Monday, October 8
Plenary Session 1
09:20–10:00

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SURFACE COLOR DATA DISTRIBUTION IN RELATION TO OCEANOGRAPHIC PROCESSES IN THE ADRIATIC/IONIAN REGION

Adriatic Sea and North Ionian are two interacting basins showing specific oceanographic patterns, resulting in quite prominent seasonal, interannual and decadal variability of the phytoplankton community features. Therefore, the use of ocean color data is rather important for understanding both ecosystem functioning and oceanographic features in the two areas. The South Adriatic Pit is characterized by a presence of the quasi-permanent cyclonic gyre, whose center is the site of the winter vertical mixing and the dense water formation. The vertical mixing is triggered by outbreaks of the cold continental air. This water represents then the main component of the bottom water of the entire Eastern Mediterranean. The vertical mixing brings to the surface deep nutrient-rich waters and triggers the spring phytoplankton bloom. The high chlorophyll concentration, on one hand enables to study the characteristics of the vertically mixed patch, and on the other hand, to quantify interannual and decadal variability of the phytoplankton biomass. Combining the satellite measurements with in situ data, provides rather complete information on the South Adriatic ecosystem. In the North Ionian, circulation is dominated by a basin-scale meander, which changes on a decadal time-scale from cyclonic to anticyclonic and viceversa, affecting nutrient distribution and nutricline depth. North Ionian is then a good study area to investigate how changes in circulation can affect phytoplankton phenology in oligotrophic regions. From in situ observations, the average distribution of isopycnals was produced for each circulation regime and a nutricline depth difference between cyclonic and anticyclonic circulation modes of about 80 m was estimated. The phytoplankton phenology metrics extracted from annual time-series of ocean color data for the period 1998-2012, associated with the two circulation regimes were compared. Results showed that the metric the most affected by circulation reversals is the initiation date for the main increase in chlorophyll-a.

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Monday, October 8
Oral Session 1
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10:50–11:10

PARTICULATE OPTICAL PROPERTIES IN THE MEDITERRANEAN AND BLACK SEAS THROUGH CALIPSO SPACEBORNE LIDAR MEASUREMENTS

Recently, new applications on global-scale plankton retrievals using the CALIOP (Cloud-Aerosol Lidar with orthogonal Polarization) lidar measurements on the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellite suggested that space-based lidars could provide information about the depth distribution of optical scattering. Assessing the oceanic surface layer's optical properties through CALIOP is one of the reasons of the extension of the CALIOP mission for another 3 years (2018-2020). Despite these results, this new application for ocean retrievals has limitations and uncertainties that need to be further assessed and estimated. The objective of this work is the evaluation of the potential CALIOP ocean products in the Mediterranean and Black seas. Within this frame, the ocean column-integrated depolarization ratio measurements at 532 nm were firstly derived through CALIOP measurements. This parameter allowed deriving the surface hemispheric backscattering coefficients (bbp) using different algorithm schemes that have been compared to the bbp at 443 nm derived by the multi-sensor L3 product (MODIS-AQUA and NPP-VIIRS data) in the Mediterranean and Black seas provided by the Copernicus Marine Environment Monitoring Systems (CMEMS). Analyses of annual and seasonal distributions of CALIOP and CMEMS bbp will be presented for both basins.

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WATER-COLUMN OPTICAL CHARACTERIZATION USING LONG-RANGE TIME-RESOLVED BACKSCATTERING PROFILES

A novel instrument capable of measuring instantaneous long-range time-resolved underwater optical backscattering profiles has been developed at Harbor Branch Oceanographic Institute at Florida Atlantic University (HBOI-FAU). The instrument, called the Ship Hull Mounted Lidar System (SHMLS) has been designed to allow for contiguous profiles of beam attenuation and backscattering to be made using depth-cascaded overlap functions defined by a complimentary pair of precisely aligned telescope apertures, aligned using multiple passes within the 12.5 meter underwater test range at FAU Harbor Branch's Ocean Visibility and Optics Laboratory. Here we present the profiles collected along multiple transects during the NATO LoGMEC exercise in the Ligurian Sea in September-October 2017. The mission provided a unique opportunity to integrate the SHMLS profiles with a range of water column data collected in parallel, including the ship's in-situ bulk Inherent Optical Property (IOP) and water quality data. The integrated data-set presented here was used for ground-truthing of optical backscattering signals, and for improving the previously developed inversion algorithms to more effectively interpret the time-resolved backscattering response to optically active discontinuities, as well as the non-invasive detection of functional scattering layers and aggregating features within the water column in order to expand the capabilities in reconstructing and mapping spatial biogeochemical and turbulence characteristics of the water column. We also present a novel 3D visualization workflow library for quantitative and qualitative exports of the multiscale and multiresolution midwater information, incorporating the range-resolved SHMLS optical backscattering data and the various in-situ instruments deployed from profiling platforms.

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A SIMPLE SOLUTION TO THE OPEN-OCEAN "MISSING" BACKSCATTERING ENIGMA

The optical backscattering coefficient is the only tool that currently allows us to monitor and understand the open-ocean dynamics of marine microscopic particles with the required high-vertical and temporal resolutions. This is because backscattering can be measured from satellite and in-situ autonomous platforms (e.g., profiling floats). However, these observations are critically limited by an incomplete mechanistic understanding of what particles generate the backscattering signal. To achieve this understanding, optical models are employed. The simplest of these models – the homogeneous sphere – severely underestimates the measured backscattering and the missing signal has been attributed to sub-micron particles. This issue is known as the open-ocean "missing" backscattering enigma. Here, we show that a slightly more complex optical model – the coated sphere – can accurately predict the measured backscattering in the open ocean and provide a simple solution to the enigma. We parameterised and validated the coated-sphere model by using more than 150 coincident measurements of particle size distribution (0.59-60 μm) and optical backscattering collected across the Atlantic Ocean, through a variety of trophic regimes including mid-ocean gyres. In stark contrast to the homogeneous sphere, the coated-sphere model suggests that most of the backscattering comes from particles >1 μm. Additional size-fractionation experiments independently confirmed the smaller-than-expected contribution of sub-micron particles to the optical backscattering. Our results demonstrate that the structural complexity of particles is critical to move towards a complete understanding of the open-ocean backscattering. Only then, we will achieve the full potential of optical backscattering observations for investigating ocean biogeochemistry.

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Monday, October 8
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CONTRIBUTION OF PHYTOPLANKTON TO THE INHERENT OPTICAL PROPERTIES OF CASE I WATERS

A growing body of literature suggests that in the open ocean the contribution of phytoplankton (particularly in the large size fraction) to the particulate backscattering (bbp) and attenuation (cp) signals is larger than previously thought. If true, this contribution would partially explain the significant underestimate in backscattering of case I water observed by most optical models: the so-called "backscattering enigma". However, the quantification of the phytoplankton signal remains a challenge given the scarcity of concurrent measurements of optical properties and microscopy. Here, the contribution of phytoplankton to cp is assessed using the theoretical efficiency factors of particulate attenuation (Qc). Several approaches are taken to estimate the efficiency factor of bbp(Qbb) and by extension the contribution of phytoplankton to bbp. The cross-sectional area of the larger size fraction of phytoplankton (7-150um) is estimated with quantitative microscopy while the cross-sectional area of smaller cells (0.8-20um) is estimated with flow cytometry. The sizes, shapes, and species composition of phytoplankton are used to explain the variance observed in Qbb and Qc. More than 5.5 million images were collected from a continuous flow-through system at the surface of the North Atlantic Ocean during the autumn, winter, spring, and summer. Measurements encompassed a wide range of physical-chemical conditions and biogeochemical provinces, with surface chlorophyll concentrations varying from 0.04 to 4.6ug/L. More than half of the observations fall within the theoretical range of the absorption efficiency factor. The larger size fraction of phytoplankton accounts for 12 to 18% of cp and 4 to 15% of bbp.

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VARIATIONS OF THE VOLUME SCATTERING FUNCTIONS MEASURED IN NORTH PACIFIC OCEAN AND EASTERN CANADIAN LAKES

The volume scattering function (VSF) were measured using the LISST-VSF in North Pacific Ocean from the Haro Straits to the Papa Station and eastern Canadian lakes from the urban areas to the Boreal Shield. In July 2017 and February 2018, a total of 145 VSFs were measured in North Pacific at 29 locations and several depths from surface to bottom (-4023 m). The particle scattering coefficients (bp) vary from 0.1235 to 2.6813 m^{-1}, the particle backward scattering coefficients (bbp) from 0.0007 to 0.0340 m^{-1}, and the particle attenuation coefficients (cp) from 0.0415 to 3.6350 m^{-1}. The phase functions vary 2 order of magnitude and the backscattering ratios (Bp) vary between 0.0037 and 0.0475. In the open ocean, the average value of Bp in winter/early spring is 0.0234, about twice as large as in summer (0.0114), while such seasonal difference was not observed in near-shore waters. The Bp values generally increase with the depth within the epipelagic zone, but Bp near the bottom is lower than it at 100 m. The simultaneously collected total suspended solids and particulate inorganic material data indicated that the sediment of particles might cause such decrease in Bp. In summer 2017, surface VSFs were measured in 21 eastern Canadian lakes. The lake water shows greater variation than seawater in bp from 0.6067 to 3.0549 m^{-1}, bbp from 0.0038 to 0.0474 m^{-1} and cp from 0.8105 to 7.0748 m^{-1}, but much less variation in Bp from 0.0056 to 0.0184.

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Oral Session 2
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ENHANCEMENT OF OPTICAL ABSORPTION AND SCATTERING AND CHANGES IN PARTICLE SIZE DISTRIBUTION IN THE SEA-SURFACE MICROLAYER COMPARED TO UNDERLYING BULK SEAWATER

The sea-surface microlayer (SML) is a thin (< 1 mm) surface layer of the ocean forming the interfacial boundary between the oceanic waters and the atmosphere. Typically, the SML has physical, chemical, and biological properties that are distinctly different from the underlying bulk seawater. Few studies have reported on the measurements of optical properties of SML, and were limited to absorption in the UV and visible spectral regions. To our knowledge, light-scattering properties of SML and particle size distributions have not been previously measured. In this study we compare the measurements of light absorption, scattering, and particle size distribution (PSD) in the SML and underlying bulk waters in contrasting Pacific Ocean environments. The spectral absorption coefficients of dissolved and particulate matter were measured with high spectral resolution either within the visible spectral range (400-700 nm) or broader spectral range (300-850 nm). The volume scattering function was measured at 532 nm within forward scattering angles (up to ~14°) or within a broader angular range (up to ~150°). The characteristics of near-surface bulk water varied greatly among the investigated sites, for example the chlorophyll-a concentration ranged from about 0.06 mg m^{-3} in ocean waters off Hawaii Islands to 1 mg m^{-3} in the Santa Barbara Channel. Our observations also included prominent slick conditions associated with a bloom of Trichodesmium species. Significant enhancement of the optical properties and particle number concentration, including significant changes in the shape of PSD, were observed in the SML compared to underlying seawater at all investigated sites.

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SPECTRAL ABSORPTION-BASED ESTIMATES OF PHYTOPLANKTON COMMUNITY COMPOSITION IN THE NORTH ATLANTIC OCEAN

The composition of the phytoplankton community during its annual cycle of growth and accumulation in the North Atlantic Ocean is of great interest due to the disproportionately large role the North Atlantic plays as a sink of atmospheric CO2 and hence on climate. The North Atlantic Aerosol and Marine Ecosystem Study (NAAMES) is a multi-year campaign spanning several seasons to study the environmental conditions and phytoplankton ecology of the bloom. NAAMES data include in situ hyperspectral absorption measurements, which can be used to estimate several phytoplankton accessory pigments via spectral decomposition. We show these optical-based pigment estimates can explain the major phytoplankton groups comprising communities in a wide variety of environmental regimes in the North Atlantic, as determined by both imaging and traditional flow cytometry. We also find that spectral decomposition provides improved accuracy in accessory pigment concentration retrievals compared to traditional relationships based on pigment co-variations with chlorophyll. This work provides both a methodology and its application for understanding phytoplankton community composition via an analytical use of in situ hyperspectral absorption measurements. Importantly, we observe regions where phytoplankton community composition deviates significantly from traditional correlations with chlorophyll concentration (e.g. that diatoms are often the dominant group present during times of increased chlorophyll concentration). The extensive spatial and temporal coverage of our data and the quantitative imagery and cytometry data used for validations highlight the capability of estimating different phytoplankton groups from in situ hyperspectral absorption measurements.

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DEVELOPMENT OF OPTICAL FINGERPRINT LIBRARIES TO EVALUATE PHYTOPLANKTON COMMUNITY COMPOSITION FROM OCEAN COLOR SATELLITE PRODUCTS

Ocean biota are responding to recent climate change. Quantifying the response of phytoplankton communities is essential for predicting future ocean food resources, occurrences of harmful algal blooms, ocean food web dynamics, carbon and other elemental cycles, etc. However, one of the best tools for quantifying the response of phytoplankton communities across relevant time scales (multi-decadal) is constrained by several factors such as adequate spectral capabilities of ocean color satellite sensors. Another limitation of remote sensing estimates of phytoplankton community composition and carbon-based biomass is adequate optical models linked to comprehensive spectral libraries of significant phytoplankton species and functional types. To address this deficiency, our project combines the expertise at the National Center for Marine Algae and Microbiota (NCMA) in culturing, physiology and biogeochemistry of phytoplankton with expertise in ocean optics and biogeochemistry at NASA Goddard Space Flight Center. Over forty strains of phytoplankton were grown to exponential and/or stationary phase for optical, physiological and biogeochemical characterization. We selected strains based on the following criteria: globally or regionally significant distributions, fulfill key ecosystem function, represent either unique or typical morphological traits, and pigment profile similarity. The optical measurements accomplished include: hyperspectral UV-Vis absorption coefficients, multi-angular and multi-spectral backscatter coefficients, volume scattering function, particle size distribution, fluorescence, and hyperspectral remote sensing reflectance. The suite of biogeochemical measurements included phytoplankton organic carbon and nitrogen, HPLC pigments, phycobilin pigments, and nutrients. Phytoplankton cell counts and biovolumes were also quantified. Preliminary results relating carbon-based phytoplankton biomass and chlorophyll-a to measured optical properties will be presented.

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THE FUNDAMENTAL ROLE OF PHYTOPLANKTON SPECTRAL SCATTERING IN PFT DETECTION

There is increasing interdisciplinary interest in phytoplankton community dynamics as the growing environmental problems of water quality and climate change demand attention. This had led to a pressing need for improved biophysical, causal understanding of Phytoplankton Functional Type (PFT) optical signals, in order that satellite radiometry may be used to detect ecologically significant phytoplankton assemblage changes. Towards this goal, a series of investigations are undertaken here using a phytoplankton Inherent Optical Property (IOP) model which has biophysically and biogeochemically consistent absorption and scattering characteristics. Coupled with Hydrolight, it allows the systematic examination of algal assemblage characteristics in relation to the bulk optical water-leaving signal. The sensitivity of the optical signal to changes in accessory pigments and assemblage effective diameter is evaluated for a selection of PFT detection case studies. These optical signals can be isolated and assessed in terms of both their magnitude and their spectral location, with direct relevance to community discussions around the value of hyperspectral sensors and satellite measurement sensitivity requirements. The potential for identifying a PFT signal with confidence from the bulk water-leaving signal, against variability in other optical components (CDOM and BBS) is also discussed, and the fundamental role of phytoplankton scattering in the accessible PFT signal is demonstrated. The full code for the IOP model have been made freely available in Matlab and Python, and it is hoped that this will stimulate new discussion around the role of phytoplankton scattering in the PFT question, and in ocean optics generally.

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ADVANCING MACHINE LEARNING FOR AUTOMATED TAXONOMIC CLASSIFICATION OF PLANKTON IMAGES FROM IMAGING FLOWCYTOBOT

Recent advances in machine learning have shown promise in improving accuracy of automated detection and classification of marine organisms from high-volume data such as images and video. Newer techniques from deep learning such as convolutional neural networks (CNNs) are outperforming virtually all other image classification approaches, and offer benefits such as eliminating the need for feature engineering. We compare several machine learning approaches on a large dataset of phytoplankton imagery produced by Imaging FlowCytobot at the Martha's Vineyard Coastal Observatory: 1) support vector machines (SVM), 2) random forest classifiers (RFC), 3) multilayer perceptrons (MLP), and 4) CNNs. All four approaches are supervised and take expert human taxonomic classifications as training inputs. The SVM, RFC, and MLP approaches classify images based on a large ensemble of hand-engineered features computed for each image with a variety of image processing algorithms. In contrast, the CNN approach operates directly on images and learns image processing features as part of the training process. In our experiments with large multi-class problems, we find that CNNs fully trained on plankton images outperform other approaches, not only those based on hand-engineered features, but also CNNs that are pre-trained for generic object recognition tasks and then partially retrained to classify phytoplankton. This work is situated in an operational workflow that supports near-realtime processing and high throughput retrospective processing to handle the dataset of ~880m images. Accurate performance for such large datasets represents a Big Data challenge that requires high performance computing resources in addition to state-of-the-art algorithms.

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Monday, October 8
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PHYTOPLANKTON COMMUNITY COMPOSITION CHARACTERIZED USING HIGH SPECTRAL RESOLUTION LIDAR

High Spectral Resolution Lidar (HSRL) systems collect quantitative measurements of depth-resolved backscatter (bbp) and the depolarization ratio which cannot be observed by existing passive remote sensing techniques. We present measurements of backscatter and depolarization collected with an airborne HSRL system in conjunction with in situ phytoplankton community composition observations to evaluate phytoplankton community composition in an anticyclonic eddy in the North Atlantic as part of the November 2015 NAAMES field campaign. We show that subsurface maxima in bbp and depolarization coincided with changes in the phytoplankton community and that the phytoplankton community changes over the anticyclonic eddy, with abrupt gradients in bbp and depolarization observed along the eddy periphery. Specifically, smaller phytoplankton cells with a greater degree of eccentricity were observed inside the eddy compared to outside and were associated with lower backscattering coefficients and depolarization ratios. This is consistent with the results of Kouzoubov et al. (1999) who observed lower polarization in the upper water column associated with spheroid cells when compared to spheres. Our work highlights the need for space-based lidar that will allow for global assessments of depth-resolved ocean properties, including phytoplankton community structure.

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