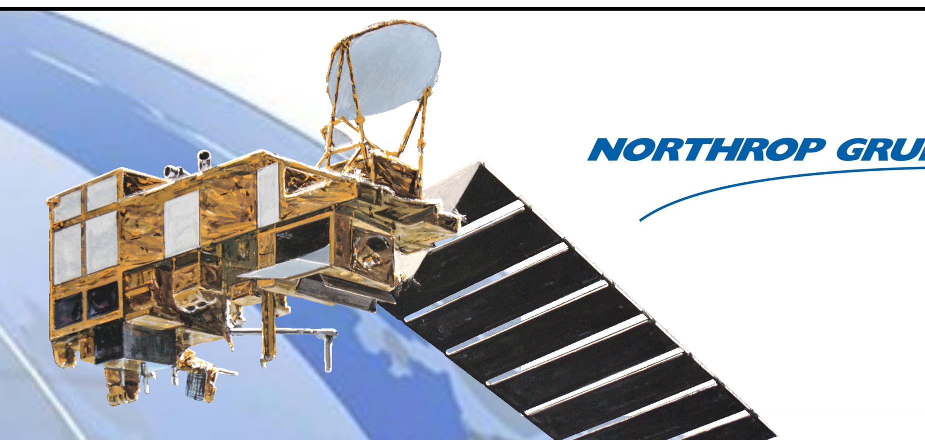


Polarization Sensitivity of the VIIRS instrument on NPP; Implementation of various sensor test data

By Patty Pratt (NGAS) & Vijay Kulkarny

ABSTRACT:

The polarization sensitivity for VIIRS is characterized during the testing phases at the instrument level. The results of a first test were abandoned along with the testing equipment in a consensus choice to use a new test configuration. A preliminary run of the new test was done in the ambient test phase. Unexpected variations across the detectors of single bands were observed. Based on these results, the test equipment was optimized and new VIIRS polarization characterization data are available from the post-TVac phase. This paper describes the two test setups and the results. A path forward for correcting VIIRS data for the sensor induced polarization is proposed and discussed.

GENERAL BACKGROUND:

Calibration methodologies for ocean scenes have been developed previously for MODIS and data are valid after several factors are corrected. Each correction if not accounted for has a unique impact to the data; however, different anomalies have similar manifestations in the data and they must be explicitly identified prior to getting good data. For instance if an anomaly is found that is affecting the data in a scan direction that is due to the instrument optics, then an anomaly would be present in all scans; whereas and anomaly that is originating in mirror side differences would appear in every other scan. Additionally, if the anomaly were a single detector, the result would appear as striping on a pixel level. If the corrections that are made for polarization along track are not done correctly then a banding would occur between scans. Various test data support the needed parameters to fully characterizer these fine

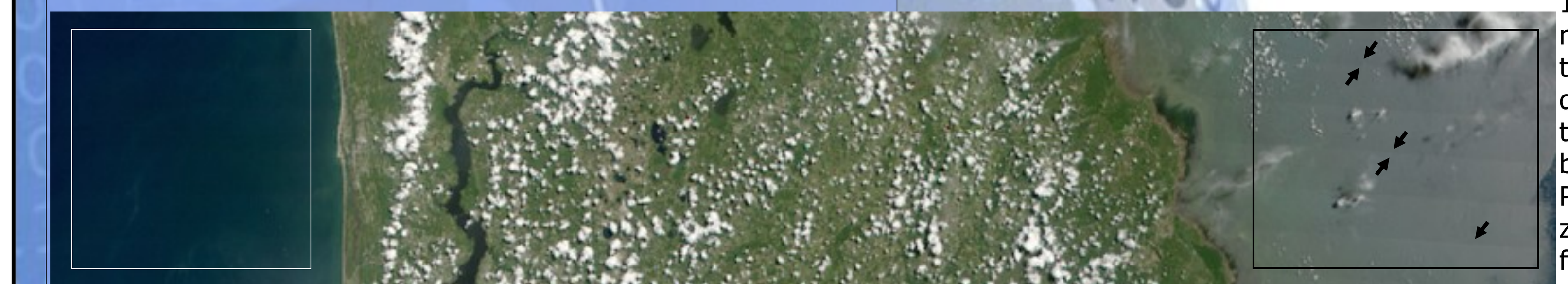


Figure 1. MODIS image showing banding (black arrows) from uniform area of bright pixels (sun glint)...expected from the small viewing angles in solar zenith. On the left, for dark blue pixels this effect is negligible (white box).

details which allow for ocean color to be retrieved. The concept is to create tests in the laboratory while the sensor is isolated from source errors. Since no test setup can truly simulate the earth's environment, it is essential that the uncertainties in the measurements also be assessed and some of the final characterization is performed on-orbit. The banding shown above in **Figure 1** on the right hand side is actually intrinsic to the measurement and simply the small change in viewing angle from what is used in the calculation. It appears in very bright pixels and in this case sun glint. On the left hand side, it does not appear in the dark ocean pixels and therefore cannot be attributed to a correction error. If however, there were along track errors, they may look like the ones in the sun glint shown above. The waterfall plots in **Figure 2** have an orange spot. This is the sun glint and cannot be corrected. Other correctable errors, cross scan and mirror side, can also be seen before and after correction. Detector, scan and mirror differences (shown in **Figure 3**) can all be accounted for with proper testing including polarization and crosstalk.

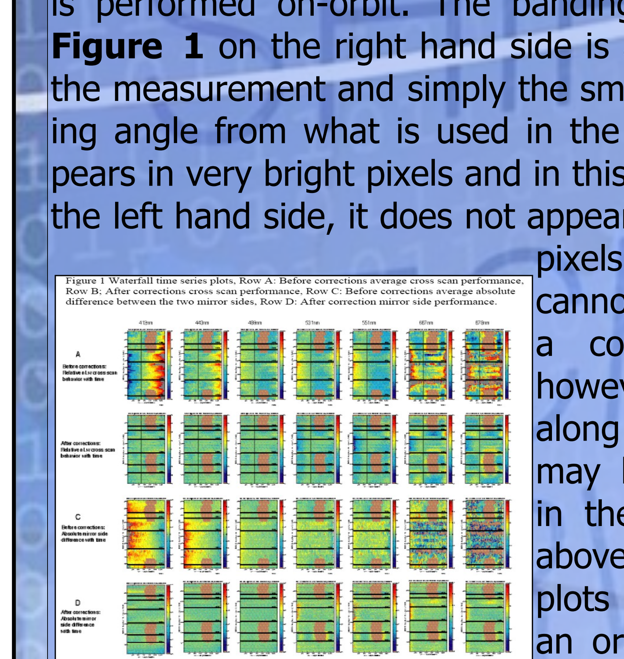


Figure2 Waterfall plots

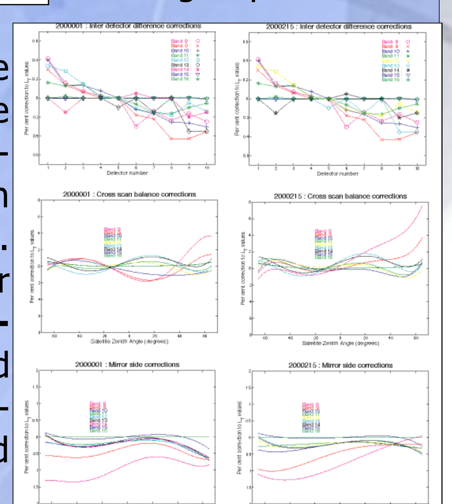


Figure 3. Detector, scan and mirror side differences from MODIS-Aqua

OBJECTIVES:

To obtain ocean color data, the scene polarization must be taken into account as well as any impact the optical instrument has on the light field. Every instrument will have a small amount of polarization unless it is specifically designed otherwise. For instance SeaWiFS has a randomizer on the aperture which scatters incoming light. On MODIS, there are no fore-optics that depolarize the incoming light; therefore the sensitivity of the sensor to polarization must be measured in the lab and applied to the polarized light emanating from the scene (see Figure 4). Many component level factors (i.e. mirror coatings and dichroic beam splitters) contribute to the overall sensitivity of the instrument as well as angle of incidence (AOI) changes which have different polarization states. The sensitivity impacts the blue bands since the polarization is dependent upon Rayleigh scattering (in the atmosphere) which is a wavelength dependent asymptotic curve decreasing with higher wavelengths (see Figure 5). There are strong seasonal and latitudinal dependencies in the scene that must be considered. In Figure 4, courtesy Dr. Ken Voss, University of Miami Physics Department, a modeled scene polarization for December for 412nm shows the natural scene variation of polarization. The polar latitudes can be as high as 70% while the equatorial latitudes have negligible scene polarization. If the sensor has a 2% contribution to the top of the atmosphere (TOA) radiance, the impact is 1.4% which translates to a 14% error in water-leaving radiances. The extra order of magnitude comes from the fact that 90% of the TOA in the blue wavelengths is path radiance and not part of the desired signal. Water-leaving radiance in this band is on the order of 10% of the signal. Therefore the impact can be significant when it comes to retrieving ocean color. Polarization can only be corrected if the sensor characterization is well known prior to launch. To properly account for the polarization all of the many contributing components must be characterized and understood. The uncertainties must also be carefully tracked to stay inside the measurement specification. VIIRS optics are remarkably depolarizing as shown in **Figure 6** for band M2. While this is desired it also makes the polarization measurement the most delicate signature to measure during testing of the reflective bands. Because the optical crosstalk could have influence on the polarization measurement itself, many ideas were considered for supplemental characterization. Several additional tests were performed in conjunction with the polarization test to inform not only the relative spectral response RSR measurement but also the potential impact to polarization. At the end of the day, the bands on the reflective filter block are now considered exceptionally characterized making VIIRS the most characterized ocean color sensor.

Optical crosstalk is defined as the light that scatters just before entering the detector in the optical path and can enter other bands and detectors. Some of this light crosses into another filter into a neighboring detector while other light scatters in the along-track detector beneath the same band. The scattered light can come directly from the bandpass or any from light that leaks through the band pass. For VIIRS, there is red light leaking in the bands of the lower wavelengths. This fact is well known and unfortunately confounds the polarization data because the polarization state of the scattered light is much different than the polarization state of the light that enters the band from the field of view.

This phenomenon happens to contribute to the detector dependence of the polarization since the scattered light has a polarization phase that causes the polarized light to constructively or destructively interfere with the polarization of the band itself. This varies with detector and either decreases or increases the polarization magnitude.

It should be noted that much consideration was given to changing the filter to eliminate the optical crosstalk, the choice was to make additional characterization studies instead, some of which are presented here. It should also be noted that the next VIIRS sensor Flight unit Two (F2) has been designed (new filter design) to prevent this extra scattered light, essentially eliminating the optical crosstalk.

A method for mitigating the optical crosstalk was created by NGAS Algorithms Team which involves the application of an "effective" RSR which is the sum of all light in each band including the out of band (OOB) contribution that arises from the extra crosstalk signal. Applying this RSR to the data via LUT, the effects of the crosstalk anomaly are markedly decreased. By incorporating knowledge of how this scattered light is polarized, the impacts to the ocean color products are further understood and are potentially decreased as well. The implications and possible uses of the new knowledge are currently being studied and the issue is being resolved collaboratively by NGAS System Performance and Algorithms and Development teams. The results of the additional testing help to further broaden the sensor knowledge thus making VIIRS the home of a well characterized filter block.

For the polarization test, there were essentially two tests done (with and without the Sonoma Filter) on bands M1-M4 that resulted in detailed data of two separate conditions providing insight into on-orbit acquisition. This presentation looks into what's possible for characterization given the two sets of polarization data and how the additional characterization of the RSR may benefit ocean color products.

This poster also presents facts that support a conclusion that a lower uncertainty exists for the most critical band (M1) which was expected to be the worst and the highest uncertainty is now defaults to M2. It should be re-stated that all uncertainties are currently meeting all sensor specifications. The overall objective is to know the polarization sensitivity biases well enough to remove them and to ensure the variation in precision is small enough to be undetectable or negligible.

The analysis captured in this poster gives insight into where (which scenes) may work the best with the polarization data in hand and indicate where caution should be exercised. The strategy is to assess the supplemental test data to the maximum level of detail with a goal that will added value for retrievals in waters that traditionally been difficult to obtain (i.e. coastal).

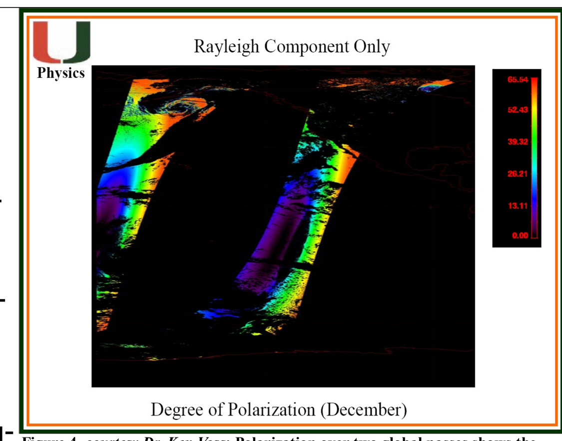


Figure 4. *courtesy Dr. Ken Voss*; Polarization over two global passes shows the variation in latitude.

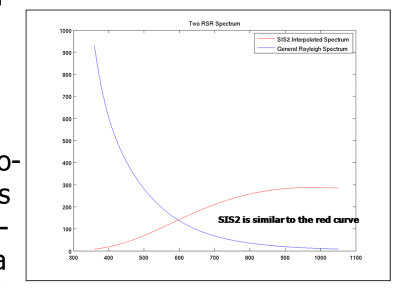


Figure 5. TOA vs source in VIIRS polarization testing

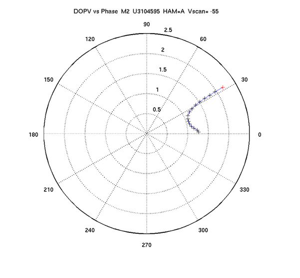


Figure 6. Sample of Polarization data shows ~2% maximum for detector 1 (red dot) and the phase variation across the band.

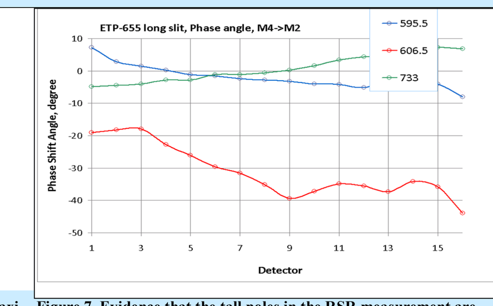


Figure 7. Evidence that the tall poles in the RSR measurement are polarization is seen above and could be responsible for the detector variation seen in the polarization data.

SCOPE:

During the polarization sensitivity testing, M1 (412nm band) showed substantial anomalous behavior that was attributed to the red leakage (650-1000nm range) in the filter itself. Additionally, the source (SIS) was noted to have a spectrum dominated by red light which would not be the case for most scenes requiring polarization correction (uniform blue ocean). The combination of these two features would confound the M1 data and anomalies were observed. Based on these facts, a new strategy was developed by the test team and working groups for the polarization test setup which included introducing a red -blocking filter (Sonoma Filter) in the optical path to reduce the OOB contributions therefore reducing the impact of the red leakage on the polarization characterization data. Other bands were not expected to be significantly impacted by red leakage and therefore the Sonoma Filter was not thought to produce substantial changes in M2, M3, and M4. However, changes on the order of approximately 0.3% were observed for M1, M2, M3, and M4 in both polarization amplitude and phase for all four bands. This analysis may provide some insight into these changes. The new polarization testing concept allowed analysts to observe the changes in the four bands for two input sources. This knowledge prospectively makes it possible to fine tune the polarization correction to increase the number of valid ocean color pixels. One possible outcome is that polarization sensitivity is scene dependent for this instrument. The difference is within the instrument specifications; however the new knowledge may contribute to a better polarization correction leading to better performance of the ocean color products.

In addition to the polarization test with the Sonoma Filter, it was observed that additional testing would be needed to characterize the light leaking internal to an individual band or from neighboring bands that may contribute polarization dependent signatures. Characterization tests beyond the scope for both polarization and RSR were performed to obtain in-depth knowledge of *polarization* of the relative spectral response. Once it was assured that the RSR was polarization dependent (see **Figure 7**), another limited test was added to measure the magnitude of this polarization. Work in this area is ongoing. This presentation will illustrate some of the unique details that each individual band and requires correcting for the extra OOB polarization or at minimum an uncertainty carried. Information learned from the customary RSR test (**see Figure 8**) along with the additional RSR and polarization tests provides the additional critical information needed to characterize and understand the test data and may lead to better retrievals. Since these additional tests provide invaluable information to characterization other than polarization (i.e. the RSR test) only partial results of these tests are presented. This analysis is needed to assess the characterization and the characterization uncertainty in the new polarization retest measurements. Though a small amount of uncertainty characterization work remains, the results indicate that VIIRS is principally insensitive to polarized light. The additional characterization in the polarization data helps to mitigate the unforeseen impacts from the optical crosstalk on polarization sensitivity.

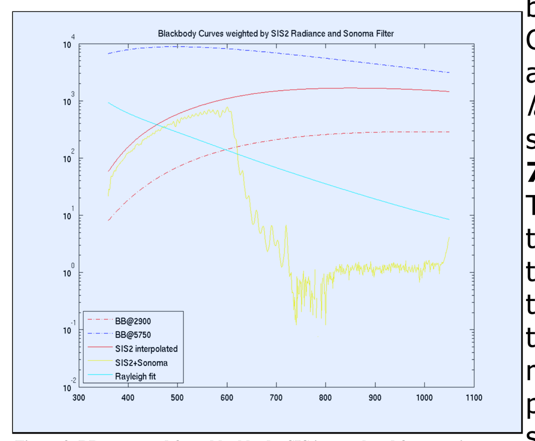


Figure 9. BB computed from blackbody, SIS interpolated from testing source radiance, Yellow curve is the SIS convolved with Sonoma Filter

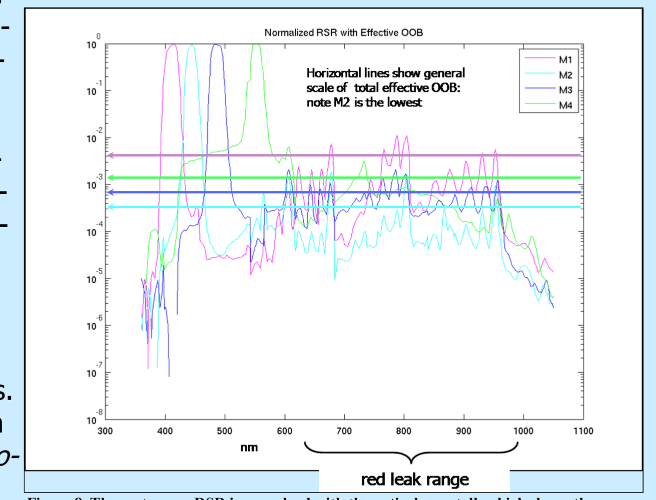


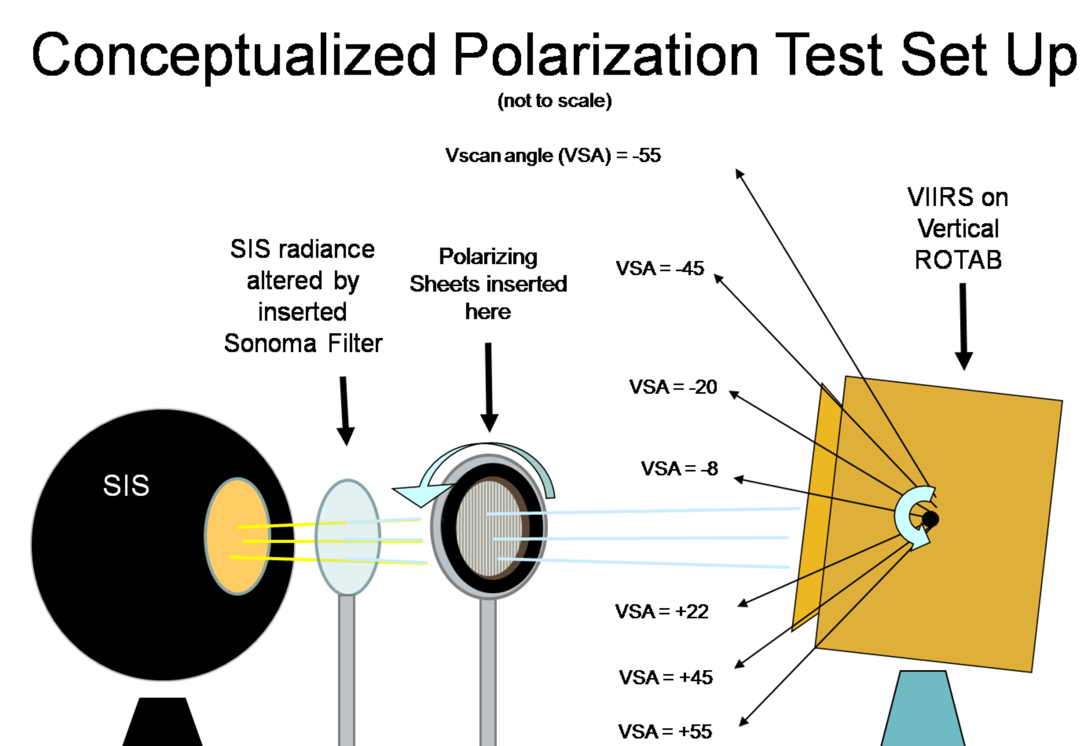
Figure 8. The customary RSR is convolved with the optical crosstalk which shows the contribution (leaking) of OOB wavelengths into bands M1-M4. M2 has the lowest red leakage.

TECHINCAL APPROACH:

The approach was to pull the relevant facts from various RSR and combine this with the different source knowledge (SIS and typical TOA…see **Figure 9**) mentioned above to support the knowledge of the polarization amplitudes and phases that were observed in the two separate polarization tests. First we examine the RSR's of four bands (see **Figure 10 a-d**) convolved with the two test sources (SIS and SIS+filter) and compare those with an RSR convolved with a typical TOA (based on Rayleigh Radiance).

The Sonoma filter has a sloped cut off region in the higher wavelengths (>609-700 nm) and full cut off beyond 900nm. Therefore, the difference in the polarization data with and without the filter comes only from the contributions higher than 609nm. However, the OOB can come from any part of the spectral range (350-609nm). The official bandpasses for bands M1-M4 are in this range also. To assess the degree to which the band may be impacted, characterized and/or corrected, this presentation breaks the convolved RSR's OOB into separate into three zones (see **Figure 11**). In any region where the OOB crosstalk is high, there is a potential of a data impact from the crosstalk itself. NGAS has developed a mitigation strategy to minimize those first order effects of crosstalk. Additionally, there may be a small uncertainty associated with the polarization state of this OOB contribution. NGAS is working on an "effective RSR" that also includes this dependency that will improve the accuracy of the ocean color retrievals by improving the Atmospheric correction over the Ocean (ACO). Another impact of the polarized state of the OOB is with respect to the polarization data. Fortunately, we now know the magnitude of some of the OOB contribution on the behavior of the polarization data. Again, it should be noted that the differences fell within the specifications of the instrument. Any use of the data to improve the ocean color signal is opportunity that was gained by the additional data.

The likelihood of the OOB impact appears to be scene dependent since the crosstalk sources will be greater for scenes that contain higher signal in the wavelengths that are the major contributors of the OOB. If the effective OOB is small for a particular region then it has no impact regardless of how polarized the signal is. Therefore, the tests that were conducted were limited by band to the "tall poles" in the OOB spectral signature. Upon interpretation of the new data, it appears that differences and uncertainties in the polarization data will vary depending upon the TOA radiances or the scene. To examine the uncertainties, the analysis team convolved the various sources and predicted on-orbit TOA's over ocean with the effective RSR's. Samples of this analysis are presented here. In this context perform Some bands better with the Sonoma filter in place and others may not.



RESULTS:

The various sources were convolved with M1-M4 and are shown in **Figure 10 a-d**. The repetitive pattern seen in the RSR indicates that the red leaks in the filters come from interference edges in the various layers of optical material. There are three bursts of energy (600-700nm; 750-800nm; & 850-950nm) in the longer wavelengths. The first burst of energy in the OOB red is not cut out completely by the filter for any bands as it spans the slope in the filter transmission cutoff. The second burst of energy is completely cut out of the polarization retest data. In real scenes, the red light in this region is still present at the TOA is still polarized. The use of the filter may have over corrected in this region. The third burst (900nm range) is likely not polarized in the test due to polarization sheet transmission, and is believed to have inconsequential contribution to the signal from natural scenes. Therefore the polarization data with and without the Sonoma filter is acting for the most part on the second burst of energy. Some of the OOB comes from left of the In-band for M2, M3, and M4. Since this energy is believed to be fluorescence in the filter substrate, it not an important component of this study. If the proportions of the Sonoma filter data show that the OOB is shifted into this region, it can reasonably be concluded that the area that loses the OOB is giving a better result in the polarization data. If the relative OOB is shifted to a region where there may be a scene contribution, there may be a need to analyze the polarization results to determine which of the two measurements is the better results. For coastal water scenes, the water often contains a significant amount of red light (see **Figure 12**) and application of the appropriate polarization should be studied further.

Also to be considered is that the red light leakage for M1 and M3 is greater than that seen in M2 as the leakage is coming from inside the filter itself rather than from a neighboring band. In all cases shown, EXCEPT for M2, the Sonoma filter suppresses a significant amount of effective OOB primarily in the red wavelengths. M2 gets most of its OOB contribution from neighboring bands that scatter into the M2 detectors and relatively none from internal filter effects. The OOB that exists for M2 in the red wavelengths comes predominantly from the OOB in M1. The Sonoma filter begins cutting off the wavelengths at 609 nm and continues with decreasing transmission until 700nm. M2 has a significant OOB contribution at 606nm from M4 and a tall pole at 672nm. These are likely the two signals that are acted on by the Sonoma filter to cause the observed difference ~0.3% in the polarization data. The second burst of energy from the red leakage is an order of magnitude less than both M1 and M3. Since the next strong pole in the M2 band is around 800 where the polarization filter itself falls off in transmission, the previous statement is further supported. For M1 and M3, and to a lesser extent M4, the polarization data with Sonoma filter appears to give the better result. Further investigation is needed and is ongoing.

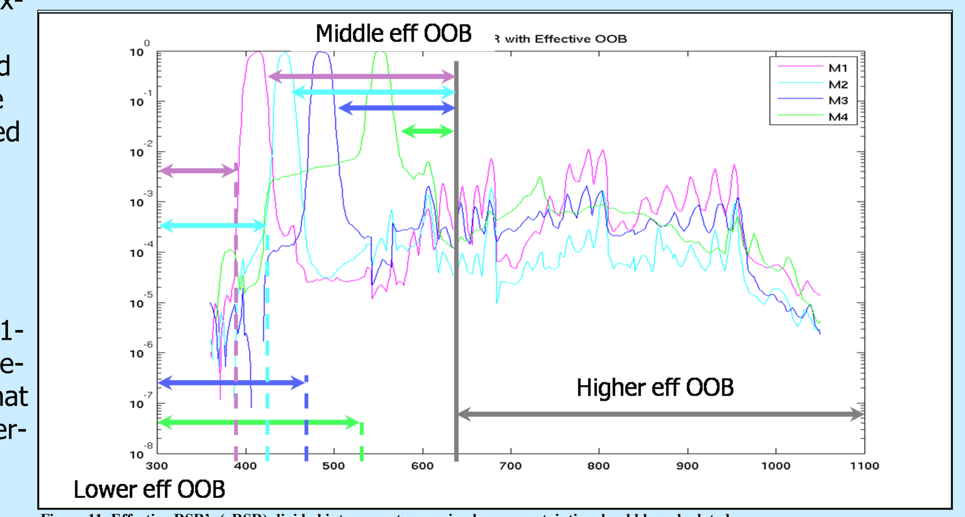


Figure 11. Effective RSR's (eRSR) divided into zones to examine how uncertainties should be calculated.

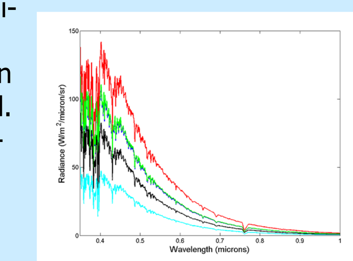


Figure 12. TOA;red is highest chlorophyll (red signal)

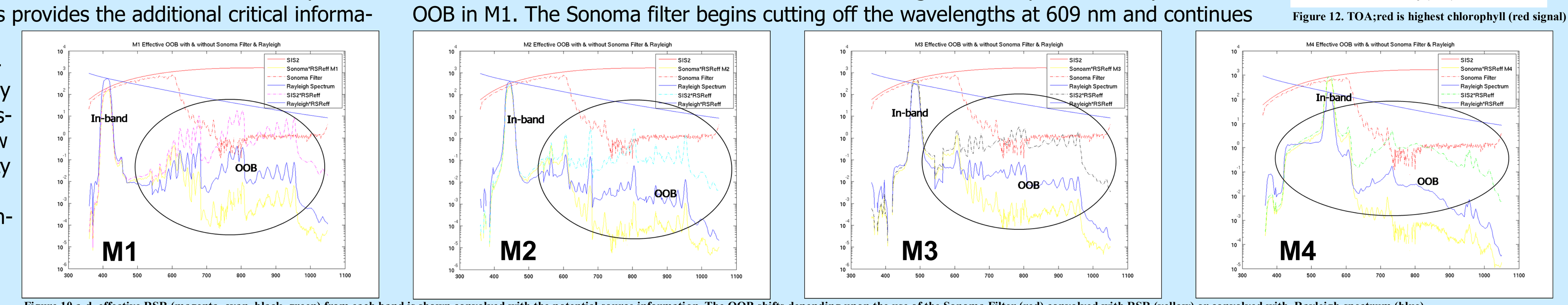
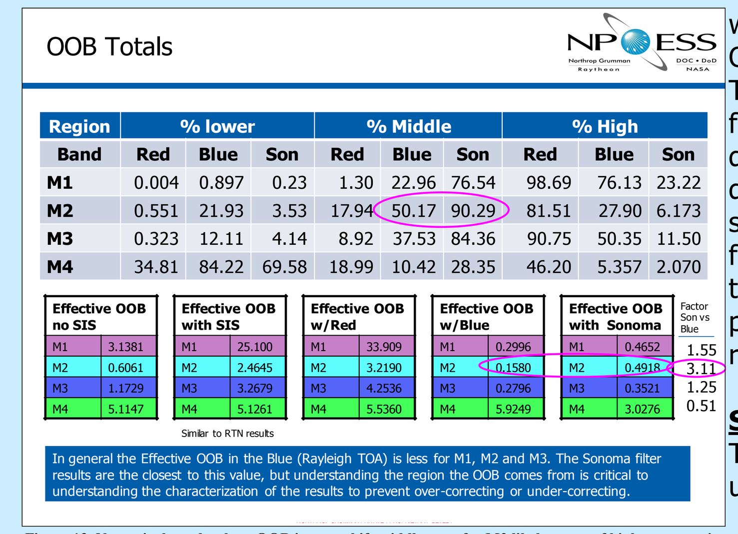


Figure 10 a-d. effective RSR (magenta, cyan, black, green) from each band is shown convolved with the potential source information. The OOB shifts depending upon the use of the Sonoma Filter (red) convolved with RSR (yellow) or convolved with Rayleigh spectrum (blue)



OOB Totals

Region	% lower			% Middle			% High		
Band	Red	Blue	Son	Red	Blue	Son	Red	Blue	Son
M1	0.004	0.897	0.23	1.30	22.96	76.54	98.69	76.13	23.22
M2	0.551	21.93	3.53	17.94	50.17	90.29	81.51	27.90	6.173
M3	0.323	12.11	4.14	8.92	37.53	84.36	90.75	50.35	11.50
M4	34.81	84.22	69.58	18.99	10.42	28.35	46.20	5.357	2.070

Band	Effective OOB no SIS	Effective OOB with SIS	Effective OOB w/Red	Effective OOB w/Blue	Effective OOB with Sonoma	Factor Son vs Blue
M1	3.1381	25.100	33.909	0.2996	0.4652	1.55
M2	0.6061	2.4645	3.2190	0.1580	0.4918	3.11
M3	1.1729	3.2679	4.2536	0.2796	0.3521	1.25
M4	5.1147	5.1261	5.5360	5.9249	3.0276	0.51

Similar to RTN results

In general the Effective OOB in the Blue (Rayleigh TOA) is less for M1, M2 and M3. The Sonoma filter results are the closest to this value, but understanding the region the OOB comes from is critical to understanding the characterization of the results to prevent over-correcting or under-correcting.

Figure 13. Numerical results show OOB impact shift middle zone for M2 likely cause of higher uncertainty.

SUMMARY:

The polarization which must be accounted for has an associated uncertainty that varies by band and by the contributors to the individual bands from OOB. Furthermore, the bands can be analyzed and characterized additionally by zone to understand how the uncertainty may change depending upon scene. This will improve the ocean color results.

When the Sonoma filter was introduced the magnitude of the polarization increased due to a reduction in the red light leakage. This is also indicative that the scattering effects seen on the first test were masking the polarization of the filter itself. For regions (i.e. coastal) where there is significant red light use the original data should be considered. However, the wavelength zones where this is significant for M1 and M3, there is little signal and likely would not result in improvement (see **Figure 13**).

In the middle zone for M2 there is more signal than in the middle zones for M1 and M3 resulting in a noticeably higher uncertainty in the polarization test data. Further assessment is needed to determine if the uncertainty and or the polarization contribution can be reduced by using the original test data, specifically in waters where the coastal constituents are greater thus making the red signal more significant. Other factors such as latitude should also be considered when considering the various alternatives (see **Figure 14**).

M1, M3, and M4 have most of the OOB coming from its own filter while M2 has contributors outside its own filter. This work provides understanding of and insight into the nature of several of the contributors (the instrument and the scene) that allows for a potential fine tuning of the VIIRS polarization sensitivity.

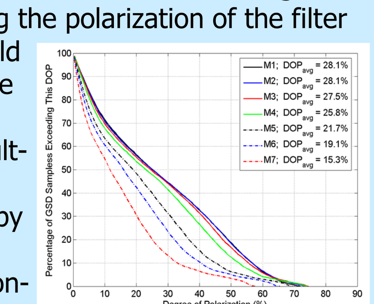


Figure 14. M7 (865nm) still shows significant polarization dependent on viewing angle.