VCST Internal Memo

Title: Estimate of Uncertainty in FP-11 Polarization Sensitivity Measurements for the VIIRS F2 VisNIR Bands
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References

[1] TP1544640-2222 Rev A, 'Polarization Sensitivity FP-11 Test Procedure,' Raytheon.
[2] VCST_TECH_REPORT_14_013, 'Update to Preliminary Analysis of Uncertainty in Polarization Sensitivity Analysis,' Jeff McIntire, February 27, 2014.
[3] 'J1 FP-11 Polarization Characterization Uncertainty,' Eslim Monroy, Raytheon, January 30, 2014.
[4] VIIRS PRD Rev C, 'Joint Polar-orbiting Satellite System (JPSS) Visible Infrared Imaging Radiometer Suite (VIIRS) Performance Requirements Document (PRD).'
[5] VCST_TECH_MEMO_14_002, 'Assessment of FP-11 Polarization Sensitivity for the VIIRS F2 VisNIR Bands,' Jeff McIntire, March 15, 2014.
[6] 'VIIRS Polarization Sensitivity Analysis,' Eric C. Fest, Page E. King, and Steve J. Herbst, Raytheon, February 10, 2014.
[7] An Introduction to Error Analysis, John R. Taylor, University Science Books, 1997.

1. Introduction

VIIRS F2 sensor polarization sensitivity was measured for the VisNIR bands during FP-11 in ambient phase II testing [1]. Preliminary Analysis was reported in [2-3]. This work will provide an overview of the uncertainty propagation and provide the final uncertainty results.

2. Objective

The objective of the FP-11 test was to determine the sensitivity of the VIIRS instrument to input linearly polarized light. There are two specifications which relate to the polarization sensitivity of VIIRS [4]:

V_PRD-12624 – The VIIRS Sensor linear polarization sensitivity of the VIS and NIR bands shall be less than or equal to the values indicated in Table 1 for scan angles less than 45 degrees off Nadir.

V_PRD-12667 – The VIIRS Sensor linear polarization sensitivity shall be measured within a characterization uncertainty of 0.5% (one sigma) for scan angles less than 55.84 degrees off Nadir.

The first specification was addressed in a previous memo [5]; the second will be addressed in this memo.

2. Individual Uncertainty Contributors

2.1 dn Uncertainty

The uncertainty on the dn used in this work consists of three sources: noise, source stability, and stray light.

The random noise associated with each measurement is determined by the standard deviation of the mean over all samples and scans used at a particular polarizer angle:

$$u = \sigma_m . \quad (1)$$

The source stability was estimated by taking the difference of repeated measurements. The polarizer sheet was rotated from 0 to 360 degrees in 15 degree increments; for a given polarizer angle α, α and α+180 are repeated measurements. Each pair of measurements was used to generate the source stability contribution to the dn uncertainty for that pair of measurements:

$$u = \left| dn(\alpha) - dn(\alpha + 180) \right| . \quad (2)$$

Here the dn is sensor response averaged over all available scans and samples.

The stray light was determined from the separate stray light testing using the lollipop obscuration. The measured stray light forms a pedestal that increases the zeroth order Fourier coefficient (assuming no modulation with polarizer angle) and as such constitutes a bias uncertainty:

$$u = \max[dn(lollipop)] . \quad (3)$$

It was not removed in the processing as the stray light was observed to be 0.1 – 0.2 dn for the majority of detectors.

2.2 Polarizer Angle Uncertainty

The polarizer sheet transmittance axis was aligned with the VIIRS RTA rotation axis. To estimate the alignment uncertainty, a cross polarizer was used to determine the deviation of the angle of maximum transmittance from the expected angle; since we expect a cos(2θ) curve, the uncertainty is

$$u = \left| \delta_2 / 2 \right| , \quad (4)$$

where δ_2 is the two cycle phase angle.

2.3 Repeatability Uncertainty

The polarization sensitivity measurements were conducted three times at -8 degrees scan angle. The range of calculated values for the polarization factor was used as an uncertainty on the repeatability of the measurement, or

$$u = \left| \max[a_2(-8)] - \min[a_2(-8)] \right| . \quad (5)$$

2.4 Scan Angle Interpolation Uncertainty

Measurements of the polarization sensitivity were made at seven discrete scan angles (-55, -45, -20, -8, 22, 45, 55 degrees). However, the sensitivity needs to be known at all scan angles. The average residual of a quadratic polynomial fit to the measurements is used to estimate the uncertainty due to scan angle interpolation, or

$$u = mean(residual) . \quad (6)$$

2.5 SIS – TOA Uncertainty

The source spectra used in the determination of the polarization factors are shown in Figure 1, along with the TOA radiance. Modeling of the transmittance of linearly polarized light has shown that the bulk of the sensitivity derives from the differences in transmittance to input polarized light at the edges of the bandpasses, especially for bands M1 – M4 [6]. As a result, the uncertainty due to differences in the source spectra from the TOA radiance needs to be included. An example of the modeled transmittance of linearly polarized light is shown in Figure 2 for band M1, detector 8 (normalized). Four input polarization states were modeled (0, 45, 90, and 135 degrees). The modeled transmittance was provided for bands M1 – M7, detectors 1, 4, 8, 12, and 16, at all seven measured scan angles. These transmittances were convolved with the input spectra, and the modeled polarization factor was derived. The modeled polarization factors for the SIS and TOA spectra are shown in Figures 3 and 4 respectively. The maximum difference between the two per band is used as the uncertainty, or

$$u = \max \left| a_{2-\mathrm{mod}\,el}(SIS) - a_{2-\mathrm{mod}\,el}(TOA) \right|. \quad (7)$$

The difference is also plotted for all cases in Figure 5. Note that the model used here was not HAM dependent.

As no modeled transmittance was available for bands I1 and I2, the difference in the polarization factor between the SIS without Sonoma filter and SIS with Hoya filter measurements was used, or

$$u = \left| a_2(SIS) - a_2(SIS / Hoya) \right|. \quad (8)$$

Here the Hoya filter is used to approximate the TOA spectra.

2.6 OOB Uncertainty

The SIS – TOA uncertainty described above for bands M1 – M7 considered only in-band effects on the polarization sensitivity. The out-of-band (OOB) could also vary with input polarized light. To estimate the potential OOB impact, the measurements with and without the Sonoma filter were compared:

$$u = \left| a_2(SIS / Sonoma) - a_2(SIS) \right|. \quad (9)$$

However, this uncertainty is only determined here for bands M1 – M3. The other bands had either saturated, had very low signal, or the Sonoma filter excluded only part of the bandpass for one of the test configurations.

2.7 Test Setup Uncertainty

The test setup uncertainty was derived by Raytheon [3] and is listed per band in Table 2.

3. Uncertainty Propagation

The uncertainty propagation follows the methodology outlined in [7]. The uncertainty tree is shown in Figure 6. First, the dn and sheet angle uncertainties were propagated through the Fourier coefficients calculated from the cross polarizer testing and then used to determined the polarizer DoLP uncertainty. Next, the dn and sheet angle uncertainties were propagated through the Fourier coefficients calculated from the polarization sensitivity testing and combined with the polarizer DoLP uncertainty to determine the measurement uncertainty on the polarization factor. This measurement uncertainty is the RSSed with the following uncertainties: repeatability, scan angle interpolation, SIS – TOA, OOB, and test setup. The final uncertainty is then compared to the specification [4].

4. Results

The final, maximum uncertainties on the polarization factors a_2 per band over detector, HAM side, and scan angle are listed in Table 3 along with the individual uncertainty contributors (in %). The total uncertainties range from 0.13 % for M4 and M7 to 0.38 % for M1. The specified maximum allowed uncertainty is 0.5 %; all bands are well under this limit. The largest contributors are the SIS – TOA and test setup uncertainties. In particular, the SIS – TOA uncertainty for M1 is by far the single largest contributor for any band at 0.34 % (as seen in Figure 5, the differences are largest for detector 1).

Note that some of the contributors that are considered biases (stray light and sheet angle uncertainties) enter into the calculation of the uncertainty in the efficiency and also in the measurement total; any possible correlations between these contributions were not considered here. However, these contributions were in general subdominant, and so the overall conclusions are expected to hold.

7. Summary

FP-11 polarization sensitivity testing was performed under ambient conditions for the VIIRS F2 sensor. Uncertainty analysis showed the following:

- Band maximum uncertainties range from 0.13 % (for M4 and M7) to 0.38 % (for M1).
- All bands are well below the specified maximum uncertainty of 0.5 %.
- The largest uncertainty contributors are the SIS – TOA and test setup; the largest single contributor for any band is the SIS – TOA uncertainty of 0.34 % for M1.

Table 1: Specified maximum polarization sensitivity [4]

Band	Sensitivity [%]
I2, M1, M7	3
I1, M2, M3, M4, M5, M6	2.5

Table 2: Test setup uncertainties in % [3]

I1	I2	M1	M2	M3	M4	M5	M6	M7
0.20	0.10	.014	0.12	0.14	0.10	0.13	0.09	0.10

Table 3: Maximum uncertainty on polarization factors (a_2) over detectors, HAM sides, and scan angles [in %]

	I1	I2	M1	M2	M3	M4	M5	M6	M7
Noise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00
Source stability	0.03	0.06	0.00	0.00	0.00	0.04	0.07	0.09	0.06
Stray light	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Sheet angle	0.01	0.04	0.06	0.03	0.02	0.02	0.04	0.04	0.04
Efficiency	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Measurement total	**0.03**	**0.07**	**0.06**	**0.03**	**0.02**	**0.05**	**0.08**	**0.10**	**0.07**
Repeatability	0.04	0.01	0.03	0.03	0.03	0.06	0.02	0.01	0.01
Scan angle interpolation	0.04	0.07	0.03	0.02	0.04	0.05	0.09	0.05	0.09
SIS – TOA	0.20	0.19	0.34	0.05	0.11	0.05	0.09	0.01	0.03
OOB	0.00	0.00	0.06	0.04	0.08	0.00	0.00	0.00	0.00
Test setup	0.20	0.10	0.14	0.14	0.14	0.10	0.13	0.09	0.10
Total	**0.28**	**0.22**	**0.38**	**0.14**	**0.20**	**0.13**	**0.19**	**0.14**	**0.13**
Specification	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**

Figure 1: Input spectra for different test configurations

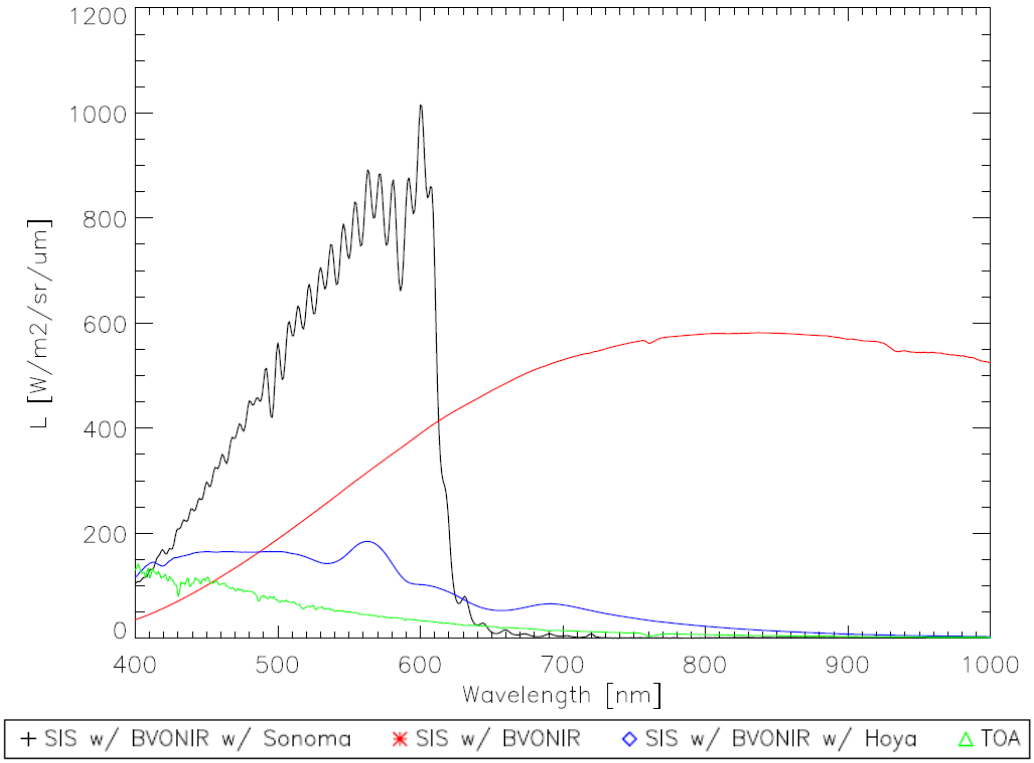

Figure 2: Modeled polarized transmittance for band M1, detector 8

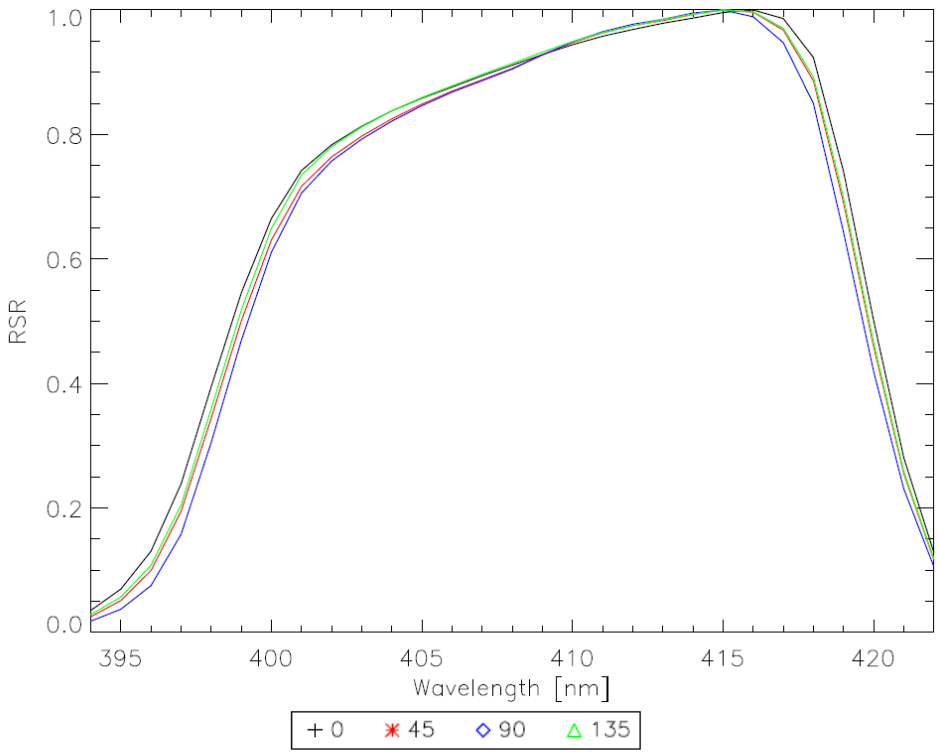

Figure 3: Modeled polarization factor a_2 in [%] across scan angles for the SIS spectra

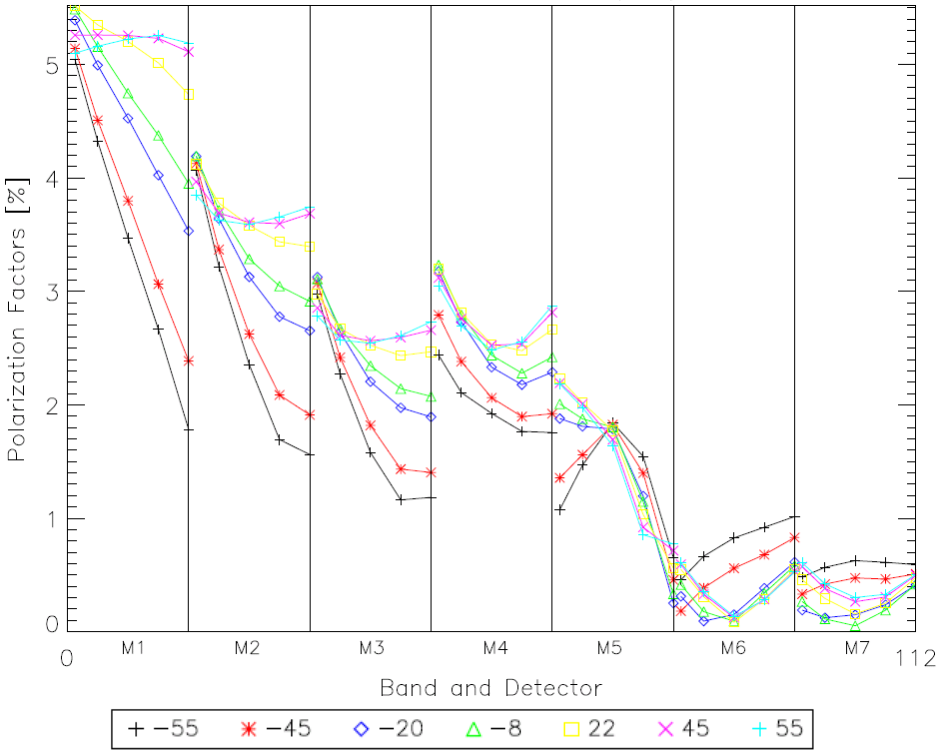

Figure 4: Modeled polarization factor a_2 in [%] across scan angles for the TOA spectra

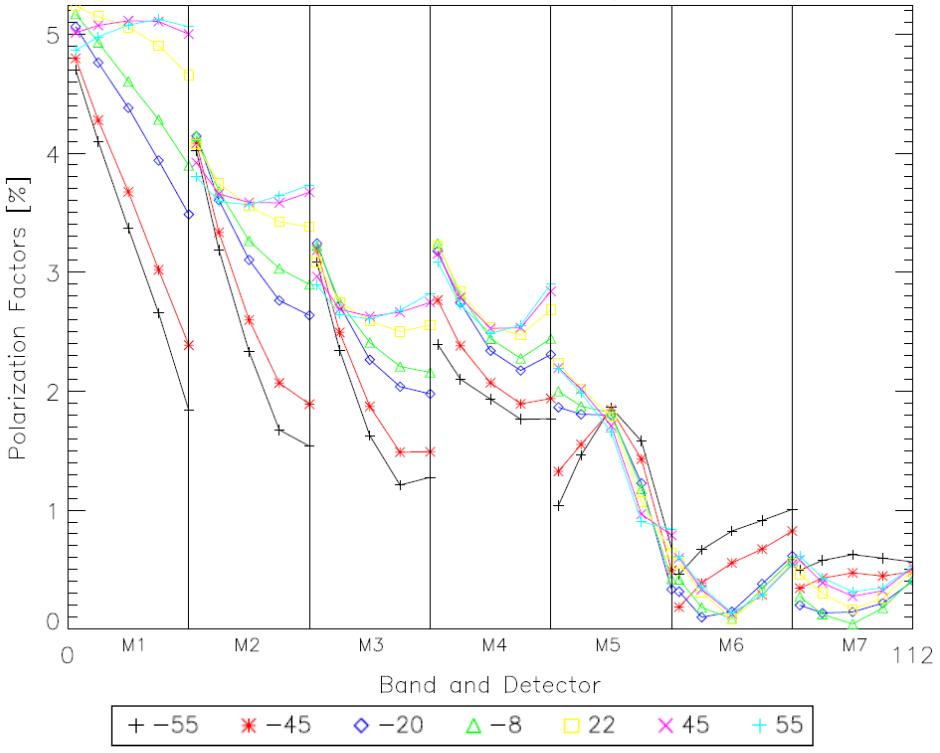

Figure 5: Polarization factor difference between SIS and TOA spectra in [%] across scan angles

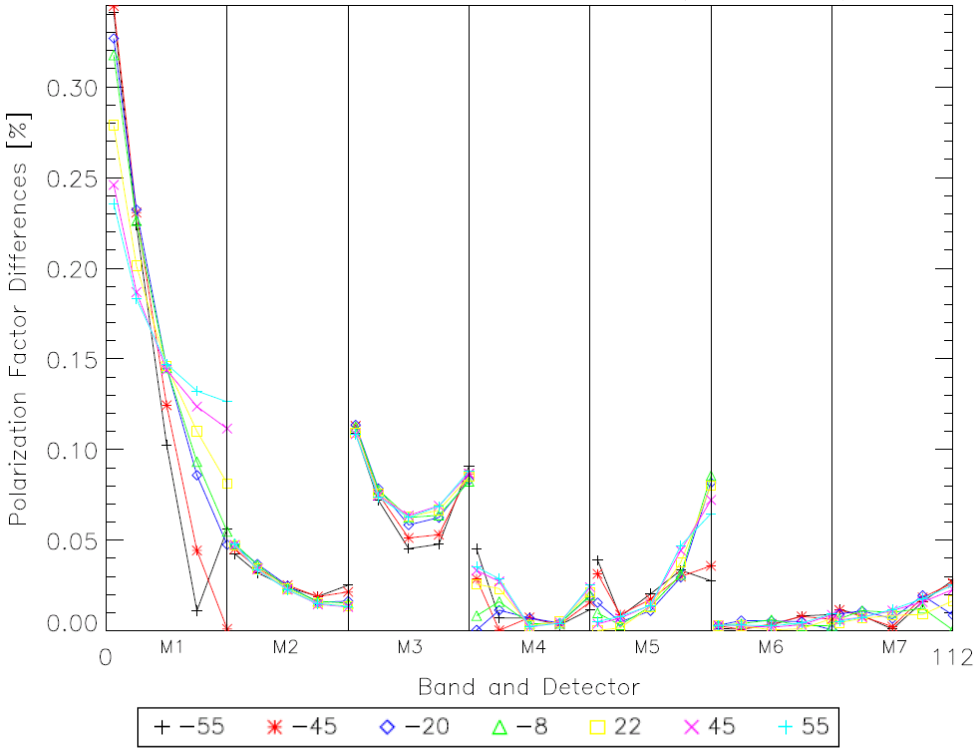

Figure 6: Uncertainty tree for the polarization factor a_2