Progress in Developing a Ground-Based Polarimetric Spectroradiometer to Support J1 VIIRS Validation

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Abstract

J1 VIIRS pre-launch testing showed polarization sensitivity that could lead to radiometric corrections on-orbit, which would rely on understanding the polarization states in the atmosphere. To aid in understanding this phenomenology, we developed a ground-based spectroradiometer for polarization measurements by combining an off-the-shelf spectroradiometer with a rotatable standard camera lens polarizer to allow polarized light into the spectroradiometer. Since these pieces do not combine easily, we built a customized adapter in-house - designed using open source software and built with a 3D printer. Preliminary measurements of the atmosphere using the spectroradiometer show stronger linear polarization (350 nm to ~650 nm) viewing 90º to the sun than towards the sun, which is consistent with polarization dominated by Rayleigh scattering. We plan to further improve the instrument and characterize the atmosphere over a larger range of sun and sensor positions and analyze the measurement uncertainties. This will improve our understanding of polarization states in the atmosphere and contribute to validation efforts of radiative transfer models used in any on-orbit corrections for J1 VIIRS.

Background

Rayleigh Scattering

- Rayleigh scattering linearly polarizes the sun's radiation according to its scattering angle, α:

$$DOLP = \frac{1-\cos^2(\alpha)}{1+\cos^2(\alpha)+2\delta/(1-\delta)}$$

where DOLP is degree of linear polarization and δ is depolarization factor.

[Hansen &Travis, Space Science Reviews (1974)]

- With the sensor viewing upward and the sun on the horizon, the photons detected have been scattered at 90º, so are highly polarized.

Example of ground measurements of the full sky taken in the early morning

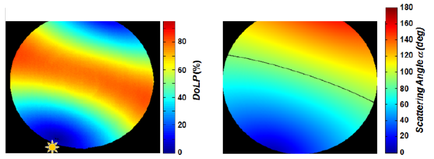
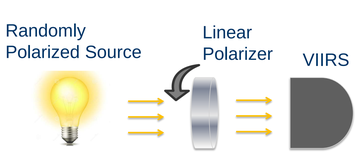


Fig. 4. (a) DoLP image at 700 nm of a clear early morning (23 May 2008) just after sunrise, at around 0620 Hawaiian Standard Time (HST, UTC −10) with the sun to the east. (b) The scattering angle (with respect to the sun) mapped to the fisheye lens image plane.

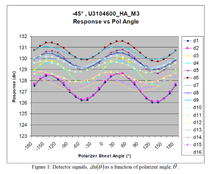
[Dahlberg et al. Optics Express (2011)]

Pre-launch Polarization Sensitivity Measurements

- Instrument polarization sensitivity contributes to radiometric uncertainty.
- Pre-launch polarization sensitivity measurements found that J1 has higher polarization sensitivity than NPP VIIRS.



NPP VIIRS Pre-launch Measurement Setup and Results

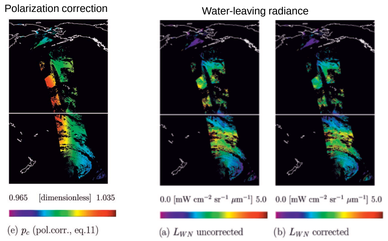


[Novitsky et al. SPIE 2012]

On-orbit Corrections

- On-orbit corrections can be applied at the EDR level:
  - Corrections are based on pre-launch polarization sensitivity measurements and atmospheric polarization states (modeled by radiative transfer codes such as 6SV and MODTRAN-P)
  - Corrections will most likely used for J1 VIIRS ocean color channels .

Polarization correction



Water-leaving radiance

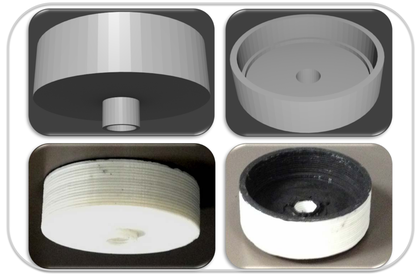
Moderate Resolution Imaging Spectrometer (MODIS) polarization corrections for ocean color
[Meister et al. Applied Optics (2005)]

- **Developing a polarimetric spectroradiometer to aid in understanding atmospheric polarization phenomenology.**

Building a Customized Spectroradiometer for Polarization Measurements

- **Objective: Use ASD* spectroradiometer with linear polarizer to create a simple polarimeter that can measure the degree of linear polarization of incoming radiation.**
- **Challenge**: ASD* spectroradiometer provides fiber holder that is incompatible with standard camera lens polarizers.
- **Solution:** Design and build custom adapter to connect the ASD with the polarizer

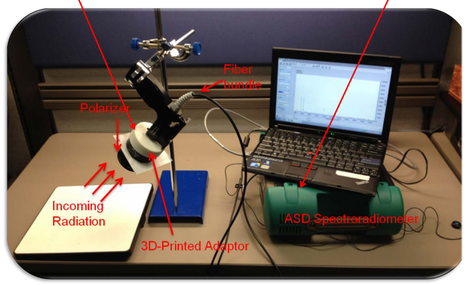
- **Designed adapter for holding the rotating polarizer using Blender***
  - Allows unobstructed path between ASD fiber field of view and linear polarizer
  - Fits the rotating stage snugly



- **Built the customized adapter in-house using a 3D printer**
  - Painted black to mitigate reflections
  - Added threads to connect to the fiber holder

- **Used ASD spectroradiometer**
  - Spectral coverage: 350 nm - 2500 nm (2151 bins)
  - Fiber input with FOV = 25º
  - Rugged design
  - Wireless communication capability
  - Calibrated at NIST
  - Low polarization sensitivity

- **Assembled spectroradiometer for measuring polarization**



Setup for initial measurement of polarization sensitivity of polarimeter

Protractor to be replaced with 3D-printed version

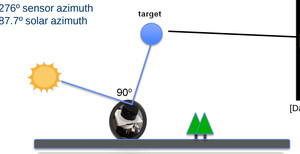
* Identification is not intended to imply recommendation or endorsement by NOAA.

Taking Measurements of the Atmosphere

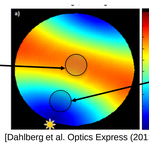
- Used polarized sunglasses to locate direction of high and low polarization

Sensor 90º to Sun

276º sensor azimuth
87.7º solar azimuth

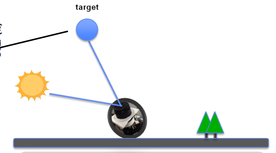


- Pointed sensor at ~90º to sun
- Measurement time: 6 minutes



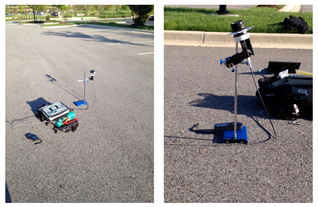
[Dahlberg et al. Optics Express (2011)]

Sensor Towards Sun



- Pointed sensor towards sun but not in a direct path to avoid detector saturation
- Measurement time: 4 minutes

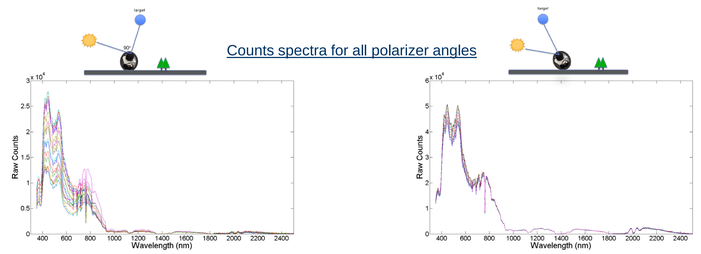
Measurement conditions



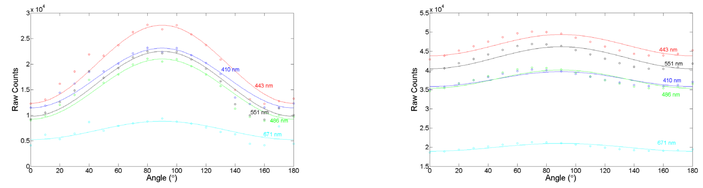
Polarimetric spectroradiometer setup (sensor 90º to sun)

Preliminary Results

Counts spectra for all polarizer angles

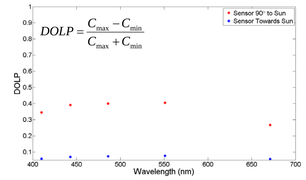


Counts versus polarizer angle for selected wavelengths



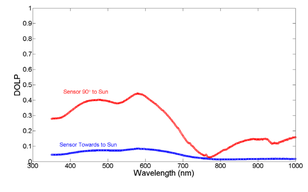
Degree of linear polarization (DOLP) at selected wavelengths

- Calculated DOLP values using sinusoidal fits [Novitsky et al. SPIE (2012)]
- Polarization increases with wavelength from 350 to 580 nm:



Degree of linear polarization at all wavelengths (< 1000 nm)

- Shows potential of the instrument to measure polarization states with high spectral resolution over a large wavelength range that covers VIIRS ocean color channels.
- Need more measurements to assess wavelength range where the linear polarizer is effective.
- Need further investigation to examine if spectral dependence is consistent with radiative transfer simulation results.



- **Results consistent with Rayleigh scattering:**
  - **Show that DOLP is higher 90º to sun than towards the sun**

Summary and Future Work

Summary:

- Designed and built a customized ASD-based polarimeter that provides a new capability for NOAA to investigate polarization phenomenology in support of J1 VIIRS.
- The preliminary sky measurements established confidence in the proto-type design, which will act as a baseline for advancing atmospheric polarization research and development.

Future work:

- Improve the polarimeter design:
  - Add 3D printed protractor to decrease uncertainty in angle.
  - Add motor control to rotate polarizer to improve efficiency.
- Conduct measurements to gain better understanding of polarization states and assess uncertainties:
  - Continue measuring atmosphere over range of sun angles.
  - Measure polarization of reflected Earth surfaces.
- Work with NIST to calibrate polarimeter
- Validate atmospheric radiative transfer models