VIIRS Polarization Sensitivity Impact on Ocean Color

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VIIRS is a Key Earth Science Instrument on NPOESS

(National Polar-orbiting Operational Environmental Satellite System)

- Nation's next-generation operational weather & climate monitoring system with radiometers, spectrometers & atmospheric sounders
- System will cover the Globe every 6 hours to produce near real-time EDRs - Environmental Data Records
- VIIRS – Visible/Infra-red Imaging Radiometer Suite with 22 bands will deliver 22 different EDRs with atmospheric and surface data
- VIIRS EDRs include Ocean Color & Chlorophyll, beside cloud and aerosol properties, and land, ocean & ice temperatures, etc.
- Poster Back-ground: Phytoplankton Blooms*, Ocean Color scenes in NASA data base from MODIS sensor on Aqua spacecraft

VIIRS will be key Ocean Color & Chlorophyll data resource

Ocean Color requires VIIRS accuracy for L_w data

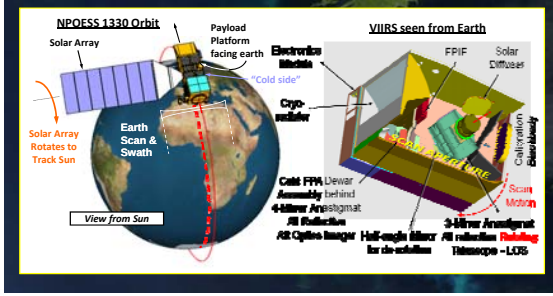
- L_w, water leaving radiance in reflective VIS-NIR bands, is the key data for determining ocean color[1] data products
- L_w is generally a small component (≈ 10 %) of the TOA (Top Of Atmosphere) radiance measured by VIIRS in sunlit ocean scenes
- Algorithms to accurately remove other components[2] to retrieve L_w
- Most of TOA radiance is Rayleigh scatter; up to ≈ 70 % polarized
- TOA radiance data needs correction, if sensitive to polarization
- Small uncertainty in VIIRS characteristics critical to L_w uncertainty

Must correct for VIIRS polarization sensitivity for Ocean Color

VIIRS design has slight sensitivity to polarization

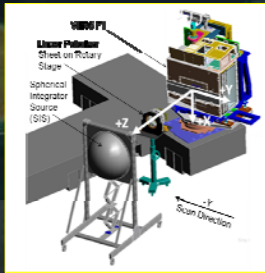
- VIIRS Flight Unit 1 (F1) on NPOESS Preparatory Project (NPP)
- 830 km Sun-synchronous orbit, Local Mean Solar Time 1330 hours
- VIIRS rotating telescope scans surface in ≈3000 km wide swaths
- VIS-NIR FPA (focal plane array) has 7 bands, each a 16 detector row, to scan an image ≈ 11 km wide within ± 56 degrees of nadir
- 2-sided Half Angle Mirror (HAM) de-rotates the light on to the FPA
- Slight polarization with HAM incidence angle varies during scan
- Polarization varies also with band (λ), detector, and HAM side

Small polarization sensitivity of VIIRS varies with parameters



VIIRS F1 polarization sensitivity characterized in detail

- Extensive, careful, accurate and repeatable measurements of VIIRS F1 polarization sensitivity performed in a Raytheon laboratory test under ambient conditions (ETP679)[3]
- Used Spherical Integrating Source (SIS) with large circular aperture and uniform, diffuse, white light, linearly polarized with a sheet polarizer on a rotary stage between SIS and VIIRS
- VIIRS was turned to 7 different angles so as to image its field-of View (FOV) through the polarizer within the SIS aperture at corresponding scan angles inside its scan of ± 56 deg. from nadir
- At each scan angle, as the polarization plane (& sheet) was rotated once around the line-of-sight, VIIRS response was nearly constant, but showed slight sinusoidal variation through two cycles



Band	Wavelength (μm)	Maximum Polarization Sensitivity	
		Maximum Measured DoLP	Requirement
M1	0.412	2.8%	3%
M2	0.445	2.1%	2.5%
M3	0.488	1.3%	2.5%
M4	0.555	1.0%	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	0.5%	3%
M7	0.862	0.5%	3%

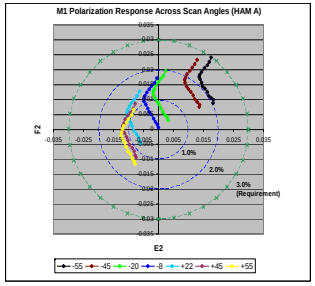
Each band, detector, scan angle & HAM side measured

- Amplitude of the 2-cycle sinusoid represents detector response to linear polarization due to VIIRS sensitivity to polarization
- Detector averaged response is the polarization insensitive part
- Degree of Linear Polarization (DoLP) = I_p = [sinusoid amplitude / averaged response] = polarization sensitivity magnitude (in %)
- Phase (angle) of polarization sensitivity = Φ_p = angle of sinusoid maximum (or peak) measured from track/flight direction
- Fourier series of each response yields the associated (I_p, Φ_p) in terms of the Fourier Coeff.s of the 2-cycle cos & sine terms, scaled by the 0-cycle Fourier Coeff. (or averaged response)

VIIRS polarization sensitivity is small & easily modeled

- In all bands, max I_p ≤ 2.5% to 3%, for |scan angle| ≤ 45 deg
- Band M1 HAM side A is example of large variations with scan angle and detectors in polar coordinates of (I_p, 2.Φ_p) or in Cartesian coordinates (E_2, F_2), the Fourier Coeff.s of 2-cycle cos & sine terms, scaled by the 0-cycle Fourier Coeff.
- For each band, detector & HAM side, 7 scan angle data points (I_p, 2.Φ_p), or equivalently (E_2, F_2), define a 2nd order curve-fit
- Using this model for VIIRS, polarized TOA radiance data can be corrected to rmove the effect of VIIRS polarization sensitivity

Can correct TOA radiance for VIIRS polarization sensitivity



Uncertainty in Polarization Sensitivity, % DoLP	
M1	0.23%
M2	0.29%
M3	0.19%
M4	0.24%
M5	0.14%
M6	0.14%
M7	0.16%
I1	0.16%
I2	0.26%

Requirement 0.5 % DoLP

VIIRS characterization uncertainty is also very small

- Uncertainty in model estimated ≤ 0.25 % DoLP 1-σ in all bands – SEE BELOW (RSS of 1-σ values of various components per analysis, test data, repeatability, curve-fit residuals, etc.)
- Uncertainties in DoLP & Phase must lie within radius ≤ 0.25 % DoLP in the DoLP & 2xPhase space or in (I_p, 2.Φ_p), or equivalently in the (E_2, F_2) space defined by Fourier Coeff.s
- This means that correction for VIIRS polarization sensitivity implies uncertainty in polarized TOA radiances ≤ 0.25 %

Polarization impact on TOA radiance uncertainty is minimal

VIIRS' Ocean Color performance based on simulations

- Polarization sensitivity model used with Global Synthetic Data (GSD) to simulate & also to correct VIIRS TOA radiance data
- GSD provides TOA radiance as VIIRS observable, synthesized from components in a large realistic sample of earth scenes
- "Atmospheric Correction over Oceans" (ACO) Algorithm[4,5] retrieves L_w from corrected TOA radiance, removing Raleigh & aerosol scattering, ocean surface reflections, etc., from sunlit scenes as attenuated by the atmosphere
- "Ocean Color & Chlorophyll" (OC/C) Algorithm[6] derives Ocean Color data products from L_w – chlorophyll concentration, absorption & backscatter in water near ocean surface

Simulations test VIIRS model/correction effectiveness

- VIIRS Ocean Color performance compared with GSD truth for three sensor cases to show impact of sensor noise, polarization sensitivity and polarization characterization uncertainty

1. VIIRS with sensor noise, but no polarization model (baseline for VIIRS on NPOESS, if insensitive to polarization)
2. VIIRS with sensor noise & polarization model per F1, but no uncertainty (case of perfectly characterized VIIRS)
3. VIIRS with sensor noise, polarization model & characterization uncertainty (realistic performance projection for VIIRS)

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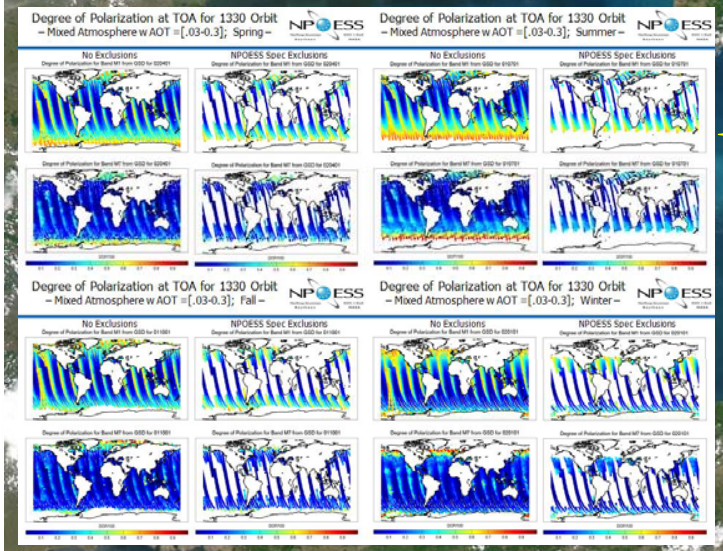
DOP of TOA Radiance in GSD - 4 Seasons, with & without sun glint exclusions

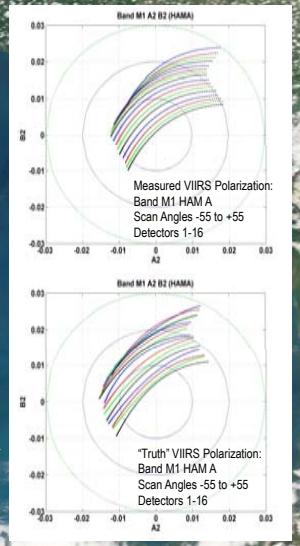


Scene Conditions Assumed in Computing TOA DoLP

- Sun-pixel-sensor geometry of NPP/NPOESS 1330 orbit with VIIRS scanning geometry
  - Zenith & azimuth of the Sun and the Sensor each
- Geophysical properties used to generate TOA radiance DOP (Degree of Polarization) sampled from GSD environmental scene datasets for each of 12 days over a year, including surface pressure & wind speed
  - MODIS 8-day AOT (MOD08E3 Aerosol Optical Thickness) quantized in steps of 0.03 from 0.03 to 0.3

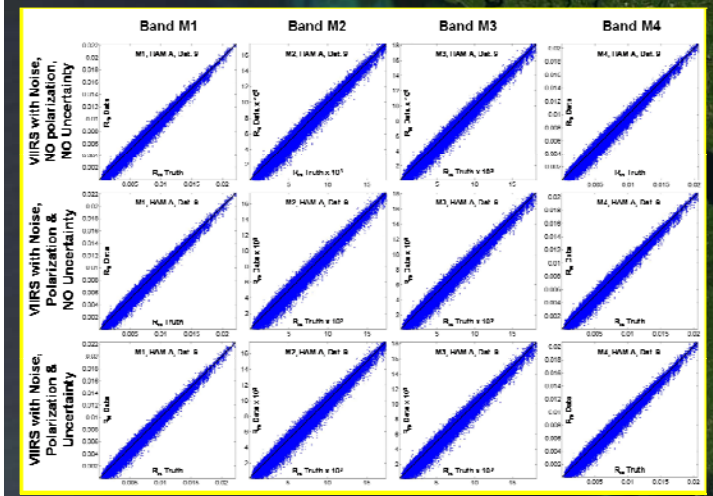
GSD Simulates VIIRS Errors also due to Polarization

- Sensor errors based on uncertainty analysis of test data: radiometric and noise, as well as polarization
  1. Polarization uncertainties are due to test equipment, test procedures and random errors (i.e. repeatability)
  2. Polarization errors are modeled as per band biases, scan angle / HAM side biases and detector level random error
  3. One "truth" VIIRS polarization generated from error model; includes 217 random draws
- Example of VIIRS Polarization Model for Band M1, HAM – A, for all 16 detectors shown with & without the uncertainty



VIIRS Polarization Sensitivity Correction Performance Projections for Ocean Color

- Water Leaving Radiance values retrieved by the algorithms are converted to Normalized Water Leaving reflectance values, R_{rs}, by scaling with normally incident solar radiance divided by pi (π)
- Simulated retrievals of R_{rs} are compared against the GSD truth as scatter plots below for the four reflective bands M1 – M4, which are key to evaluating the major Ocean Color data products, in the three sensor cases identified: 1. VIIRS noised with no polarization or uncertainty; 2. VIIRS noised with polarization & no uncertainty; & 3. VIIRS noised with polarization & characterization uncertainty
- While there are basic differences between the data points from the truth diagonal, such as shifted average and spread or standard deviation of data points, which are the accuracy and precision, these differences are very similar for all 3 sensor cases, implying acceptable polarization correction



Accuracy		Noised, No Polarization/ Uncertainty	Polarization, Noised, No Uncertainty	Polarization, Noised, with Uncertainty
Normalized Water Leaving Reflectance	M1	-3.9429	-3.9507	-5.0555
	M2	-4.2795	-4.2837	-5.3285
	M3	-3.8426	-3.8415	-3.6131
	M4	-5.5758	-5.5768	-5.7075

Precision		Noised, No Polarization/ Uncertainty	Polarization, Noised, No Uncertainty	Polarization, Noised, with Uncertainty
Normalized Water Leaving Reflectance	M1	9.124	9.15	9.9853
	M2	8.1246	8.129	8.5027
	M3	6.4796	6.4557	6.4988
	M4	10.7574	10.7486	10.8424

VIIRS Ocean Color Performance Projections

- The performance illustrated in the scatter plots is further quantified in the table with numerical comparisons of the accuracy and precision for the 4 bands in the 3 sensor cases evaluated for VIIRS on NPOESS
- Polarization correction seems to work very well, except for a small effect of characterization uncertainty, primarily on the accuracy, and much less on the precision
- The consistency and similarity between the 3 cases is suggestive of errors in algorithm performance

- This basic polarization performance of VIIRS on NPOESS evaluated with GSD simulations using a polarization model based on thoroughly characterized VIIRS F1 unit appears quite acceptable for the Ocean Color EDR of NPOESS
- This also implies that NPOESS with VIIRS sensors would become a major global remote sensing resource for good Ocean Color data products, such as chlorophyll, absorption and scattering in the water under the ocean surface

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* ***Background Images from MODIS Aqua provided by NASA Visible Earth Catalog***