence on the FP-15 measurements (Figure 7). A forward model based approach (LBLRTM) was used at Univ. Wisconsin to simulate M9 RSR measurements in the presence of measured water vapor in the ambient laboratory. Due to the sensitivity of the water vapor correction on the RSR, spectral offsets were necessary for each detector to obtain a high quality water vapor correction. These offsets were determined via the forward modeling and are included in the retrieved RSR of M9. This water vapor correction was supplied to Raytheon for direct use in their RSR analysis.

• M13 RSR measurements are influenced by CO2 absorption in a portion of the wing and near out-of-band response zone (4.2 – 4.5μm). Forward modeling (LBLRTM) to simulate the impact on the RSR in this spectral region has been used to separate those measurements that are strongly affected from those that are less impacted. Strongly affected measurements are likely not recoverable due to the magnitude and uncertainty of the correction, whereas modestly affected measurements may be corrected and restored with simple linear interpolation applied to recover data at discarded wavelengths. This correction is not contained in the Raytheon RSR product but will be adopted in the Government RSR analysis.

• Raytheon RSR are primarily compliant with RSR compliance metrics (band center wavelength, bandpass, 1% response, maximum integrated out-of-band); however minor non-compliances exist for band center (M5, M16A, M16B), bandpass (M1, M8, M14, DNBMGS), 1% response (DNBLGS, DNBMGS, I5) and maximum IOOB (M16A, M16B). Many of these non-compliances were also present in F1 (SNPP). The JPSS-1 non-compliances have been reviewed and deemed acceptable (waiver). Of note, F1 non-compliances on maximum IOOB for VisNIR bands have been eliminated by a redesign of VisNIR integrated filter assembly (IFA) for JPSS-1.

• A preliminary analysis (no filtering or correction of poor quality data) of VIIRS RSR as measured by the NIST T-SIRCUS (warm focal plane bands only) has been reviewed. This early review reveals that minor electronic crosstalk is present (Figure 8) in all warm focal plane M-bands, similar to what was observed in F1 (SNPP) T-SIRCUS based RSR measurements. I-bands also exhibit some evidence of electronic crosstalk but the lower SNR of the I-band out-of-band measurements limits the information content. Filter leaks observed in SpMA measurements of VIIRS RSR are also found in VIIRS RSR from T-SIRCUS measurements.

The Raytheon RSR product has been reviewed at Univ. Wisconsin and approved for release as a JPSS-1 VIIRS V0 (Beta) RSR product for use by the VIIRS science community in their early testing and evaluation of SDR and EDR performance. The release includes detector level RSR for all bands and a README document. This release will be made available initially through the NASA JPSS-1 eRoom while awaiting removal of all ITAR restrictions.

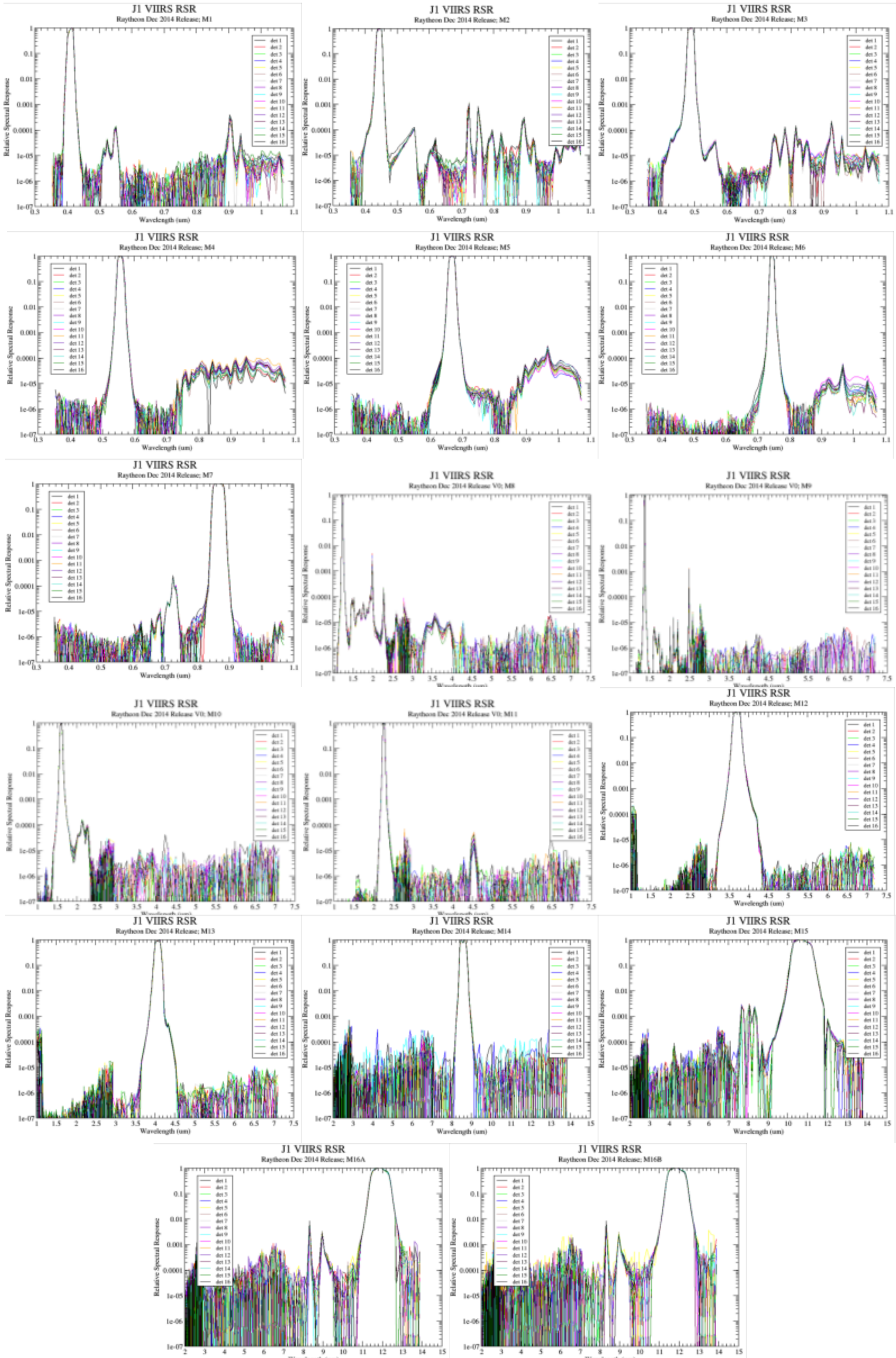

Figure 6. JPSS-1 VIIRS M-band RSR, release V0.

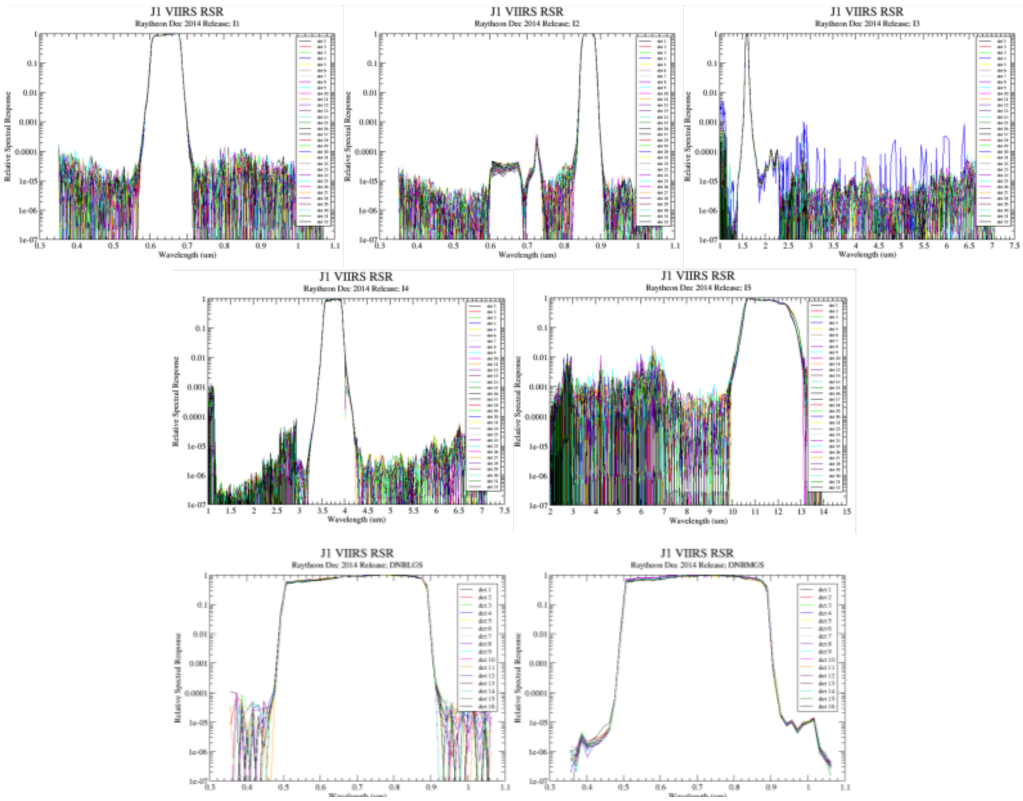

Figure 6 (cont.). JPSS-1 VIIRS I-band and DNB RSR, release V0.

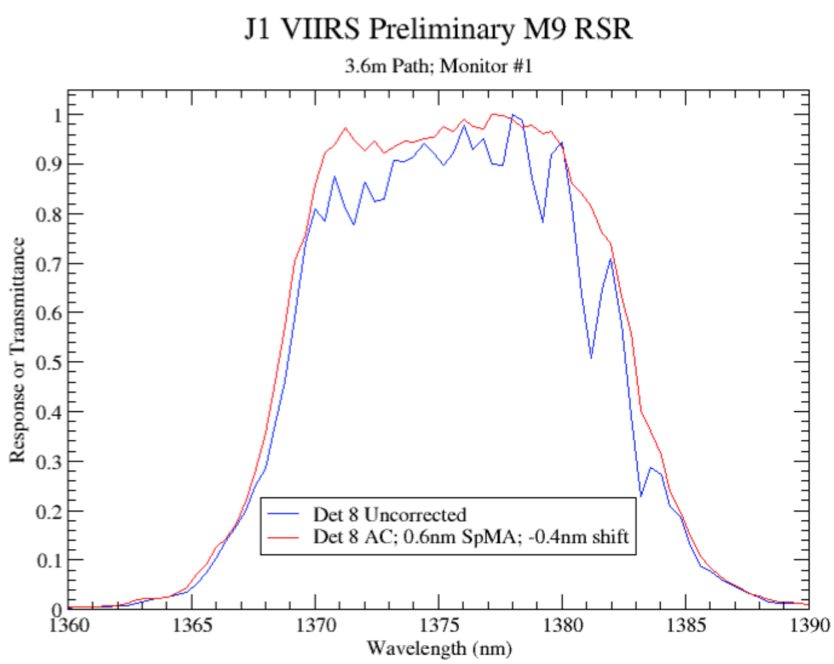

Figure 7. Example of water vapor corrected RSR for JPSS-1 VIIRS band M9. Water vapor correction restores response suppressed by water vapor absorption in the ambient portion of the test setup.

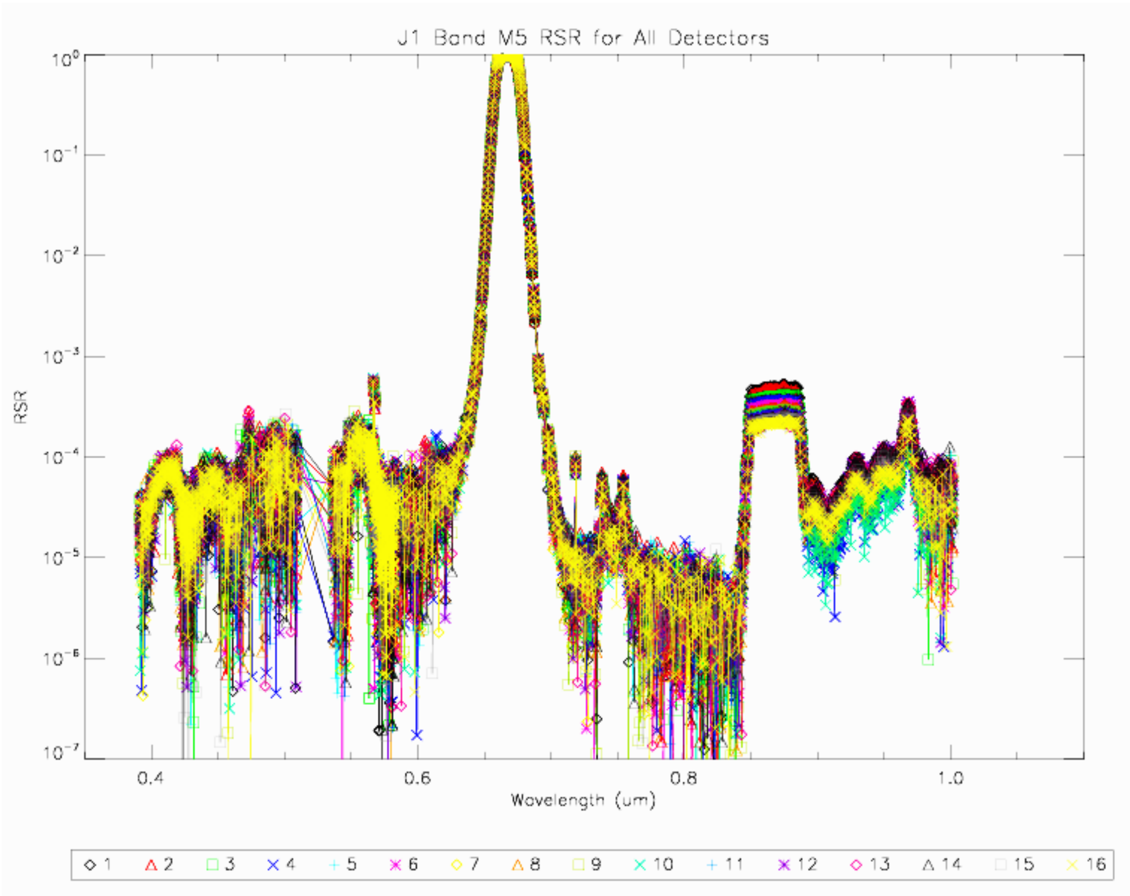

Figure 8. JPSS-1 VIIRS band M5 RSR from T-SIRCUS measurements. T-SIRCUS provides flood illumination of the VIIRS warm focal plane, integrating filter, electronic and optical crosstalks into the measurement. The elevated response near 0.85 – 0.90 um is due to electronic crosstalk from band M7 or I2 into band M5.