Measurements and Analysis of Polarized Light Field in Oceanic Waters

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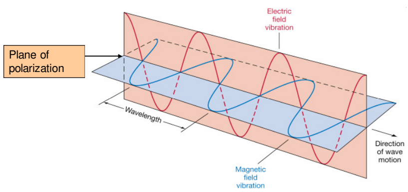
INTRODUCTION

Physical Meaning of polarization of light

Light can be treated as a transverse electromagnetic wave. Polarization of light is a phenomenon that describes the orientation of wave oscillations.
In scientific community, polarization is notated by orientation of electrical filed (e-vector).

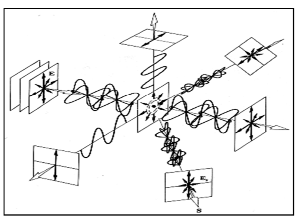


What produce polarized light?

Polarization by interaction with matter:

- Polarization by transmission through materials of anisotropic structure
- Polarization by scattering
- Polarization by reflection and refraction

Natural light such as sunlight or lamp light is un-polarized, which means that radiated light is the sum of randomly oriented polarization of wave trains. When un-polarized light hit particles or gets transmitted through crystal, transmitted light or scattered light will be linearly polarized in certain direction. For remote sensing applications, circular polarized light is ignored.



Scattering of unpolarized light by particle

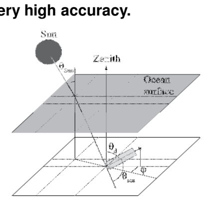
Motivation

The purpose of this work is to validated the underwater and above-water Degree of Polarization (DOP) measurements using our newly developed instrument and compare it with Radiation Transfer Simulations (RT). The validation process allow more Intensive and accurate research using the measurement collected from the instruments.

Polarization characteristics of underwater light contain useful additional information on
inherent optical properties (IOP), concentrations and size distributions of water constituents
when compared with standard reflectance data. In addition, Polarization measurements from space have got a potential applications and deployments on future satellite such as NASA Glory Mission.

The great potentiality in space polarization measurements is avoiding radiometer sensor calibration problems which allow to have measurement with very high accuracy.

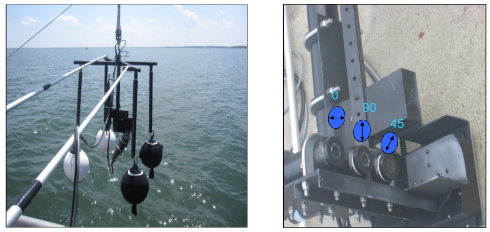
GEOMETRY OF OBSERVATION



INSTRUMENTATION

Measurements were taken during a cruise on the R/V "Connecticut" in the coastal areas of New York Harbor - Sandy Hook, NJ region, on July 21-23 2008 and Virginia 2009. Polarization measurements were taken using a newly developed hyperspectral and multiangular polarimeter. The instrument consists of:
Three Satlantic Hyperspectral radiance sensors mounted on a scanning system. An underwater electric stepper motor that rotates the sensors in a vertical plane to cover the full 0-180º range of scattering angles (5° steps).Linear polarizers are attached in front of the sensors; the polarizers are oriented at 0º (vertical), 90º (horizontal) and 45º. The DOP is calculated as:

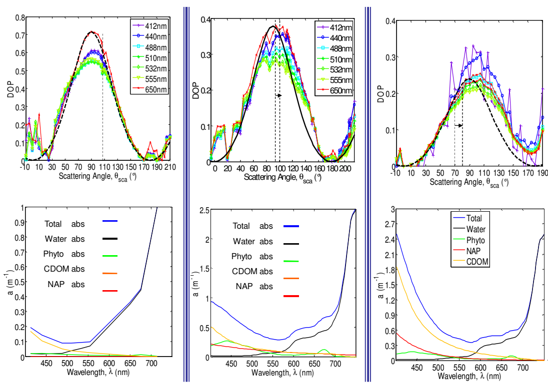
$$DOP = \frac{\sqrt{(L_0 - L_{90})^2 + (2L_{45} - L_{90} - L_0)^2}}{L_{TOT}}$$



Polarimeter Instrument with three polarizer filters on the top of each radiometer oriented at 0,90 and 45 degree from reference horizontal

THE UNDERWATER POLARIZED LIGHT FIELD

Plots of the DOP vs. Scattering Angle and Total Absorption Spectrum for Different Cases of Water



- It is assumed that Rayleigh scattering was the dominant process in case I waters, being the concentration of suspended particles very small.
- We therefore, plotted the equation for isotropic Rayleigh scattering in the graphs above (black curve) of DOP

$$DOP_{Rayleigh} = DOP_{MAX} \frac{\sin^2(\theta_{sca})}{1+\cos^2(\theta_{sca})}$$

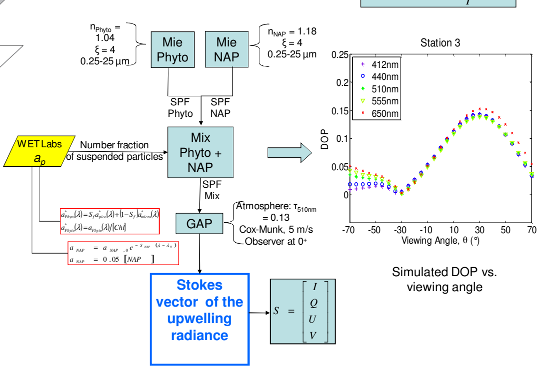
considering DOP_{MAX} = max [DOP (650 nm)], vs. the

scattering angle, θ_{sca}

- A shift in the max of DOP from 90 to 100 degree scattering angle with the increasing turbidity of the water.

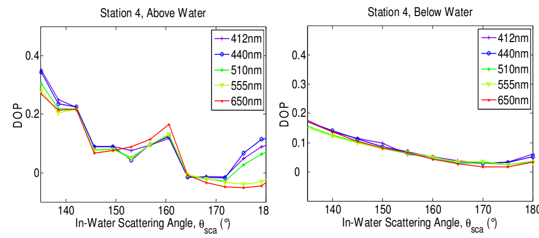
ADDING-DOUBLING RT SIMULATIONS

$$DOP = \frac{\sqrt{Q^2 + U^2}}{I}$$



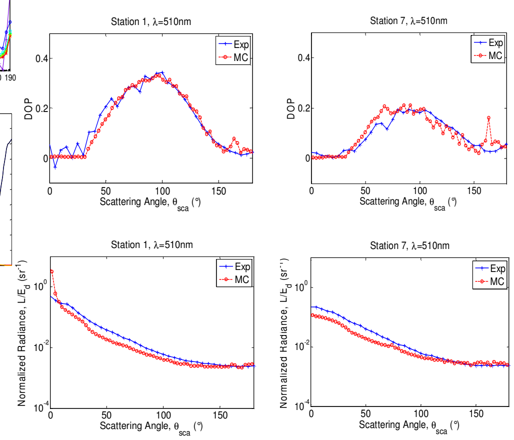
Simulated DOP vs. viewing angle

Comparison of above- and under-water measurements for remote sensing applications.



MONTE CARLO RADIATIVE TRANSFER MODEL

The measurements were compared to the results of a vector radiative transfer model that uses the Monte Carlo method to solve for the complete Stokes vector.
This is an updated version of the code used in Adams and Kattawar [4] and is a plane-parallel model of a coupled atmosphere ocean system and allows for a number of layers in both the atmosphere and ocean.
The Monte Carlo simulations were simulated by D. Gray.
Comparison with radiative transfer computations is shown in the graphs below. The agreement between the magnitudes of the measured and modeled DOP and normalized radiance is remarkable, even in a situation of overcast skies (Station 7).



CONCLUSIONS

A new hyperspectral multiangular polarimeter was developed to accurately measure the underwater polarized light field.

For the examined waters the angular distribution of DOP exhibits a bell shape with a maximal value of 0.7 around 90° scattering angle for Case I water and 0.4 for Case II and turbid waters around 100° angle.

The results were confirmed by the Monte Carlo simulations.

Polarization characteristics of under and above water light contain useful additional information on inherent optical properties (IOP), which can be accurately measured using Seaborne or Spaceborne instruments that can greatly contribute to the Research of Ocean Color community.

REFERENCES

[1] J. Chowdhary, B. Cairns, L. D. Travis, "Contribution of water-leaving radiances to multiangle, multispectral polarimetric observations over the open ocean: bio-optical model results for case 1 waters," Appl. Opt. 45, 5542-5567 (2006).

[2] Tonizzo, A., Zhou, J., Gilerson, A., Gross, B., Moshary, F., and Ahmed, S., "Multiangular Hyperspectral investigation of polarized light in case 2 waters", Proc. SPIE, Vol. 7473, 747306 (2009).

[3] A. Gilerson, J. Zhou, M. Oo, J. Chowdhary, B. Gross, F. Moshary, S. Ahmed, "Retrieval of fluorescence from reflectance spectra of algae in sea water through polarization discrimination: modeling and experiments," Appl. Opt. 45, 5568-5581 (2006).

[4] Adams, J.T. and Kattawar, G.W., "Neutral points in an atmosphere-ocean system.1: Upwelling light field," Appl. Opt. 36, 1976-1986 (1997).