

Exploring Techniques for Improving Retrievals of Bio-optical Properties of Coastal Waters

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LONG-TERM GOALS

Development of algorithms for improved retrievals and monitoring of inherent water optical properties (IOP) from satellite imagery of coastal waters with current and future sensors for improvement of Navy electro-optical system performance utilizing: 1) VIS-NIR channels, 2) polarization characteristics of light in sea water and 3) advanced atmospheric correction schemes.

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OBJECTIVES

Enhancement of algorithms for IOP retrieval from reflectance spectra with utilization of VIS and NIR bands through: a) the use of reflectance characteristics obtained from red-NIR measurements as additional constraints in basic inversion models, b) utilization of satellite data (SeaWiFS, MODIS, MERIS, etc.) and the data from the LISCO offshore platform.

Utilization of underwater and above water polarization components of reflectance spectra for the improvement of in-water visibility by particle type discrimination, and algorithm development through: a) the simulation of polarization components of reflectance for coastal water environments using polarized radiative transfer and b) measurements of polarization characteristics in field conditions to validate radiative transfer modeling and assess possibilities for the separation of organic and inorganic particulate components, improvement of underwater visibility and target detection.

Development of advanced atmospheric correction models including a) incorporation of additional constraint for atmospheric correction in coastal waters, b) development of an interface to perform retrievals based on real time radiometer and lidar observations.

APPROACH

Enhancement of algorithms for IOP retrieval from reflectance spectra with utilization of VIS and NIR bands Data from the multispectral SeaPRISM instrument on the Long Island Sound Coastal Observatory (LISCO) is used for the validation of VIIRS and MODIS sensors on the coastal site, compared with WaveCIS site in Gulf of Mexico. Two Neural Networks (NN) approaches are explored for the retrieval of chlorophyll concentration on the global scale.

Utilization of under and above water polarization components of reflectance spectra for improvement of in-water visibility, particle type discrimination and algorithm development Extensive vector radiative transfer simulations for a very broad range of ocean and coastal water parameters were used for the analysis of the underwater polarized light fields and their relationships with characteristics of water particulates, specifically retrieval of the attenuation-to-absorption ratio from below and above surface measurements of Stokes components of upwelling polarized light. Data from the integrated system of the polarimeter, thrusters and full Stokes vector video camera in various water environments was successfully used for characterization of the target polarization properties.

Development of advanced atmospheric correction models Aerosol characteristics at the LISCO site are compared with ones at the WaveCIS site, showing the necessity for the expanded range of atmospheric correction models.

WORK COMPLETED

- The Long Island Sound Coastal Observatory (LISCO) located on an offshore platform and operational since the fall 2009 as a part of NASA AERONET and AERONET-OC networks, combining multispectral SeaPRISM and hyperspectral HyperSAS instruments, has evolved into one of the key elements for validation of OC satellite data. Quality of the data is continuously evaluated through matchups between instruments on the platform as well as with the satellite data of VIIRS and MODIS. VIIRS data of two NASA – OBPG processing schemes which apply different vicarious calibration gains and of the NOAA – IDPS system are analyzed based on in-situ

data from LISCO and WaveCIS . They showed different effects for LISCO (heavy coastal) and WaveCIS (closer to the open ocean) sites.

- Two neural network algorithms for [Chl] retrieval were used to generate global [Chl] maps and compared with OC-3 algorithm, showing good match.
- Based on extensive radiative transfer simulations using the vector radiative transfer code RayXP, it is demonstrated that the underwater degree of linear polarization (DoLP) is closely related to the attenuation-to-absorption ratio (c/a) of the water body, a finding that enables retrieval of the attenuation and scattering coefficients from measurements of the Stokes components of the upwelling underwater polarized light field. The quality of possible retrievals is estimated for above water conditions for the whole range of azimuth and viewing angles. Main dependencies on the sun angle and typical water conditions were also evaluated.
- Polarized and unpolarized targets were imaged underwater at various water conditions, depths, illumination and azimuth angles, with a full Stokes vector imaging camera mounted on the integrated polarimetric system. An algorithm for the retrieval of the target properties from the image is proposed (also part of the MURI program – PI M. Cummings, see details in the MURI report).
- Aerosol optical thicknesses (AOT) and distributions of Angstrom coefficients from MODIS, MERIS and VIIRS are estimated for the LISCO and WaveCIS sites and compared with SeaPRISM data.

RESULTS

Enhancement of algorithms for IOP retrieval from reflectance spectra with utilization of VIS and NIR bands

Validation of the satellite imagery using LISCO data

To support present and future multi- and hyper-spectral calibration/validation activities, as well as the development of new measurement and retrieval techniques and algorithms for coastal waters, City College (CCNY) along with Naval Research Laboratory at Stennis Space Center, has established an off-shore platform, the Long Island Sound Coastal Observatory (LISCO) which is in operation since October 2009. This site combines multi-spectral (SeaPRISM) and hyperspectral (HyperSAS) radiometer measurements, for comparisons with satellite and in situ measurements and radiative transfer simulations for coastal waters, and helps to provide more effective closure for the whole measurement validation/ simulation loop.

Evaluations of the VIIRS sensor's performance for retrieving OC data of typical coastal water environments were carried out through time-series, as well as qualitative and quantitative match-up comparison analysis between in-situ and satellite retrieved OC data for a year period (January to December, 2012). These showed that VIIRS data exhibits strong temporal and statistical agreements with AERONET-OC data demonstrating a potential in enhanced coastal water monitoring from space. VIIRS data of two NASA – OBPG processing schemes which apply different vicarious calibration gains and NOAA – IDPS system are analyzed based on in-situ data of LISCO and WaveCIS AERONET-OC sites (Long Island Sound and Gulf of Mexico respectively) as well as OC retrievals of the MODIS sensor. The underlying cause of the discrepancies observed in VIIRS retrieved normalized water-leaving radiances is also investigated. The histograms of distributions of normalized water

leaving radiances at the LISCO site along with the spectral shape are shown in Fig.1 (VIIRS data are for initial and 2012.2 gain sets) and typical matchups for both WaveCIS and LISCO sites in Fig.2.

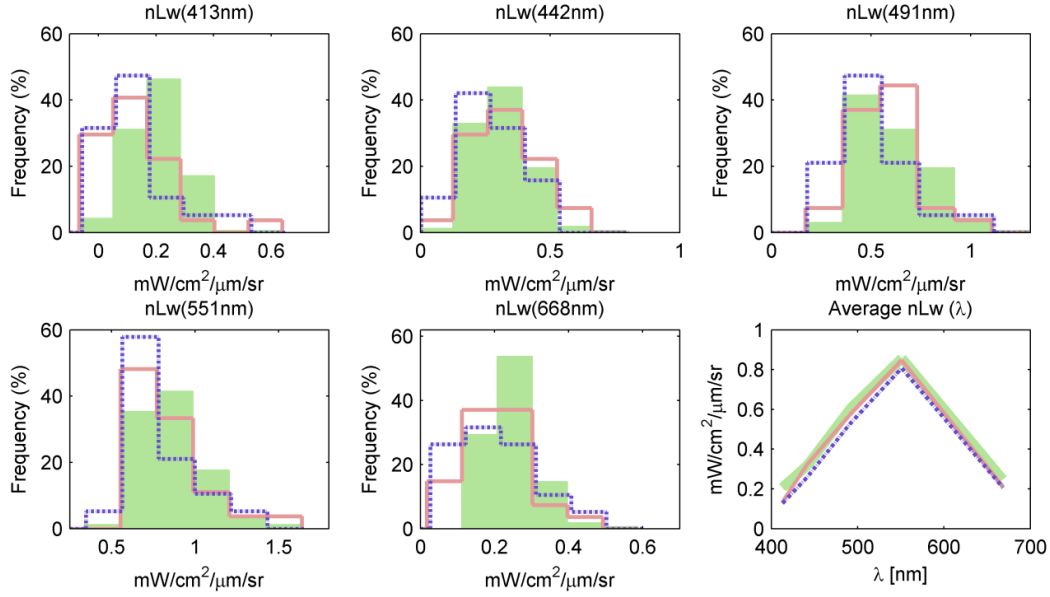


Fig. 1. Distributions of the nLw data at the LISCO site for VIIRS initial (in brown), VIIRS12.2 (in blue) and SeaPRISM (in green) at 413, 442, 491, 551, 668 nm along with the overall average nLw (λ) spectral (2nd row 3rd column).

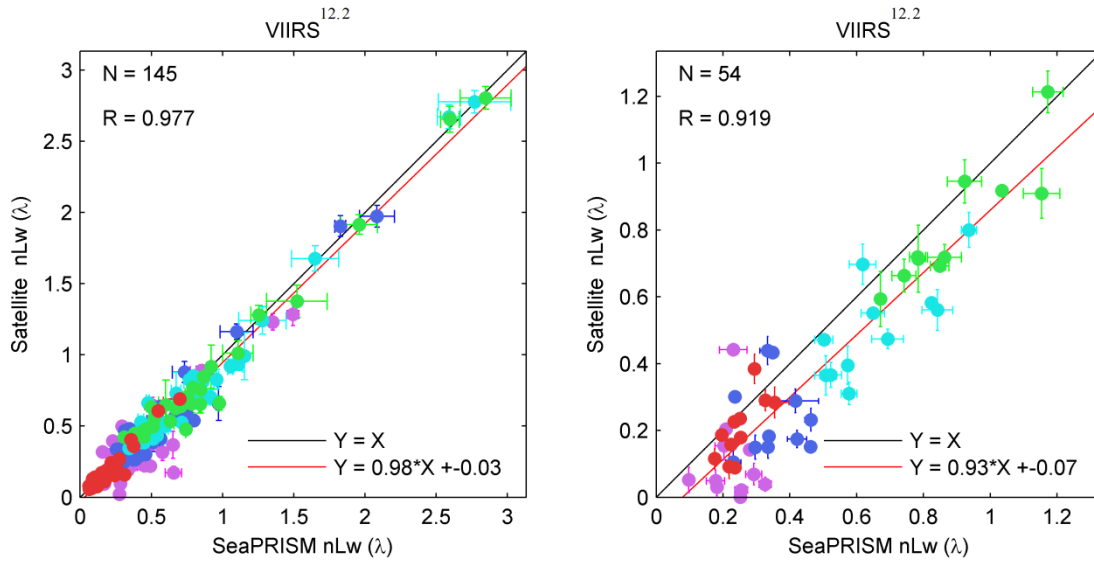


Fig. 2 Matchup comparison between the normalized water-leaving radiance nLw(λ) (in $mW/cm^2/\mu m/sr$) retrieved from SeaPRISM and VIIRS12.2 for WaveCIS (left) and LISCO (right) sites. Horizontal and vertical error bars represent the temporal and spatial variations in SeaPRISM and satellite data, respectively.

Development of a neural network approach to retrieve inherent optical properties and chlorophyll concentration in sea water based on MODIS bands

Two neural network (NN) algorithms for retrieval of chlorophyll concentration [Chl] (one trained on NOMAD dataset – NN [Chl] and second which included derived IOPs, combined with measured Rrs values – IOP NN [Chl]) were compared with the OC-3 algorithm on a global scale. An example of global [Chl] distributions derived by NN [Chl] algorithm is shown in Fig. 3. Seasonal variations from three algorithms are presented in Fig. 4 with NN [Chl] and OC-3 having very good match and results from IOP NN [Chl] slightly higher which can be further studied.

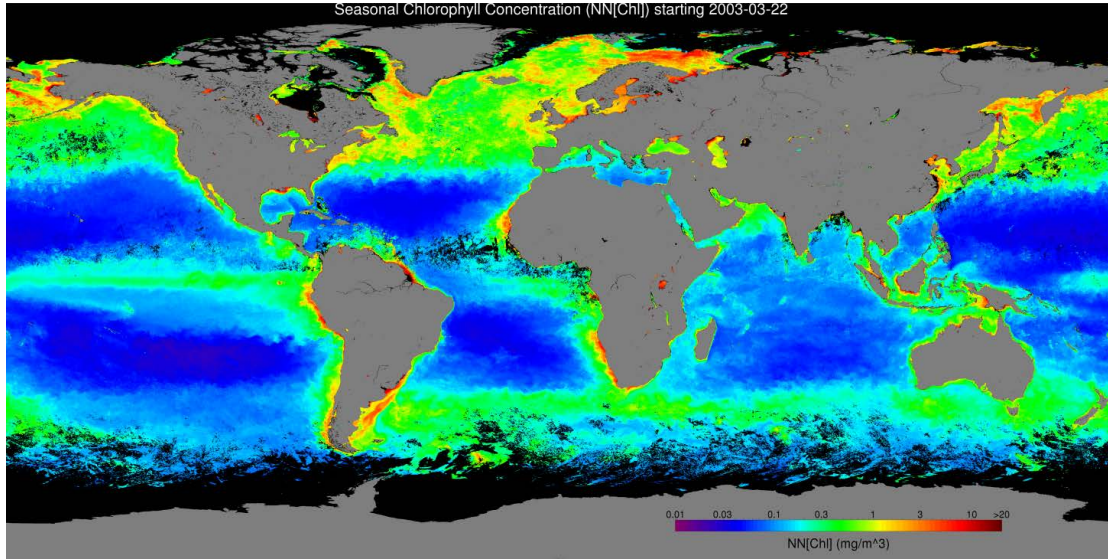


Fig. 3 Image of NN [Chl] for Spring 2003

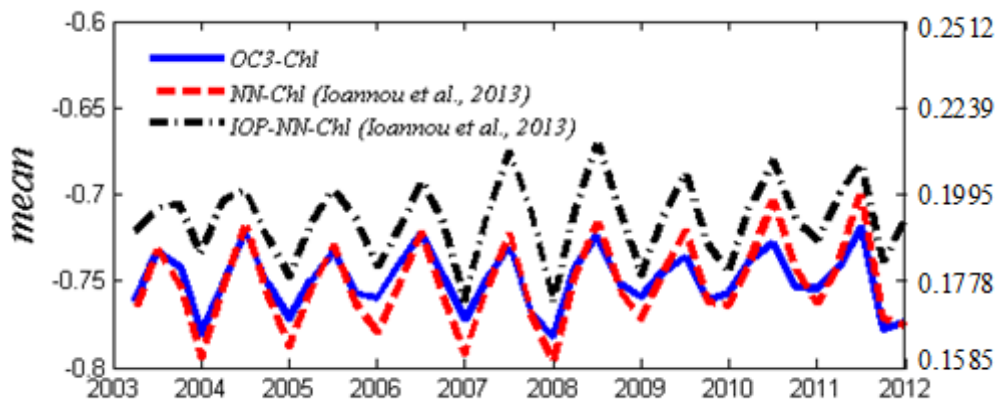


Fig. 4 Seasonal variation of the mean of $\log_{10}([Chl])$ using OC-3 and two NN algorithms for years 2003 through 2012. The equivalent values for mean of [Chl] in $mg\ m^{-3}$ are shown on the right.

Utilization of underwater and above water polarization components of reflectance spectra for improved retrievals of particle type discrimination and algorithm development

Estimation of the attenuation coefficient of the water body using polarimetric observations

The attenuation coefficient of the water body is not directly retrievable using measurements of unpolarized water-leaving radiance. Based on extensive radiative transfer simulations using the vector radiative transfer code RayXP, it is demonstrated that the underwater degree of linear polarization (DoLP) is closely related to the attenuation-to-absorption ratio (c/a) of the water body, a finding that enables retrieval of the attenuation coefficient from measurements of the Stokes components of the upwelling underwater polarized light field. The relationship between DoLP and the c/a ratio is investigated for the upwelling polarized light field for a complete set of viewing geometries, at several wavelengths in the visible part of the spectrum, and for varying compositions of the aquatic environment, whose constituents include phytoplankton, non-algal particles, and color dissolved organic matter (CDOM) as well as for varying microphysical properties such as the refractive index and the slope of the Junge-type particle size distribution (PSD).

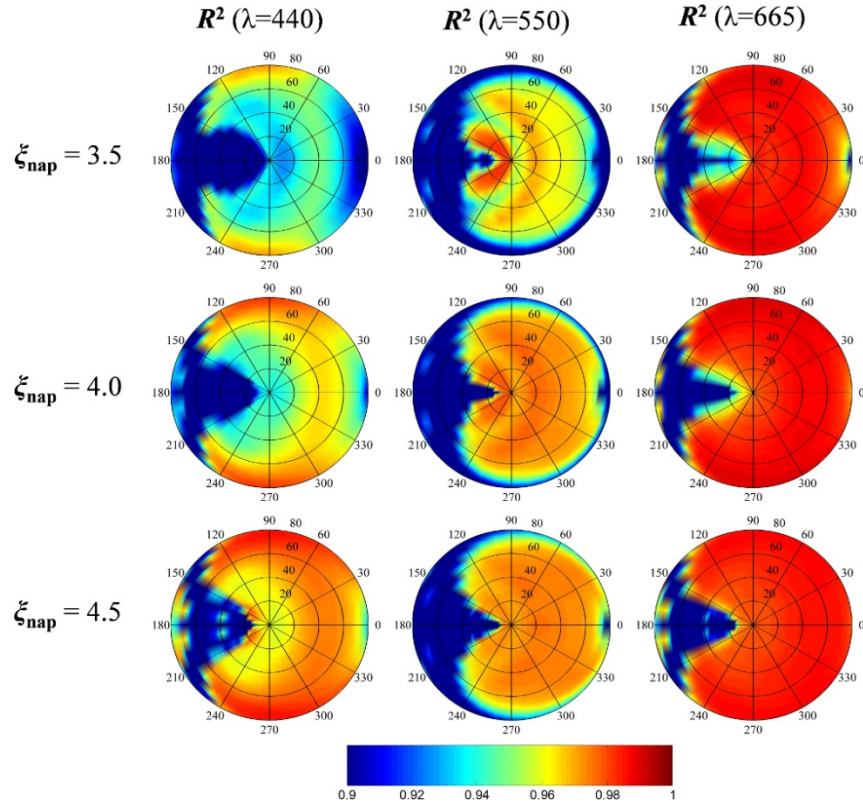


Fig. 4. Synoptic view of the coefficient of determination R^2 at just above the air-water interface for sun relative azimuth from 0° to 360° (0° azimuth is for sun and sensor are in opposition) and viewing angle of upwelling polarized light from 0° to 80° (0° viewing angle is for sensor looking vertically downward).

As the result this study reveals the possibility for retrieval of additional inherent optical properties (IOPs) from air- or space-borne DoLP measurements of the water-leaving radiation. The maximal DoLP typically falls at scattering/viewing angles outside Snell's window. As a result, the maximal range of DoLP is undetectable from above water measurements. A further analysis has been done in order to propose a set of viewing geometries optimal for above-water detection. In Fig. 4, a synoptic view of the coefficient of determination R^2 is calculated to assess the relationship between the DoLP and the c/a ratio for three PSDs, three wavelengths and all geometries at just above the water surface.

The sun zenith is a major factor that can change both the magnitude of DoLP and R^2 values versus the geometry. In Fig. 5 the DoLP of water-leaving radiance (DoLP₀₊) is shown versus the sun zenith angle from 0° to 70° for four cases of water conditions ranging from clear oceanic waters to turbid coastal waters, while ξ for both types of particles is fixed at 4.0, and for fixed CDOM absorption coefficient a_g at 400 nm at 0.6, with 60° viewing and 90° azimuth angles to ensure a detectable polarized signal above-water.

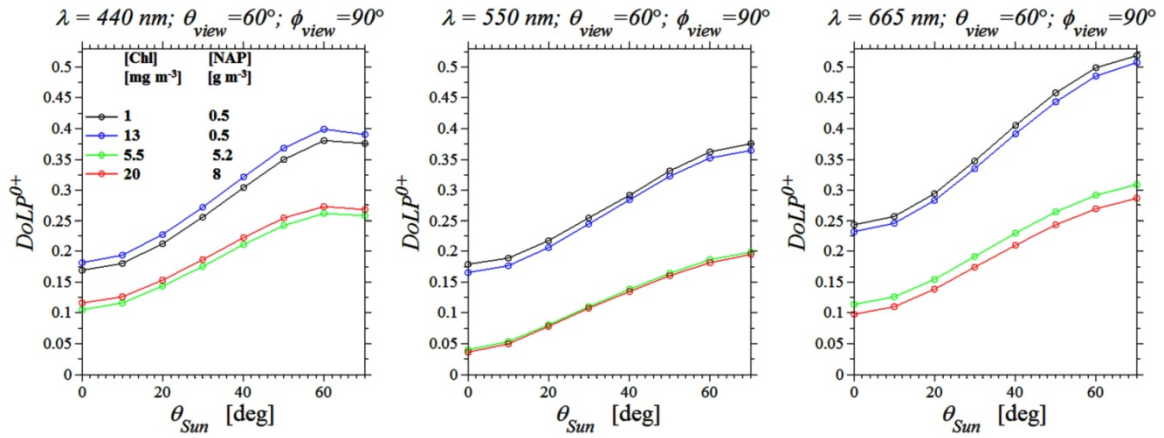


Fig. 5. DoLP versus the sun zenith angle $\theta_{Sun} = 0^\circ$ - 70° for $\theta_{view} = 60^\circ$, $\phi_{view} = 90^\circ$ at 440, 550, and 665 nm

Underwater polarization imaging using integrated polarimetric system

An integrated system for polarimetric underwater measurements and imaging, which includes a hyperspectral polarimeter for multi-angular hyperspectral polarimetric measurements, thrusters for orientation control of the system relative to the sun rays under water, and a full Stokes vector imaging camera in the underwater housing for polarization imaging (up to 15frames/s, currently in the green band, 520-550nm) was successfully used in various water environments for combined measurements of polarization light fields and polarization imaging of targets, shallow bottoms and ruffled water surfaces in various water environments (Florida Keys, August 2011, Curacao, 2012, Long Island Sound and NY Bight, 2012, Chesapeake Bay, 2013). Light fields of intensity (Fig. 6, center) and degree of linear polarization (DoLP) (Fig. 6, right) from a special target with different polarizers fixed on the mirror recorded by a camera in NY Bight waters are shown in Fig. 6. Since water between the target and the camera changes not only the intensity of light from the target but DoLP as well, an imaging model for the propagation of the Stokes vector fields in water was developed and algorithms for the restoration of the DoLP on the target were considered. More details are shown in the report for MURI project (PI- Molly Cummings).

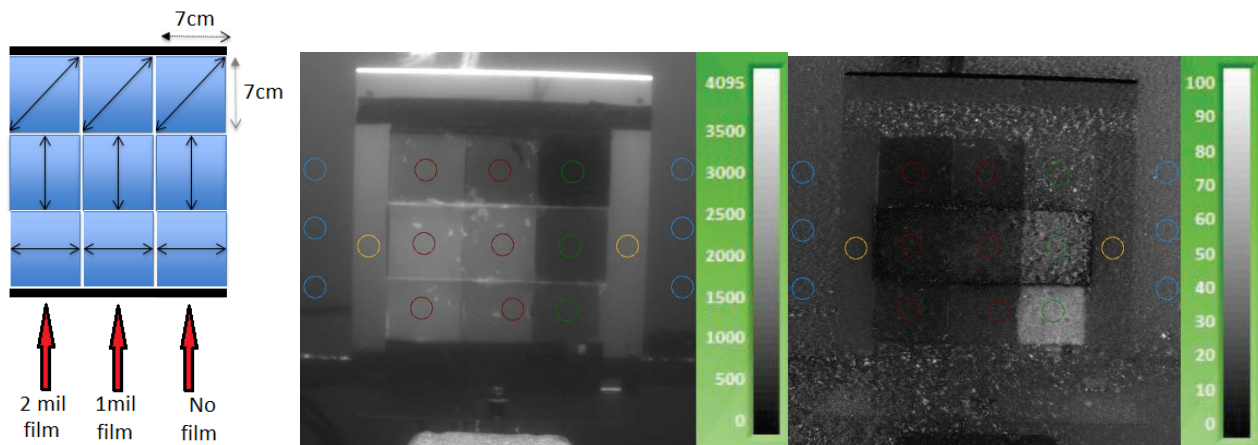


Fig. 6. Schematic diagram of the target (left): the double arrows indicate the orientation of the axis of the linear polarizer, images of I component (center) and DoLP (right) for the target on the mirror and surrounding water area.

Development of advanced atmospheric correction models

Our previous study of the distributions of the Angstrom coefficient from ocean color satellites (MODIS, MERIS and VIIRS) and SeaPRISM at the LISCO site showed discrepancies suggesting the need for broader aerosol models for coastal waters. This was further confirmed by the comparison of the Angstrom coefficient distributions at the LISCO and WaveCIS sites as shown in Fig. 7.

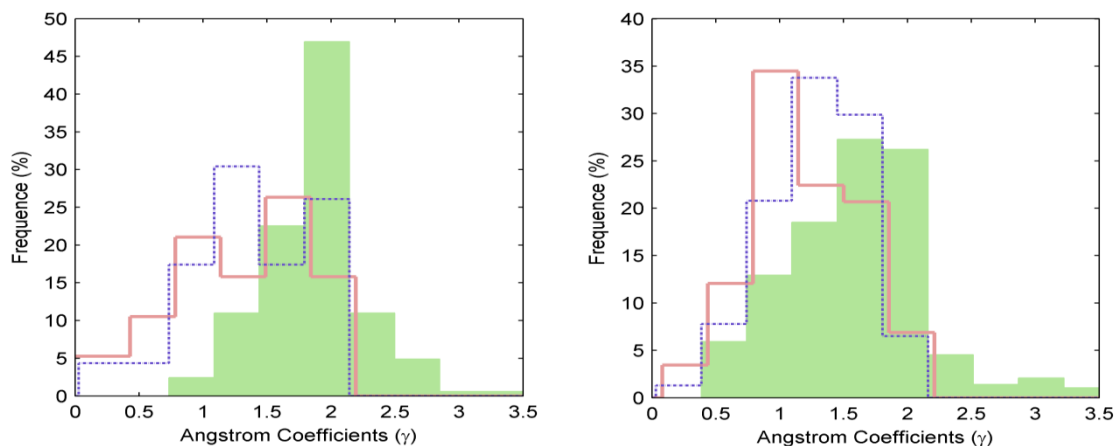


Fig. 7. Histograms of the % distribution of the Angstrom (γ) exponent values observed for the LISCO (left) and WaveCIS (right) sites. SeaPRISM is plotted in green, MODIS in blue dotted lines and VIIRS in brown thick lines.

IMPACT/APPLICATIONS

AERONET and AERONET-OC data from Long Island Sound Coastal Observatory (LISCO) site is now used continuously for validation of ocean color satellites, water monitoring and algorithm

development in coastal waters, including JPSS-VIIRS data after sensor launch in October 2011. Distribution of Angstrom coefficient on the LISCO site suggests the necessity for broader aerosol models for coastal waters.

A new technique for the retrieval of the attenuation/absorption ratio from polarized measurements of upwelling radiance is proposed based on radiative transfer simulations. This technique opens a possibility of retrieval of attenuation and scattering coefficients from future aircraft and airborne instruments with polarization sensitivity. Our newly developed integrated system for underwater polarization measurements and imaging opens possibility for the precise validation of polarization techniques as well as advanced imaging of polarized and unpolarized targets and deconvolution of the targets properties from polarized images.

RELATED PROJECTS

This ONR project, on improvement of retrieval of bio-optical properties, benefits from the leveraging of funding by NOAA CREST in which remote sensing of coastal waters is an important component.

Starting 2009 the CCNY group also studied polarization characteristics of light in water through another award from ONR N000140911054 for years 2009-2014 with the emphasis on underwater animals vision and camouflage properties and applications.

PUBLICATIONS

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