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Ocean Color Impact of VIIRS Polarization Sensitivity and Uncertainty

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The Visible/Infrared Imaging Radiometer Suite (VIIRS) is a key science instrument on the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NPOESS is the nation's next generation operational weather and climate monitoring system. VIIRS is built to deliver 22 Environmental Data Records (EDRs). One of the EDRS, ocean color [1], requires accurate and precise estimation of water leaving radiances [2], L_W, in the reflective VIS-NIR bands, which is a small component of the top of the atmosphere (TOA) radiances observed by VIIRS. The accuracy of measuring the total TOA radiance becomes critical, especially when the other large components of the signal due to atmospheric scatter are substantially polarized, which have to be subtracted out by the Atmospheric Correction over Ocean (ACO) algorithm [3]. Errors due to minor sensitivity of VIIRS to such polarization can be corrected with data processing algorithms, but the polarization sensitivity characteristics of VIIRS must be known to within a very small uncertainty or tolerance.

Flight Unit 1(F1) of VIIRS will fly on the NPOESS Preparatory Project (NPP) spacecraft at 830 km altitude in a sun-synchronous orbit at 1330 Local Mean Solar Time. Through a rotating telescope assembly, the detector rows of all bands of the VIS-NIR Focal Plane Array (FPA) image successive scans of Earth's surface, each ≈ 11 km wide in track direction, to generate data on ≈ 3000 km wide swath across the ground track, as shown in Figure 1.

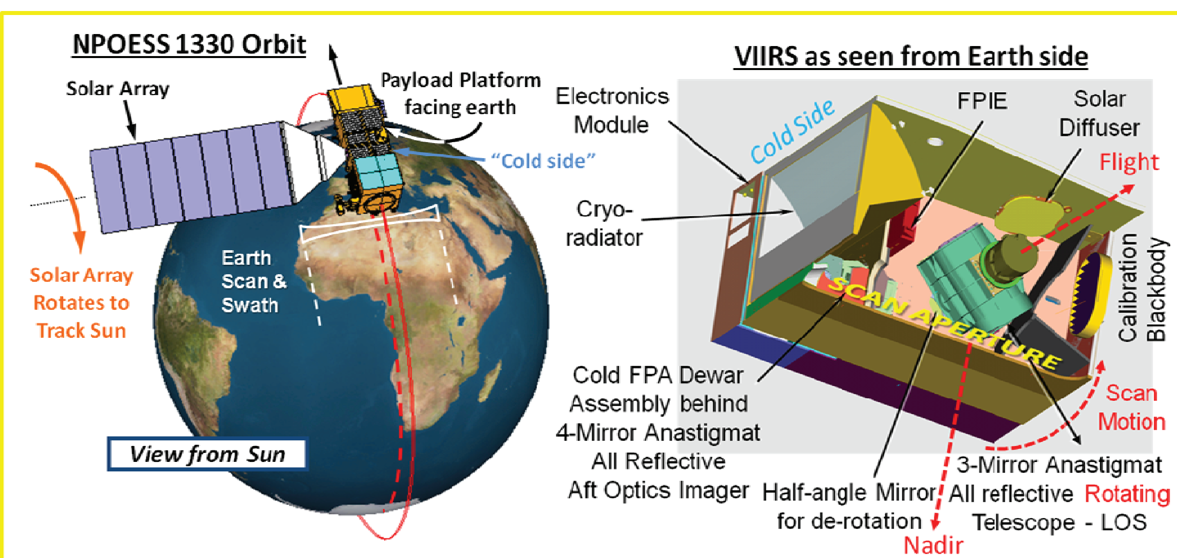
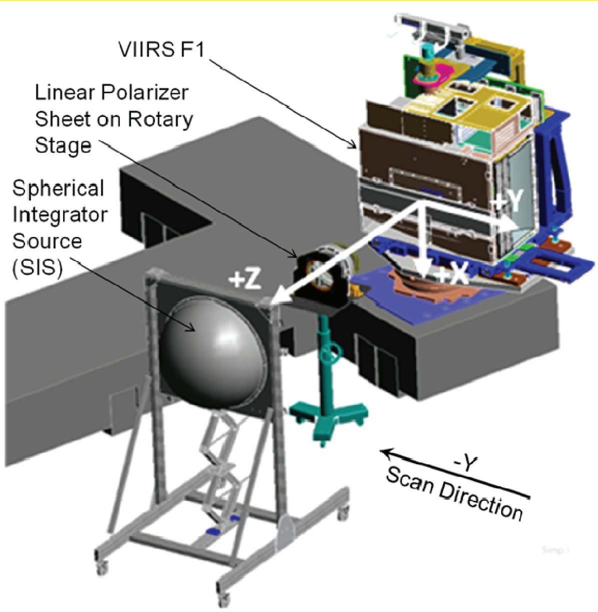


Figure 1. VIIRS rotating telescope scanning Earth surface from orbit

The optical design of VIIRS, tailored for this mission, has inherent, but small sensitivity to polarization, which differs for each band, and also slightly with each side of the Half-Angle Mirror (HAM) that de-rotates the beam of light for projection on to the FPA. Also, the polarization sensitivity varies continuously with the scan angle and along the detector row in each band. This behavior of polarization sensitivity of VIIRS Flight Unit 1 (F1) and its uncertainty was characterized in detail with extensive, careful, accurate and highly repeatable measurements performed in a Raytheon laboratory test (ETP679) [(4)]. Figure 2 shows the basic test set up. The Spherical Integrator Source (SIS) has a large circular aperture with uniform diffuse white light observed by VIIRS in the nadir direction +Z through a transparent linear polarizer sheet on a rotary stage, with +X being the track (flight) direction and +Y being against the scan direction (i.e., VIIRS scans along -Y). VIIRS also is mounted on a turntable and is turned around the +X direction to point different scan angle configurations down the line of sight (LOS). As the sheet and the plane of polarization are turned around the LOS (+Z) through one rotation, the polarization sensitivity responses of various VIIRS detectors are sinusoids of two rotations. The degree of linear polarization (DoLP) and the phase angle of the maximum response (peak of the sinusoid) with respect to the track (flight) direction are evaluated from the data. Note that,

DoLP = (Amplitude of the sinusoid) / (Cycle Averaged Response or Pedestal)



Band	Wavelength (µm)	Maximum Polarization Sensitivity: Maximum Measured DoLP	Maximum Polarization Sensitivity: VIIRS Specification Requirement
M1	0.412	2.8%	3%
M2	0.445	2.1%	2.5%
M3	0.488	1.3%	2.5%
M4	0.555	1.5%	2.5%
I1	0.640	1.3%	2.5%
M5	0.672	1.0%	2.5%
M6	0.746	1.2%	2.5%
I2	0.865	0.6%	3%
M7	0.865	0.5%	3%

Figure 2. ETP679 Test set up to characterize VIIRS F1 polarization sensitivity & data

The Table in Figure 2 shows the maximum DoLP measured in each band for scan angles less than or equal to ±45 deg., which is within the requirement. The polarization sensitivity variation described above is shown in Figure 3 with an example of measurements for Band M1 (for all 16 detectors at 7 scan angles for HAM side A only), which shows the highest sensitivity and variation [4].

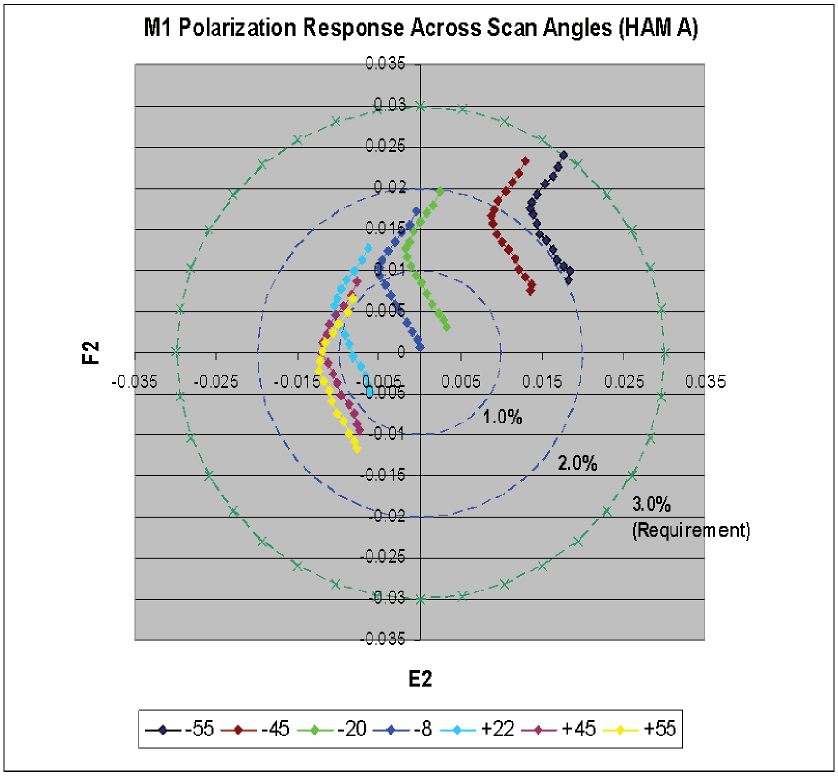


Figure 3. VIIRS F1 Polarization Sensitivity Data, Band M1 (HAM A), shown here in (DoLP, 2xPhase Angle) space

The current estimates of band-average uncertainty in these measurements, based on RSS of components from analysis, test data, repeatability, and curve-fit residuals are fairly small as shown in the Table in Figure 4, which lie within the required tolerance of 0.5% 1-sigma DoLP for all bands [4].

M1	M2	M3	M4	M5	M6	M7	I1	I2
0.23%	0.29%	0.19%	0.24%	0.14%	0.14%	0.16%	0.16%	0.25%

Figure 4. Current Estimates of the Polarization Sensitivity Uncertainties (1-sigma DoLP)

The sensitivity of ocean color to VIIRS' polarization charcteristics is evaluated with numerical simulations. The sensor model employs the above polarization characteristics of VIIRS F1, as well as other radiometric errors and noise to simulate the sensor measurements of the polarized TOA radiances in each reflective band from the Global Synthetic Data (GSD) model as seen along the sensor's instantaneous line-of-sight (LOS). The errors in polarized TOA radiances caused by F1 polarization sensitivity lead to large errors in the L_w retrieved using the ACO algorithm [3] – Case 1: polarization impact. The sensor polarization model can also be used again to correct those polarization errors in TOA radiances before retrieving the L_w using the ACO algorithm, but with zero uncertainty – Case 2: perfect correction, and with the uncertainty as estimated above – Case 3: realistic correction. The ACO algorithm is used also to take out the ocean aerosol and ocean surface reflectance contributions from the TOA radiance [5]. Then the Ocean Color & Chlorophyll (OC/C) algorithm [6] can be employed to retrieve the data products, Chlorophyll concentration and Inherent Optical Properties – absorption and back-scatter (IOP_a and IOP_b).

As a preliminary assessment, the polarization performance of VIIRS on NPOESS basically appears to be good for the Ocean Color EDR, based on preliminary sensitivity evaluations using GSD simulations and a VIIRS polarization model based on thoroughly characterized VIIRS F1. The evaluations show that correction for VIIRS' polarization sensitivity works well and significantly suppresses errors in L_w, comparing cases 1 and 3 above. The evaluations also show that VIIRS' polarization characterization uncertainty has a modest effect on L_w accuracy, and a minor effect on L_w precision. The paper provides a more complete quantitative description of the results on the impact of VIIRS' polarization sensitivity on Ocean Color, in terms of L_w truth vs retrieval, and accuracy, precision, and their stratification with L_w, etc., toward assessing the polarization performance of VIIRS for good ocean color capability on NPOESS.

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