OCEAN OPTICS XXIV

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https://oceanopticsconference.org

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Poster 4

HOW MUCH CARBON STORED IN THE LAKES AND COASTAL WATERS ORIGINATES FROM PHYTOPLANKTON?

A global inventory of lakes has shown large proportion of lakes in higher latitudes, where also an increase in organic carbon concentration resulting in lake browning has been reported, affecting the ecosystems from directly reducing underwater light field to altering lake food webs. Based on the dataset measured in the Nordic inland and coastal waters, we focused on estimating phytoplankton related parameters in the Particulate Organic Carbon (POC) fraction in the carbon cycle and its derivation from remote sensing (RS) data. We have compared various models to estimate primary production (PP) from RS data. The individual PP model parameters, derived from RS data, describing light conditions (Kd(λ)) and water temperature, show high accuracy (R^2>0.9), when validated against in situ data. The quantification of absorption by phytoplankton is associated with higher uncertainties, but is more straightforward when using absorption coefficient at 442 nm (aph(442)) than the Chl-a based approach, due to the high variability (although R^2>0.7) between Chl-a and aph(442) over Case-2 waters, especially in more productive waters (Chl-a > 20 mg/m^3, aph(442) >2 m^{-1}). In addition to PP, Carbon-to-chlorophyll ratio and conversion factors between biomass of different phytoplankton groups and carbon from literature were analysed and applied to estimate their contribution to the POC fraction. By the synergy of optical and thermal RS sensors on board of ENVISAT, S3, S2 satellites, the analyses offer insight into carbon cycling that show high spatial and temporal variability indicating RS as an essential source of information to monitor these processes.

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EXTRACTING SPATIAL DISTRIBUTIONS OF OPTICALLY ACTIVE CONSTITUENTS FROM AIRBORNE HYPERSPECTRAL OCEAN COLOR DATA USING A BLIND-SOURCE SEPARATION APPROACH.

Airborne ocean color sensors provide the flexibility to sample rapid local physical processes, as high temporal and spatial resolutions are required to study their role in advection and mixing of tracers in the surface ocean. Provided short revisiting times, effective removal of the instrument artifacts and atmospheric effects would result in water-leaving reflectances with temporally consistent spatial patterns, only distorted by the advective flow field. However, calibration and atmospheric correction errors often result in significant spatiotemporal discrepancies, that propagate to the abundance maps of optically active constituents (OAC), like chlorophyll concentrations, derived with bio-optical algorithms. A novel approach to obtain consistent abundance maps from airborne ocean color time series is presented. It uses Independent Component Analysis, a blind-source separation technique, to extract the signal-variability patterns due to changes in the OACs directly from the at-sensor signal. Thus, it does not require highly accurate instrument calibration or explicit atmospheric correction. Each extracted component corresponds to the signal of an OAC-assemblage with variable concentrations in the targeted region. An OAC-assemblage is described by two factors: a spectral signature, determined by its inherent optical properties (IOPs), and a signal-score, proportional to relative changes in its concentration. The method is illustrated with a ~1.5-hour long time series of ~20 images of a coastal submesoscale eddy collected with an experimental hyperspectral push-broom sensor at ~3.000 m altitude. Results show a single OAC-assemblage which spectral signature appears to be dominated by chlorophyll-like pigments. Spatiotemporally consistent signal-score maps are evidence of the absence of atmospheric effects.

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VARIATIONS IN SURFACE PHYTOPLANKTON SIZE STRUCTURE OF A CYCLONIC EDDY IN THE SOUTHWEST INDIAN OCEAN

Phytoplankton size classes were derived from weekly-averaged MODIS Aqua chlorophyll a data over the southwest Indian Ocean in order to assess changes in surface phytoplankton community structure within a cyclonic eddy as it propagated across the Mozambique Basin in 2013. Satellite altimetry was used to identify and track the southwesterly movement of the eddy from its origin off Madagascar in mid-June until mid-October when it eventually merged with the Agulhas Current along the east coast of South Africa. Nano- and picophytoplankton comprised most of the community in the early phase of the eddy development in June, but nanophytoplankton then dominated in austral winter (July and August). Microphytoplankton was entrained into the eddy by horizontal advection from the southern Madagascar shelf, increasing the proportion of microphytoplankton to 23 % when the chlorophyll a levels reached a peak of 0.36 mg m^{-3} in the third week of July. Chlorophyll a levels declined to < 0.2 mg m^{-3} in austral spring (September and October) as the eddy propagated further to the southwest. Picophytoplankton dominated the community during this spring period, accounting for > 50 % of the population. As far as is known, this is the first study to investigate temporal changes in chlorophyll a and community structure in a cyclonic eddy propagating across an ocean basin in the southwest Indian Ocean.

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BIOGEOCHEMICAL CONTROLS OF CDOM FLUXES FROM SEDIMENTS AND THE ASSOCIATED EFFECTS ON THE GULF OF MEXICO WATER COLUMN OPTICAL PROPERTIES

Because of the importance of Colored Dissolved Organic Matter (CDOM) in the transfer of carbon from land to sea, CDOM is a frequent target of satellite remote sensing efforts. Simultaneously, CDOM can interfere with the detection of other optical properties such as chlorophyll or suspended sediments. It is thus essential to understand the controls of the production, alteration, and transport of both terrestrial and marine-derived CDOM, as well as associated absorption effects. However, despite a potentially large role in shallow regions, sediment-derived CDOM inputs and the associated effects on water column optical properties have received little attention. During a summer, 2017 cruise to the northern Gulf of Mexico, shelf and slope sediment pore water hyperspectral CDOM absorption was measured as part of a larger campaign to examine sediment respiratory processes. Absorptions (a440; 0.3 to 56 m^{-1}) were elevated relative to surface waters and typically increased with depth. Additionally, spectral slopes (S350-440; 0.006 to 0.027) diverged significantly from the relatively constant values of surface waters (0.015 – 0.018). While surface CDOM spectra were characterized by monotonic exponential decrease, sediment pore waters displayed several discrete inflection regions. CDOM properties were most affected by disparate microbial processes between shelf and slope sediments, but overall iron mineral dissolution and complexation played the largest role. Finally, results will be presented from a simple shelf and slope system sediment/water column box model, in which absorption properties were associated with dissolved pore water organic carbon concentrations and diffusive fluxes were calculated for each site.

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ESTIMATION OF THE COLORED DISSOLVED ORGANIC MATTER FROM OCEAN COLOR REMOTE OVER OPEN OCEAN WATERS AND ANALYZE OF ITS SPATIO-TEMPORAL VARIABILITY USING GLOBCOLOUR OCEAN COLOUR ARCHIVE (SEAWIFS, MODIS-AQUA, VIIRS, OLCI/SENTINEL3 DATA)

Colored dissolved organic matter (CDOM) refers to a complex mixture of water-soluble organic substances including mainly humic and fulvic acids. CDOM plays a crucial role for a variety of marine biogeochemical processes. While numerous algorithms have been documented for estimating CDOM from ocean color remote sensing in coastal areas, studies dedicated to open ocean waters are still relatively scarce. The main issue for a proper estimation of CDOM absorption, acdom(l), from OCR stands in our ability to distinguish it from the non-algal particles (NAP) absorption. This represents a real challenge considering the similarity of the CDOM and NAP absorption spectral shape. As a matter of fact, CDOM and NAP are usually described in oceanic waters by a single component acdm(l) which refers to the absorption of colored detrital matter. CDOM is usually considered as the major contributor to acdm(l) in case 1 waters, however the spatio-temporal variability of the relative contribution of acdom(l) to acdm(l) in response to the impact of the diverse source and sink controlling processes needs to be further investigated. In this context, the present study is dedicated to the assessment of acdom(l) over open ocean waters. Recent existing acdom(l) inversion algorithms will be tested over synthetic and in situ data sets, while a new approach will be proposed. This algorithm will be applied to the Globcolour ocean colour archive (including OLCI/Sentinel3 data) for match-up analysis as well as for characterizing the spatio-temporal variability of acdom(l) and its relative contribution to acdm(l) (i.e. acdom/acdm).

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PHYTOPLANKTON OPTICAL PROPERTIES FOR STUDYING PHYTOPLANKTON ASSEMBLAGES IN THE TROPICAL INDIAN OCEAN

The Indian Ocean is the third largest ocean in the world covering approximately 20% of the total ocean area of world. To date, field observations, especially of phytoplankton, are scarce in the Indian Ocean and large areas of the Indian Ocean remains understudied, despite their importance in the controlling global primary production and biogeochemical cycles. In this study optical properties, measured in July-August 2014 during the SO235-OASIS (OrgAnic very short lived Substances and their air sea exchange from the Indian Ocean to the Stratosphere) cruise from Port Louis, Mauritius to Male, Maldives are used to characterise the phytoplankton assemblages regarding community structure and physiological condition in this tropical ocean by combining the results obtained with different optical measurements (high performance liquid chromatography, spectrophotometry, fast repetition rate fluorometry (FRRf), flow cytometry and hyperspectral radiometry, and satellite remote sensing) and microscopic cell counts. In addition, this in-situ information are then utilised to evaluate satellite products on phytoplankton and optical properties for this part of the World's Ocean.

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A HYPERSPECTRAL PERSPECTIVE ON THE GULF OF MAINE.

Previous biogeochemical surveys in the Gulf of Maine (GoM), provide an understanding of the water properties in the area. However, a hyperspectral optical characterization of the GoM waters has yet to be undertaken. Here we present a preliminary view of hyperspectral and multispectral characteristics of a GoM section and the associated spatial and temporal variability of optical constituents of the water. We conducted 5 surveys in 2017 from July to October along a transect from Yarmouth (NS, Canada) to Portland (ME, U.S.A.). Water optical properties were measured underway using an in-line flow-through system (AC-9), while above-water reflectance was recorded using hyperspectral sensors (HyperSAS). This analysis focuses on 3 bio-physically distinct regions: i) the Scotian Shelf, ii) Jordan Basin (center) and iii) coastal Gulf of Maine. Optical constituents in the water vary spatially, with dissolved organic matter (CDOM) and particles higher near the coastal regions. Phytoplankton contribution to the total reflectance spectra increased over time and is higher in the last cruise in all regions. A separation of the spectral signatures of the regions is evident through time, except towards the end of the summer. Over Jordan Basin, values of the spectral slope of CDOM displays a peak through June to August, likely related to the retention time of water masses in the area and contribution from coastal environments. These findings highlight the increased information content of hyperspectral data compared to multispectral data, and provide new insights into the optical complexity of surface waters in the Gulf of Maine.

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MATCHUP DATA BASE FOR SENTINEL-3 OLCI OCEAN COLOUR PRODUCTS VALIDATION

Continuous monitoring and validation activities of Ocean Colour products from Sentinel-3 OLCI are required to provide to users accurate estimation of the accuracy and the limitations of the data provided. Comparative analysis using in situ measurements thus needs to be performed continuously alongside products delivery. As a tool supporting validation activities, a Matchups Data Base (MDB) builder was set up to provide, on a monthly basis, netCDF files containing matching OLCI Ocean Colour Level2 extracts and in situ quality checked data, from MOBY (Marine Optical BuoY) (Clark et al., 1997) and AERONET-Ocean Colour (Zibordi et al., 2004) sites, which provide continuous water radiometric measurements, useful for the validation of the OLCI water reflectance product. These monthly netCDF files contain both original data from OLCI full resolution products, extracted on the basis of a 25 by 25 pixels window, centred over in situ stations, and in situ measurements. In addition, for OLCI data, Remote Sensing Reflectance, corrected for angular effects through Bidirectional Reflectance Distribution Function (BRDF), is provided. For AERONET-OC, where there is discrepancy in central wavelengths between AERONET's and OLCI's bands, a bandshifting correction (Mélin et al., 2015) is applied. MDB NetCDF files are accompanied with a Python module, used for reading data and providing statistics and plots for products validation, using a predefined set of filtering criteria for matchups (Bailey and Werdell, 2006) as well as user-defined criteria. Further development will include also matchups for chlorophyll and suspended matter concentrations, as well as Inherent Optical Properties from other sources.

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OPTICS AND ACOUSTICS FOR NEAR-BED PARTICLE CHARACTERIZATION AND QUANTIFICATION OF TURBULENCE

Sediment fate and transport models are often utilized to address questions related to the environmental impacts of remediation efforts, the likelihood of natural recovery, and potential impacts of extreme events. In order to effectively implement these models, bed erosion and deposition rates must be accurately parameterized. These processes are dependent on physical forcings, the suspended sediment distributions, and sediment properties such as bulk density, settling velocity, and biogeochemical composition. We deployed in-situ acoustical and optical instrument platforms coordinated with laboratory experiments to measure the flow and physio-biogeochemical characteristics of sediment in a turbulent, current- and wave-driven shallow estuarine environment. Results show that in different flow environments, turbulence can act to resuspend relatively dense, inorganic particles or disaggregate less dense, organic flocculates. The field and laboratory observations of the sediment characteristics will inform a high-resolution large-eddy simulation (LES) model that resolves details of the turbulent, sediment-laden boundary layer. The suite of data obtained from the field observations, laboratory experiments, and LES model will be used to understand the relationship between particle size distributions and turbulence in wave-driven estuarine environments and how these dynamics affect and are affected by biogeochemical properties of the suspended particles.

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BIO-OPTICAL CHARACTERIZATION OF THE NORTHERN ANTARCTIC PENINSULA WATERS: ABSORPTION BUDGET AND INSIGHTS ON PARTICULATE BACKSCATTERING

A comprehensive set of bio-optical properties is presented for the northern Antarctic Peninsula in the Southern Ocean. The relative contributions of phytoplankton, colored dissolved organic matter (cdom) and detritus to light absorption highlight the importance of phytoplankton, but cdom is often significative in the blue range of the spectra, despite its roughly constant values at 443nm in contrast with the three orders of magnitude of total chlorophyll-a concentration, [TChl a], (0.019-2.91mgm^{-3}) observed in the upper 100m. The particulate backscattering coefficient, b bp(λ), was remarkably low if compared to other oceanic waters, but agrees with previous studies in the Southern Ocean. Even with very low absorption, detritus was the component better correlated with particulate backscattering in the Antarctic Peninsula, while phytoplankton cells (dominant in the particles pool) mostly covaried with particulate scattering. Particulate backscattering ratios (bbp(λ) divided by the particulate scattering coefficient, bp(λ)) were also below values observed in other oceanic waters. The spectral diffuse attenuation coefficient, Kd(λ), was highly correlated to [TChl a] (R^2=0.90 at 443nm) and showed no dependence on bbp(λ). Indeed, Kd(443) and non-water absorption coefficients at 443nm were related by a 1 to 1 dependence. The shape of the spectral remote sensing reflectance varied little responding mainly to variability in [TChl a], while [TChl a] vs. maximum band ratios dependence deviated from global trends in a very similar fashion as in other studies of the Southern Ocean, likely due to very low bbp(λ).

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ADVANCES IN OIL SPILL RESPONSE PLUME TRACKING: TOOLS FOR DECISION-MAKING

Oil spill monitoring efforts in remote locations such as the deep sea, offshore waters and under-ice environs is vastly improved by advances with in situ optical measurements. Parameters such as fluorescence, scattering, radiometry and reflectance provide for droplet size distribution, hydrocarbon (particulate and dissolved) and gas concentration, and proxies for dispersion efficiency. This is critical information for decision-making during spill response efforts. Presented here will be an examination of reliability of fluorescence measurements (Sea-Bird Scientific WET Labs Inc. ECO and Chelsea Technologies Group AQUA Tracka) at providing a subsurface oil footprint and estimating oil concentrations during the large-scale Deepwater Horizon Oil Spill in the Gulf of Mexico, USA. This spill served to demonstrate the forensic value of in situ optical data during such events. More recently, in 2017 a Remote Environmental Monitoring UnitS Autonomous Underwater Vehicle (REMUS AUV) equipped with fluorescence and backscatter (Sea-Bird Scientific WET Labs Inc. ECO Puck) capabilities was used to track a 90 m subsea oil plume discharged from a chronic leak site within the Northern Gulf of Mexico. Data from this mission further supports the need for high-spatial and temporal resolution measurements to allow for improved understanding of the behavior and transport of spilled oil.

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EFFECT OF MULTIPLE INTERACTIONS OF THE UPWELLING RADIANCE WITH THE WATER-AIR INTERFACE ON THE RADIANCE TRANSMITTANCE

The radiance transmittance equation, originally known as the n2 - law for radiance, was derived based on geometrical radiometry for the radiance interacting with the interface only once. In natural waters, the phenomenon is completely different which involves multiple interactions of the radiance with the interface. This study examines the role of multiple interactions of the upwelling radiance with the water-air interface and the influences of water optical properties on the radiance transmittance. An expression for the water-air (or water side) reflectance factor for natural waters is also derived. This study quantifies the effect due to the multiple interactions which is significant in coastal and inland waters where there is considerable presence and variable amounts of particles in the water. The results suggest that by accounting the multiple interactions of radiance with the interface on the radiance transmittance we achieve significant improvement in the determination of the water-leaving radiances and remote sensing reflectances especially in turbid coastal and productive inland waters. This study will be useful for the calibration and validation of satellite ocean colour sensors and development of bio-optical algorithms.

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POTENTIAL USE OF OCEAN COLOR DATA TO RETRIEVE MORE THAN PARTICLE CONCENTRATION IN A HIGHLY REFLECTIVE DREDGING PLUME IN THE RÍO DE LA PLATA (ARGENTINA)

The Rio de la Plata (RdP) waterway is an essential link between the Atlantic Ocean and numerous ports in Argentina allowing the exportation of grain and agricultural by-products, major drivers in the Argentine economy, to reach destinations all over the world. Given the shallow nature of the estuary, the navigation channels demand regular dredging. Therefore, water quality control in this highly active and human impacted area is fundamental and the knowledge of its dynamics as well as the particle size composition using remote sensing data is highly desired and of great importance. From mid-May until the end of October 2016 an unusually intense dredging plume was detected in the upper RdP estuary using remote sensing imagery. In September 25 2016 a field campaign was performed in the upper estuary and measurements of water refelectance (ρw), turbidity, total suspended matter, and particle size distribution (PSD) were performed in and close to the plume. Samples collected inside the plume showed different spectral characteristics, smaller median particle size, and turbidity (T) values ten times higher (T~500 FNU) than the surrounding waters. In this study ocean color imagery was used to detect the highly reflective plume in May-October 2016. Existing models to retrieve bbp(λ) from ρw(λ) were tested and bbp*(λ)/ap*(λ) ratio were estimated from saturated water reflectance. Backscattering spectral slope and mass-specific inherent optical properties were then related to observed variability in measured PSD in and outside the plume showing their potential use in retrieving relevant information besides particle concentration (like size) from ρw(λ).

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ERROR ANALYSIS IN ESTIMATION OF WATER LEAVING RADIANCE BY NEGLECTING THE POLARIZATION OF OCEAN SURFACE AND ATMOSPHERE

Most inverse algorithms for ocean color from reflected solar spectrum are taken under clear sky, where the total atmospheric optical depth is small and the light reflected by ocean could penetrate the whole atmosphere and could be detected by the space-born sensors, therefore, ocean surface reflectance couldn't be neglected though it is less than several percent. Moreover, most retrieval algorithms use scalar radiative transfer model as a tool of inverse method, while the ocean surface reflectance and atmospheric scattering is polarized, neglecting effect of polarization, especially in the direction of sun glint area in forward simulations could introduce extra errors in estimation of ocean color and atmospheric correction. Through a full vector radiative transfer simulations which takes the ocean surface polarization in account, the effect of atmospheric polarization and ocean polarization on the estimation of ocean color are analyzed. It show that, depending on the wavelength, error of several percent could be introduced in the total radiance of satellite measurement given Lambertian ocean surface, and it is a little larger if the BRDF & BPDF is not taken into account, which results in tens percent in the estimation of water leaving radiance.

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AUTONOMOUS OPTICAL OBSERVATIONS FROM A RAPID PROFILING WIREWALKER DURING NASA EXPORTS

A month-long record of hourly profiles from a wave-powered Wirewalker are presented from the 2018 EXPORTS cruise in the North Pacific. The Wirewalker rapidly traverses the upper 500m of the water column, outfitted with a dissolved oxygen optode, chlorophyll, PAR, beam attenuation and backscatter sensors. These highly detailed records capture the physiological rhythms of the surface phytoplankton community and the variability of the particle field below. Ultimately these data will allow us to estimate net community production from the submeso- to mesoscale contributing to this major field campaign aimed at improving our understanding of the biological pump.

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POLARIMETRIC SCATTERING MATRICES OF MINERAL HYDROSOLS

With the upcoming launch of several Earth-observing satellites with polarimetric capability, and a rising interest in polarimetric data acquired in-situ, it is becoming increasingly important to understand the radiative properties of oceanic hydrosols in polarized mode. In this work we present the results of an experiment to measure the scattering matrices of select mineral hydrosols in a laboratory setting. The full 16x16 scattering matrix is presented for a subset of scattering angles (55 to 125 degrees), limited by the geometry of the experiment and the refractive effect of Snell's window. A rotating Fresnel rhomb and laser source is used to generate a known incident polarization state, while a spectropolarimeter acquires measurements of polarized radiance (including circular). The scattering matrix is inverted from the measurements in a least-squares sense using polarimetric data reduction techniques. Measurements of the near-forward scattering phase function (0-10 degrees) are acquired using a LISST-100X particle size analyzer and are integrated into the results. Matrices are presented for two wavelengths, 406nm and 633nm, and spectral differences are compared and contrasted. Validation of the results is achieved through measurement of suspended spherical particlulates with known microphysics, and comparison with Mie scattering theory.

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NASA MULTI-MISSION OCEAN COLOR REPROCESSING 2018.0

The NASA Ocean Biology Processing Group (OBPG) recently reprocessed the multi-mission ocean color time-series from SeaWiFS, MODIS-Aqua, MODIS-Terra, and VIIRS using common algorithms and improved calibration. Calibration changes included updates to the vicarious calibration using the recently improved MOBY straylight characterization and associated reprocessing of the MOBY time-series. Here we present an analysis of the quality and consistency of the resulting satellite ocean color retrievals, including spectral water-leaving reflectance and chlorophyll a concentration. Statistical analysis of satellite retrievals relative to in situ measurements will be presented for each sensor, as well as an assessment of consistency in the global time-series for the overlapping periods of the missions. Results will show that the satellite sensor ocean color data records are highly consistent over the common mission lifespans, and in good agreement with in situ measurements, with a notable reduction in satellite to in situ bias errors due to the vicarious calibration update.

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THE INFLUENCE OF MESOSCALE EDDIES ON THE TIMING AND MAGNITUDE OF NORTH ATLANTIC PHYTOPLANKTON BLOOMS

The advection of nutrients and living phytoplankton cells, both horizontally and vertically, occurs on a myriad of scales in the open ocean. In the North Atlantic, this include basin-scale processes like the Gulf Stream and deep winter convection in the subarctic region. At the oceanic mesoscale, eddies and meanders with horizontal scale of O(10-100 km) account for the largest proportion of kinetic energy and are known to generate order-1 perturbation of the ambient nutrient and light field. Furthermore, non-linear mesoscale eddies, those that contain vast regions of water trapped within their interiors, act to transport ecosystems over hundreds to thousands of kilometers. These trapped ecosystems are characterized by biological and physical signatures that reflect their region of origin, but that have also undergone local modification via air-sea exchange and predator/prey interaction within the eddy. As a result of this isolation from the ambient water surrounding the eddies, the seasonal evolution of phytoplankton communities is expected to be different in eddies when compared to areas around them, as well as when comparing temporal changes in photoautotrophic communities between cyclone and anticyclonic eddies. Using a combination of satellite observations of ocean color and physics with in situ observations of stratification, I shown that the North Atlantic spring bloom begins later in anticyclonic eddies and earlier in cyclonic eddies. These difference in initiation are consistent with differential near-surface mixing observed in cyclones and anticyclones, suggesting that the influence of these eddies on mixed layer depth are related to their influence on bloom dynamics.

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ASSESSING PHYTOPLANKTON PHENOLOGY IN A TYPICAL TROPICAL MARINE ECOSYSTEM USING SATELLITE, MODEL AND BGC-ARGO - BASED APPROACHES

In oligotrophic tropical marine ecosystems, thermal stratification (under warm conditions) may contribute to a shallowing of the mixed layer above the nutricline and a reduction in the transfer of nutrients to the surface lit-layer, ultimately limiting phytoplankton growth. We study such linkages in the northern Red Sea (NRS) - a typical tropical marine ecosystem. First, we utilise satellite-derived chlorophyll-a observations (OC-CCI – European Space Agency), in conjunction with a Biogeochemical - Argo dataset, and assess the capability of remote sensing to estimate phytoplankton phenology metrics in the NRS. Remotely sensed phenology matches bloom-timing metrics derived from an in situ chlorophyll-a dataset with a surprising degree of precision. Satellite-derived phenology metrics also successfully capture the predominant mechanisms affecting regional nutrient availability (convective mixing and a cyclonic eddy). These findings offer important insights into the capability of ocean colour remote sensing for monitoring food availability in the tropics and encourage the use of satellite-derived phenology in data-limited regions. Following this, we assessed the interannual variability (1998-2015) of both phytoplankton biomass (indexed by chlorophyll-a concentration) and phenological indices (timing of bloom initiation, duration and termination) in relation to regional warming in the NRS. We demonstrate that warmer conditions are associated with substantially weaker winter phytoplankton blooms, which initiate later, terminate earlier and are shorter in their overall duration. Analysis of modelled datasets reveals that these alterations are directly linked with the strength of atmospheric forcing (air-sea heat fluxes) and vertical stratification (mixed layer depth).

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PHYSICAL/BIO-OPTICAL CHARACTERIZATION OF FRONTS AND LAYERS NEAR THE MISSISSIPPI RIVER DELTA

Surface ocean fronts and subsurface layers represent areas of strong property gradients, and often enhanced currents, mixing, and/or biological activity, with vertical and horizontal structure that can vary over short time and space scales. In March 2016, we conducted a 2-week field campaign on the shelf/slope in the northern Gulf of Mexico near the Mississippi River Delta. Our goal was to characterize fronts and layers across a variety of complex oceanic regimes spanning coastal to offshore waters using in situ hydrographic, optical, biological, and geological data sets, satellite imagery (MODIS, VIIRS, CALIPSO), and hydrodynamic modeling (Navy Coastal Ocean Model, NCOM). We deployed a line mooring at an offshore location along a CALIPSO track to assess the ability of the spaceborne LiDAR to resolve vertical bio-optical structure. The mooring operated for 5 days, with a coincident CALIPSO overpass at roughly the middle of the time-series. We collected hydrographic and bio-optical data along transects (using a towed, undulating vehicle; scanfish) and at CTD stations, and compare these to coincident vertical sections of temperature, salinity, and currents extracted from a hydrodynamic model. An underway above-water ship LiDAR system also provided information on subsurface particle distributions for comparison with the CALIPSO and scanfish data. HPLC pigments and total suspended solids (partitioned into organic and inorganic components) were determined at select stations. These data sets allow us to assess the hydrographic and bio-optical characteristics of the water masses in the area, and interpret the dynamic interactions of fresh river plume pulses with saltier offshore waters.

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WATER COLOR AND BRIGHTNESS – NEW LIGHT SHED ON OLD QUESTIONS

Aided by a coupled atmosphere-ocean radiative transfer model, we revisit old questions about the perceived color and brightness of water: (1) To what degree is the ocean color determined by surface reflection of skylight, in contrast to being governed by water constituents? (2) Why do storms make oceans look green? (3) Why are some Norwegian mountain lakes green while others are blue? (4) Would an ocean of the ultrapure water presented at the previous Ocean Optics conference give violet oceans instead of blue? (5) Why would a hypothetical ocean without absorption be white? (6) Are oceans really so bright that they reflect enough ultraviolet radiation to explain why we easily get sunburned at sea, or to what degree do other factors contribute to the extra UV dose? When answering these questions, we calculate the angular dependent spectral radiance for different atmospheric and water conditions, color coordinates are obtained by applying the CIE color matching functions, which give fisheye plots showing the angular distribution of colors for varying conditions. Also, we do a brief detour to look at the blue light seen in the water surrounding nuclear power reactors, which is generated by electrons traveling faster than the speed of light in the water. Finally, we simulate the sunset and show that the ozone layer surprisingly becomes important for the perceived water color.

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AEROSOL MODELS FROM THE OCEAN COLOR SATELLITE SENSORS AND AERONET-OC AND THEIR IMPACT ON REFLECTANCE SPECTRA IN COASTAL WATERS

The choice of aerosol model in the atmospheric correction procedure is critical for the derivation of water leaving radiances from satellite Ocean Color (OC) imagery. At sea level, SeaPRISM radiometric instruments, which are installed on ocean platforms and which are part of the NASA AERONET and AERONET-OC networks, estimate the water leaving radiances from measurements of the total water and sky radiance; aerosol parameters are determined from the latter. The discrepancies between satellite and AERONET data are often significant in coastal areas which are primarily due to the complex atmospheres near the coast, therefore associated with less accurate atmospheric correction. Using NASA SeaDAS software for OC satellite data processing, characteristics of aerosols in atmospheric correction models for VIIRS and MODIS sensors are retrieved and compared with the ones from AERONET-OC data in terms of aerosol optical depth (AOD) and phase functions at the several AERONET OC sites. The impact of the Sun-sensor geometry and wind speed on the differences in aerosols parameters are evaluated and correlated with the accuracies in retrieval of the remote sensing reflectance spectra from ocean waters. Significant dependence of AOD on the wind speed is demonstrated, which is most likely related to the modeling of the state of the ocean surface and at least partially associated with dependence of sea surface reflectance on the wavelength, AOD and polarization effects.

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WATER MASS STRUCTURE IN THE NORTHERN BERING SEA RELATED TO LIGHT ABSORPTION OF CDOM

The northern Bering Sea (NBS) is one of the most productive regions in the world. Several currents with different water characteristics pass through the NBS and high productivity is sustained in a boundary of those currents. However, these currents have similar temperature and salinity (T-S) seasonally and it is difficult to classify of water masses using T-S diagram. Here we attempted to use light absorption coefficient by colored dissolved organic matter (CDOM) to distinguish the water mass in the NBS. Water samples were taken at 23 stations during the cruise of T/S Oshoro-maru in July 2017. CDOM absorption coefficient between 250-750 nm was measured and spectral slopes in the two ranges of 275-295 and 350-400 nm (S275-295 and S350-400) were calculated. Mean values of CDOM absorption at 350 nm, a(350), and spectral slopes of Alaskan coastal water (ACW), Bering summer water (BSW) and Bering winter water (BWW) are significantly different each other. While the ACW, which distributed at the surface of NBS widely in this season, was hard to separate using CDOM characteristics, the BSW was successfully divided two waters using relationship between a(350) and S275-295. The two waters had similar CDOM characteristics to the ACW and BSW. These results suggested that mixing process of the water masses to create productive water in the NBS might be speculated using CDOM absorption spectra.

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THE POTENTIAL FOR OCEAN REMOTE SENSING WITH SPACEBORNE HIGH SPECTRAL RESOLUTION LIDAR

The CALIOP lidar, operating since 2006 on the CALIPSO satellite, has demonstrated that spaceborne lidar has the sensitivity to provide scientifically valuable ocean data products. These products include a fundamental optical property, the particulate backscatter coefficient, and two key carbon cycle stocks, phytoplankton biomass and particulate organic carbon. Because lidar provides information regardless of sun angle and through gaps between clouds, it is a natural complement to ocean color and often provides sampling in regions and times of the year beyond the capability of passive sensors. CALIOP is a standard backscatter lidar and was not designed for ocean measurements. Its coarse vertical resolution limits ocean retrievals to surface-weighted column estimates rather than providing depth resolved information. Since 2012, a high-vertical-resolution airborne lidar employing the high-spectral-resolution lidar (HSRL) technique has demonstrated the value of this more advanced approach for providing depth-resolved profiles of key optical properties (particulate backscatter coefficient and attenuation coefficient) from which higher-order science products can be derived. The approach is being considered for the future satellite observing system defined in the US 2017 Decadal Survey for Earth Science and Applications from Space. We will present example ocean retrievals from airborne HSRL and simulations of the resolution and precision achievable from various space configurations. We also explore the lidar science value as a function of capability, with CALIOP at one end of the spectrum and a multi-wavelength HSRL with laser-excited chlorophyll fluorescence sensitivity at the other end.

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IMPROVING SATELLITE GLOBAL CHLOROPHYLL-A DATA PRODUCTS THROUGH ALGORITHM REFINEMENT AND DATA RECOVERY

A recently developed algorithm to estimate surface ocean chlorophyll-a concentrations (Chl in mg m^{-3}), namely the ocean color index (OCI) algorithm, has been adopted by the U.S. NASA to apply to all satellite ocean color sensors to produce global Chl maps. The algorithm is a hybrid between a band-difference color index (CI) algorithm for low-Chl waters and the traditional band-ratio algorithms (OCx) for higher-Chl waters. In this study, the OCI algorithm is revisited for its algorithm coefficients and for its algorithm transition between CI and OCx using a merged dataset of HPLC and fluorometric Chl. Results suggest that the new OCI algorithm (OCI2) leads to lower Chl estimates than the original OCI for Chl < 0.05 mg m^{-3} but smoother algorithm transition for Chl between 0.25 and 0.40 mg m^{-3}. Evaluation of Chl data products from SeaWiFS and MODISA using in situ data suggests similar accuracy between OCI2 and the original OCI. Similar to the original OCI, the OCI2 algorithm can provide significantly improved image quality as well as improved cross-sensor consistency between SeaWiFS, MODISA, and VIIRS over the OCx algorithms for oligotrphic oceans. Furthermore, data statistics showed that on average, valid Chl retrievals over the global oceans can be increased by 40% (i.e., from the original 5% to the current 7%) with the OCI2 algorithm without sacrificing data quality. Such an increase will not only improve the spatial/temporal coverage but also reduce uncertainties in Chl retrievals.

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A 20-YEAR ANALYSIS OF PHYTOPLANKTON IN THE NORTHEAST U.S. CONTINENTAL SHELF LARGE MARINE ECOSYSTEM WITH IMPLICATIONS FOR FISHERIES

The Northeast U.S. Continental Shelf (NES) Large Marine Ecosystem is a highly productive, temperate system that is warming much faster than the global ocean. With two decades of continuous ocean color remote sensing data, we can now observe long-term spatio-temporal patterns in phytoplankton biomass and primary production. Furthermore, advances in phytoplankton size class and functional group algorithms have expanded the ability to assess spatial and temporal variability in phytoplankton community composition. To increase the accuracy of the remote sensing observations, in situ phytoplankton pigments, primary production, species composition, and radiometry data are being used to generate and validate regional algorithms of phytoplankton parameters in the NES. These data are then used in a bottom-up food web based approach to estimate ecosystem production and fisheries exploitation rate potentials. In some regions of the NES, primary production has been steadily increasing since 1998, while the ratio of microplankton to smaller nano- and picoplankton has more sharply increased since 2005. These changes correspond to a general increase in fish and invertebrate biomass in the NES. Changes in total production and the fraction of microplankton production ultimately control fish and shellfish production and set constraints on the amount of production available to be extracted from the ecosystem at sustainable levels. By gaining a better understanding of the spatial and temporal changes in the phytoplankton community composition and associated primary production, we can better predict overall ecosystem production and subsequently, sustainable harvest levels and possible consequences of climate change.

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EVALUATION OF THE PERFORMANCE OF INVERSION ALGORITHMS TO ASSESS PHYTOPLANKTON AND COLORED DETRITAL MATTER ABSORPTION COEFFICIENTS FROM OLCI/SENTINEL-3 OBSERVATIONS.

In the frame of the EUMETSAT project aiming to derive IOPs from Remote Sensing Reflectance (Rrs) from OLCI/Sentinel-3 observations, this study tested a two-steps algorithm approach. The first step used Loisel & Stranski (2018) algorithm (LS2) to obtain total absorption and total backscattering from Rrs. The second step focusses on the estimation of the absorption coefficient of phytoplankton (aphy) and colored detrital matter (acdm) from non-water absorption coefficient (anw). For this purpose, different approaches are tested against synthetic (not subject to measurement errors) and in situ datasets. The algorithms tested for this second step are: Zhang et al., 2015, Zheng et al., 2015 and Bricaud & Ciotti 2012. The synthetic dataset developed as part of the International Ocean Colour Coordinating Group (IOCCG) Working Group (IOCCG, 2006), where IOPs are mainly driven by the chlorophyll concentration, and the one developed in the frame of CoastColour Round Robin for coastal waters (Nechad et al., 2015), are used for that purpose. The in situ datasets covers a broad range of oceanic and coastal marine environments, as well as inland environments. The algorithms performance is evaluated by using the initial constraints and by testing different band combinations. An uncertainty analysis is also performed for the proposed algorithms, adding a standard normal distribution noise with different weights to anw. This analysis aims to test the robustness of the latter algorithms to uncertainty propagation. Lastly, the algorithms are implemented on a OLCI image over the global ocean, to assess the noise on aphy and acdm estimates.

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THE RELATIONSHIP BETWEEN PHYTOPLANKTON ABSORPTION COEFFICIENT AND CHLOROPHYLL-A CONCENTRATION FOR REMOTE SENSING APPLICATIONS IN OPTICALLY COMPLEX WATERS.

Phytoplankton main pigment Chlorophyll a (Chl a) has been a proxy for phytoplankton biomass for a long time despite of its variable content in a cell. Phytoplankton pigment absorption (aph) is an important parameter to support models for bio-optical remote sensing (RS) algorithms for Chl a retrieval. RS of Chl a in highly turbid inland and coastal waters represent a challenge, due to masking of the Chl a signal by various amounts of highly absorbing coloured dissolved organic matter (CDOM). In Estonian lakes CDOM is the main absorber, especially in dark-water lakes, where CDOM absorption might account for up to 100%. We studied the relationship between aph at 442 and 670 nm and Chl a concentration in Estonian large lakes Peipsi (N=346) and Võrtsjärv (N=94) together with small lakes (N=59) during 2012-2017. Linear relationship fitted for all studied lakes, but power function suited better for L. Võrtsjärv. Strong relationship (R^2> 0.6) between Chl a and aph was evident in all studied lakes. Correlation between Chl a and aph was stronger using aph values at 670 nm (R^2= 0.7), whereas strongest correlation and lowest RMSE was found in small lakes (R^2= 0.89). Seasonal variation of phytoplankton absorption was studied in Estonian large lakes: average absorption was generally lower in May and June, and highest in August-September in case of Peipsi and Lämmijärv and in October in Võrtsjärv. Various bio-optical models are tested on Sentinel-3/OLCI data to estimate the retrieval of aph and its suitability to generate a product for Chl a.

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BIO-OPTICAL PROPERTIES AND EMPIRICAL ALGORITHMS ON VICINITY WATERS OF SVALBARD, ARCTIC

Chlorophyll (Chl) concentration is one of the key indicators identifying changes in the Arctic marine ecosystem. However, current Chl algorithms are not accurate in the Arctic Ocean due to different biooptical properties from those in the lower latitude oceans. In this study, we evaluated the current Chl algorithms and analyzed the cause of the error in the western coastal waters of Svalbard, which are known to be sensitive to climate change. The NASA standard algorithms showed to overestimate the Chl concentration in the region. This was due to the high non-algal particles (NAP) absorption and colored dissolved organic matter (CDOM) variability at the blue wavelength. In addition, at lower Chl concentrations (0.1–0.3 mg m^3), chlorophyll-specific absorption coefficients were 2.3 times higher than those of other Arctic oceans. This was another reason for the overestimation of Chl concentration. OC4 algorithmbased regionally tuned-Svalbard Chl (SC4) algorithm for retrieving more accurate Chl estimates reduced the mean absolute percentage difference (APD) error from 215% to 49%, the mean relative percentage difference (RPD) error from 212% to 16%, and the normalized root mean square (RMS) error from 211% to 68%. This region has abundant suspended matter due to the melting of tidal glaciers. We evaluated the performance of total suspended matter (TSM) algorithms. Previous published TSM algorithms generally overestimated the TSM concentration in this region. The Svalbard TSM-single band algorithm for low TSM range (ST-SB-L) decreased the APD and RPD errors by 52% and 14%, respectively, but the RMS error still remained high (105%).

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SEADAS: NASA SOFTWARE FOR THE ANALYSIS OF EARTH-VIEWING SATELLITE DATA

SeaDAS is a comprehensive software package developed by NASA OBPG (Ocean Biology Processing Group) for the processing, display, analysis, and quality control of remote-sensing Earth data . SeaDAS is open-source and serves as the official distribution point of the NASA OBPG Science Software. This science processing component of SeaDAS applies the OBPG algorithms to satellite data in order to characterize and calibrate the data and generate science quality OBPG products. Additional coinciding ancillary data are retrieved and used to correct for and calibrate out the atmospheric components of the signal in order to determine an Earth/ocean surface component of the signal and consequently to generate higher order products in the optical path such as Chlorophyll, SST, KD_490, etc. SeaDAS processing provides a standardized data format across a multitude of satellites, currently supporting over 15 US and international satellite missions. The visualization and analysis tools can also be used on many other satellite missions. Customized algorithms can be developed and applied within SeaDAS to evaluate ocean, land and atmospheric data, as well as to produce True Color imagery. SeaDAS can also integrate SeaBASS format field measurement (in situ) data for comparative analysis with relevant satellite data. Scientific data products can be exported from SeaDAS in file formats readily readable by many third party GIS analysis packages.

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EXPLOITATION OF THE OLCI OCEAN COLOUR SENSOR IN REMOTE SENSING OF SELECTED OPTICAL WATER PROPERTIES IN THE NORDIC SEAS

The IOP variability in the Nordic Seas depends on large scale circulation patterns and mixing of distinct water masses, phytoplankton dynamics and sea ice melting processes. Considering that in the Arctic climate warming was the most pronounced, the environment has changed drastically in the last decade. The increase of the loads of melted water, the area of ice-free surface exposed to solar irradiance that penetrates the water, along with the expansion of Atlantic Waters in the Nordic Seas resulted in a shift of phytoplankton phenology. Particularly, the northward propagation of the opportunistic coccolithophore species has been observed in the high Arctic. The aim of this study was to develop algorithms for remote sensing of the absorption properties in the area, with a particular focus on the Sentinel-3 Ocean and Land Colour Instrument (OLCI). The analysed database had been collected during three field campaigns conducted in following summer seasons 2013 – 2015 in the Nordic Seas. The possible influence of the shift in phytoplankton communities on particle absorption was examined initially. The empirical formulas between the phytoplankton pigments absorption, the particulate absorption and the total absorption at 443 and 670 nm were investigated. The operational performance of the OLCI sensor was taken into account, so relationships were adjusted to its bands. The developed and validated relationships between absorption properties and the remote sensing reflectances of the new spectrometer constitutes a valuable upgrade in case of the dynamic changes in the area and ensures retrieving reliable satellite information from the Nordic Seas.

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MULTI-PARAMETER ASSESSMENT OF PHYTOPLANKTON COMMUNITY COMPOSITION FROM ABSORPTION, REFLECTANCE, AND QUANTITATIVE IMAGING

The composition of phytoplankton pigments differs between phytoplankton groups, making pigments useful chemotaxonomic markers for determining phytoplankton community structure. The composition and concentration of pigments directly affect the shape and magnitude of spectral phytoplankton absorption (aph), an Inherent Optical Property (IOP), making absorption a proxy for taxonomy. aph in turn affects the shape and magnitude of spectral remote-sensing reflectance (Rrs), an Apparent Optical Property (AOP). While these optical properties can be used to determine phytoplankton taxonomy, the gold standard for assessing phytoplankton community composition is through cell quantification with microscopy and imaging. Thus, phytoplankton pigments provide the logical link between optical properties (absorption and reflectance) and measured phytoplankton taxonomy (imaging). Here, we perform a multi-parameter assessment of phytoplankton taxonomy in a tidally variable coastal Maine estuary using IOPs, AOPs, and cell imaging. Our IOP data include aph measured with the Quantitative Filter Technique and extracted pigment absorption spectra, which is then decomposed into phytoplankton pigment composition and concentration. Our AOP data include in- and above-water Rrs. We use a reflectance inversion algorithm to derive aph from Rrs and compared the measured and inverse-modeled aph, as well as the measured and forward-modeled Rrs. We confirm these results with direct assessment of phytoplankton community composition from quantitative imaging of fluorescing cells via the Imaging FlowCytobot. Our results show coherence between the optical proxies and the quantitative imaging data, and suggest a dominance of dinoflagellates at the time of sampling, indicated both by cell counts and spectral features in the optical data.

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REMOTE SENSING OF RIVERINE SURFACE REFLECTANCE WITH SENTINEL-2A AND LANDSAT-8 IMAGERY IN GOOGLE EARTH ENGINE

Atmospheric correction remains a major source of uncertainty in the retrieval of inland water properties from space. While increasing radiometric and spatial sensor resolution allows us to observe the earth at even finer spatial and temporal scales, the fidelity of surface reflectance retrievals over rivers remains mainly untested. Here we evaluate surface reflectance products derived from NASA's Landsat-8 and ESA's Sentinel-2A satellites. We compare surface reflectance from the Landsat-8 Surface Reflectance Code (LaSRC) to those produced by two aquatic techniques: SeaDAS and ACOLITE. Using Google Earth Engine for analysis, we then validate remote sensing reflectance and consequent chlorophyll-a and turbidity estimates using field data collected over two major global rivers: the Columbia and the Amazon. For sites where radiometric data was available, both terrestrial and aquatic approaches show strong correlations with in situ measurements. LaSRC produced a brighter spectra than aquatic methods with an average bias across sensors of 0.009 sr^{-1} . That gap was almost 75% larger for Sentinel-2 spectra, where the average difference was 0.02 sr^{-1} compared to the 0.004 sr^{-1} difference observed in Landsat-8. Both terrestrial and aquatic methods were able to estimate surface reflectance within <15% mean absolute percent difference of field measurements. While satellite surface reflectance showed a strong correlation with field measurements in most cases with mean absolute percent errors ranging from 1.6 - 13%, uncertainties for bio-optical algorithms were higher (15 - 30%), suggesting more work needs to be done constraining uncertainties in Rrs estimates and bio-optical algorithm products in rivers.

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INFORMATION CONTENT OF IN SITU AND REMOTELY SENSED CHLOROPHYLL-A: LEARNING FROM SIZE-STRUCTURED PHYTOPLANKTON MODEL

The distribution of phytoplankton shows high spatial and temporal variability. Chlorophyll-a concentration (Chl-a) derived from satellite remote sensing reflects both real phytoplankton variability and inherent uncertainties. Ocean colour data are commonly used to calibrate marine biogeochemical models; therefore, understanding the distribution of errors in the remotely sensed Chl-a product is critical. Here, we explore the relationship between phytoplankton size structure and an ocean colour product (GlobColour) using both model simulations and in situ observations. We focused on the offshore eastern Australian ocean region, largely characterised by oligotrophic waters in which phytoplankton primarily define the optical properties of the water column. To explore the properties and relationship of the satellite ocean colour product and in situ observations, theoretical experiments were performed through a coupled biogeochemical-optical model. Specifically, an optical model was used to calculate the inherent optical properties (IOPs) of seawater from size dependent multi-phytoplankton biogeochemical model simulations and convert them into remote-sensing reflectance (Rrs). Then, Rrs was used to produce a satellite-like estimate of the simulated surface Chl-a concentration through the OC3M algorithm. The information content of simulated in situ and simulated remotely-sensed data sources was investigated through theoretical experiments that suggested the OC3M algorithm underestimates the simulated Chl-a concentration because of the weak relationship between large-sized phytoplankton and Rrs. This concept was tested with data collected in the same area during an oceanographic voyage. The consequent ocean colour match-up points confirmed the underestimation of in situ Chl-a concentrations when phytoplankton larger than 10 µm dominated the photosynthetic community.

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HABITAT SUITABILITY INDEX MODEL FOR CHUB MACKEREL (SCOMBER JAPONICUS) IN THE SOUTHERN SEA OF SOUTH KOREA USING GEOSTATIONARY OCEAN COLOR IMAGER (GOCI) AND VISIBLE INFRARED IMAGING RADIOMETER SUITE (VIIRS)

The decline of fishery landings driven by the climate change in South Korea has been a big concern over the last several decades. The climate-induced warming in Korean waters has led to not only a decrease of fishery landings but also a change of habitat location of many marine fishes. For instance, the landed amount of commercial fish had decreased for about a million ton during the last decade. Moreover, the populations of warm-water fish species are growing while the cold-water fish species are being reduced by the increased SST in Korea. Accordingly, monitoring the distribution of the fishery resources is becoming increasingly important. Habitat suitability index (HSI) model has been widely used to locate fishing spots with satellite dataset. In this study, we used the commercial catch data of the chub mackerel (Scomber japonicus) and environmental factors derived by Geostationary Ocean Color Imager (GOCI) and Visible Infrared Imaging Radiometer Suite (VIIRS) to calculate the HSI for chub mackerel in the South Sea of South Korea. Optimal environmental conditions for the chub mackerel were found to be SST, chlorophyll-a (chl-a) concentration, and primary production of phytoplankton. Approximately more than 85% of the total catch was found in the areas with the ranges of 0.17-0.39 mg m^{-3} for chl-a, 10.85-23.26°C for SST, and 289.31-641.32 mg C m^{-2} d^{-1} for primary production. We expect that the high spatio-temporal resolution data from GOCI will provide us a diurnal variation of the chub mackerel's habitats in the South Sea of South Korea.

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HYPERSPECTRAL REMOTE SENSING OF HARMFUL ALGAL BLOOMS IN LAKES (GREAT AND SMALL) AND RIVERS

In the Great Lakes region, despite the diversity of toxic cyanobacteria that have been historically present, there has been a recent proliferation and dominance of cyanobacteria blooms by the genus Microcystis. In many cases, these blooms have been associated with high concentrations of the toxin microcystin, which is particularly troubling given the impact to wildlife and the usage of these fresh water resources for drinking water and recreational activities. There is significant need for improved remote sensing capabilities to both monitor and study these blooms. A multi-year research activity to develop remote sensing algorithms that will improve the capability to remotely sense water quality from space began in 2015. The algorithms are focused on improving the capability to assess harmful algal blooms across North America, including the Laurentian Great Lakes, rivers, and small inland lakes, all of which are impacted by eutrophication and changes to their ecology. The research team has utilized water sampling data, airborne hyperspectral data, and satellite observations to develop remote sensing algorithms that delineate algal types and other water constituents important to algal bloom development, such as phytoplankton competitors and sediment plumes. Algorithms being developed and assessed include: Spectral Decompostion by Varimax-Rotated Principal Component Analysis (VPCA), Adaptive Cyanobacterial Index (CI), Scum Index, Ensemble Machine Learning and Atmospheric Correction for Adjacency Effect for Rivers and Small Lakes and bio-optical model based approaches. The algorithms are being developed utilizing both hyperspectral and multispectral data and the efficacy of the algorithms to the different operational platforms is assessed.

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COMPONENTS AND THEIR IMPACTS ON THE RETRIEVAL OF CHLOROPHYLL CONCENTRATION VIA THE SPECTRAL OPTIMIZATION SCHEME

Compared to the one-step empirical ocean color algorithm for chlorophyll concentration (Chl), the spectral optimization algorithm (SOA) can be perceived as a multi-component and multi-step algorithm for the retrieval of Chl from an Rrs spectrum. However, although SOA is rooted in ocean-optics and radiative transfer, studies have found that even after optimization of the model components of an SOA, the resulted Chl to the best is just "equivalent" to the Chl obtained from the standard empirical approach, which is thus not matching the goal of SOA for the estimation of Chl from ocean color. Here we use both synthetic and measured data to diagnose the impact of the components associated with SOA on the derivation of Chl, where the objectives include 1) to understand the effect of each individual component on the retrieval of Chl via SOA, and 2) to highlight the important or key components that are critical to improve the overall SOA scheme for Chl retrieval. The results indicate that the key source of errors come from the model of the spectral shape of detritus-gelbstoff absorption coefficient, while the spectral models of particle backscattering and phytoplankton absorption coefficients have a lesser impact. Ways to improve the estimation of detritus-gelbstoff absorption spectral shape and the advantages and limitations of both empirical and SOA schemes are discussed.

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MERGING GLOBAL SNPP AND NOAA-20 VIIRS OCEAN COLOR DATA PRODUCTS

The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (SNPP) and NOAA-20 has been providing large amount of global ocean color data, which are critical for monitoring the ocean optical and biological processes and phenomena. However, VIIRS-derived daily ocean color image either on the SNPP or NOAA-20 is limited in ocean coverage due to its swath width, high sensor zenith angle, sun glint, and cloud, etc. Merging VIIRS ocean color products from the SNPP and NOAA-20 significantly increases the coverage of daily images. Two VIIRS sensors on the SNPP and NOAA-20 have similar sensor characteristics, and ocean color data are derived using the same ocean color data processing system. Therefore, the merged ocean color data are expected to have high quality with consistent statistical property and accuracy. In this presentation, a suite of merging methods is explored, including simple binning, weighted average, optimal interpolation, and machine learning method, to account for different satellite passing time and different solar and sensor zenith angles. In particular, since the spectral band wavelengths are slightly different between the two sensors, before merging process, the NOAA-20 normalized water-leaving radiances [nLw(l)] are converted to the VIIRS SNPP bands using the relationship obtained from the MOBY in situ measurements. Results of merged VIIRS products, i.e., normalized water-leaving radiances nLw(l) at 410, 443, 486, 551, 638, and 671 nm, chlorophyll-a concentration (Chl-a), and water diffuse attenuation coefficient at 490 nm, Kd(490), as well as comparisons among different merging methods will be presented and discussed.

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EVALUATING TIME-SERIES OBSERVATIONS OF PHYTOPLANKTON COMMUNITY DYNAMICS AT THE MARTHA'S VINEYARD COASTAL OBSERVATORY IN THE CONTEXT OF REGIONAL VARIABILITY

The northeastern U.S. continental margin is a highly productive ecosystem and is increasingly experiencing the impacts of changing climate and human activity. Phytoplankton community dynamics can profoundly influence food web and biogeochemical processes, but sustained temporal observations of phytoplankton variability in relation to environmental drivers are limited. An ongoing, multi-year time series at the Martha's Vineyard Coastal Observatory (MVCO), located between the highly productive waters of the Georges Bank and the Middle Atlantic Bight, has provided preliminary evidence pointing to trends in phytoplankton community response to changing ecological and environmental drivers, including changes in major taxa, persistence of seasonal diatoms blooms despite environmental extremes (warming conditions), and optical proxies consistent with an overall increase in the composite cell size index for the phytoplankton community. We describe efforts involving a combination of high temporal and spectral resolution radiometry at MVCO complemented by in situ time-series of environmental variables and boat-based observations (~monthly at MVCO including depth and optical profile sampling). Additional information includes in situ characterization of diversity in the phytoplankton through the automated submersible flow cytometers (FlowCytobot and Imaging FlowCytobot). Satellite-based (MODIS, VIIRS) remote sensing enable the interpretation of the observations at MVCO in the context of regional scale spatial-temporal variability. We examine the MVCO time-series in the context of regional patterns in satellite-derived indices of phytoplankton biomass and community composition with the objective of providing an improved understanding of drivers of coastal ecosystem change in the New England shelf region.

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Poster 160
REMOTE SENSING OF A MASSIVE DINOFLAGELLATE HAB EVENT IN SOUTHERN BRAZIL

Harmful algal blooms (HABs) are deleterious ecological phenomena that can have severe impacts on coastal ecosystems, fisheries resources and public health all over the world, therefore, our ability in detecting and monitoring them should be improved. Different HABs species have distinct spectral characteristics due the specific absorption of their accessory pigments, allowing us to monitor then through remote sensing. On June 2016, a major Dinophysis cf. acuminata bloom hit the southern Brazilian coast causing damage to the local mariculture along its trajectory. During its peak, the bloom reached an area of 201km^2 along the Paraná coast with abundances of 1,310,000 cells.L^{-1}, leading the authorities to issue the shellfish harvesting ban in Santa Catarina and Paraná states. In order to observe its passage and evolution, we performed weekly sampling cruises in estuarine and inner shelf of Paraná. Remote sensing reflectance (Rrs) data were performed with FieldSpec ASD, along with environmental parameters (water temperature, salinity, Secchi depths, chlorophyll and particulate matter concentration). Images from MODISA, VIIRS and Landsat8 were processed with SeaDas software to quantify the magnitude of the HAB. The event was associated with low salinity and marked stratification. The Rrs values of satellite and in situ data where compared and a good relationship between Landsat8 and Rrs just above water where found (correlation of 0.71 at Rrs481nm band). The Rrs spectral shape present patterns related to the abundance of the dominant phytoplankton, where, the highest values in abundance of Dinophysis are related with flatted Rrs, due to the package effect.

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Poster 164
DEEP LEARNING MODEL FOR BENTHIC CLASSIFICATION FROM REMOTE SENSING REFLECTANCE

Deep learning and Artificial Intelligence have been described as the new electricity. In recent years, the use of deep learning has achieved state of the art performance in fields such as computer vision, natural language processing and image segmentation just to name a few. Deep learning is driving new innovation in self-driving cars, the manufacturing sector, gaming, precision medicine and various analysis. Google's deep learning model, AlphaGo, is now able to beat a human Go grandmaster. As the volume of available data increases, machine learning models continually achieve greater than human level accuracy. Currently, remote sensing optical models are built using an understanding of optical radiative transfer. These models can be complex and computationally intensive for computers to solve. One advantage of using a machine learning model is, the model does not need to know anything about optical physics. Machine learning models are universal function approximators. Using deep learning, the computer discovers the best model based purely on the training data it is provided. As such, these models are able to discover much simpler and faster models with comparable recall accuracy. In this paper we present a data driven, optical model, built with no prior knowledge of radiative transfer or prior domain specific knowledge. The model was trained using simulated and labelled remote sensing reflectance spectra. The deep learning model is able to accurately classify benthic class from remote sensing reflectance. All of the source code and data are published in a jupyter notebook on Github under creative commons licence.

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TRACING TREND IN FLUX OF DISSOLVED ORGANIC CARBON OBSERVED IN MOUTHS OF MAJOR ARCTIC RIVERS: A SATELLITE VIEW

Global warming is affecting a broad spectrum of terrestrial and marine environments in high northern latitudes. River discharge has increased in both North American and Siberian sides of the Arctic region particularly since late 20th century. Significant amount of organic carbon originating from permafrost thaw is anticipated to be delivered by river discharge into the Arctic Ocean. We estimated, for the first time, the flux of dissolved organic carbon (DOC) in the Mackenzie River mouth from 2003 to 2013 using satellite ocean color data with known uncertainty. Our results show that there was no trend in DOC flux for the period considered. This is mainly attributed to no trend in river discharge. However, the depth of active layer of soil that annually thaws and freezes increased significantly. Doxaran et al. (2015) showed that the flux of particulate organic carbon (POC) has a positive trend in the same period. Given the age of POC observed in our study areas is old (thousands of years from the present; Guo et al., 2007), these findings suggest that organic carbon originating from permafrost thaw is already being observed in the Mackenzie River mouth. Possibilities regarding the difference of trends in DOC and POC fluxes will be further discussed.

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STATISTICAL EVALUATION OF VIIRS OCEAN COLOR DATA RETRIEVALS

Validation of satellite ocean color data requires extensive comparisons with in-situ data. However, sparsity of in-situ data prohibits validation at global scales. Instead, time averaged satellite data itself can be used as a global reference to verify the data statistical consistency. This is especially justified in the open ocean where the relevant time scales of changes in water optical, biological, biogeochemical properties are longer and span time period of multiple satellite observations. We have used the recently improved Multi-Sensor Level-1 to Level-2 (MSL12) ocean color data processing system to obtain the normalized water-leaving radiance spectra from the Visible Infrared Imaging Radiometer Suite (VIIRS) measurements. We investigate the deviations of the normalized water-leaving radiances from the time averaged values, and collect the statistics of these deviations with respect to various retrieval parameters and sensing conditions. We demonstrate that MSL12 produces statistically consistent retrievals in the open ocean, with respect to majority of the retrieval parameters. We observe slightly increased radiances near clouds, however the band ratios used for deriving chlorophyll-a concentration and the water diffuse attenuation coefficient at 490 nm Kd(490) are much less affected. In difficult retrieval conditions with very high solar- and sensor-zenith angles, MSL12 produces lower than average normalized water-leaving radiances, and this study yields the ranges of parameters in solar- and sensor-zenith angle for valid retrievals. Some statistics results from VIIRS ocean color data performance over coastal and inland waters will also be presented and discussed.

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OPTICAL DETECTION OF CORAL REEFS

An effective and validated index that is simple to implement would be highly useful for long-term management and monitoring of coral reefs and identifying the location and distribution of the coral reefs are important for exploring their health conditions in the vast shallow coastal water environments. The present work is therefore focused on combining the optical visible remote sensing reflectance bands and coral reef index (CRI) for mapping the coral reefs in the Gulf of Mannar along the coast of Tamil Nadu. In particular, the colour composite image generated using the Landsat 8 OLI bands in the near infrared (865 nm) and shortwave infrared region (1609 nm and 2201 nm) and near-infrared band (865 nm) along with the CRI [(865-1609)/(865+1609)] have been shown to be effective in identifying the location, spatial distribution and health status of coral reefs in the Gulf of Mannar region. Caution should be exercised when interpreting these products as the detected spatial distribution and intensity are dependent on the effect of tidal variation, water turbidity, bottom reflectance and sensor characteristics.

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SINKING CARBON ASSOCIATED WITH COCCOLITHOPHORE BLOOMS IN THE SUBPOLAR OCEANS FROM BIOGEOCHEMICAL-ARGO PROFILING FLOATS

Coccolithophores, calcifying phytoplankton, form extensive annual blooms in the Subpolar Oceans, producing large quantities of calcite in the surface ocean. They are thought to enhance the sinking of organic carbon to the deep ocean by increasing the density of organic particles, or by protecting the more labile organic carbon from degradation while sinking. Here, we investigated this so-called ballast hypothesis using optical measurements on Biogeochemical-Argo profiling floats in conjunction with remotely sensed calcite concentration from ocean color satellites. Based on a match-up analysis, we first developed an algorithm to identify coccolithophore blooms in the surface ocean and estimate their calcite concentration from floats using measurements of chlorophyll-a fluorescence and particulate backscattering and beam attenuation coefficients. Next, we examined (i) carbon fluxes at depth using existing optical sediment trap methods, (ii) their transfer efficiency, (iii) the sinking speed of particles, and (iv) changes in their bulk refractive index (obtained from the particle backscattering ratio) during sinking. Our results show that Biogeochemical-Argo floats successfully identified coccolithophore blooms and allowed a reliable estimation of associated calcite concentration. The floats captured well the seasonal signal of carbon export and transfer associated with coccolithophore blooms in the Subpolar Oceans. Further, our observations of increased refractive index of particles with increasing depth and over time provide support for the hypothesis that calcite protects organic carbon from degradation while sinking, thereby enhancing long-term storage of carbon in the deep ocean.

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A TIME-LAPSE SEQUENCE OF PARTICLE ARRIVALS IN THE 2018 EXPORTS SEDIMENT TRAPS

Custom time-lapse cameras (“SnoCams”) were mounted below gel-based sediments traps at three depths spanning the upper twilight zone during the recent EXPORTS 2018 cruise. These cameras took photos of the particles accumulated in the gel every 10 minutes, spanning the month-long experiment. The cameras are compact (<0.5 litre), low cost (<$100) and use a novel power-switching solution to optimize energy efficiency - with sufficient battery life to take hourly images for 4 months. The preliminary findings from this first-time deployment are presented and interpreted in the context of high resolution bio-optical profiles made by a Wirewalker platform deployed near the traps.

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VALIDATION OF OCEAN COLOR SATELLITE PRODUCTS AND SERVICES AS PART OF THE DATA CUBE SERVICE FOR COPERNICUS PROJECT (DCS4COP)

The overall objective of DCS4COP project (EU-H2020, 2018-2020) is to set-up, demonstrate and establish a novel DataCube service for the value-adding Earth Observation industry at highly competitive costs. The specific objectives are (1) to provide a novel service to intermediate business users, (2) to exploit the scientific excellence of precursor projects, (3)To develop and establish a DataCube environment for Copernicus data, and (4) to exploit European EO infrastructure. Today, ocean color observations represent one of the most used tools in oceanography. Satellite products are available are at hourly, daily, monthly, seasonal and annual temporal resolutions and now at spatial resolutions (20-300-1000 m) well adapted for the operational monitoring of coastal waters). In DCS4COP the DataCube service will be available in several European coastal areas. It combines autonomous field measurements, satellite observations together with outputs from physical and biogeochemical models. From these datasets key DataLayers such as SST, turbidity, concentrations of chlorophyll-a and the total suspended matter will be generated, quality controlled and re-projected to a common grid to facilitate ingestion into the Data Cube. The validation of each DataLayer will be done using validation protocols designed during the HIGHROC project (www.highroc.eu) for ocean color satellite products. It is based on numerous high-quality match-ups between autonomous field data and satellite products in various European coastal waters.

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WISPSTATION: A NEW AUTONOMOUS ABOVE WATER RADIOMETER SYSTEM

A new autonomous above water radiometer system (WISPstation) was developed based on the experience with the handheld WISP-3 system. The instrument records reflectance with an extended wavelength range of 350 to 1100 nm in two viewing directions, which enables continuous and autonomous high-quality measurements for autonomous water quality monitoring and satellite validation. All channels are measured with a single spectrometer. This design makes resulting reflectances less sensitive to radiometric and spectral calibration errors and drifts. In various Copernicus projects (Tapas, EOMORES, CoastObs and Monocle) the WISPstation is being tested in highly diverse water types and environmental conditions, ranging from case-1 in Mediterranean coastal waters to turbid waters with cyanobacteria proliferation in lakes and lagoons. In view of its initial scientific application, the system is designed to reliably produce high frequency observations to quantify variability in physical and biological water system parameters. The WISPstation results are stored in the online database WISPcloud allowing users to extract data for analysis. A webinterface is being set up to visualise the measurements. We present spectral results, time series analysis, drift analysis, and satellite match-up validation results for various locations.

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Poster 199
EMBRACING VARIABILITY: HOW CAN WE USE PATCHY DATA TO ACCOUNT FOR SUBMESOSCALE PROCESSES?

The ocean is a highly dynamic system, a confluence of biological, chemical and physical process. These processes happen at different spatial and temporal scales and their interaction often results in non-linear dynamics. The common practice is to average results across a meaningful spatial or temporal resolution and compare the means. Our hypothesis is that understanding the fine scale variability (rather than solely the broad mean) might provide better insight and predictive ability. One of the biggest challenges is obtaining high spatial and temporal resolution global data. Here we use satellite, modeling, Bio-ARGO floats and in situ data to investigate the role of fine scale temperature variability on phytoplankton community dynamics. To our knowledge, no study has focused on the variability aspect or studied all 4 components simultaneously. Using pigment ratio variability as a proxy for variability in phytoplankton community composition, we compiled a quality-controlled dataset of HPLC pigment records (MAREDAT, NASA, HOT, BATS, PALMER) combined with BIO-ARGO profile data, focusing on surface samples (<20m, ~ 84,000 and ~275,000 data points, respectively). We then selected forty 5x5 degree bins from environmentally different locations with abundant HPLC or ARGO data and matched those with MODIS SST. Ideally, we could bridge the limited HPLC and Bio-ARGO observations using global satellite data. Some of our initial findings suggest that 1) the open-ocean oligotrophic regions are more dynamic than we previously expected, 2) ARGO and MODIS show similar ranges of temperature variability, 3) temperature variability could serve as a predictor of variability in community composition.

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Poster 203

NOVEL TECHNOLOGY TO EXPLORE THE MESOPELAGIC OCEAN

The ocean's mesopelagic zone (≈ 200 – 1000 m) is largely uncharacterized despite indicators that it plays a critical role in ocean ecosystems, with a biomass estimated at 10 billion metric tons. Novel, complementary techniques are needed for exploration of the biogeochemical composition of the mesopelagic, and to better understand dynamic distributions of organisms and their relationship with surface productivity, fisheries, and biomass transfers. We have developed a vertical profiler combining acoustic and optical techniques to assess organism distribution and patchiness on a spectrum of spatial scales, filling the gap between long range ship-based acoustics and the small scales typically resolved with optical techniques. The instrumentation package consists of a next generation Spatial PLankton Analysis Technique (SPLAT) bioluminescence imaging system, Unobtrusive Multi-Static LIDAR Imager (UMSLI), Inherent Optical Properties (IOP) package, Acoustic Zooplankton Fish Profiler (AZFP), Aquadopp acoustic current meter, and EK80 - Wide Band Acoustic Transceiver (WBAT). The profiler was successfully deployed to between 300 and 500 m during a March 2018 technology-demonstration cruise aboard the NOAA Okeanos Explorer in the northern Gulf of Mexico. Data collected will be utilized to examine the propagation of mechanically stimulated bioluminescence, diel vertical migration, organism distribution and identity, small-scale turbulence and shear regimes, and bulk particulate properties. We present a quantitative data synthesis for this unique exploration system, and demonstrate the importance of an integrated approach to studies in this environment. The insights gained during this project will be invaluable for further research in the important yet under-sampled "twilight" mesopelagic zone.

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Poster 207

CHARACTERIZATION OF NON-PHOTOCHEMICAL FLUORESCENCE QUENCHING BY PHYTOPLANKTON TYPE USING MULTISPECTRAL FLUOROMETRY AND THE PARTICULATE ABSORPTION COEFFICIENT: A LAKE ERIE CASE STUDY

Chlorophyll-a fluorescence is widely used as an in-situ estimate of phytoplankton abundance as the measurement is easy to make and many instruments exist for a variety of applications. Profiles of chlorophyll-a fluorescence can provide detailed information on the vertical structure of phytoplankton biomass in environments ranging from the deep ocean to shallow lakes. The presence of non-photochemical quenching (NPQ) can lead to anomalous vertical biomass structures as near surface fluorescent yields can be artificially low relative to deeper assemblages experiencing lower levels of incident irradiance. Methods have been developed to correct for the effect of NPQ on vertical structure which either use night-time measurements or coincident backscattering observations. Both of these methods have limitations for their application in highly dynamic case II waters where significant horizontal and vertical changes in phytoplankton biomass occur between day and night as well as the substantial contribution of non-algal particles to measured backscatter. This study examines a method using the particulate absorption chlorophyll line height profiles measured with a WETLabs AC-S in conjunction with a profiling radiometer to quantify and potentially mitigate NPQ effects on vertical structures measured with a multi-spectral fluorometer that is capable of determining phytoplankton type. Vertical profiles were measured weekly from May-October at 8 sites in Lake Erie in 2016, 2017, and 2018. Weekly observations throughout the Spring-Fall period captured the progression of the phytoplankton community dominance from diatoms to cyanobacteria. The effect of NPQ is shown to be variable depending on chlorophyll concentration and phytoplankton group composition.

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Poster 211

LESSONS LEARNED FROM THE APPLICATION OF FRRF AS A TOOL TO ESTIMATE CARBON–BASED PHYTOPLANKTON PRIMARY PRODUCTIVITY

Fast repetition rate fluorometry (FRRF) provides a non-intrusive, instantaneous and potentially autonomous technique to monitor phytoplankton photo-physiology with unmatched spatial and temporal resolution. Numerous studies have examined the feasibility of quantifying carbon-based primary productivity from high-resolution FRRF measurements, utilizing simultaneous estimates of FRRF-derived of electron transport rates and incubation-based 14C-uptake rates. These studies have shown that the electron requirement for carbon fixation (phi_e,C, mol e- mol C) can vary significantly as a function of environmental conditions and phytoplankton community composition. More recent studies have also demonstrated that the magnitude of the conversion factor correlates with the expression of non-photochemical quenching (NPQ) in the pigment antenna, which can also be estimated from FRRF measurements. This correlation improves our ability to constrain variability in phi_e,C, enabling more robust estimates of phytoplankton primary productivity from FRRF measurements. In this presentation, instead of aiming to constrain values of phi_e,C, we focus on the insights which can be gained by observing its variability. We will show results derived from a synthesis of published and unpublished datasets, demonstrating that the slope of the phi_e,C : NPQ correlation changes depending on growth environment, and that understanding this variability provides insight into the bottom-up control of photosynthetic carbon fixation in the oceans. Specifically, we will present field data of region-specific diurnal variability in phi_e,C, reflecting the degree of phytoplankton nutrient limitation. We will also discuss the opportunity to extend the NPQ : phi_e,C correlation to remote sensing approaches.

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Poster 215

APPLICATION OF CLUSTERING SCHEME ON BATHYMETRY DERIVATION FROM LANDSAT 8 (L8) IMAGES

By incorporating image segmentation technique, an innovative cluster Spectral Optimization scheme for bathymetry derivation from Landsat-8 (L8) images is proposed. The scheme is based on the HOPE model developed in the 1990's (Lee et. al., 1998 & 1999). The reliability of this scheme is validated by SHOALS (Scanning Hydrographic Operational Airborne LiDAR Survey) measurements in Kaneohe Bay. Besides, comparison was made among the bathymetry derived from traditional HOPE model, regression based scheme (i.e., Pacheco et. al., 2015) and the proposed cluster scheme. Among 20662 match up pixels with depth less than 15 m, the proposed cluster scheme has the best performance with RMSE = 1.01, while the RMSE vale of the other two schemes is 1.89 and 1.79, respectively. The result indicates that the cluster scheme could significantly improve the bathymetry derivation from L8 images.

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Poster 219

PHENOLOGY OF PHYTOPLANKTON BIOMASS IN THE ARABIAN SEA FROM REMOTELY SENSED OCEAN COLOR OBSERVATIONS

The Arabian Sea is one of the most biologically productive regions, and is subjected to seasonality changes, which might alter the phytoplankton productivity. For more accurate prediction of phytoplankton dynamics with respect to climate changes, a better understanding of its phenology is required. The phytoplankton phenology studies are a unique way to identify the periodical changes of phytoplankton biomass in their annual cycles. From the past literatures it is evident that chlorophyll-a concentration is considered as the proxy of phytoplankton biomass abundance. In this study, we have examined the phenology of phytoplankton biomass using 15 years (2003-2017) Level 3 (L3) MODIS-Aqua daily chlorophyll-a concentration data. The aggregated chlorophyll-a concentration data were used to estimate the monthly climatology, interannual variations, chlorophyll-a concentration anomalies and min-max chlorophyll-a concentrations using statistical indices. The Fast Fourier Transform and threshold methods were also used to estimate the phytoplankton peak months and its potential time shift's in the Arabian Sea, which are often influenced by physical and biochemical forcing. The fine-scale resolution analysis of chlorophyll-a concentration phenology is qualitatively realistic, and is strongly coupled with influencing factors such as sea surface temperature, winds, and photosynthetic available radiation (PAR). The results obtained from the above metric gives a better understanding of the phytoplankton biomass dynamics in the Arabian Sea and its reaction towards the consequences of extreme changes over climatic and biochemical cycles.

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Poster 223

QUALITY OF BIO-OPTICAL PRODUCTS FROM OCEAN AND LAND COLOUR INSTRUMENT (OLCI) IMAGERY ON BOARD SENTINEL-3 THE EAST COAST OF AUSTRALIA

OLCI Imagery on board Sentinel-3 was launched in 2016 for continuous water quality monitoring. The reprocessed OLCI level-2 full-resolution products for open-ocean waters have been validated against in situ data from the east coast of Australia, collected in September 2017. The study region is strongly influenced by the Eastern Australian Current which forms eddies that stimulate phytoplankton growth and enhance primary production. Although oligotrophic open-ocean waters are usually dominated by small-sized phytoplankton, mesoscale features such as eddies can generate seasonally favourable conditions for the growth of large phytoplankton cells. We tested the performance of OLCI remote-sensing reflectance, absorption of coloured detrital matter (CDM), and concentration of chlorophyll a and total suspended matter (TSM). The OLCI water-leaving reflectance gave good agreement with in situ reflectance in cyclonic eddies. In anticyclonic eddies, the reflectance was overestimated, mostly in the blue part of the spectrum. The in situ values of chl-a were on average 2 times higher than OLCI values. Results showed that the satellite chl-a estimation was somewhat effective (R^2=0.53, slope=1.37, and SE=0.3) in the study area. However, a systematic underestimation of higher chl-a concentrations was found in the region of cyclonic eddies characterised by increased primary production and domination of large-sized phytoplankton. The large cells, that have a greater package effect, are less visible to the bands used in the chlorophyll algorithm. Observed CDM absorption and TSM were very low (mean values of 0.015m-1, and 0.27g·m-3 respectively) and poorly remotely estimated (R^2=0.32, slope=2.2, SE=0.6 and R^2=0.14, slope=2.7, SE=0.9, respectively).

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Poster 227

CHLOROPHYLL-A ESTIMATION FROM SENTINEL-2 IMAGERY IN EBRO DELTA BAYS: APPLICATION TO AQUACULTURE MANAGEMENT

Shellfish farming in Ebro Delta (NE-Spain), mainly mussel aquaculture (Mytilus galloprovincialis), has a major socioeconomic impact. Phytoplankton is the main source of food as well as one of the most important hazards for shellfish farming and consumers when harmful algal blooms (HABs) occur. In the long term, the spatiotemporal dynamics of phytoplankton in Ebro Delta bays are driven mainly by the nutrient input coming from the evacuation of freshwater used for the irrigation of the rice paddies, opened or closed depending on the rice growth stage. The aim of this study was to obtain a time series of chlorophyll-a (Chl-a) maps of Ebro bays from Sentinel2 MSI data, as indicators of phytoplankton abundance, to understand and analyze the spatial distribution of phytoplankton under the influence of closed or opened irrigation channels. By adjusting several algorithms with ground Chl-a data of $R^2>0.5$, NRMSE<30% was achieved for images covering different seasons of the year and varying states of the irrigation channels. This allowed a preliminary analysis of the suitability of the current location of the farms according to the phytoplankton trends and a preliminary assessment of the Chl-a depletion within the mussel farms. The applied methodology needs to be improved but these initial results showed the potential of using Sentinel2 as a tool not only for mapping the phytoplankton biomass distribution but also for encouraging better future practices in the management of the aquaculture in Ebro Delta bays, a key sector for the integral management of the coastal zone.

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Poster 231
ASSESSMENT OF INVERTING AN UNDERWATER LIDAR TO DERIVE IOPS

A synthetic bio-optical dataset of inherent optical properties (IOPs) was created based on Chlorophyll concentrations ranging between 0.01 and 30 mg m^{-3}. Dissolved and particulate fractions of absorption were varied to account for the natural ranges in values. The IOPs were then used as inputs to a time-resolved Monte-Carlo radiative transfer model to generate accurate lidar backscatter time history wave forms. The primary lidar geometry in the model matched an existing system developed at HBOI under NOAA-OAR funding. The system uses blue and green pulsed laser sources (473 and 532 nm, respectively) and has two telescopes arranged at a 10° offset from one another. The field of view of the telescopes is set at 1°. Results from investigating approaches in inverting simulated lidar results to derive input water column IOP properties will be presented. Results are also tested through application to lidar measurements collected in an experimental tank with known suspended particle types and concentrations as well as field measurements made in waters with varying optical properties.

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Poster 235

PRIMARY PRODUCTION FROM SATELLITE FOR DEFINING GOOD ECOLOGICAL STATUS IN NW EUROPEAN SEAS

Phytoplankton primary production (PP) is the base of the marine food web and is a critical component of the carbon cycle and a key driver for transferring carbon the food chain. Changes in phytoplankton PP are driven by a range of different environmental factors including light, nutrients and temperature. There is a growing consensus that phytoplankton production is an important indicator of Good Environmental Status, but there is currently no coordinated monitoring of PP in Europe and Globally. Over the past two decades there has been a concerted effort to develop accurate satellite models of PP to fill this data void which has been spear-headed by NASA's satellite PP model inter-comparison. In this paper, we use one of the most accurate satellite PP models to define baseline conditions of Good Ecological Status using 20 years of merged ocean colour satellite data from the Copernicus Marine Environment Monitoring Services (CMEMS) in North West European waters. The magnitude and shape of the PP climatology is used to define ecological classes that have dynamic temporal boundaries. The Celtic Sea, English Channel & Outer Hebrides have higher baseline thresholds and a different phenology to the Northern & southern North Sea. All regions exhibited a similar pattern in PP with a decline from 1998 to 2007, followed be a recovery from 2009 to 2014 and a further decline from 2014 to present. Within each ecological class, we assess the multi-decadal trends in PP in relation to changes in atmospheric and hydrodynamic conditions over the region.

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Poster 239

CHARACTERIZATION OF BIO-OPTICAL ANOMALIES IN THE KERGUELEN AREA, SOUTHERN OCEAN, FROM SHIP-BASED SAMPLING AND BGC-ARGO PROFILING FLOATS

In spite of its major role in regulating the global carbon cycle, the Southern Ocean remains largely unknown due to a large surface area, remoteness from lands and harsh weather conditions yearlong. Satellite remote sensing of ocean color stands as a powerful tool for gaining insights into the dynamics of phytoplankton biomass and associated carbon fluxes. Yet, the Southern Ocean shows bio-optical anomalies that induce large uncertainties in ocean color-based biogeochemical products. Our objective is threefold: (1) to collect concurrent in situ optical and biogeochemical measurements in a drastically under-sampled region; (2) to characterize the origins of the bio-optical anomalies; (3) to examine the space-time variations in the anomalies. The SOCLIM (Southern Ocean and CLIMate) cruise was conducted in October 2016, in the vicinity of Kerguelen Islands in the Indian Sector of the Southern Ocean. The collected SOCLIM data show a substantial deviation in the relationship between phytoplankton absorption and chlorophyll a concentration compared to data collected in other open ocean waters. This trend is especially pronounced in the iron-fertilized waters downstream of Kerguelen and may result from a dominant contribution to the phytoplankton assemblage of large-sized cells and/or cells with atypical photophysiological status. In contrast, the bio-optical relationships involving either absorption by colored dissolved organic matter or particulate backscattering do not show any anomalous behavior. The shipborne observations are confronted to bio-optical indices measured by BGC-Argo floats deployed during SOCLIM for determining the regional and seasonal variability in the bio-optical anomalies.

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Poster 243

JOINT MONITORING PROGRAMME OF EUTROPHICATION IN THE NORTH SEA WITH SATELLITE DATA

The Marine Strategy Framework Directive (MSFD) is currently one of the most important drivers for monitoring the coastal and offshore waters in Europe with the objective of reaching a 'good environmental status' (GES) by 2020. Human-induced eutrophication is one of the criteria for assessing the extent to which GES is being achieved and is established by monitoring of chlorophyll-a (CHL) concentration as a proxy of phytoplankton biomass. While in situ data acquisition is still considered as the main monitoring tool, there is a growing tendency to use optical remote sensing as a supporting tool to achieve a coherent assessment of CHL in the North Sea. In the JMP-EUNOSAT project we present the evaluation of publicly accessible satellite-based chlorophyll products available from Copernicus Marine Environment Monitoring Services (i.e. CMEMS), European Space Agency (i.e. ODESA) and other data providers (i.e. IFREMER) and determine their validity for different water types in terms of CHL, suspended matter (SPM) and colored dissolved organic matter (CDOM) concentrations. The validity of each CHL product was determined using the Coast Colour Round Robin dataset which was designed to test algorithms and assess their accuracy for retrieving water quality parameters. The quality controlled CHL products were subsequently merged together into a coherent CHL product to enable a definition of cross-border assessment areas based on ecosystem characteristics, rather than national borders. The blended CHL product is compared to in situ datasets for all assessment areas found in the North Sea and its suitability for eutrophication monitoring is assessed.

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Poster 247

IMPACT OF TCHLA ESTIMATE ON THE DETERMINATION OF VICARIOUS ADJUSTMENT COEFFICIENTS

The System Vicarious Calibration (SVC) is the process used to adjust the spectral calibration coefficients of ocean color (OC) space borne sensors in order to meet the desired accuracy in retrieving the marine leaving radiance. Simplifying, OC-SVC consists in comparing concurrent in situ and satellite retrievals of fully normalized water leaving radiance in the best possible observation conditions to minimize data uncertainties, and then adjust satellite measurements onto field measurement. Current OC-SVC processing schemes require knowledge of Total Chlorophyll-a (TChla) at several stages of the adjustment coefficients calculation (so called g-factors). TChla is used, for example, as input for the BRDF correction look up tables. High Performance Liquid Chromatography (HPLC) analysis of discrete samples is the most accurate technique used for the determination of TChla. To extend our capability to measure TChla at temporal and spatial scales not compatible with HPLC analyses, numerous methods have been developed to estimate TChla with in situ or remotely deployed instrumentation based on optical proxies (e.g., fluorescence, reflectance, etc.). Here we evaluate different methods estimating TChla and their impact on the determination of Sentiel3A-OLCI g-factors. To this scope we use a long-term time series of optical properties and HPLC data collected at the BOUSSOLE site (NW Mediterranean Sea).

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PRESENT STATUS OF THE MARINE OPTICAL BUOY (MOBY) REFRESH AND MOBY-NET

The Marine Optical Buoy (MOBY) has provided the primary vicarious calibration data for many ocean color satellite systems over the last 20 years. Over the last 4 years we have been working on replacing several of the systems on MOBY with a goal of improving the operation of the system, in a process we are call MOBY-Refresh. In addition, with the support of NASA we have developed the MOBY-Net concept, which takes many of the features of the MOBY-Refresh effort and adds to this additional components to allow deployment of the MOBY-Net system in another location. In this presentation we will give information on the present status of the systems and how they have developed over the last few years.

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Poster 255
BIASED SATELLITE REMOTE SENSING REFLECTANCE IN GLOBAL OCEANS

It is critical to assure the data quality of remote sensing reflectance (Rrs) from ocean color satellites for study of ocean biology, especially the long-term ocean climate. Level-3 satellite ocean color products are spatially binned high-quality data records and widely used. In this study, we conducted an independent assessment of SeaWiFS and MODISA Level-3 daily Rrs products in global oceans. An objective quality assurance (QA) model was adopted to quantify the Rrs data quality. It is found that low-quality data are persistently present in some open oceans and marginal seas, including the North Atlantic Gyre (NAG) and Mediterranean Sea (MED). It is also revealed the degrading trends towards the end of missions as well as seasonal variability. The analysis suggests that the Rrs measurements in NAG and MED are subjected to systematic biases. For instance, MODISA Rrs band ratios, Rrs(412)/Rrs(443) and Rrs(443)/Rrs(547), are misrepresented by -5% and +10%, respectively, in NAG. In the Mediterranean, these ratios are also biased by about -10% and +20%, respectively. We argue that these residual biases with satellite Rrs products are likely a consequence of strongly absorbing aerosols present in the atmosphere. We further assessed the impacts of these residual biases on the estimation of chlorophyll a concentration and bio-optical properties (absorption and backscattering coefficients and diffuse attenuation coefficient). In particular, we show that these biases have impacted the long-term ocean chlorophyll trends in open oceans. Necessity is suggested for further calibration and quality assurance of the satellite Rrs data for ocean climate study.

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Poster 259

UNIFYING THE EUPHOTIC ZONE DEPTH DETERMINED BY OPTICS AND BIOLOGY

Traditionally the euphotic zone (ZeuPAR) is defined as a layer where the bottom of this layer has 1% of the photosynthetically active radiation (PAR) at the ocean surface. While the euphotic zone (ZeuNPP) in biology term is defined as a layer where there is no net production at the bottom of this layer, also termed as the compensation depth (Zc). Clearly ZeuPAR is very different from ZeuNPP, and there has been debate for decades which one should be used to represent the "euphotic zone". In this study, based on field-measured profiles (14 stations) of primary production in South China Sea, ZeuNPP is first calculated. Further, the compensation irradiance (Ic) corresponding to ZeuNPP is determined from matching profiles of hyperspectral downwelling irradiance. We then evaluated the ratio of Ic to surface PAR and to surface USR (usable solar radiation), respectively, where the latter is the spectrally integrated solar irradiance in the 400-560 nm domain (Lee et al. 2014). It is found that the ratio Ic/PAR(0) is generally ~0.41% (± 0.32%), while the ratio Ic/USR(0) is generally ~0.97% (± 0.12%), which indicates ZeuPAR could be too shallow to represent "euphotic zone". On the other hand, if we use the depth of 1% surface USR (ZeuUSR), it appears ZeuUSR closely matches ZeuNPP. Furthermore, all subsurface chlorophyll maximum are found above ZeuUSR, but can be much deeper than ZeuPAR. These results suggest that ZeuUSR could be a good candidate to unify the determination of the "euphotic zone", at least for such subtropical waters.

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IMPACT OF HURRICANE IRMA ON THE SUBSTRATE IN FLORIDA KEYS FROM REMOTE SENSING

Hurricane Irma made landfall at the Florida Keys on September 10, 2017, and caused far-reaching and devastating damages to the vegetation and properties on the ground. However, its impact on the substrate of the Florida Keys is less documented. In this study, we first validated the Rrs products from multi-sensors (i.e., NOAA-VIIRS, NASA-VIIRS, MODIS-Aqua, Sentinel3-OLCI and Landsat8-OLI) with field measurements collected in the Florida Keys from January 10 to 14, 2018. The comparisons show that NOAA-VIIRS Rrs product is overall of the highest quality in both shallow and deep waters, in terms of both the Rrs and derived inherent optical properties (IOPs) using the QAA model (Lee et al., 2002 & 2009). However, Rrs product from Landsat8-OLI, atmospherically corrected by the cloud shadow method (Lee et al., 2007), show comparable performance with NOAA-VIIRS. The promising quality of Landsat8-OLI Rrs product allowed us to derive the bottom information of the Florida Keys with a high spatial resolution of 30 meters. Bathymetry and bottom reflectance were derived from Landsat8 images acquired before and after the Hurricane Irma using the HOPE model (Lee et al., 1998 & 1999). Results from before and after Irma landfall show significant differences in both bathymetry and bottom reflectance (indicating types of substrates) in the Florida Keys. These differences imply there are substantial changes at the seabed in these regions due to hurricane Irma.

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BUILDING A RADIOMETRIC SIMULATOR FOR THE PACE MISSION: RADIATIVE TRANSFER MODELING AND SCIENCE APPLICATIONS

NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission aims to extend and improve NASA's long-term satellite observation record of global ocean biology, aerosols, and clouds; and to advance the atmospheric and oceanic science with unprecedented spectral coverage and multi-angle polarized measurements. The primary science instrument planned for PACE is the Ocean Color Instrument (OCI): a spectrometer that will measure spectral radiance in the range of 350-885 nm at 5 nm spectral resolution, in combination with several discrete shortwave infrared bands. In addition, PACE is expected to carry two polarimeters, Hyper Angular Rainbow Polarimeter (HARP-2) and Spectro-Polarimeter for Planetary Exploration (SPEXone). In order to facilitate the level-2 algorithm development and explore information content for the PACE instruments, it is essential to build a PACE simulator with sufficient fidelity to represent the physical processes in the combined atmosphere and ocean system. We will present a radiative transfer model that include all major light-matter interaction mechanisms, which includes the following key features: a) Atmosphere and ocean coupling; b) Gas absorption and particle scattering coupling; c) Rigorous polarization simulation; d) Inelastic scattering in ocean waters including Raman scattering and fluorescence. Simulations will be performed for a range of parameters for different atmospheric and oceanic conditions to demonstrate its applications. The synthetic dataset will be packaged into a compact look-up table that can be interpolated into different orbit and viewing geometries to generate synthetic PACE data for both OCI and the polarimeters, which can then be used in level-2 algorithm development and testing.

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UNDERWATER RANGED-RESOLUTION MULTI-SPECTRAL MONITORING FOR PHYTOPLANKTON

Discrimination technology for phytoplankton has been established by chlorophyll fluorescence excitation spectra. The spectral technique is utilized widely to analysis the level of eutrophication and phytoplankton diversity. Therefore, research of the species composition and distribution of phytoplankton give us insight in to develop an underwater spectral remote instrument. We developed a low-cost inelastic hyperspectral lidar based on Scheimpflug formed continuous-wave lidar. The lidar has good resolution to detect submillimeter target with counter and multi-spectral identification function. The lidar system can record the ranged-distribution of aquatic particle with a tangential rang resolution. The real-time laser-induced fluorescence signal from different targets distributed at different distances can also be discriminated and recorded separately. Therefore, the instrument is very suitable for monitoring phytoplankton and descripts the chlorophyll concentration distribution. In this work, we descript the range-resolved laser-induced fluorescence of phytoplankton chlorophyll, and water Raman spectra in the clear water. The instrument shows more than 5 m detection range and 5 nm spectral resolution. The algae monitoring in an indoor water tank with condition controlled will be presented. The analysis method of the LIF data of phytoplankton will be represented, which plays a key role for classification. The system provide a kind of new technique to study aquatic organisms.

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