International Ocean Colour Science Meeting 2023

SUBMITTED ABSTRACTS - Alphabetical Order by Theme

New and emerging technologies

Includes new technologies related to observational platforms, sensors, algorithms, capabilities, and in-situ measurements.

No. 1

Leveraging mixture density networks to compensate for aerosol contribution over inland and nearshore coastal waters

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Abstract

A primary challenge in aquatic remote sensing is to develop a robust atmospheric correction (AC) method to estimate remote sensing reflectance (Rrs) products, defined as the ratio of water-leaving radiance to downwelling irradiance just above the water. Our AC method, based on a machine learning model referred to as Mixture Density Networks (MDNs), has been implemented and widely tested with 2000+ co-located Rrs matchups of Landsat-8/-9 (Operational Land Imager; OLI) and Sentinel-2 (Multispectral Instrument; MSI) images over inland and coastal waters. Here, we describe an extension of this approach to the hyperspectral domain by generating products for the Hyperspectral Imager for the Coastal Ocean (HICO). Our processing system, termed Aquaverse, begins by leveraging a coupled ocean-atmosphere radiative transfer model to simulate top-of-atmosphere reflectance for various imaging geometries and atmospheric conditions void of absorbing gases and Rayleigh effects, via in situ hyperspectral Rrs measurements. The in situ Rrs and simulated spectra are then resampled with HICO spectral response functions and subsequently used to train an ensemble of MDNs to retrieve Rrs from. Our trained ensemble is then applied to Rayleigh-corrected HICO imagery, which is validated with available in situ data in select lakes and coastal estuaries across the U.S. The performance of our models trained with hyperspectral data is expected to match that of OLI and MSI with median uncertainties ranging from ~ 16% (green bands) to ~ 35% (blue bands), indicating major improvements (i.e., ~2x in the blue bands) compared to existing AC models. Aquaverse-generated maps (Rrs and downstream products like chlorophyll-a, total suspended solids, and absorption by colored dissolved organic matter) for several HICO images will be demonstrated and compared with those produced via other processors. Validation uncertainties of Aquaverse in fresh and coastal waters on HICO imagery will serve as a proxy for future global space-borne spectrometers.

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No. 2

A retrospective assessment of product consistency from MODIS/MERIS/VIIRS over global inland and coastal waters

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Abstract:

The simultaneous retrieval of water quality parameters and inherent optical properties from *hyperspectral* satellite imagery over coastal and inland waters was recently demonstrated using Mixture Density Networks (MDNs). In this study, we developed a robust MDN model to retrieve 10 relevant biogeochemical and optical variables, including chlorophyll-a (Chla) and total suspended solids (TSS), as well as the absorbing components of inherent optical properties (IOPs) from *multispectral* satellite-derived remote sensing reflectance (R_{rs}). The MDN is trained and validated on *in situ* spectra from an augmented version of the GLORIA database (N=7,572), which has globally distributed *in situ* IOP measurements added to it. For training and validation, the hyperspectral *in situ* radiometric and absorption datasets were resampled, via the relative spectral response functions of MODIS (aboard Aqua and Terra), MERIS, and VIIRS (on Suomi NPP), to simulate the response of each multispectral mission. The retrieved parameters from the validation dataset have variable uncertainty represented by the Median Symmetric Accuracy (MdSA) for each parameter and sensor combination. The average MdSA over all 10 variables was 26.7%, 31.5%, and 28.5% for MERIS, VIIRS, and MODIS, respectively. Of the 10 MDN-estimated variables, MERIS retrieves $a_{cdom}(443)$ with a minimum MdSA, while MODIS and VIIRS retrieve $a_{ph}(443)$ with the minimum MdSA. TSS was the parameter with the highest MdSA for all three sensors (MODIS, VIIRS, and MERIS). The MDN's product accuracy is further validated through a matchup analysis. The average MdSA from all estimated variables for each sensor from the matchup analysis is 53.8% for MODIS/A, 57.5% for MODIS/T, 71.2% for MERIS, and 156.5% for VIIRS. The MdSA of the MDN estimates from satellite-derived R_{rs} is higher in comparison to estimates from *in situ* R_{rs}. The MDN model is sensitive to the instrument noise and uncertainties from atmospheric correction present in multispectral satellite derived R_{rs}. The overall performance of the MDN model presented here was also analysed for the near-simultaneous images of MODIS/A and VIIRS as well as MODIS/T and MERIS to understand the multi-mission robustness and consistency in retrieved variables. In summary, the developed MDN is shown to be capable of robustly retrieving 10 water quality variables for monitoring coastal and inland waters from multiple multispectral satellite sensors (MODIS, MERIS, and VIIRS).

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PACE Ocean Color Instrument (OCI) Hyperspectral Surface and Underwater UV Irradiance Algorithm

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Knowledge of underwater UV radiation is important for the evaluation of ecosystem properties, e.g., productivity of phytoplankton and coral health, the decomposition of dissolved organic matter, and the degradation of microplastics (a growing threat for oceanic ecosystems). We demonstrate an OCI hyperspectral surface (E_S) and underwater UV irradiance algorithm by combining satellite measurements of extraterrestrial solar irradiance from TSIS-1 with ozone and cloud/surface UV reflectivity from Aura/OMI, as well as chlorophyll from Aqua/MODIS. We estimate E_S uncertainties at ~7%-10% for OMI scenes with non-absorbing aerosols, confirmed by MOBY E_S measurements near Lanai in Hawaii. UV-absorbing aerosols attenuate E_S much more strongly than clouds and non-absorbing aerosols of similar optical depth, thus requiring an additional correction based on OCI UV Aerosol Index (UVAI) or retrieved aerosol absorption optical depth (AAOD) in UV.

To calculate underwater downwelling irradiances, we use look-up-tables computed with the Hydrolight radiative transfer model. We also calculate hyperspectral diffuse attenuation coefficients, K_d, and 10% penetration depths for DNA action spectrum weighted irradiances. Major uncertainties of the underwater irradiance are introduced by our inherent optical properties (IOPs) spectral model for Case 1 waters. One difficulty of modelling the IOPs in UV is related to strongly absorbing mycosporine amino acids (MAA) which may not be well-correlated with photosynthetic pigments. An additional source of IOP uncertainty is pure water absorption in UV. We estimated uncertainties using a comparison of computed K_d values with those derived from in situ measurements of underwater UV irradiance from the ACE cruise in the Northern Pacific Ocean, and the BIOSOPE cruise in the Southeast Pacific Ocean. The relative error for all the cruise stations did not exceed 20%. We accept this as a maximum uncertainty of our UV underwater irradiance products. We plan to compare with the new PACE vicarious calibration systems data when available.

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Developing a data-driven model to minimize adjacency effects in Landsat-8 imagery

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Atmospheric Correction (AC) is an important tool in achieving accurate aquatic science products from remotely sensed optical measurements. A key aspect of AC, and a largely unaddressed problem, is that of adjacency effects (AE) in nearshore observations of medium to high spatial resolution optical imagery. The purpose of this work is threefold. First, to characterize the AE and its various environmental and physical drivers. Second, to develop a machine-learning model that minimizes the corresponding effects, and third, to apply the said model to all water types, including inland lakes and coastal waters, and validate its performance through the AERONET-OC measurements and other *in situ* methods. For this study, we used Landsat-8/OLI as there is nearly a decade's worth of imagery to use through the Google Earth Engine environment where a broad range of co-located auxiliary environmental and physical data are readily accessible. To determine the drivers of AE, it was first determined where the AE was located within an image with respect to shoreline distances and other such environmental factors. From there, high-correlation variables were determined to characterize the major drivers behind AE. These variables were used to train a machine-learning model to predict the AE for any water pixel within an image and minimize AE. Results of these models indicate a reduction in adjacency effects without overcorrecting when compared to imagery without the AE removal in all visible-near-infrared bands, suggesting the viability of methodology in addressing the contribution of AE in nearshore satellite measurements.

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A Bayesian approach to retrieve water optical parameters and bathymetry from Remote-Sensing reflectance in optically complex waters

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Remote-sensing reflectance (R_{rs}), from either *in situ*, airborne or spaceborne observations, is often used to retrieve bulk water inherent optical properties (IOPs) in coastal ocean waters, i.e., non-water absorption ($a_{\text{t}-\text{w}}$) and particulate backscattering coefficients (b_{bp}), using inversion of semi-analytically (SA) parameterized radiative transfer equation. Bulk IOPs could be further used to estimate biogeochemical (BGC) variables, such as Chlorophyll concentration ($[chl]$), dry mass of suspended particulate matter (SPM) and absorption of coloured detrital matter ($a_{\text{dg}}(\lambda)$). In optically shallow waters, bottom depth (H) and benthic albedo (R_{B}) are also retrieved when they contribute significantly to R_{rs} spectral shape and magnitude. The *state-of-the-art* inversion methods in optically complex waters either use a 1. pre-computed Look-Up table (LUT) of R_{rs} indexed by its associated input vector of water optical properties (IOPs/ BGCs) and shallow parameters (H and R_{B}) or 2. a finite order bounded differentiable objective function, which is minimized/maximized using a Gauss-Newton or gradient descent based optimization routine. However, multiple combinations of IOPs/BGCs and shallow parameters can produce very similar R_{rs} (i.e., ambiguity), making the inversion a mathematically *"ill-posed"* problem. Here we propose a Bayesian inversion scheme for optically complex waters to retrieve the full probability densities of the parameters in order to quantify the uncertainty in the RT inversion. We incorporated the multivariate probability distribution of observed *in situ* BGCs/IOPs, H and R_{B} as *a-priori* ($P_{\text{a-priori}} \in \mathbb{R}^+$) along with the probability density of the SA RT model likelihood ($P_{\text{likelihood}} \in \mathbb{R}$) that estimates the probability distribution of the variance in the SA model. The Posterior probability of each of the parameters ($P_{\text{posterior}} \in \mathbb{R}^+$) used in the *a-priori* is retrieved through a delayed rejection-based Markov Chain Monte Carlo (MCMC) scheme that maximizes the sum of log *a-priori* and log-likelihood probability distribution function, i.e., arg max$\{\log(P_{\text{a-priori}}) + \log(P_{\text{likelihood}})\}$ of the RT model. The point-based estimates from each of the posterior distributions are retrieved as *Maximum-a-posterior* (MAP) estimates whereas the associated uncertainty in the MAP estimates is calculated with Bayesian credible intervals. The method has been tested with both synthetic data sets and *in situ* observations of R_{rs} in optically deep and shallow waters.

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No. 6

Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR) Instrument Overview

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GLIMR is a NASA Earth Venture Instrument (EVI) project led by Principal Investigator Dr. Joseph Salisbury of the University of New Hampshire (UNH). The GLIMR investigation uses a Raytheon-built hyperspectral imaging radiometer in geostationary orbit to enable a new class of ocean color science data collection. As NASA stated in the EVI project selection announcement: "GLIMR fills significant gaps in the current suite of ocean color sensors. Current NASA ocean color missions do not provide the temporal or spatial resolution necessary to describe processes in the dynamic coastal zone." GLIMR data enable quantification of biological and biogeochemical processes including primary production; tracking of carbon inventories in time and space; and the examination of impacts of tides, surface currents, and river discharge on distribution and fluxes of ocean materials. GLIMR provides federal, state, and local agencies with vital information on coastal hazards (e.g., oil spills, harmful algal blooms, post-storm assessment, water quality) for improved response, containment, and public advisories both at sea and along the coast. This paper reports on key design features and capabilities of the GLIMR instrument.

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The Rotation of Reference Frame Dependent Polarimetric Variables for Equidistant Fisheye Lens Projections

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Abstract

Fisheye lenses are especially useful in simultaneously measuring the distribution of light for a large range of viewing angles. This property makes them useful tools for atmospheric and oceanic optical measurements. However, there is a distortion inherent to all fisheye lenses due to the geometric issues of projecting a 3-dimensional scene on a 2-dimensional plane (Miyamoto 1964). For equidistant fisheye lenses, parallel lines in space are projected with curvature on the image plane (Hughes et al. 2010). Similarly, this curvature is observed when light passed through a flat linear polarizer is imaged at non-normal viewing angles. Therefore, reference frame dependent polarimetric variables including the Angle of Linear Polarization and Stokes parameters Q and U, are altered. In the lab, polarimetric calibration coefficients are often retrieved near the optical center and account for the lens's effects. But their effectiveness at larger viewing angles is not well documented. We show an improvement in the intra-sensor variability in the retrieval of reference frame dependent polarimetric variables after compensating for the expected curvature of on the image plane. We conclude that calibration variables determined near the optical center also perform well at larger viewing angles.

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First investigation of freshwater hyperspectral backscattering across multiple trophic levels in the Laurentian Great Lakes

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The color of fresh water is largely determined by the mixture of phytoplankton, non-algal particles, and CDOM which together dictate the water's inherent optical properties (IOPs). Understanding these properties is crucial to the generation of robust remote sensing algorithms, so an extensive dataset of IOPs has been compiled throughout the Great Lakes over the last 20 years. This dataset includes hyperspectral absorption and attenuation (using a Seabird ac-s) and 9-band multispectral backscattering (using a Seabird ECO-BB9). Multispectral backscattering has been sufficient for the algorithm generation and product validation for the existing generation of multispectral satellites, but hyperspectral backscattering would provide additional value in helping to distinguish between phytoplankton communities and better characterize the in-water particulates. Additionally, with the planned launch of NASA's hyperspectral PACE satellite in January 2024, the ability to measure backscattering at similar spectral resolutions is crucial to fully take advantage of the new sensor. MTRI began making hyperspectral backscattering measurements throughout the Great Lakes in summer 2022 using a Sequoia Hyper-bb sensor. Measurements have been made across a range of trophic states, from the oligotrophic waters of Lake Michigan to the eutrophic waters of western Lake Erie and Saginaw Bay, including during significant harmful algal bloom events and heavy sediment plumes (conditions that have often saturated the ECO BB9 sensor). This dataset currently includes over 150 measurements, with $b_{bp}(530)$ values ranging from 0.002 to 0.4 m^{-1} and associated chlorophyll-*a* values ranging from 0.9-190 mg/m^3. We have begun to observe relationships between the hyperspectral backscattering and other data collected alongside, including surface reflectance, particle sizes, and a suite of biogeochemical properties. This dataset will further aid in our understanding of freshwater optical properties, help us to generate improved hyperspectral algorithms, and provide validation to products generated from the PACE satellite mission.

Mapping *Posidonia oceanica* in Oristano (Italy) using PRISMA images

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Coastal processes are the result of forces acting on coastal areas and leading to the alteration of these environments. Both natural and anthropogenic activities can lead to the degradation of these environments (coastal changes, loss of biodiversity, sea level rise, seawater intrusion, coastal erosion, and flooding). Coastline mapping and change detection are essential for safe navigation, resource management, environmental protection, and sustainable coastal development and planning. Satellite remote sensing has been used for about 50 years to obtain environmental information to support effective management of such landscapes.

In this context, the OVERSEE project financed by the Italian Space Agency (ASI) delivers useful integrative Earth Observation information for coastal risk assessment and coastal landscape planning, aiming at a sustainable management of natural and man-made hazards in order to reduce environmental and socio-economic vulnerability. In this work we present the activities related to evaluating the status of benthic substrate in the Oristano Gulf (Italy) target area using PRISMA hyperspectral images in synergies with Sentinel-2 images and in situ data. The Remote Sensing Reflectance images or downloaded directly as Level 2 from the ASI portal or corrected with the code ACOLITE, validated with spectral ground truth, were converted into maps of marine substrates and bathymetry using bio-optical modelling (BOMBER) parametrized with specific Inherent Optical Properties collected in situ. The maps obtained revealed how some coastal areas, influenced by currents, mussel farms, and the turbidity of the lagoons that flow into the sea, present a high seasonal variability in the coverage of *Posidonia oceanica* in shallow water areas. The PRISMA images, integrated with the Sentinel-2 images, proved to be very useful for characterizing the different substrate areas.

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No. 10

Laboratory for Medium Resolution Ocean Colour Products through ODATIS data centre

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The "ODATIS" ocean data and services hub brings together data management and scientific expertise activities in oceanography at French national level. Its general objective is to promote and facilitate the use of observation data carried out in the ocean or at its interface with other environments, based on in situ measurements and remote sensing. ODATIS, steered by CNES and scientific advisory board, thus contributes to describing, quantifying and understanding the ocean in its entirety, offshore and coastal. In this context, a large reprocessing of Medium Resolution Ocean Colour products (MERIS 300m, OLCI-A&B 300m, MODIS 300m) is under way using a variety of algorithms. The objective is to put to the test and intercompare a large panel of products using different atmospheric correction schemes as well as innovative processor for IOP retrieval. The processing has been completed for the French "near to the coast" (ie 200km) marine waters for evaluation and could be expanded to other parts of the world. Products are publicly and freely available through a web interface. On top of products evaluation, final objective is to democratise such types of products towards the whole coastal scientific community.

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A low-cost opensource profiling package for monitoring aquatic environments: A lab on a Secchi disk

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A simple hand-held device (mini-Secchi disk), designed to measure the Secchi depth and water colour (Forel Ule colour) of lake, estuarine and nearshore turbid waters, was developed in 2013 for low-cost monitoring of water colour and clarity. The mini-Secchi disk is manufacture using a 3D printer and basic workshop tools. It is lightweight, easy to use, and has proven useful for citizen science projects monitoring water quality. Here, we extend the device by integrating a small environmental sensor package (Arduino-based) into the Secchi disk. The package measures GPS, spectral light, temperature, and pressure. It is charged and transfers data wirelessly, is encased in epoxy resin, and can be used to derive vertical profiles of spectral light attenuation and temperature. We present a series of deployments of the device, compare its performance with commercially available instruments, and demonstrate its use a tool for validation of remotely sensed data.

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Title: Potentially Underappreciated UV Absorption Influences for Emerging Ocean Color Sensors

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NASA's PACE mission is fast approaching with new hyperspectral capabilities into the UV spectrum (e.g. 340 nm for PACE vs. 412 nm for current systems). UV knowledge gaps persist, particularly with respect to major ocean ions, dissolved oxygen (DO), and the hydrogen-ion and carbonate system. These variables display non-negligible absorption in the UV and near VIS (370 to 420 nm), a range of particular interest for CDOM characterization, for example. Laboratory work on UV absorption is hindered by the lack of necessary background information regarding the absorption of constituents of sea water. For example, the comparability of NaCl to artificial seawater, the effects of pH, and the impact of temperature in the UV are not well characterized, despite these factors often serving as a simplified matrix for UV laboratory studies. Furthermore, DO absorption below 370 nm is not well characterized, potentially limiting application of ocean color measurements related to monitoring trending global deoxygenation and regional hypoxia. Therefore, preliminary research characterizing UV absorption of these important seawater components will be presented to fill information gaps for future ocean color work.

This study is partially motivated by ongoing research characterizing the absorption of sediment pore waters, which are exemplary systems in which all these abovementioned effects may present. Sediment pore waters comprehend a highly variable ionic/redox matrix and thus full characterization of potential interferences is required to deconvolute the absorption of analytes of concern. In turn, sediment pore water absorption (<450 nm) of coastal margin sediments appears dominated by organic and organometallic (i.e. iron) interactions, and these compounds can flux to the overlying water column. Combined with this understanding, the new UV-absorption capabilities afforded by PACE may provide an opportunity for elucidating global carbon and trace metal dynamics if these absorption signatures are conserved during transport from marine sediments to surface waters.

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A machine learning tool to assist the validation of high-performance liquid chromatography (HPLC) measurement of phytoplankton pigments at NASA GSFC

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Measurements of phytoplankton pigments (PPigs) of the utmost quality are essential for the calibration and validation of ocean color sensors. For that reason, quality-assured high performance liquid chromatography (HPLC) analytical methods are employed in their quantitation. NASA uses a centralized, quality-assured laboratory to perform HPLC analysis of PPig samples collected by NASA-funded investigators. Since 2011, the Field Support Group of the Ocean Ecology Laboratory at NASA Goddard Space Flight Center (GSFC) has processed over 30,000 samples collected in all the major ocean basins, and inland waters. However, despite the accuracy and precision of this methodology, uncertainties in peak identification for co-eluting peaks can lead to analytical errors when quantifying pigment concentrations from *in situ* water samples. We developed a machine learning-based tool to assist peak identity validation based on the accumulated history of such tasks performed manually since the facility's inception. The tool was trained on a labeled HPLC chromatogram dataset consisting of common artifacts such as retention time and misidentified peaks. The model is based on a convolutional neural network that combines both chromatographic peak image data (spectral response vs retention time) with sample metadata (e.g., retention time, concentration, peak height for individual peaks). Performance tests on validation and test data subsets showed the tool can accurately detect peak identification errors and improve data quality. The tool will make the analyst's workflow more efficient and contribute to the development of high-quality datasets for regional and global pigment algorithms from *in situ* HPLC measurements.

Assessing high spectral resolution lidar as a tool for measuring particulate backscatter in the ocean and evaluating satellite ocean color retrievals

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Airborne high spectral resolution lidar (HSRL) measurements of particulate backscatter (b_{bp}) offer dramatic improvements in spatiotemporal coverage over *in situ* techniques, filling observational "blind spots" that limit our ability to study ocean processes. However, the technique has been assessed in only a few limited cases, and uncertainties remain regarding its applicability across diverse optical domains. Here, we present the first comprehensive comparison of b_{bp} derived from airborne HSRL, satellite ocean color, and *in situ* measurements to increase confidence in HSRL b_{bp} retrievals and to demonstrate the value of airborne HSRL for assessing/improving satellite ocean color algorithms. Retrievals of b_{bp} performed using the NASA Langley HSRL-1 instrument agreed with *in situ* measurements performed across a diversity of optical and ecological domains. Comparisons across multiple campaigns revealed regional and seasonal dependencies in the ocean color retrievals that likely resulted from applying a single configuration of the ocean color retrieval across multiple distinct domains. In two case studies, atmospheric measurements from HSRL-1 and systematic differences in b_{bp} between HSRL and the 2018 NASA ocean color distribution provided evidence of insufficient atmospheric correction of the ocean color retrieval. These differences in b_{bp} were absent from comparisons against the 2022 ocean color distribution, suggesting that changes made to the algorithm resulted in improved retrievals. These cases highlight the advantages of airborne HSRL for assessing ocean color retrievals, namely its ability to provide simultaneous, independent profiles of atmosphere and ocean optical properties and to improve the spatiotemporal coverage of satellite matchups.

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No. 15

An initial assessment of the impact of system spectral response parameters on driving ocean color applications for the GeoXO ocean color instrument (OCX)

Monica Cook[1], Francis Padula[1], Aaron Pearlman[1], Boryana Efremova[1], Michelle Tomlinson[2], Ryan Vandermeulen[3], Amir Ibrahim[4], Andy Heidinger[5]

NOAA's Geostationary Extended Observations (GeoXO) program is planning to include a hyperspectral ocean color instrument (OCX) in geostationary orbit slated for operations by the early 2030s. Shared international focus has led to a diverse legacy of space-based remote sensing ocean color missions that have and will continue to provide ocean color products into the future at a variety of spatial, temporal, and spectral resolutions. This work reports on an investigation of the impacts of system spectral response parameters on spectral shape and algal bloom detection for the planned OCX instrument. A dataset of high resolution (1 nm spectral sampling) in-situ spectra of red tide collected with an above water spectrometer, and associated K. brevis cell concentrations, were used to simulate OCX observations of varying system spectral response parameters. The OCX Performance Operational Requirements Document (PORD) level spectral resolution and sampling are varied concurrently and the location of band centers is varied independently. The impacts to the spectral shape using hyperspectral signature analysis, as well as the impacts to two heritage multispectral algal bloom detection algorithms – red band difference (RBD) and Karenia brevis bloom index (KBBI) – are assessed considering both changes in resolution/sampling and band center location. This work provides a quantitative assessment of the impacts of system spectral response requirements on both the spectral shape of observations as well as the algal bloom detection to provide insight on how various instrument performance parameters influence science and operational utility of OCX. Future work will seek to expand this analysis to include a larger dataset that considers additional water cases.

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FLuorescence for Ocean Research and Observations (FLORO) experiment investigating lidar measurements to identify and characterize marine debris

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Plastics are a common material in marine debris; they travel long distances and are present in most aquatic environments. Passive imaging systems exploit unique plastic reflectance features in the NIR and SWIR, but this approach is limited to surface observations and is further impacted by foam, sun glint, clouds, atmospheric aerosol, and illumination/observation geometries. Building upon near/below surface studies of phytoplankton using CALIPSO data and oil spills using fluorescence measurements, we are exploring the feasibility of using fluorescence signatures to identify and characterize near surface and submerged marine plastic debris for possible future airborne and spaceborne systems.

We gathered fluorescence measurements in a laboratory setting to develop a concept for a fluorescence lidar instrument. The aim was to understand the fluorescence properties of different types of plastic samples, including those obtained from commercial sources as well as those found as beached litter, abandoned fishing nets, and with biofilm growth.

The experiment consisted of three distinct segments. In the first segment, our objective was to calculate the ratio of absorbed to fluorescence photons emitted by a hard target. We used a modified DeMello method to calculate quantum yield of a hard target that incorporated an integrating sphere into the setup. The second segment focused on collecting data regarding the spectral response and lifetime decay of fluorescence. To accomplish this, we used a spectrometer to measure the spectral characteristics, and a separate detection scheme utilizing time-correlated single photon counting (TCSPC) to capture the temporal response. In the final segment, we conducted the experiment on a larger scale by simulating a lidar-like retrieval scenario within a tank. This allowed us to assess the performance and viability of a fluorescence lidar concept under conditions that resemble realistic deployments.

We present an overview of our progress, including updates from the laboratory, the results obtained from the data analysis, and our future plans for this project.

Large-scale remote monitoring of riverine litter to evaluate effectiveness of clean-up technologies

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In June 2023 the Horizon Europe project INSPIRE kicked off. INSPIRE will fight against the plastic pollution in rivers by introducing 20 scalable technologies to prevent and eliminate litter. The technologies will be demonstrated in 6 rivers across Europe. Monitoring of the plastic load in the river and the riverbanks is essential to develop a baseline and evaluate effectiveness of the technologies. Here we introduce a camera and drone-based system to monitor plastic flux in the river and macroplastic densities on the riverbanks. The fixed camera system consists of a series of Commercial Of-The-Shelf (COTS) cameras with housing and real-time datalink. The cameras work autonomous and will provide a continuous feed of data uploaded to the cloud. The drone system consists of a high resolution RGB and multispectral Micasense camera. Specific attention goes to the conversion from the raw data into standardized Analysis Ready Data including: (1) image alignment of the multispectral camera, (2) converting raw data into reflectance products, and (3) sensor fusion, to align high spatial resolution RGB with high spectral resolution MicaSense data.

For plastic detection and characterization robust machine learning models are used including new pre-trained foundation models like Segment Anything. Feature detection techniques like SIFT (Scale Invariant Feature Transform), SURF (Speeded-Up Robust Features) or ORB (Oriented FAST and Rotated Binary Robust Independent Elementary Features) are being tested in combination with a feature matching algorithm to transform the camera-based plastic detections into a plastic flux product. Here, we will present the INSPIRE project and its first results demonstrated at the Temse bridge and riverbanks along the Scheldt river (Belgium).

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Advancing Remote Sensing of Floating Marine Microplastics: Information Content Analysis of Simulated and Historic Ocean Color Spectra

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Floating microplastics concentrate along large-scale convergence zones associated with Ekman dynamics in the five major ocean basins, but a comprehensive analysis of the spatial and temporal distributions is lacking and the monitoring tools are not well developed to assess global distributions. Through the NASA-funded project Spaceborne Quantification of Ocean MicrO-Plastics (SQOOP), we have conducted a feasibility study of remote detection of floating microplastics based on anomalies in spectral reflectance from ocean color imagery. Simulations of mixed pixel models of floating biofilmed microplastic reflectance to the Top of the Atmosphere (TOA) have been conducted with varying background water chlorophyll concentrations, atmospheric conditions, and instrument and solar viewing geometries. An extensive information content analysis of the uncertainty estimates and retrieval error covariance matrices from over 100,000 simulations revealed the fraction surface coverage required for at least 95% probability of detection under different environmental and observational conditions. Results show that microplastics generally must represent more than 0.01 fractional coverage at the sea surface to be detectable or 100 times more concentrated than measured concentrations in the gyres. Under high wind and aerosol conditions, microplastics must represent 0.1 fractional coverage or more. Under certain ideal environmental conditions, however, microplastics may be detectable at lower concentrations. We predict the long-term increase in floating microplastics may be observable in the historic MODIS ocean color satellite record by observing trends in multiple retrieved parameters in the ocean color gyres under best-case environmental conditions. Analyses of MODIS Aqua and Terra imagery in the Great Pacific Garbage Patch assess long-term trends consistent with the exponential increase in microplastics under optimal environmental conditions. In collaboration with visual artist Oskar Landi, we are producing an art exhibit "Floating Points: Exploring the Plastisphere with NASA" will open November 9, 2023 at the University of Connecticut Avery Point Alexey von Schlippe gallery.

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Title: **A Machine Learning Approach for Chlorophyll-a Estimation in Coastal Waters from Top-of-Atmosphere VIIRS Satellite Data**

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Satellite remote sensing of chlorophyll-a concentrations (Chl-a) is instrumental in comprehending aquatic ecosystems, offering invaluable insights into their health. Most Chl-a models rely on spectral water-leaving radiances or reflectance data as inputs. Typically, this data is acquired at the top-of-the-atmosphere (TOA) level, necessitating additional atmospheric correction models. However, water, being a dark target, results in water-leaving radiances constituting only a fraction of total satellite TOA measurements. In this study, we propose a novel approach that directly utilizes satellite-derived TOA radiances in Chl-a remote sensing models within the Florida and Chesapeake Bay regions. Additionally, we introduce an attention-based, data-driven atmospheric compensation (DAC) model that leverages contextual features such as sea surface pressure, sun azimuth, and zenith angle to enhance Chl-a predictions. Machine learning models, including Multilayer Perceptrons (MLP) and 1-D Convolutional Neural Networks (CNN), are employed to predict Chl-a concentrations. We integrate an DAC model to mitigate atmospheric effects. Our experimental results reveal several key findings: 1) The predictive capabilities of machine learning models using Level-1B (L1B) data surpass those relying on Remote Sensing Reflectance (Rrs) data. 2) The performance improvements gained by incorporating the DAC model with machine learning models on L1B data. 3) The significance of including secondary L1B data, that fail the VIIRS ocean color level-2 flag check and don't qualify for Rrs data, in Chl-a predictions. Our innovative approach demonstrates superior predictive capabilities compared to conventional blue-green ratio algorithms. Furthermore, the DAC model makes a positive contribution to the accuracy of our models. By including secondary L1B data, we extend Chl-a predictions into areas that were previously excluded. This study offers a promising avenue for more effective monitoring and assessment of aquatic ecosystem health using satellite remote sensing and machine learning techniques.

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A Principal Component and Machine Learning Approach to Gap Fill Hyperspectral Ocean Color Satellite Retrievals

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Retrievals of ocean color properties from space are important for monitoring the health of the ocean ecosystem but such retrievals can be limited spatially due to conditions such as clouds, aerosols, and sun glint. Gap filling of ocean color retrievals is typically performed by combining retrievals from multiple satellites or temporally averaging multiple days of retrievals. Despite these techniques large gaps still exist posing challenges for near real time monitoring of events like harmful algae blooms.
To address these limitations, we developed a spatial gap filling approach applying machine learning approach to hyperspectral instruments to learn how to perform an atmospheric correction under challenging retrieval conditions. In this approach a principal component analysis is used to decompose the hyperspectral measurements into spectral components that describe the scattering and absorption of the atmosphere mixed with the surface spectral signatures. The coefficients of the principal components are used to train a neural network to predict ocean color properties derived from a standard MODIS ocean color algorithm. We apply the approach to two hyperspectral UV/VIS sensors, the Ozone Monitoring Instrument (OMI) and TROPOspheric Monitoring Instrument (TROPOMI) to show that it can be used to estimate ocean color properties such as chlorophyll, remote sensing reflectance, and fluorescence line height. This method could be used as a gap-filling technique for the future Ocean Color Instrument (OCI) onboard upcoming NASA's Plankton, Aerosol Cloud, ocean Ecosystem (PACE) satellite to provide additional information for monitoring the health of our global oceans. Additionally, it could be applied to the first NASA and Smithsonian geostationary Tropospheric Emissions: Monitoring of Pollution (TEMPO) spectrometer to better understand diurnal variability in inland and coastal ocean ecology.

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Field Calibration of HyperNav Spectroradiometer at Mauna Loa Observatory, Hawaii

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Satellite ocean color remote sensing requires accurate calibration of the observing radiometer. This necessitates System Vicarious calibration (SVC), therefore in situ measurements by systems like MOBY and HyperNav. These systems are characterized and calibrated in the laboratory (e.g., using integrating spheres or classical lamp-plaque methods with traceable light sources), but it is highly desirable to check the calibration in the field using natural sunlight, i.e., the very light source that controls the signal backscattered by the ocean. Here we describe the field calibration of a typical HyperNav system at Mauna Loa Observatory, where the atmosphere is less influenced by pollution, boundary layer aerosols, and where ancillary measurements of atmospheric composition (aerosols, ozone, water vapor, trace gases) are available. The methodology consists in viewing a horizontal plaque of know bidirectional reflectance with the Sun disk unobscured and masked, allowing a determination of the direct component of downwelling planar irradiance. This measured component is compared to the output of an accurate 3-D Monte Carlo code with proper k-distribution to account for gaseous absorption at the HyperNav 2 nm spectral resolution. Field and laboratory calibrations agree to within 2% in the visible to near infrared, but differences reach 5% in some spectral regions of the near ultraviolet domain. Correlation analysis indicate good spectral accuracy for the HyperNav system, amply sufficient for the PACE mission. We conclude by discussing the utility and feasibility of performing systematically this type of calibration pre- and post-deployment near the locations of the measurement sites.

VIIRS-OLCI chlorophyll-a algorithms for the Chesapeake Bay

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Harmful algal blooms with high chlorophyll-a concentrations (Chla > 50 mg/m^3) often occur in the Chesapeake Bay, especially in the Upper Bay and Potomac River areas, and need to be traced for efficient coastal management. To this end, there are three VIIRS sensors (on SNPP, NOAA-20 and NOAA-21 platforms) and two OLCI sensors on Sentinel-3A and 3B currently in space. These two groups of sensors are expected to provide reliable and stable ocean color (OC) data for the next decade and beyond. It is important to develop algorithms to trace HABs by taking advantage of multiple observations per day, so as to make detection and monitoring less sensitive to cloudy and other unfavorable conditions. Standard Chla algorithms based on blue-green bands usually do not provide accurate Chla estimations in coastal waters. Results are presented here for the development of a neural network (NN) algorithm for VIIRS, which utilizes normalized water-leaving radiances at 486, 551, 671 nm bands together with the I1 imaging band (600 – 680 nm) centered at 638 nm and based on NOAA MSL12 processing. The algorithm avoids the blue 443 nm band, which is vulnerable to atmospheric correction. The NN algorithm is compared and reconciled in performance with an OLCI NIR/red (709/665 nm) bands algorithm, which also usually performs better than blue-green bands algorithms in coastal waters. Because of higher uncertainties in the OLCI remote sensing reflectance product in EUMETSAT processing, NOAA and NASA atmospheric correction processing schemes are also considered. Performance of algorithms are tested on field data from several Chesapeake Bay campaigns as well as on satellite – in situ matchups.

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No. 23

Deriving inherent optical properties and associated uncertainties from decomposition of hyperspectral non-water absorption

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Semi-analytical algorithms (SAAs) developed for multispectral ocean color sensors have benefited from various approaches for retrieving the magnitude and spectral shape of inherent optical properties (IOPs). SAAs generally follow two approaches: 1) simultaneous retrieval of all IOPs, resulting in pre-defined bio-optical models and spectral dependence between IOPs, and 2) retrieval of bulk IOPs (absorption and backscattering) first followed by decomposition into separate components, allowing for independent retrievals of some components. Algorithms used to decompose hyperspectral remote sensing reflectance into IOPs follow the first strategy or, more recently, leverage machine learning approaches to decompose spectra based on statistical relationships. Here, a spectral deconvolution algorithm for incorporation into the second strategy is presented that decomposes total non-water absorption estimating absorption due to phytoplankton and colored detrital material (CDM) free of explicit assumptions. The algorithm described here, Derivative Analysis and Iterative Spectral Evaluation of Absorption (DAISEA), originally provided estimates of phytoplankton and CDM absorption over a spectral range from 350 to 700 nm, suitable for discrete measurements. Recent updates also allow this range to be restricted, starting at or near 400 nm, enabling DAISEA to now be applied to common in-water spectrophotometer datasets. Additional updates implement curve fitting via genetic algorithms to allow for improved estimates of these components across diverse water types and uncertainty estimates for individual components. DAISEA also implements a choice of model for describing CDM – either a traditional exponential or hyperbolic shape can be used. Overall, updated DAISEA demonstrates a maximum mean absolute difference of 0.029 m^{-1} across all wavelengths for water types with greater than 10% contribution of phytoplankton at 440 nm. Here, we present our findings, including the application of the algorithm to in situ absorption data, and discuss future applications to hyperspectral satellite sensors, such as NASA's PACE mission.

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Hyperspectral UV-Blue Atmospheric Correction for the Ocean Color Instrument (OCI)

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Ultraviolet (UV) ocean color information can improve the separation of inherent optical properties (IOPs) of phytoplankton, colored dissolved organic matter (CDOM), and non-algal particles (NAP). The Ocean Color Instrument (OCI) on the Plankton, Cloud, Aerosol, ocean Ecosystem (PACE) mission features new hyperspectral UV capabilities to enhance discrimination of these IOPs. Atmospheric correction in the UV region is challenging due to uncertainty in aerosol optical properties (AOP) and large effects from molecular and aerosol scattering and absorption. We have developed a novel physics-based algorithm for UV-blue atmospheric correction using AOP profiles from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), which assimilates Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) at 550 nm and extends AOPs into UV wavelengths. As a proxy for OCI, we retrieve remote sensing reflectance (Rrs) using hyperspectral measurements from the Ozone Monitoring Instrument (OMI) aboard NASA's Earth Observing System (EOS) Aura mission (2004 – present) in the 315 to 500 nm wavelength range, smoothing the high-resolution OMI spectra prior to retrieval to emulate the 5 nm OCI resolution. The retrievals utilize Jacobians for the top-of-atmosphere reflectance with respect to water-leaving radiance, calculated using a version of the Vector Linearized Discrete Ordinate Radiative Transfer (VLIDORT) model adapted for ocean-atmosphere simulations. We compare OMI Rrs retrievals with the Marine Optical Buoy (MOBY) near Lanai in Hawaii. Between 350 and 400 nm, the retrieved OMI Rrs spectra agree with MOBY within the 15% PACE requirement without using vicarious calibration. To achieve this agreement, we find it necessary to scale MERRA-2 AOD to agree with OMI-retrieved AOD in UV, and to remove highly absorbing black carbon (BC) aerosols from the MERRA-2 AOP profiles over the Pacific near Hawaii. We also demonstrate our retrievals in other regions and show spatial variations across the global oceans.

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Introduction of the novel OLCI Atmospheric Correction for Diverse Optical Water Types A4O

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We introduce a novel method for atmospheric correction of Sentinel-3 OLCI ocean colour imagery called A4O. The scope of A4O aims to maximise usability for all optical water types (OWT) with seamless transition from inland, coastal and ocean waters. The method is a further development of the neural network-based algorithms of Doerffer and Schiller (1999, 2007) and Brockmann et al. (2016); the current version of their C2RCC algorithm is implemented in the Sentinel-3 OLCI Level-2 processing as the Alternative Atmospheric Correction (and in-water algorithm) for optically complex waters. The core of A4O is an ensemble of several neural networks that approximate fully normalized remote-sensing reflectance at 16 OLCI bands from the top-of-standard-atmosphere reflectance spectrum. Special attention is paid to a comprehensive coverage of all natural waters, as well as a good classifiability of the results, i.e. Rrs, with a newly developed OWT classification scheme (Bi and Hieronymi, in prep.), which in turn is based on state-of-the-art bio-geo-optical modelling (Bi et al., 2023). We present the fundamental evolution steps of A4O and show a comparison of the performance with different atmospheric correction methods in view of usability for different optical water types (Hieronymi et al., 2023).

Developing a water quality and HAB monitoring tool for drinking water utilities using Planet SuperDove imagery

Thomas Howard[1]

Planet SuperDove satellites provide a promising solution for drinking water utilities that are interested in incorporating remote sensing into water quality monitoring programs. The Planet SuperDove constellation, initially launched in March 2020, consists of approximately 130 CubeSats capable of measuring eight spectral bands in the visible and near-infrared ranges (431-452 nm, 465-515 nm, 513-549 nm, 547-583 nm, 600-620 nm, 650-680 nm, 697-713 nm, and 845-885 nm). With a spatial resolution of 3-5-meters and a near-daily revisit cadence, this platform is well-suited to resolve waterbodies at the spatial and temporal scales needed for effective source water monitoring and management. In this study, we paired over 1,400 HPLC chlorophyll-a and Secchi disk depth measurements collected between 2020 and 2023 from lakes, reservoirs, and rivers in 19 US states with coincident Planet SuperDove surface reflectance products. This data was used to train and test an XGBoost regressor to estimate Secchi depth-derived trophic state index (TSI(SD)) and chlorophyll-a concentration. Testing on nearly 300 holdout samples yielded a coefficient of determination of 0.82 and a mean absolute percentage error of 8% for the TSI(SD) model as well as a coefficient of determination of 0.76 and a root mean square error of 10.9 µg/L for the chlorophyll-a model. An operational dashboard was then built using these models along with data retrieved from the US Water Quality Portal. The dashboard tool was used to monitor HABs at several drinking water reservoirs and assess model performance throughout time at multiple virtual buoy locations. This poster presentation will discuss how this work, and other efforts using SuperDove data to estimate turbidity and phycocyanin concentrations, may supplement and improve inland water quality monitoring and assessment programs.

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Using the Phyto-Plankton Light Scattering (PPLS) instrument to investigate the effects of concentration, time of day, and phase of culture on phytoplankton hyperspectral backscattering spectra and determining its use to differentiate among dinoflagellate species

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Satellite remote sensing reflectance (Rrs) is related to the ratio of absorption and backscattering processes in the ocean. For phytoplankton, absorption is significantly controlled by pigments and is assumed to be similar within taxonomic groups. Unlike absorption, backscattering is also related to the cell shape, size, and index of refraction, which can vary within taxonomic groups. Given the lack of a hyperspectral backscattering sensor until recently, phytoplankton backscattering has not been as well documented or explored and previous studies of backscattering by phytoplankton have been restricted to multispectral measurements. For this study, the Phyto-Plankton Light Scattering (PPLS) instrument prototype was used to capture the first hyperspectral backscattering measurements of six dinoflagellate species monocultures (including harmful algal bloom species *Akashiwo sanguinea, Alexandrium ostenfeldii* and *Karenia brevis*). Experiments with cultures at varying concentrations, time of day, and phases were conducted to investigate the potential influence of these factors on backscattering spectra. Experimental measurements taken with the PPLS were combined to evaluate the use of derivative and clustering analyses for distinguishing dinoflagellate phytoplankton species using hyperspectral backscattering spectra. Results indicate that concentration, time of day, and phase of culture can impact the spectra by either flattening or completely changing the spectral shape. Measurements of samples with a transmission between 50-85% and an exposure time of 400 milliseconds were determined to be optimal for the backscattering signal. Preliminary work does not support the use of derivative and cluster methods to separate dinoflagellate species due to the combination of intra-species variability and significant similarities between species within the same phytoplankton group.

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Validation protocol for the evaluation of space-borne lidar particulate back-scattering coefficient b_{bp}

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Space-borne lidar measurements from sensors such as CALIOP were recently used to retrieve the particulate back-scattering coefficient, b_{bp}, in the upper ocean layers at a global scale and those observations have a strong potential for the future of ocean color with depth-resolved observations thereby complementing the conventional ocean color remote sensed observations as well as overcoming for some of its limitations. It is critical to evaluate and validate the space-borne lidar measurements for ocean applications as CALIOP was not originally designed for ocean applications. Few validation exercises of CALIOP were published and each exercise designed its own validation protocol. We propose here an objective validation protocol that could be applied to any current and future space-borne lidars for ocean applications. We, first, evaluated published validation protocols for CALIOP b_{bp} product. Two published validation schemes were evaluated in our study, by using *in-situ* measurements from the BGC-Argo floats. These studies were either limited to day- or nighttime, or by the years used or by the geographical extent. We extended the match-up exercise to day-and nighttime observations and for the period 2010–2017 globally. We studied the impact of the time and distance differences between the *in-situ* measurements and the CALIOP footprint through a sensitivities study. Twenty combinations of distance (from 9-km to 50-km) and time (from 9 h to 16 days) differences were tested. A statistical score was used to objectively selecting the best optimal timedistance windows, leading to the best compromise in term of number of matchups and low errors in the CALIOP product. We propose to use either a 24 h/9 km or 24 h/15 km window for the evaluation of space-borne lidar oceanic products.

Machine Learning-based Inherent Optical Properties Estimation using the Remote-Sensing Reflectance

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Inherent optical properties (IOPs) helps us to understand the physical and optical properties of the ocean. Therefore, IOP estimation is crucial for monitoring the marine environment. Satellite data is being efficiently utilized for IOP estimation. Various models have been developed over the decades based on various mathematical formulas and optical theories to establish the relationship between remote-sensing reflectance (R_{rs}) and IOP. In this study, we estimated IOP from simulated R_{rs} using machine learning approaches, which have gained prominence in recent years. Due to the absence of in-situ data for developing the IOP estimation model, we utilized a radiative transfer simulation dataset (RTSD) generated by the Korean Ocean Satellite Center, considering the wavelength of the Geostationary Ocean Color Imager (GOCI)-II, instead of observed R_{rs} in GOCI-II. The HydroLight radiative transfer code was used to simulate RTSD. Simulated R_{rs} of GOCI-II 7 bands (412, 443, 490, 510, 555, 620, and 660 nm) and their ratios were used as input variables, and the target values were the absorption coefficient of phytoplankton (a_{ph}) (443 nm), the absorption coefficient of the combination of detritus and gelbstoff (a_{dg}) (443 nm), and the backscatter coefficient of particles (b_{bp}) (555 nm). We employed random forest (RF), gradient boosted regression trees (GBRT), and support vector regression (SVR) as machine learning approaches. As a result of validation with a 20% test sample from the entire dataset not used for model training, GBRT and RF, both tree-based model, outperformed SVR irrespective of the target. Among the three targets, accuracy was highest in the order of b_{bp}(555 nm), a_{dg}(443 nm), and a_{ph}(443 nm). These findings confirm the potential for estimating IOP from GOCI-II Rrs using machine learning approaches.

Multi-sensor assessment of accidental oil spills in the Bay of Campeche

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Abstract: The Bay of Campeche in the southern Gulf of Mexico has vast oil reservoirs and numerous oil seeps and oil platforms. Accidental oil spills from the platforms occasionally occur, with the most recent one reportedly caused by an explosion on the *Nohoch Alfa* platform on 7 July 2023, which was repaired by 18 July 2023 according to the oil company. However, using multi-sensor satellite imagery of optical, radar, and thermal data, we found continuous oil spill even after the claimed repair, as well as another oil spill from a nearby platform that has not been reported. This latter spill started before the reported explosion, with a much larger spilled area for the period of July 4 to July 24. The cumulative oil footprint reached ~1250 km^2 with ~14% being thick oil emulsions. The temporal changes of the accidental oil spills were determined by combining SAR and optical observations. Further characterization of oil types and estimation of oil volume was also achieved using optical data. Thermal imagery revealed continuous oil spill from deep waters, as the surface oil showed lower temperatures than the surrounding surface waters. These findings suggest that multi-sensor satellite data, together with appropriate algorithms, can provide more information than traditional ways at no cost to most people, and thus is expected to improve near real-time monitoring and post-spill assessment for future spills.

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No. 31

Operational Application of Satellite Ocean Color Data to Improve Ocean Model Performance

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Abstract:

Numerical ocean models must have a designated algorithm to quantify the penetration of incident solar shortwave radiation into the upper ocean. This radiative transfer calculation then determines the heating rate and thermal balance for each ocean model time step, and thus it may broadly impact thermal and density state variables. These state variables, in turn, have an impact on the simulated currents and air-sea thermal energy exchange rates in coupled ocean-atmosphere simulations. The default radiative transfer calculation in many operational ocean models is still based upon a simple table of approximated *Jerlov* water types. We have developed an operational system that instead utilizes the Global Optical Processing System (GOPS) level-3 surface optical property products derived from the present constellation of ocean color satellites. Gap-free GOPS products at 1 km global scale are produced via a two-dimensional variational analysis and assimilated into the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). When the COAMPS radiative transfer scheme for solar shortwave is corrected with realistic and satellite-based optical attenuation data, forecast fidelity to surface temperature observations is markedly improved in a variety of oceanographic settings. Moreover, significant changes in simulated air-sea turbulent energy exchange are observed leading to divergences in the forecast of atmospheric properties. Examples of COAMPS physical state variables space improvements when satellite ocean color data are utilized will be shown from the Gulf of Mexico and the Black Sea.

Studies of oceanic geophysical turbulence using observations of geostationary ocean color imageries

Eun Ae Lee[a] and Sung Yong Kim[a]

Oceanic geophysical turbulent characteristics are examined with energy spectra of the submesoscale maps of chlorophyll concentrations at hourly and sub-kilometer resolutions, obtained from geostationary ocean color imageries in a coastal region off the east coast of Korea over a period of at least ten years. As independent and complementary observations, coastal surface currents by an array of high-frequency radars at hourly and O(1)-km resolutions are examined, and their energy spectra are compared to evaluate the geophysical turbulent characteristics of currents and passive tracers. The energy spectra of the surface currents in the wavenumber domain (k) become steeper at a scale of approximately 10 km from a slope of $k^{-5/3}$ to slopes between k^{-2} and k^{-3} at a length scale of 2 km. Moreover, the energy spectra of the surface chlorophyll concentration exhibit anisotropy associated with bathymetric effects and regional circulation, and their decay slopes change from $k^{-5/3}$ to k^{-1} at O(10) km scales and from k^{-1} to k^{-3} at sub-kilometer scales, which is consistent with the two-dimensional quasi-geostrophic turbulence theory on the currents and passive tracer. The spectral decay slopes of these energy spectra show weak seasonality, which can be interpreted with the baroclinic instability in the weak seasonal mixed layer and the persistent and non-seasonal regional circulations.

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Spatial and Temporal Dynamics of Water Quality in Lake Okeechobee and its Impact on Environmental Health

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Bhaskar.

Abstract

The increasing deterioration of inland waters such as lake Okeechobee is a major environmental concern in Florida, resulting not only in increased treatment costs for drinking water but also in impacts on tourism, commercial fishing and aquaculture and risks to human, ecological and environmental health. As a result of that, there is a greater need for effective monitoring strategies of water quality parameters. The objective of this study is to monitor and map the spatial and temporal trends in Chlorophyll-a, Nitrogen, and Phosphorus concentrations, and water turbidity in order to develop water quality monitoring algorithms using satellite imagery. A combination of in situ measurements and Landsat satellite imagery were used. Water quality data from fifteen (15) sampling stations were obtained from a public platform known as the South Florida Water Management District DBHydro. Cloud free Landsat 8 images corresponding to the in situ sampling dates were obtained from the USGS Glovis website. These images were processed in ERDAS ER Mapper software and best subsets regression analysis was conducted to find the algorithms to map the water quality parameters. The nutrients in the Lake water at different stations, and Chlorophyll-a content exceeded the water quality standards, which resulted in classifying the locations as either eutrophic or hypereutrophic. From the water quality data of 2017-2023, the Chlorophyll-a and total Phosphorus and Nitrogen, exceeded the criteria limits at most of the sampling locations. Positive correlations were found between Turbidity, Phosphorus, and Nitrogen. This study provides insights on the water quality hotspots which need urgent remediation. The study highlights the need for continued monitoring and research to better understand and address the complex issue of algal blooms in Lake Okeechobee, especially with newer high-resolution satellites.

Keywords: Lake Okeechobee, Water quality, Landsat, Planet, Satellite imagery, Nutrients, Remote sensing

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Global automated extraction of bathymetric photons from ICESat-2 ATL03 data

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The ATLAS photon-counting lidar instrument on ICESat-2 is capable of providing information on both water quality and bathymetry due to its ability to penetrate the surface ocean and provide geolocated photon information from below the water surface. However, a fundamental requirement for use of ICESat-2 data in ocean science is the ability to determine the provenance of the geolocated photons, i.e. to determine whether they were scattered in the atmosphere, at the sea surface, in the water column, or at the seafloor. By leveraging the PointNet++ model for segmentation and classification of 3D point clouds, we developed a fully automated method to a) identify photons reflected by the sea surface, then b) identify photons reflected from the seafloor, after which c) identification of photons scattered in the atmosphere and water column, respectively, is straight-forward. Training data consisted of manually classified seafloor-reflected photons from ATL03 data granules covering >100 degrees of latitude and encompassing a wide range of seafloor characteristics and variations in ICESat-2 data features. The trained model obtained precision, recall and F1 scores of 0.9291, 0.9315 and 0.9303, respectively, when evaluating its ability to classify these seafloor-reflected photons at independent test sites. Model performance varied between test sites, with most errors occurring in areas with a high density of photons scattered in the water column near the seafloor. Our model is a first step toward automated classification of geolocated photons from ICESat-2 that will facilitate the use of this unique dataset in ocean science. The model is publicly available for use and further development.

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Effects of atmospheric and glint correction approaches on remote sensing reflectance estimation from airborne imaging spectroscopy

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Imaging spectroscopy is a powerful tool for monitoring of aquatic ecosystems on large spatial scales, but harnessing the high spectral information density from these data requires accurate correction for non-water spectral components, including atmospheric effects and specular reflection of sky and sun light at the water surface. Existing approaches for the removal of glint mainly focus on sun glint, and the influence of sky glint is often neglected. Gege (2012) adopted equations of Gregg and Carder (1990) to describe a physics-based three-component surface reflectance model (3C) where sky radiance is described as the weighted sum of direct solar irradiance and two diffuse components: Rayleigh scattering and aerosol-scattering. This approach can be used to divide the bottom-of-atmosphere reflectance into spectral water and surface components through inversion by incorporating a bio-optical model and treating the relative intensities of each component as fit parameters. We investigate the impact of different processing schemes on estimates of remote sensing reflectance from Global Airborne Observatory VSWIR imaging spectroscopy data. We compare outputs to simultaneously collected field spectroscopy measurements in Hawaiian coastal waters in January 2023, test each combination of two atmospheric correction processors (ATREM, ISOFIT) and two post-hoc glint correction approaches (3C, Gao & Li 2021) and compare the resulting remote sensing reflectance spectra. The agreement of field and remotely sensed spectra attests to the advantage of the 3C-based glint correction for the retrieval of remote sensing reflectance, both in optically deep and shallow water. The approach improves both the magnitude and the spectral shape of inverted spectra, especially in shorter wavelengths. Results further indicate that the 3C-based glint removal approach may also remove non-glint related residuals, for example, remaining from an incomplete atmospheric correction.

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Accuracy of SeaHawk-HawkEye standard reflectance products in globally distributed aquatic sites

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Abstract:
HawkEye is an ocean color instrument aboard SeaHawk CubeSat launched in 2018 to provide high quality, high resolution (~120 m) images of open ocean, coastal, inland, and estuarine waters. The Hawkeye instrument collects radiance in 8 spectral bands, similar to the SeaWiFS sensor with an additional 750 nm channel. Accuracy assessment of remote sensing reflectance products is crucial owing to their use in deriving water quality parameters like Chlorophyll, diffuse attenuation coefficient, turbidity, etc. The present work aims to evaluate the accuracy of HawkEye's Level 2 (L2) reflectance products in the visible range over globally distributed aquatic sites. For this assessment, L2 remote sensing reflectance (Rrs) from Hawkeye is compared with *in-situ* Rrs from ocean color component of Aerosol Robotic Network (AERONET-OC). 27 cloud-free images over seven inland and coastal water AERONET-OC sites covering various water types were used for matchup analysis. We used seven statistical measures for evaluating the matchups. In general, HawkEye Rrs showed good agreement in comparison with AERONET-OC Rrs for wavelengths greater than 500 nm and an overall overestimation in the blue region (412, 443 and 490 nm) that is expected to improve with a comprehensive and ongoing reprocessing, led by NASA's OceanColor group. The quality of HawkEye Rrs was further evaluated with respect to ancillary parameters like Chlorophyll-a, aerosol optical depth, observation and illumination geometry. Results indicate that HawkEye reflectance products match well with AERONET-OC data and hence will be useful for ocean color remote sensing applications. This analysis will be expanded to include 15 more AERONET-OC locations and *in situ* Rrs data collected in South Atlantic Bight.

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Absorption coefficient and chlorophyll concentration of oceanic waters estimated from band difference of satellite measured remote sensing reflectance

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Abstract

Absorption coefficient and chlorophyll concentration (*Chl*) are important optical and biological properties of the aquatic environment, which can be estimated from the spectrum of water color, commonly measured by the remote sensing reflectance (R_{rs}). In this study we extended the band-difference scheme for *Chl* of oceanic waters developed a decade ago to the estimation of absorption coefficient at 440 nm (*a*(440)). As demonstrated earlier for the estimation of *Chl*, *a*(440) product from the band difference of R_{rs} showed much smoother spatial pattern than that from a semi-analytical algorithm. More importantly, it is found that the upper limit of using band difference of R_{rs} can be extended from -0.0005 sr^{-1} (the upper limit set a decade ago for the estimation of *Chl*) to ~0.0005 sr^{-1} (corresponding to *a*(440) ~0.08 m^{-1}), which covers ~91% of the global ocean. We further converted *a*(440) to *Chl* based on the "Case-1" water assumption, and found that the standard *Chl* product of oligotrophic waters (*Chl* ~ 0.1 mg/m^3) distributed by NASA is generally ~20% higher than *Chl* converted from *a*(440), possibly a result of different datasets used to determine the algorithm coefficients. These results not only extended the application of the band-difference scheme for more oceanic waters, but also highlighted the need of more accurate field measurements of *Chl* and R_{rs} in oligotrophic oceans in order to minimize the discrepancies observed in satellite *Chl* products, where both algorithms followed the same "Case-1" concept, except one takes a one-step empirical approach, while the other takes two-steps.

Using Planet Satellite Imagery to Map and Quantify Harmful Algal Blooms in Chesapeake Bay Tributaries

Mary LePere[1], Dr. Victoria Hill[1]

This project aims to utilize 8-channel Planet satellite imagery to map and quantify harmful algal blooms (HABs) within Chesapeake Bay tributaries. Satellite imagery is able to encompass a far larger area than conventional boat-based data collection, and the 3 m resolution of Planet is able to resolve spatial heterogeneity in HAB distribution.

We used a ratio between the red and rededge bands to construct a Normalized Differential Chlorophyll Index (NDCI). Chlorophyll concentrations were derived from this index using a Transformed Normalized Differential Chlorophyll Index (TNDCI) specifically created for shallow, turbid coastal environments. Preliminary results show success in mapping extensive HABs. Retrieved chlorophyll concentrations aligned with corresponding in-situ data in both the York and Lafayette Rivers in 2020, 2021 and 2022. Satellite-based mapping enables quantification of total HAB area and biomass, which is unobtainable when making point-based measurements.

Planet's high-resolution, high-frequency imagery captures the entire scope of coastal HABs and highlights areas where blooms may not be seen by traditional methods of data collection. Through the successful implementation of the TNDCI and its validation against ground-truth data, the project offers a promising framework for ongoing efforts to monitor and mitigate the impacts of HABs in coastal ecosystems.

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Enhancing the reliability of GCOM-C/SGLI-derived chlorophyll-a data in the upper Gulf of Thailand

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Abstract

The Second-generation Global Imager (SGLI) aboard the Global Change Observation Mission-Climate (GCOM-C) platform has been instrumental in providing high-resolution ocean color observations at 250 meters, facilitating the monitoring of coastal environmental changes since January 2018. In addition to these efforts, the Japan Aerospace Exploration Agency (JAXA) offers a chlorophyll-a (chl-a) product derived from GCOM-C/SGLI data, which is valuable for global algal bloom monitoring. This year, unprecedented green *Noctiluca scintillans* blooms occurred near the northeastern coast of the upper Gulf of Thailand (uGoT) during the southwest monsoon, leading to extensive fish mortality and adverse community health effects due to foul odors. However, certain areas in the uGoT where blooms occurred have shown low chl-a concentration estimates on the GCOM-C/SGLI chl-a product.

The purpose of this research is to validate and improve the accuracy of the standard GCOM-C/SGLI chl-a algorithm in the uGoT region. To enhance estimation reliability, we implemented a previously employed local empirical method designed for MODIS data, adapting it to wavelengths compatible with SGLI data, and incorporated Rrs correction techniques for SGLI data. By utilizing in-situ remote sensing reflectance (Rrs) data to estimate chl-a, we observed that the standard GCOM-C/SGLI chl-a estimate for low (high) chl-a concentrations tended to be overestimated (underestimated) compared to the actual chl-a concentration. In comparison to in-situ chl-a and local red tide incident reports, the modified local empirical method demonstrated the ability to reduce the errors and accurately reproduce high chl-a levels in bloom areas on the improved GCOM-C/SGLI chl-a data. Our presentation will provide a comprehensive analysis of these method enhancements, thereby making a significant contribution to the field of coastal red tide monitoring.

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Advanced Polarimetric Slope Sensing technique for retrievals of wave slope statistics

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Polarization of light contains information about the media it travels through or reflects from by changing the light's polarization state. The degree of linear polarization (DoLP) in conjunction with Stokes vector components allows to keep track of how the media affects the light's polarization. In ocean color applications ocean roughness and wave slopes statistics play a role in atmospheric correction that is performed on satellite data to estimate water leaving radiances. It was suggested that wave slope statistics can be measured using a Polarimetric Slope Sensing (PSS) technique (Zappa, 2008), which uses the reflected polarization of light from the water surface to determine its roughness. However, this technique has several practical limitations. A proposed advanced PSS technique allows to measure more reliably and validate Cox and Munk statistics in various weather conditions and water types. A polarized camera system was assembled using Teledyne Dalsa's Genie Nano – M2450 polarized camera and a filter wheel attached to it providing multi-spectral capabilities. The data gathered using the polarized camera system consists of shipborne measurements above 10 meters from the sea surface during the VIIRS Cal/Val Cruises in the Gulf of Mexico in 2021, Hawaii in 2022, and at the North-West U.S coast in 2023, as well as pier measurements from a Brooklyn pier platform in New York from the same height. The slopes recovered using advanced PSS technique are analyzed and compared to Cox-Munk statistics showing consistency of Cox-Munk relationships in open ocean, coastal and even near shore waters. Results are further used to evaluate uncertainties in measurements of polarized and unpolarized radiances from different heights above ocean surface carried out in the ocean cruises and from the helicopter in the Chesapeake Bay area.

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Abstract for: IOCS Florida, November 2023

HydraSpectra: low-cost optical near-surface sensor deployed as part of Australia's AquaWatch Mission

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The joint SmartSAT CRC/CSIRO AquaWatch Australia Mission proposes a step change in monitoring technologies to support the scales and speeds at which modelling is now required for water quality forecasting, ultimately to safeguard Australia's inland and coastal waters. We are developing an integrated nationwide ground-to-space national monitoring platform incorporating satellite and in situ sensor observations together with a dedicated data analysis platform. A nationwide in situ water quality monitoring sensor network requires Internet of Things (IoT) sensor nodes that are cost-effective to construct and operate, easy to maintain, to deliver timely and credible data to complement satellite observations for appropriate decision making.

We developed a novel spectrometer, HydraSpectra, to reliably measure surface spectral reflectances across the visible spectrum at a relatively low cost. Eight optical inputs are fed through a single spectrometer to simultaneously measure E_d, L_{sky} and L_{water} contributions across a range of viewing geometries and two cameras are integrated to record sky and water surface conditions. We found the device to measure reflectances comparable to those made using more expensive scientific grade equipment. The device has now been deployed as part of the AquaWatch mission, permanently mounted at remote pilot sites with wireless data upload; platforms have varied from fixed pylons to floating buoys.

The poster will highlight example deployments, sensor calibration and device performance. Data processing workflows include retrieval of reflectances, and application of QA processes and water quality algorithms. Results show the capacity to deliver rich temporal datasets for TSS, CDOM, and chlorophyll with accuracies similar to other devices. The system provides high density match up data for validation of satellite observations via the AquaWatch data integration platform, as well as data for parametrisation of hydrodynamic/growth models for forecasting water quality events.

Overview of IOCCG Ocean Optics & Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation with a Focus on the CDOM Absorption Protocols

Antonio Mannino[1], Michael Novak[2], Joaquin Chaves[3], Chelsea Lopez[3], Aimee Neeley[3]

Knowledge of and reduction of uncertainties of ocean color satellite data products requires high-quality field measurements used for (1) bio-optical algorithm development as well as (2) the performance evaluation of the satellite data products. Prior and current programs and activities (e.g., SIMBIOS, Sea-HARRE, AERONET-OC, FRM4SOC/-II) have demonstrated the value and necessity of standardized field measurement protocols. Under the auspices of the IOCCG, measurement experts from the aquatic community have convened over the past 10 years to develop consensus field measurement protocols. At present, six protocol volumes on ocean optics and biogeochemistry have been published with two other protocol documents (CDOM absorption and scattering properties) to be completed in the coming months. Additional protocol activities are being planned, and the IOCCG will be soliciting applications from experts in the scientific community to participate. Key elements of measurement protocols will be presented with particular attention to CDOM absorption and particulate organic carbon.

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No. 43

SeaHawk Low-Cost Ocean Color CubeSat Produces High Spatial Resolution and High-Quality Data: A Comparison with NOAA-20 VIIRS, NASA MODIS-Terra and MODIS-Aqua

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Abstract

SeaHawk, with its multispectral HawkEye sensor, is the first dedicated ocean color (OC) non-commercial CubeSat satellite mission in orbit. This mission was designed to demonstrate that a low-cost CubeSat could retrieve high-quality, high spatial resolution data from around the world. Here we present the first in-depth assessment of SeaHawk's performance with respect to three other operational OC missions: MODIS-Terra, MODIS-Aqua, and VIIRS. We selected 11 locations that represent a variety of optical water types and compared data on the days when there were available data for all four sensors. For each image of a location, we extracted data from 20,000 randomly selected points. We selected 4 bands present in all sensors (412nm, 447nm, 488nm, 555nm) and compared the matchups at 3 different levels of processing (top of the atmosphere (TOA) reflectance, remote sensing reflectance (R_{rs}), and chlorophyll-a concentration). We then compared five statistical approaches: root mean squared error (RMSE), mean percentage change (MPC), Concordance Correlation Coefficient (CCC), Robust regression (R^2), and bias. Overall, TOA results show good agreement between HawkEye and all other sensors (irrespective of bands), particularly MODIS-Terra. R_{rs} results show band-specific patterns instead of sensor-specific patterns; based on R^2, CCC, and MPC, 555nm and 412nm seemed to be the best and worst performing bands. One of the reasons for the lower performance of 412nm is the known degradation of this band since launch, as evidenced in lunar calibrations. Interestingly, chlorophyll-a concentration products show better agreement among sensors than R_{rs}. In addition, MODIS-Terra orbit is the most similar to SeaHawk, explaining the superior matchups between them. Not all locations show good matchups; discrepancies could be due to a combination of spatial, geophysical, temporal, and technical aspects, e.g., resolution, hydrodynamics, time difference, or solar/sensor zenith angles. Corrections implemented in the mission-reprocessed data further improved our results.

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New data and functionality of the NOAA Ocean Color Viewer (OCView)

Karlis Mikelsons[1] and Menghua Wang[2]

In this presentation, we showcase recent additions and improvements to the NOAA Ocean Color Viewer (https://www.star.nesdis.noaa.gov/socd/mecb/color/ocview/ocview.html), developed by the NOAA Ocean Color Science Team at NOAA Center for Satellite Applications and Research (STAR). One of the most impactful introductions is the global false color imagery, derived from VIIRS-SNPP satellite data, and fine-tuned for floating algae detection and observation in global oceans, where it has proved to be especially useful. Another recent introduction is the global clear sky imagery, derived from multi-sensor daily imagery time series, and produced on 8-day, monthly, and yearly basis, and used to augment satellite derived ocean and water color measurements, but also adding value to land surface observations. Gap-filled global ocean color data products also provide a much more complete picture by filling the gaps frequently occurring in satellite ocean color observations. These are results of the state-of-the-art data gap filling algorithms and highlight the dynamics of chlorophyll-a, water diffuse attenuation coefficient at 490 nm, and suspended particulate matter (SPM) in global oceans on a daily time scale. We also list several new experimental ocean color data products incorporated in the OCView, including SPM, water class, shallow water bathymetry, and others. Further recent changes include the updated land mask and bathymetry data layers to support the ocean color data visualizations. Finally, we overview new interactive features and functionality to be included in the upcoming version of the OCView.

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No. 45

Hyperspectral particulate backscattering coefficient retrieval from hyperspectral satellite imagery of inland and coastal waters

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The hyperspectral particulate backscattering coefficient ($b_{bp}(\lambda)$) is a dominant inherent optical property (IOP) that shapes the ocean's color. Accurate remote estimation of $b_{bp}(\lambda)$ can inform users of the composition, concentration, and distribution of particulate matter (e.g., suspended sediment) in surface waters. Standard b_{bp} retrieval models, including the Quasi-Analytical Algorithm (QAA, Lee et al. 2002) and the Generalized IOP (GIOP) model (Werdell et al. 2013), are not designed or optimized for optically complex coastal and inland waters. In this work we estimate hyperspectral b_{bp} by initializing QAA, GIOP, and a semianalytical model (Gordon et al. 1998) with remotely estimated absorbing IOPs, including non-algal particle, colored dissolved organic matter, and phytoplankton absorption, as well as biogeochemical parameters (chlorophyll *a* concentration, chl*a*). The chl*a* concentration and absorbing IOPs are simultaneously derived via application of a previously developed machine learning model, a mixture density network (MDN) developed specifically for retrieval from inland and coastal waters (O'Shea et al. 2023), to the measured hyperspectral remote sensing reflectance (R_{rs}, the upwelling radiance normalized by the downwelling solar irradiance). We quantitatively compare the results of the MDN-initialized (and default) QAA, GIOP, and Gordon et al. models using a large (N=~500) dataset of *in situ* measured multispectral b_{bp} representing multiple optical scenarios. We qualitatively compare the hyperspectral retrievals to both the multispectral b_{bp} dataset from multiple regions and a fully hyperspectral b_{bp} dataset measured within Lake Erie. Finally, we estimate b_{bp} from images captured by the hyperspectral imager for the coastal ocean (HICO), to visually identify the impacts of uncertainties in the atmospheric correction approaches to derived b_{bp}. Overall, we expect the MDN-initialized hyperspectral retrievals to represent a wider range of optically complex scenarios than the default b_{bp} retrieval algorithms.

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No. 46

MODIS to VIIRS and OLCI: Effects of sensor continuity on satellite-derived dynamic seascapes

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Abstract:
Marine ecosystems are changing in response to warming waters, changes in ocean chemistry and increasing coastal development and demand for marine resources. Satellite derived seascapes provide a way to scale observations and interactions between variables to larger spatial extents and to address issues of complexity, patchiness and scale in the marine environment. Variables derived from ocean color satellite sensors such as chlorophyll-a concentration (Chla), sea surface temperature (SST), normalized fluorescence line height (nflh) and absorption by CDOM and detritus (adg) are essential ocean variables which are integral in understanding biophysical interactions in the oceans. As the MODIS satellite sensor reaches the end of its operational life, a transition must be made to a newer sensors such as VIIRS and Sentinel-3 OLCI. In this study, we compare time series of seascape input variables using the MODIS and VIIRS sensors across an overlapping time frame (2013-2022) for Chla, SST, and adg. Time series of nflh are compared between MODIS and Sentinel-3 OLCI, as VIIRS does not have the needed bands to estimate fluorescence. To assess sensitivity of seascapes to inputs from different sensors, seascapes derived from the two sets of sensors (MODIS vs. VIIRS/OLCI) are also compared, using seascape extent and the dominant (mode) seascape in a particular area of interest. The products most sensitive to the quality of MODIS observations are adg at 443nm and nflh, with shifts becoming more prominent after 2020-2021. As we move into the future with sensors such as PACE, differences in input variables into the seascape classification model need to be considered carefully.

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No. 48

Genetic Algorithm-based Atmospheric Correction (GAAC): A Tool for moderate to high spatial resolution imagery over inland and coastal waters

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Atmospheric correction (AC) over inland waters is extremely challenging in small-scale aquatic remote sensing (lakes, rivers, streams). This is due to the complex optical properties of all three components of the problem: the sky glint, the surrounding environment or so-called adjacency effects (AE), and the water itself. Rough assumptions, typically used for ocean color data processing, are not enough to separate the signal from these three components. None of the current methods of AC succeeds in removing the AE reflectance due to complex geometries and unknown aerosol type and concentration. The traditional AC method that retrieves aerosol without considering AE or treats AE separately systematically fails for small lakes, with remote sensing reflectance retrieval errors greater than 100% in the visible bands. Here we present a novel AC algorithm, GAAC (Genetic Algorithm-based Atmospheric Correction) able to retrieve simultaneous: AE reflectance, sun glint, aerosols optical thickness and types, and the water remote sensing reflectance. The results of the validation and intercomparison show that the proposed algorithm has improved significantly (>50% improvement over the most popular algorithms, e.g., ACOLITE) the water reflectance retrieval over complex lake environments for various water types. In addition, a case study shows that adjacency effect correction can also improve the accuracy of satellite-derived bathymetry.

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No. 49

Phytoplankton communities distribution along a physical gradient in the eastern Indian ocean based on their pigment and absorption properties.

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Abstract

Bio-optical and bio-physical properties of ocean waters along 110° E in the southeast Indian Ocean were investigated during a research voyage carried out on R/V Investigator in May-June 2019. The data set was collected along a 3300 km transect starting from mesotrophic conditions (chlorophyll concentration of about 0.5 mg m^{-3}) around 40°S to oligotrophic conditions (0.04 mg m^{-3}) near 10°S. These observations were used to test the efficacy of a cluster analysis applied to phytoplankton absorption spectra, which was compared with the respective clustering of phytoplankton pigment data (HPLC), in which the absorption-based clusters serve as a reference for identifying different phytoplankton pigment group compositions. An unsupervised spectral cluster analysis was employed to analyse phytoplankton absorption spectra in order to better understand the pigment distribution in the study area with respect to absorption spectra. The results of our analysis indicate that the cluster analysis of phytoplankton absorption using a Euclidean distance for the oligotrophic water provides better discrimination of phytoplankton pigment assemblages than the traditional methods. Based on this study, it is concluded that the differences among phytoplankton communities are better identified through their optical properties, which are related to pigment composition, cell size, and intracellular pigment concentration. This approach can be valuable to categorise the phytoplankton community in India Ocean waters based on the absorption spectrum, which is associated with specific pigment compositions, and expand our understanding of deviations in global optical algorithms when applied to Indian Ocean waters.

Keywords: Phytoplankton pigments; absorption of phytoplankton; Cluster analysis; Indian Ocean; IIOE2

No. 50

Impacts of GOCI-II On-orbit Calibration on Ocean Color Data Record

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One of the primary objectives of the Geostationary Ocean Color Imager-II (GOCI-II) is to provide the data continuity of Ocean Color data records over East Asian waters for operational and research applications. The long-term geostationary ocean color data can resolve the ocean phenomenon with the diurnal, day-to-day, seasonal, and interannual variation. Artificial bias in sensor calibration data (Level-1B data) can be propagated to GOCI-II ocean color Level 2 images and finally to Level 3 time series data. The improvement of GOCI-II sensor calibration data is performed on-orbit radiometric solar calibration to consider the time-varying sensor degradation effects. In this study, two sets of initial and improved GOCI-II sensor calibration data (Level 1B data) were used to reprocess atmospheric correction and ocean color products (remote sensing reflectance and Chlorophyll-a concentration) for Level 2 and Level 3 data evaluations. We compared the GOCI-II reprocessed level 2 remote sensing reflectances and Chlorophyll-a concentration at the earlier and recent mission periods with MODIS-Aqua and VIIRS data. The current results show that on-orbit calibration significantly improves the consistency between GOCI-II and the polar-orbit satellite data, confirming the capability of the GOCI-II data for climate application.

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Spatial-temporal dynamics of phytoplankton functional types on the West Coast of Canada derived from HPLC pigments data and hyperspectral remote sensing Reflectance

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Spatial-temporal dynamics of the phytoplankton functional types (PFTs) were addressed using output results from CHEMTAX (derived from HPLC pigment data) and hyperspectral remote sensing reflectance (Rrs) across the west coast of Canada during 2018 and 2019. Surface water samples for the HPLC pigment were collected from ~ 2 m depth using a seawater pump installed on the passenger ferry Queen of Alberni (QA). Hyperspectral remote sensing reflectance was derived from the autonomous above-water radiometer installed on the passenger ferry. Here, we adapted a previously proven Empirical Orthogonal Function (EOF) algorithm developed using matchups between CHEMTAX-derived PFTs and EOF scores derived from hyperspectral Rrs (N=87). Model training using hyperspectral Rrs showed highly significant ($p \leq 0.0001$) retrievals for all PFT; however, the best performances were noted for diatom, raphidophytes, green algae, and cryptophytes (R^2 = 0.71, 0.68, 0.66, 0.59, respectively). Moderate retrievals were noted for dictyochophytes, haptophytes, dinoflagellates, and cyanobacteria (R^2 = 0.42, 0.50, 0.36, 0.43, respectively). PFTs derived from CHEMTAX and hyperspectral Rrs showed remarkable spatial-temporal variability across the region, with diatom dominating spring and fall bloom and the prevalence of high-diversity small flagellates. In addition, we noted a large bloom of raphidophytes mainly comprised of Heterosigma *akashiwo,* across the Strait during the summer of 2018. To our knowledge, this is the first study that combines in situ HPLC pigment data and hyperspectral Rrs data to elucidate major PFTs on the West Coast of Canada. Ultimately, the results obtained from this study hold great significance in the context of the forthcoming NASA PACE mission.

Convolutional neural network outperforms other empirical SDB models

Galen Richardson[a1], Anders Knudby[a2]

The mapping of water depth in nearshore waters is significant for a range of human uses including navigation of coastal regions. Satellite-derived bathymetry (SDB) using optical satellite imagery is a cost-efficient solution for this purpose. However, the relative performance of SDB models, and its dependence on environmental factors, data quality, and specific model implementation is unclear. We compared five different models on their performance at predicting water depth from a Sentinel-2 image composite of Corsica. Airborne lidar data provided by the French Hydrographic Service (SHOM) were used to calibrate and test the models. To avoid spatial autocorrelation across the calibration, validation, and test data, we implemented a blocking strategy; 1600m^2 blocks were created along the coastline and split between the datasets, reducing spatial autocorrelation while allowing for samples across the image composite.

The neural network and random forest models outperformed the parametric multi-band and band-ratio models. The convolutional neural network (CNN) model performed the best, with a MAE of 1.13m on the test dataset. The Random Forest (RF) model with neighbourhood median pixel information ranked second in this task, with a MAE of 1.23m. The CNN performed exceptionally well in relatively deep (10-20 m) waters, sandy sea floors, and regions containing seagrass. The CNN took substantially longer to develop than the RF and parametric models. We suggest that use of information from neighbouring pixels, within CNNs or RF models with neighbourhood medians, outperform single-pixel models and should be common practice in SDB.

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Unveiling submesoscale processes with high resolution ocean optics

Sara Rivero-Calle[1], Srinivas Kolluru[1], Md Masud-Ul-Alam[1,2], Benjamin Lowin[1], Mallory Hunt[1], Ashley Ohall[1], Francisco Joao Dias Silva [1,3].

Abstract (284 words)

Heterogeneous submesoscale processes require high spatio-temporal resolution measurements, the Rivero-Calle Lab has been focusing on collecting and analyzing high spatial, temporal and spectral resolution optical data to describe patterns and ranges of variability related to patchy phytoplankton blooms, Harmful Algal Bloom species, internal waves, and primary production. Here we present five ongoing projects that have benefited from increased resolution optical observations: 1) the Gulf of Alaska is a patchy highly productive region, using flow-through ACS absorbance data collected during 4 cruises in different seasons we show that not accounting for temporal variability in the relationship between the line height absorption and chlorophyll can underestimate chlorophyll concentrations by 26%. 2) using a shipboard flow-through PIGI system we are compiling the first high resolution records of spatio-temporal variability in Net Community Production estimates across the South Atlantic Bight. 3) Internal waves are often considered rare submesoscale events that can lead to an increase in primary production but that are limited to a few locations. We created an Artificial Intelligence algorithm trained on high spatial resolution satellite data from SeaHawk-HawkEye and Sentinel-OLCI to automatically identify and quantify the global frequency of these phenomena in the last three years. 4) High spatial resolution satellite data from SeaHawk-HawkEye and Sentinel-OLCI suggest that we are underestimating global chlorophyll-a concentration, particulate inorganic and organic Carbon associated with patchy phytoplankton blooms. Lastly, 5) Using the Phytoplankton Light Scattering (PPLS) instrument, a new device specifically designed to characterize phytoplankton optical properties in the laboratory, we explored inter and intraspecific variability in hyperspectral phytoplankton backscattering due to cell concentration, culture phase, species and time of day, and how those factors can affect our estimates and ability to distinguish between phytoplankton species from space. As extreme events become increasingly frequent, detecting and quantifying heterogeneous, submesoscale, and patchy phenomena becomes critical.

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GLIMR - NASA's newest ocean color mission, is the world's first to combine high spectral and temporal ocean color observations.

Joseph Salisbury[1], Antonio Mannino[2], Maria Tzortziou[3]

The NASA Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR) is a hyperspectral radiometer that will be launched in geostationary orbit during (scheduled for 2027) that will be used to study and monitor coastal ecosystems. GLIMR science will focus on understanding net productivity rates, phytoplankton physiology and material fluxes in coastal waters, while application efforts are directed at oil spill dynamics and harmful algal blooms. To help address the science and applications, GLIMR will collect ~200 bands of data in the visible to near infra-red (350-1020nm) with ~hourly coverage in our primary region of interest, the Gulf of Mexico. Other selected regions in the Western Hemisphere will be imaged at least twice a day. Below is an overview of the instrument capabilities, science, societal applications, data processing and data availability. We also give a stratus update and highlight new science enabled by GLIMR.

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No. 55

Assessment of density-based neural networks for the dual estimation of water quality indicators and uncertainties from multi- and hyperspectral remote sensing

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Satellite remote sensing of water quality indicators (WQIs) over lakes and coastal waters faces an array of uncertainty sources, such as atmospheric correction or complex inherent optical property compositions. Recent advancements have seen the use of neural networks (NNs) for precise WQI estimation and well-calibrated uncertainty provision. The challenging duality of this task has led to the development of two distinct NNs rooted in probabilistic reasoning: Mixture Density Network (MDN) and Bayesian Neural Network based on Monte Carlo Dropout (BNN-MCD). These two NNs, however, possess considerable model complexity, incorporating thousands of trainable parameters and modifiable hyper-parameters. The model complexity makes comprehending their operational mechanisms, uncertainty provision, and suitability for satellite applications challenging. Compounding the model complexity, both the MDN and BNN-MCD were trained and evaluated on distinct datasets, which precludes direct model comparisons and leaves questions about the optimal choice for specific applications. To bridge these knowledge gaps, we conducted an exhaustive analysis of both the MDN and BNN-MCD under identical conditions - utilizing the same parameter settings, training, and test sets. Further investigations considered these models for individual vs simultaneous estimation of groups of WQIs, held out datasets under the Leave-One-Out scenarios, and performance on satellite matchup datasets. Finally, some qualitative analysis was carried out on acquired images from various multi- and hyperspectral satellite sensors. Across all these investigations the prediction performance of the two algorithms is quite comparable across a variety of regression metrics. The main differences are in the uncertainty estimation, wherein the BNN-MCD is more confident while the MDN uncertainty provides a better upper-bound on the predictive error. In concert, these tools can be used to provide end-users a clearer picture on possible errors present in specific predictions and how best to leverage them in real world applications.

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Potential for the Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR)

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The Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR) will provide high temporal frequency observations of the United States coastal waters. The spatial, temporal, and radiometric resolutions of GLIMR are evaluated and compared to other satellites typically used for water quality measures. GLIMR's median 391 m pixel resolution is within the range necessary for resolving oil spills, half of CONUS estuaries, and most sub-estuaries. Temporal resolution ranges from 6 to 12 hours in a day, with up to six revisits per day for the coastal United States. GLIMR scan times can change from the mission default of 0.76 seconds depending on the signal-to-noise ratio (SNR) application requirement and to leverage multi-mission observations. Across the visible wavelengths, SNR is sufficient for classifying binary oil detect and non-detect at the default scan time as well as at double and 0.7 times this scan time. Glint thresholds are mapped in two-hour increments for the December solstice, June solstice, and March and September equinoxes. Sub-daily, hyperspectral observations from GLIMR may supplement existing water quality observations particularly at lower latitude coastal areas. GLIMR has the potential to provide unprecedented observations of ocean color dynamics, in addition to harmful algal bloom and oil spill event response, valuable for management applications.

Deep learning for Environmental Ecological Prediction, eValuation, Insight with Ensembles of Water quality (DEEP-VIEW) for coastal applications

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Working closely with water quality and shellfish aquaculture practitioners, we identified priorities for satellite applications, namely harmful algal bloom detection and water safety indices, i.e. clarity, potability. State water quality monitoring agencies currently sample 800 sites around the Chesapeake Bay in boats every month, likely missing features in time and space located in between their point source observations. Nearshore processes that impact water quality for boating, swimming and aquaculture happen at scales where current satellite data lack spatial or spectral resolution. Upcoming government and commercial satellite missions aim to fill this gap. The fusion of many sources of satellite data through machine learning algorithms trained to optimize feature discrimination with in situ observations has the potential to detect impairments to water quality that was not previously possible through traditional techniques. Our methodology integrates multiple satellite data sets of different spatial, spectral, and temporal resolution within Deep learning for Environmental Ecological Prediction, eValuation, Insight with Ensembles of Water quality (DEEP-VIEW) to improve predictions of aquatic features such as algal blooms, changes in water clarity, and estuarine impacts of runoff from land that are needed by coastal resource managers and other stakeholders to safeguard health and safety.

South Florida estuaries are warming faster than global oceans

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Abstract: Estuarine water temperature increasingly emerges as a crucial driver of ecosystem structure and function under climate warming, and can directly or indirectly affect physical, chemical, and biological processes, including photosynthesis, water stability, fish, algal species diversity, and species interactions. Sparse spatiotemporal coverage of *in situ* water temperature cannot meet the research requirements of interdecadal variations in heterogeneous estuarine environments. From extensive evaluations, it is found that, of all satellite data products of sea surface temperature (SST), MODIS SST is the most appropriate in assessing long-term trends of water temperature in the South Florida estuaries. Long-term SST data show significant warming trends in these estuaries during both daytime (0.55 °C/decade) and nighttime (0.42 °C/decade) between 2000 and 2021. The warming rates are faster during winter (0.70 °C/decade and 0.67 °C/decade for daytime and nighttime, respectively) than during summer (0.48 °C/decade and 0.28 °C/decade for daytime and nighttime, respectively). Overall, the South Florida estuaries experienced rapid warming over the past two decades, 1.7 and 1.3 times faster than the Gulf of Mexico (0.33 °C/decade and 0.32 °C/decade for daytime and nighttime), and 6.9 and 4.2 times faster than the global oceans (0.08 °C/decade and 0.10 °C/decade for daytime and nighttime). The progression of these trends will necessitate ongoing monitoring and assessment of water temperatures in these ecologically and economically significant estuaries.

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IOCS2023-abstract

Characterization of Short-term Ocean Color Variability using Gap-free Ocean Color Dataset: Three Case Studies

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The valid retrievals of satellite ocean color observations can only cover small amount of the total satellite coverage due to the issues such as cloud, sun glint, and other unfavorable conditions. Thus, it becomes very difficult to study the short-term ocean variability on daily basis. With the Interpolating Empirical Orthogonal Function (DINEOF) technique, the gap-free ocean color dataset can be built with good accuracy. In this presentation, we show various applications of this new dataset to study the day-by-day and intra-seasonal variability in: (1) tropical instability wave modulation of chlorophyll-a (Chl-a) in the Equatorial Pacific, (2) synchronous Chl-a and sea surface salinity (SSS) variability on the daily basis in the Equatorial Pacific Ocean, and (3) daily ocean variability following Hurricane Ian in 2022. These three cases demonstrate that the gap-free DINEOF daily ocean color product is critical and indispensable in order to address the short-term variability, and it provides a new tool and data stream to better monitor the ocean environment and study the daily-based ocean variability from satellite observations.

Ocean Color Remote Sensing Insights into the Spatiotemporal Distribution of Surface *Calanus finmarchicus* in the Gulf of Maine

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The marine copepod *Calanus finmarchicus* (Calanus), serves as an essential intermediary in the oceanic food chain, connecting phytoplankton with higher-level consumers. It is the main food source for the critically endangered North Atlantic right whale (NARW). It is difficult to provide adequate distributions of Calanus abundance over the spatial and temporal scales they occupy using traditional offshore sampling methods. By integrating ocean color remote sensing, radiative transfer modeling, and an enhanced RGB (eRGB) color matching technique, this study provides novel insights into the spatiotemporal distribution patterns of Calanus in the Gulf of Maine region.

The pigment astaxanthin in Calanus absorbs blue and green light, with potential to significantly affect reflective remote sensing signals when abundance is high. This attribute offers a promising avenue for incorporating ocean color remote sensing to detect surface Calanus concentrations. Using a method developed off the coast of Norway, we estimated Calanus surface concentrations in the Gulf of Maine over 20 years using daily time records of MODIS-Aqua satellite data (2003 – 2023).

The results demonstrate the potential of this eRGB color matching method in estimating the spatial and temporal distribution patterns of Calanus in the Gulf of Maine. The analysis uncovers seasonal patterns of potential surface concentrations of Calanus, revealing higher concentrations during the spring and summer months and reduced levels in the fall and winter months, as expected from the Calanus life cycle. However, this approach also captures signals from phytoplankton and other zooplankton rich in astaxanthin. We are currently assessing the impact of these other species on estimating the spatial and temporal distribution of Calanus. Overall, this study emphasizes the importance of understanding all of the significant contributions to ocean color remote sensing signals and highlights the potential of eRGB color matching methods for identifying the occurrence of high abundances of astaxanthin-rich species.

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New Hyperspectral Absorption and Backscattering Instruments in Support of Ocean Color Validation

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Measurements of in-water absorption and backscattering with coincident in situ and satellite-measured radiometry are keys to refining and calibrating ocean color algorithms and developing next generation (e.g., NASA PACE) hyperspectral ocean color products such as phytoplankton community composition. Beyond ocean color applications, these in situ instruments also offer the capability to measure particle and dissolved material properties directly applicable to ocean biogeochemistry research.

Currently, commercial instruments exist for in situ measurement of hyperspectral radiometry and absorption coefficient, while measuring backscattering with a single instrument has been limited to multispectral. We have developed and commercialized a new submersible single-angle hyperspectral backscattering sensor (Hyper-bb) using a white LED source, linear variable bandpass, and a sensitive photomultiplier detector. More recently, we have also developed a new hyperspectral absorption sensor (Hyper-a) using an integrating cavity to reduce measurement uncertainty due to scattering errors characteristic in the reflective tube design. This new design is based on a broadband xenon lamp source, dual (reference and signal) spectrometers, and employs a solid standard for routine field calibration to avoid uncertainties and difficulties associated with field calibration using nigrosine solution standards.

We will present an engineering overview of the Hyper-bb and Hyper-a instruments and measurement methodology, some challenges underlaying hyperspectral inherent optical property (IOP) instrument design, results of characterization and calibration studies, and field data including an examination of closure between IOPs and radiometry.

Miniaturization of Ocean Lidar for Surface and Subsurface Applications

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Lidar technology has a well-established history in remote sensing applications for ocean optical properties, initially starting with aircraft-based systems and later expanding to include shipboard and satellite platforms. While its effectiveness has been demonstrated, the widespread adoption of lidar for routine oceanographic sampling faces challenges, primarily due to the availability of systems designed specifically for ocean applications. To address this, we are developing compact oceanographic lidar systems capable of being deployed above or below the water surface, across a diverse array of platforms including surface vessels, moored stations, and autonomous vehicles. One system features a compact (17 x 67 cm) housing incorporating a miniature polarized, pulsed (ns) semiconductor laser and photomultiplier tubes for detecting the co- and cross-polarized return signal. A second, similar system uses a higher pulse energy frequency doubled Nd: YAG laser. Both systems incorporate a custom 8 channel digitizer/controller board engineered by Nalu Scientific. We are testing the ability to provide depth-resolved estimates of diffuse attenuation (K_d), direct backscattering (b_π), depolarization (δ), particle size, abundance, and composition within the euphotic zone of the Mid Atlantic Bight off the coast of Virginia and in the Chesapeake Bay. This location offers a unique opportunity to assess these systems across an optical gradient comprising nearly Case 1 waters along the outer continental shelf and Case 2 waters in the vicinity of Chesapeake Bay. The development of compact oceanographic lidar system represents a promising step forward in expanding the accessibility and effectiveness of lidar technology in ocean research. By addressing the challenges posed by size and complexity, these systems have the potential to increase our understanding of ocean optical properties and improve the precision of oceanographic sampling across diverse marine environments.

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VisualSeaBASS3 – a NASA developed in-water AOP processor

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Vertical profile measurements of the underwater light field in the ocean are a critical ground truth measurement to perform calibration and validation of ocean color satellites. At-sea measurements of the Apparent Optical Properties (AOP) upwelling radiance (L_u) as well as downwelling and surface irradiance (E_d, E_s) are the basis for generating remote sensing reflectance (R_{rs}) values which are required for validating all future PACE data products and OC satellites in general. Historically the data processing software that converts vertical profiles into remote sensing reflectance has been either in-house or proprietary. Commercial in-water radiometer packages have different rates of data acquisition which presents challenges for accurate calculations. NASA's OEL has developed VisualSeaBASS3 (VSB3), an AOP processing software planned for public release which includes important recommendations for radiometric processing from the oceanographic community, outlined in the 2019 IOCCG protocols for in situ optical radiometry. Notable features follow directly from issues raised in the 2019 protocol. Where AOP data acquisitions are very close in space and time, the new multicast grouping feature allows separate proximal casts to be merged in user-defined groups. The increase in data density provides more robust regression statistics and can reduce the variability due to wave perturbations. Surface irradiance normalization provides a useful QA/QC metric and accounts for the effects of changes in the light field during data collection. Highly configurable parameters with defaults from the 2019 protocol balance the need for out-of-the-box processing with general purpose and specialized use. VSB3 is designed to ingest, display, and facilitate QA/QC of AOP profiles for generating the precise R_{RS} needed for the next generation of ocean color satellite missions.

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Filling gaps in data coverage for coastal resource managers: using boat mounted sensors to augment broad-area coverage by Earth observing satellites

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Satellites can provide resource managers with an additional tool for monitoring water quality over broad areas to efficiently target their field observations. However, remote sensing of localized, areas of interest is limited by spatial resolution and frequency of observation. Compounding the problem is the fact that coastal remote sensing is impacted by cloud cover, complicated atmospheric correction, and land adjacency, which limits the availability of valid aquatic data at the land-water interface. Our project explores the use of in situ measurements collected from a boat-mounted flow-through instrument to augment coarse satellite data product near land and under clouds. This study quantifies variability observed within the coarser grids of typical government satellite resolution (e.g. 1km, 300m, 30m) to understand features that may be captured or missed by current and future satellite products such as MODIS, OLCI, and Landsat-8. These findings will contribute to training and validation efforts within a larger project that fuses multiple in situ and satellite data products in a machine learning architecture for coastal water quality application.

No. 65

Possibilities to use remote sensing data in modeling primary production in Lake Geneva.

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Phytoplankton primary production (PP) is basis of an ecosystem of the inland waterbodies and the PP assessments using models are crucial in carbon cycle research. The modeling of the PP has been a great challenge, due to the complexity of the processes involved. In this study, we analyze the *in situ* PP and its relationships with the water transparency measured with Secchi disc (SD) and chlorophyll *a* (Chl-a) in Lake Geneva based on 291 unique PP *in situ* measurements from 2002 to 2021. Although the PP measurements have been carried out regularly once a month or bimonthly, the measurements still could potentially miss PP events (additionally there is 3-month break in measurements due to COVID-19) and are representing just a single point of the lake. Therefore, incorporating remote sensing data to the PP models enables advanced estimates of spatial and temporal PP information. Furthermore, this deep lake is an interesting study object from remote sensing point of view, due to its non-uniform vertical profiles of Chl-a. The lake can have very clear water and high Chl-a only below the first optical depth of the water, making it undetectable by satellite sensors. Both MEdium Resolution Imaging Spectrometer (MERIS, operational 2002-2012) and the Ocean and Land Color Instrument (OLCI, operational since 2016) data are used in a bio-optical model to predict the PP estimates and fill in the gaps of the *in situ* measurements and to detect the long-term trends in the PP of Lake Geneva. The model has been pre-tuned with *in situ* measured input values. The complex nature of the PP in a deep lake is demonstrated, when PP is not only determined by the light condition and Chl-a in the water, but also by the seasonal and yearly differences of third parameters in the water.

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Evaluation of EnMAP water reflectance product during the commissioning phase and first operational year

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The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission designed to monitor and characterize the Earth's environment on a global scale. EnMAP was launched on April 1, 2022, and is currently in its operational phase, which began in November 2022. Here, we evaluate the normalized water leaving reflectance product from EnMAP during the commissioning phase validation activities in July-October 2022 and operational phase activities in November 2022-August 2023. The L2A atmospheric correction is based on the Module Inversion Program (MIP). Hyperspectral in situ measurements from international partners, projects and extensive field campaigns have been used to validate the EnMAP L2A water product at six core sites: Aqua Alta Oceanographic Tower (Italy), Lake Constance (Germany), Lake Trasimeno (Italy), Lampedusa (Italy), Lucinda Jetty Coastal Observatory (Australia) and Oostende (Belgium). The results show that the EnMAP normalized water leaving reflectance products meet the mission accuracy requirements at these sites and are of the same magnitude and shape as the spectral variability of the in situ measurements. Overall, the EnMAP water reflectance product underestimated the in situ measurements in the 400 nm to 550 nm wavelength range, producing larger residuals than at longer wavelengths. A recent update to the EnMAP processor, v010301, shows an improvement in the normalized water leaving reflectance products compared to v010106 (e.g. median percentage error v010106 = -4.85%, v010301 = -0.62%). We also investigated the differences in EnMAP water reflectance products obtained from the Polymer and ACOLITE atmospheric correction algorithms and the results showed similar performance of all three atmospheric correction algorithms (MIP, Polymer and ACOLITE).

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No. 67

Reconstructing hyper-spectral downwelling irradiance from multi-spectral measurements

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The current HyperNav radiometer/float systems measure water-leaving radiance L_w at about 2 nm spectral resolution in the ultraviolet to near infrared, but downwelling irradiance E_s in only four 10 nm wide spectral bands centered on 412, 489, 555, and 705 nm. To obtain remote-sensing reflectance (L_w/E_s) at the same spectral resolution as L_w, the multi-spectral E_s data acquired in clear sky conditions are used to reconstruct via multi-linear regression the hyper-spectral E_s signal at 0.5 nm resolution from 315 to 900 nm. After correction for gaseous absorption and normalization by the top-of-atmosphere incident solar flux, the spectral atmospheric diffuse transmittance is expressed as a linear combination of E_s measured in those 4 spectral bands. Based on simulations for Sun zenith angles from 0 to 75^o and a wide range of (i.e., expected) atmospheric and surface conditions, the E_s spectrum is reconstructed with a bias less than 0.4% in magnitude and an RMS error ranging from 0 to 2.5%, depending on wavelength. In the presence of typical noise on E_s measurements and uncertainties on the ancillary variables, the bias and RMS error become 2.8% and 0 to 5.3%, respectively. Using a General Additive Model with coefficients depending on Sun zenith angle and aerosol optical thickness improves statistical performance in the absence of noise, especially in the ultraviolet, but provides similar performance on noisy data, indicating more sensitivity to noise. Comparisons between measured and reconstructed E_s spectra acquired by the MOBY spectro-radiometer show agreement within predicted uncertainties, i.e., biases less than 2% in magnitude and RMS differences less than 5%. The results indicate that it is sufficient, for many scientific applications involving hyper-spectral E_s, to measure E_s in a few coarse spectral bands in the ultraviolet to near infrared and reconstruct the hyperspectral signal using the proposed multivariate linear modeling.

Analysis of the performance of a new in situ, hyperspectral, integrating-cavity absorption meter (Hyper-a)

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The forthcoming NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, scheduled for launch in January 2024, represents a significant advancement in oceanic research with its main component, the Ocean Color Instrument (OCI), having hyperspectral scanning radiometric capabilities. This instrument presents an opportunity to enhance our comprehension and representation of the complex oceanic environment and its optical properties. However, to develop novel retrieval algorithms, rigorous in situ validation of the retrieved inherent optical properties remains necessary.

Among these properties, the measurement of light absorption is crucial in optical remote sensing. Conventional approaches, such as the reflective tube design, necessitate scattering correction. In response, we have introduced a new hyperspectral absorption sensor (Hyper-a), employing an integrating cavity to limit measurement uncertainties from scattering errors. With Monte Carlo ray tracing and sensitivity analysis (incorporating a matrix of absorption coefficients, scattering coefficients, reflectivities, and cavity geometries), we have evaluated the theoretical performance of the sensor. This development shows potential for greatly improving the accuracy and reliability of optical absorption measurements in oceanic research, playing an essential role in the success of the upcoming PACE mission and advancing the understanding of marine ecosystems.

Characterizing the Optical Properties of Natural Biofilms on Marine Microplastics from the Great Pacific Garbage Patch and their Effect on Ocean Color Chlorophyll Retrievals

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Spectral libraries of floating marine microplastics have been developed to inform remote sensing-based plastic detection techniques. One relatively unexplored characteristic of marine microplastics is the modification of spectral reflectance by natural marine biofilms. With support from the NASA project Spaceborne Quantification of Ocean MicrO-Plastics (SQOOP), we report bulk spectral reflectance measurements of freshly collected microplastic pieces with natural biofilms from the Great Pacific Garbage Patch (GPGP) alongside measurements of the same pieces after a cleaning procedure. Biofilmed and cleaned pieces exhibit similar absorption features at the characteristic wavelengths of 931, 1215, 1417, and 1732nm. Band depths at the 1215 and 1732 nm absorption features, occurring within windows of atmospheric transparency, did not vary significantly between the biofilmed and cleaned microplastic measurements. These results suggest that plastic detection approaches using these NIR and SWIR wavelengths are robust to spatiotemporal variability in the biofilm coverage on plastic pieces. Additionally, biofilmed microplastics exhibited high absorptance in the blue and red parts of the spectrum, consistent with the presence of photosynthetic pigments. Mixed-pixel simulations suggest that floating, biofilmed microplastics would have a significant impact on ocean color chlorophyll-a retrievals at concentrations greater than 2.8×10^8 pieces/km^2. This concentration is two orders of magnitude greater than currently reported microplastic concentrations measured in the GPGP. Additional analyses are being conducted on these biofilms to investigate the biodiversity of the biofilm microalgal community.

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No. 70

Improving water constituent retrieval through uncertainty modelling of Sentinel-2 atmospheric correction products

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Abstract

Atmospheric correction (AC) algorithms are essential for deriving accurate aquatic remote sensing products from the Sentinel-2 MultiSpectral Instrument (MSI). Despite their significance, these algorithms often lack built-in mechanisms for uncertainty quantification, a shortcoming that becomes especially pronounced when applied to challenging environments like perialpine lakes. Our study employs a two-step approach to address this issue.

First, we rigorously validate three leading AC algorithms - POLYMER, C2RCC, and ACOLITE - using two different MSI resolutions: 20m and 60m. By comparing the AC-derived remote sensing reflectance (R_{rs}) products to *in situ* radiometric measurements from a range of perialpine lakes, we determine that a 20m resolution offers the best balance between error reduction and spatial detail preservation. For larger lakes such as Garda and Geneva, errors in the blue - green bands are generally below 30%. However, smaller systems like Caldonazzo and Aegeri exhibit increased inaccuracies. Particularly concerning are the red and near-infrared bands, where errors often exceed 50%. These significant inaccuracies not only compromise the reliability of the AC algorithms but also raise questions about the utility of downstream applications. Given that we have quantified these errors, Bayesian modelling emerges as an inherently suitable tool for error propagation.

Building on this, we apply Bayesian modelling to both quantify and propagate these known errors to water variables like Total Suspended Matter (TSM) and Secchi depth (Z_{SD}). The likelihood functions in our Bayesian approach are directly shaped by the error statistics obtained from the validation stage. Using the same match-up dataset that informed the R_{rs} validation, we establish well-grounded priors, enhancing the Bayesian model's reliability. This methodology results in a probabilistic representation of TSM and Z_{SD} with quantified uncertainties, increasing their utility in downstream tasks like 3D hydrodynamic particle-tracking.

No. 47

A simulated PACE dataset to evaluate optical closure and phytoplankton community composition algorithms

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With the planned launch of NASA's PACE satellite mission in January 2024, we will enter a new era of hyperspectral remote sensing of the global oceans. Hyperspectral remote sensing reflectance (R_{rs}) will provide additional information over existing multispectral data and associated algorithms through high spectral resolution that can discern subtle differences in spectral absorption and reflectance from absorbing phytoplankton pigments. Knowledge of the spatial and temporal distribution of phytoplankton community composition (PCC) is vital for understanding many aspects of aquatic ecosystems such as assessing water quality (including harmful algal blooms), food web dynamics relating to global fisheries, and the carbon cycle. This work focuses on developing a simulated PACE data workflow to study the performance of PCC retrieval algorithms. First, we derive monthly global distributions of optical constituents (e.g., phytoplankton groups and detrital components) and R_{rs} from the NASA Ocean Biogeochemical Model (NOBM) coupled with the Ocean-Atmosphere Spectral Irradiance Model (OASIM). Next, we incorporate this forward modeled R_{rs} into NASA's Python Top Of Atmosphere Simulation Tool (PyTOAST) to generate top-of-atmosphere Level-1B files. Then, we use NASA's standard Level-2 generator (l2gen) to apply atmospheric correction procedures and derive monthly global distributions of apparent optical properties (e.g., R_{rs}). At this point, the dataset becomes useful for performing semi-analytical inversions and PCC retrieval models to derive inherent optical properties (IOPs, e.g., phytoplankton absorption) and metrics of community composition. Optical closure can then be assessed by: 1) Comparing PyTOAST simulated R_{rs} values to NOBM-OASIM derived R_{rs}, 2) Comparing simulated IOP concentrations to NOBM-OASIM derived IOP concentrations, and 3) Comparing estimated PCC to NOBM-OASIM concentrations of phytoplankton groups. This work will include a preliminary performance assessment of PCC retrieval approaches at a global scale and provide a simulated PACE dataset, in OCI orbit dimensions and geometries, for researchers to test and assess PACE retrieval algorithms.

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Merging satellite datasets to observe decadal trends in Cyanobacterial Index and turbidity products for Lake Okeechobee, FL, USA

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Over the past century, human induced land use change has greatly impacted both the morphology and hydrology of Lake Okeechobee, FL, and its greater watershed. This has led to increases in runoff and nutrient/sediment pollution, resulting in persistent, annual harmful algal blooms. We use imagery data from Sentinel and MERIS satellites to quantify and interpret decadal trends in Cyanobacterial Index (CI), bloom extent, and turbidity. We also assess the viability of various methods in building a Landsat imagery proxy to the MERIS CI product. The determination of a reliable proxy between Landsat-MERIS offers the possibility of extending the Lake Okeechobee CI time series by up to two decades.

Adjacency-effect correction in remote sensing of coastal and inland waters for Sentinel-2 MSI and Landsat-8 OLI imagery

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The adjacency effect distorts the top-of-atmosphere (TOA) spectral signals of coastal and inland waters, and it remains a challenge for remote sensing of water properties in such environments. To address this issue, we present a preprocessing tool designed to correct for the adjacency effect for Sentinel-2 MSI and Landsat 8 OLI imagery.

The tool takes the original level-1 files along with ancillary atmospheric and aerosol data from the NASA Ocean Color website as input. Then, a Monte Carlo radiative transfer model (Wu et al., 2023) is used to calculate the point-spread function of the atmosphere and other correction coefficients. The tool convolves level-1 images with point-spread functions, and the differences between level-1 and convolved images are used to correct for the adjacency effect. The output of the tool consists of modified TOA reflectance values that adhere to the homogeneous-surface assumption in most atmospheric correction (AC) tools — pixels are corrected to the TOA reflectance as if surrounded by pixels of similar reflectance. The modified level-1 files can subsequently be input to any other AC tool.

Preliminary results show significant improvement in water-leaving reflectance retrieval, as validated against in-situ data from the GLORIA dataset (Lehmann et al., 2023). Specifically, when applied to Sentinel-2 imagery and compared to GLORIA matchups within 200 meters from shore (n = 63), where the adjacency effect is pronounced, the tool reduced the RMSE of ACOLITE-retrieved water-leaving reflectance for bands between 740 and 865 nm by 35-49%. This enhancement is critical for accurate chlorophyll and suspended-matter retrieval in case-2 waters. Landsat-8 OLI data and matchups from AERONET-OC sites will be analyzed to further assess the performance of the adjacency-correction tool, in conjunction with additional AC algorithms such as SeaDAS, C2RCC, and POLYMER.

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Hyperspectral optimization for optically shallow water retrievals: application to HICO and implications for the PACE mission

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NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is scheduled to be launched in 2024, and will carry the hyperspectral Ocean Color Instrument (OCI). Prior to launch, new and existing algorithms will be implemented within the OBPG processing framework to take advantage of the new spectral richness. Toward that end, we have developed and tested PACE/OCI-specific approaches to derive depth and biogeochemical parameters in optically shallow waters. Such environments include coral reefs and seagrass beds, which are extremely important to coastal ecology and economies. Traditionally, remote sensing of these environments employs spectral matching, which is made up of a Semi-analytical (SA) model and an optimization algorithm to solve the minimization function. When applied to multi-spectral satellite data, this technique yielded serviceable results, but the approach suffered from the fundamental problem of deriving too many parameters from too few bands. Here we demonstrate how the additional spectral information from hyperspectral sensors such as PACE/OCI will enable much improved retrievals. Additionally, we have developed methods to improve the initial parameter estimates (as required for the optimization), to minimize the frequency of settling on local minimum during optimization. Specifically, various depth initials (with the interval of 6 m), benthic albedo spectra, and particulate backscattering coefficients are iterated to find the best possible results. Prior to the launch of PACE, we used Hyperspectral Imager for the Coastal Ocean (HICO) data collected for the Florida Keys to assess the spectral matching method. The optimization retrievals were evaluated against lidar data and show promising results, but may be hampered by higher atmospheric correction uncertainties in HICO data.

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Application of Dove/SuperDove imagery in monitoring Harmful Algal Blooms in nearshore and inland waters

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Medium-resolution satellite data have been widely used to monitor Harmful Algal Blooms (HABs) in coastal waters. However, these data do not have the required resolution to capture HABs in nearshore waters and small inland waterbodies that are directly relevant to local communities. The PlanetScope constellation comprises over 200 CubeSats equipped with either Dove (4-band; 2014-2022) or SuperDove (8-band; 2019-), offering near-daily observations at a remarkable 3-m spatial resolution over most nearshore and inland waters. Here, we demonstrate the application of Dove/SuperDove imagery in monitoring cyanobacterial HABs and *Karenia brevis* HABs in freshwater and saltwater environments. We first developed a deep learning (DL) model to detect a cyanobacterial HAB in the Caloosahatchee River (Florida, USA) in summer 2018 using Dove imagery. The daily sequence revealed the westward transport of the HAB following the upstream water discharge. Then, we used SuperDove imagery to observe a *Karenia brevis* HAB in early 2023 in nearshore waters around Charlotte Harbor (Florida, USA). The enhanced Red-Green-Blue (ERGB) SuperDove images clearly revealed the detailed distributions and morphological bloom features as well as their daily changes in both nearshore waters and small estuaries. Because of the near-daily coverage of global nearshore and inland waters, the PlanetScope constellation is expected to fill the gaps in monitoring HABs in these dynamic environments towards more effective management and mitigation.

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No. 75

Hypoxia forecasting for Chesapeake Bay using artificial intelligence

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Seasonal hypoxia is a recurring threat to ecosystems and fisheries in the Chesapeake Bay. Hypoxia forecasting based on coupled hydrodynamic and biogeochemical models excel in accounting for the effects of physical forcing on oxygen supply, but may fall short in replicating the more complex biogeochemical processes that govern oxygen consumption. Satellite-derived reflectances could be used to indicate the presence of surface organic matter over the Bay, but it is difficult to tease it apart from the total signal. Here we present a deep neural network to improve short-term (daily) hypoxia forecast using inputs from a vast suite of variables that could potentially affect oxygen in the water column. The physical inputs include wind velocity reanalysis information, together with 3D outputs from an estuarine hydrodynamic model, including current velocity, water temperature, and salinity. Satellite-derived spectral reflectance data are used as a surrogate for the biogeochemical factors. These input fields are time series of weekly statistics calculated from daily information, starting 8 weeks before each oxygen observation was collected. To accommodate this input data structure, we adopted a model architecture of long short-term memory networks with 8 time steps. At each time step, a set of convolutional neural networks are used to extract information from the inputs. Ablation and cross validation tests suggest that among all input features, the strongest predictor is the 3D temperature field, with which the new model can outperform the state-of-the-art by ~20% in terms of median absolute error. Our approach represents a novel application of deep learning to address a complex water management challenge.

A Low-Cost Spectroradiometer System for Measuring the Radiometric Properties and Color of Natural Waters

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In situ radiometry represents a key optical measurement for understanding ocean color, ecosystem productivity and underwater visibility. While expensive instruments (>$10,000) capable of measuring the spectral properties of the submarine light field have been in existence for some time, low cost instruments (£$1,000) have generally been limited to single channel measurements of broadband radiation across the visible, or photosynthetically active, portion of the electromagnetic spectrum. With the impending launch of PACE, GLIMR and other hyperspectral satellite systems, there will be greater need for ground-based and in water measures of spectral radiance, irradiance and other radiometric properties of natural waters. Using a miniature sealed spectrographic chip from Hamamatsu, we designed a low-cost radiometer system that covers the spectral range from 340 to 850 nm in 288 channels (~1.7 nm) at 13-bit resolution using sampling times from 1 to 9000 ms, capable of measuring the range spectral irradiance from moonlight to sunlight at noon on a clear day. Wavelength and radiometric calibrations are temporally stable, and thermally stable above -2° C. The chip is controlled by an Arduino-based microcontroller and custom software capable of autonomous operation for several days using 6 AA batteries. The system is housed within cylindrical tube (7 x 18 cm) and can be deployed with radiance or plane irradiance collecting optics to depths of 100 m for moored or profiling modes to facilitate the measurement of downwelling or upwelling diffuse attenuation, radiance attenuation and in water reflectance. It can also be moored above water for measurement of remote sensing reflectance and ocean color. Example data from deployments in the Chesapeake Bay, DelMarVa coastal lagoons and coastal waters of the mid-Atlantic bight will be provided and compared to simultaneous measures derived from expensive commercial systems.

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Examining ecosystem function & change

Cool new ways from ocean colour, including carbon from space.

No. 77

Monitoring long-term changes in the optically complex transition waters of Lake Vembanad

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Coastal oceans and transitional waters (defined here to include lagoons, estuaries, and deltas) represent less than one fifth of the planet's surface but support up to 90% of the global fishery catch and a substantial portion of primary production worldwide. These systems are also heavily impacted by anthropogenic activities and climate change effects. Lake Vembanad is the longest lake in India, located in the state of Kerala, and contains unique wetland systems recognized to be of international ecological importance. Increasing resource exploitation through agriculture (e.g. land cover use and change), industry, intensive aquaculture, wastewater/plastic/hydrocarbon pollution, and tourism activities together with uncontrolled urbanization and coastal infrastructure development all impact water quality. The situation is exacerbated by decreased water exchange across the Thanneermukkom saltwater barrier which severely restricts the natural flushing of pollutants. In-situ monitoring of water quality over the scale of decades is not available, thus support through long-term satellite datasets could prove beneficial. The joint NASA/USGS Landsat program represents the longest high resolution dataset available for Earth Observation research. Water color in Lake Vembanad is primarily influenced by colored dissolved organic matter, phytoplankton and suspended sediments. Optical water type (OWT) classification of remote sensing water color products serves to categorize water parcels with differing properties, thus allowing quantification over time of variations in spectral properties associated with water quality metrics. The OWT analysis scheme developed in the EU H2020 CERTO project, building on OC-CCI, is implemented on Landsat mission data to build fuzzy c-means OWT classes that are used to determine multi-decadal changes in bio-optical conditions within the Lake Vembanad system. Cluster comparison and performance evaluation relative to other Landsat OWT sets, built based on in-situ or simulated remote sensing reflectance from inland and coastal waters, will be discussed.

Analysis of biological response time of environmental variables affecting chlorophyll blooms in the Central Yellow Sea

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It has been known that there are time lags of marine environmental changes to develp the phytoplankton blooms. Specifically, previous studies have indicated that there is typically a time lag of approximately 14 days between the supply of aerosols from the atmosphere and the occurrence of CHL blooms in the ocean. Hence, this study aimed to investigate the temporal impact of aerosols induced from the atmosphere on the ocean environment and ecosystems. Beyond aerosols, we considered various physical factors known to influence CHL, including aerosol, photosynthetically active radiation (PAR), sea surface temperature (SST), mixed layer depth (MLD), wind, and precipitation. Therefore, we assessed the individual time lags between each variable and CHL. Given the need for daily observations to examine the time lag between physical factors and CHL, we utilized long-term ocean color remote sensing data, which offers broad-area and extended-duration coverage. However, ocean color data needs some data due to cloud cover and other atmospheric conditions. So, we solved the issue of missing data using the Random Forest (RF) algorithm to reconstruct daily CHL data. We utilized various physical factors, including Aerosol, PAR, SST, MLD, wind, and precipitation, as input data, with CHL as the output variable. In conclusion, we anticipate that our research, which focuses on comparing reconstructed daily CHL data with various physical factors, will enable calculating time lags between these variables.

Assimilating multi-platform, multi-band remote sensing reflectance into a coastal biogeochemical model of the Great Barrier Reef

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Marine biogeochemical (BGC) models are routinely used to simulate the time-evolving state of the coastal ocean. The assimilation of observations in BGC models is used to constrain uncertainty and improve predictions of the coastal marine BGC state. However, *in situ* observations of BGC properties are sparse both in space and time relative to the variability of the coastal ocean, and in some cases may be completely absent. Here we demonstrate a method using a bio-optical model to simultaneously assimilate multi-spectral remote sensing reflectance observations from MODIS-Aqua, VIIRS-SNPP and OLCI Sentinel-3A/B into a coupled physical-biogeochemical model of the Great Barrier Reef region using a hybrid Ensemble Kalman Filter. The optically complex waters of the GBR contains mixtures of white carbonate and brown non-carbonate suspended sediments, green microalgae, dark colour dissolved organic matter and a reflective bottom of sediment, corals and seagrass visible from a surface view. The multi-spectral approach allows the assimilation system to update the differing constituents simultaneously, achieving a reduction in mean absolute forecast errors in the predicted apparent optical properties by up to 30% compared to a non-assimilating experiment. In an independent assessment against withheld *in situ* Chl-a, the assimilation of multi-platform multi-spectral reflectance data reduced the mean absolute error by 26% and bias by 73%, and provided estimates of uncertainty from the ensemble simulation. These results indicate that remotely-sensed reflectance can be used to constrain the prognostic variables of coastal marine BGC models when a bio-optical model is used to simulate remotely-sensed observations. Highly colour-varied marine environments, such as the Great Barrier Reef, have the most potential for multi-band data assimilation of remote-sensing reflectance.

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Mapping the Water Quality Characteristics of Lake Victoria Using Satellite Imagery

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Abstract

Lake Victoria is of great socio-economic importance to the region as it supports millions of people living around its shores. Spatial variations in the water quality characteristics of Lake Victoria are critical for the ecological and biological sustainability. Hence, the purpose of this research is to develop geospatial models to continuously map and monitor the water quality using remote sensing. Long-term, continuous remote sensing monitoring data were utilized to quantify and assess the Chlorophyll a, and Secchi disk distribution in the waters of Lake Victoria. We hypothesize that the variations in pigment concentrations will affect the intensity and spectral characteristics of the water and these relevant spectral signatures can be identified and mapped using satellite remote sensing. The specific objectives are to: 1) Analyze and map the spatial and temporal trends in the water quality characteristics of the Lake Victoria; 2) Identify the best water quality indicators for satellite monitoring of the environmental and ecological changes. The in situ water sampling data collected was used in conjunction with Landsat remote sensing data. The best Landsat 8 spectral ratio models that were developed showed a significant correlation of 0.75 and 0.73 with Chlorophyll a and Secchi depth, respectively. The chlorophyll a model was tested with the withheld datasets and has shown good correlation between the actual vs predicted chlorophyll a concentration. The application of Chlorophyll a and Secchi depth models for the Landsat images can help us to quantify the lake water quality. The models that were developed are successfully tested for robustness by applying it to withheld data sets and has significant implications in mapping the water quality characteristics of Lake Victoria.

Generalized Optical Water Type Classification for Ocean-Coast-Inland Waters: Leveraging a Novel Bio-Geo-Optical Model

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The concentrations of various water constituents and their inherent optical properties differ significantly in ocean, coastal, and inland waters. This has an influence on the color of the waters, i.e., their remote-sensing reflectance, which can be remotely sensed by satellites to obtain biogeochemical information about the water constituents. We introduce a bio-geo-optical model for natural waters that includes revised spectral absorption and scattering parameterizations, based on a comprehensive analysis of precisely measured IOPs and water constituents. In addition, specific IOPs of the most significant phytoplankton groups are modeled and a system is proposed to represent the optical variability of phytoplankton diversity and community structures. The model provides a more accurate representation of the relationship between bio-geo-optical properties and can better capture optical variability across different water systems. Based on the evaluation both using the training and independent testing data, our model demonstrates an accuracy of within ±5% for most component IOPs throughout the visible spectrum.

The use of fuzzy logic optical water type (OWT) classifications as part of the satellite data processing is increasingly used to select the best possible water retrieval per water type and to ensure seamless transitions of the products. It has been shown that previous OWT frameworks are too focused on either ocean or inland water applications. We want to overcome this with a novel generalized OWT framework that is valid for all natural waters. The novel framework adopts a “knowledge-driven” approach, defining water types based on forward simulation of optical properties to capture the most variability. It employs three effective optical variables derived from remote-sensing reflectance, encompassing both spectral shape and magnitude, enhancing the framework’s versatility and adaptability to different satellite missions; in this study this is demonstrated specifically for application to Sentinel-3/OLCI. A key emphasis of this development lies in generating highly usable classifications, which also incorporate a degree of error tolerance to accommodate potential uncertainties arising from in situ measurements or atmospheric correction processes. This novel OWT framework not only enhances the interpretation of optically complex water systems but also holds promise for advancing ecosystem monitoring applications.

Validation of ESA's Ocean Colour Climate Change Initiative (OC-CCI) Kd_{490} products for assessing water clarity status and long-term trends in North America's largest lakes

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North America's inland freshwater systems are of enormous socio-economic value, providing important drinking, industrial and recreational water resources, contributing to global biogeochemical cycling, and serving as sentinels of anthropogenic influence on aquatic environments. Water clarity, as reported by Secchi disk depth (Z_{SD}) or diffuse attenuation ($Kd_{(\lambda)}$), is an important measure of ecosystem health, while also playing a central role in regulating pelagic and benthic primary productivity, heat transfer, and impacting a waterbody's aesthetic value. The European Space Agency's Ocean Colour Climate Change Initiative (OC-CCI) aims to deliver stable, long-term, satellite-based essential climate variable (ECV) data products suitable for trend assessments. Here we demonstrate the value of the OC-CCI products for reporting on water clarity status and long-term spatiotemporal variability in North America's largest lakes. Extensive matchups of the OC-CCI Kd_{490} with in situ Z_{SD} observations spanning 23 years enabled robust algorithm validation over a wide range of water clarity conditions (R^2 = 0.96, MAPE = 28%, N=3331). No significant differences in Z_{SD} retrieval uncertainty between the SeaWiFS, MERIS, MODIS, VIIRS and OLCI mission periods provided confidence in the assumption of seamless continuity in this multi-mission time-series, thereby allowing long term trend assessments. Derived monthly Z_{SD} was subsequently analysed for nine large lakes across Canada and the U.S., including the Laurentian Great Lakes, Lake Athabasca, Lake Winnipeg, Great Slave and Great Bear Lakes. Seasonal, inter-annual and inter-decadal variability and trends in water clarity were evaluated and agree with documented periods of ecosystem change in response to the cumulative impacts from harmful algal blooms, nutrient status, and extreme events such as flooding.

A machine learning framework to estimate global diatom biomass from space

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Understanding the distribution of global-scale diatom biomass and how it varies in time and space is needed to further our knowledge on ocean ecosystem dynamics, including the carbon and silica cycles and transfer of particulate carbon to higher trophic levels. Remote sensing is a powerful tool to assess broad-scale surface ocean phytoplankton communities, and algorithms that integrate multiple types of in situ data during model development have the potential to improve prediction of diatom biomass on regional-to-global scales. Using data collected during multiple oceanographic expeditions spanning diverse oceanic regimes, we integrated in situ optical and environmental measurements together with diatom biomass derived from automated cell imagery data. Diatoms are identified in phytoplankton cell imagery using a convolutional neural network and then subsequently used to derive diatom carbon biomass in situ. We then train a random forest regression model, where the model inputs are in situ optical and environmental parameters including temperature, latitude, chlorophyll *a,* and particulate backscattering, and the model targets (i.e., the parameter to be predicted) are the imagery-based diatom biomass values. The trained model is deployed on MODIS Aqua chlorophyll *a,* particulate backscattering, and sea surface temperature data, enabling creation of global-scale maps of diatom biomass, with the exception of regions with optical and environmental conditions outside of the model training data (mainly subtropical regions). In addition, phytoplankton accessory pigments including chlorophylls *b* and *c,* and photoprotective carotenoids are tested as model inputs, which improves model accuracy. These accessory pigments will be estimated from hyperspectral remote-sensing reflectance to be measured by the PACE Ocean Color Instrument (OCI) in early 2024, thus enabling estimation of diatoms on a global scale with a model that takes advantage of the added information available in hyperspectral remote-sensing reflectance.

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Statistical implications of multi-platform satellite missions for water quality monitoring

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Satellite data allow for long-term trend assessments and provide image archives to perform retrospective change detections. There are several currently operational Earth observation constellations that includes functionally identical sensors mounted on multiple satellite platforms; these platforms follow the same orbit, but are offset in their phase to increase temporal coverage. For example, the Copernicus Program's Sentinel-3 satellite series consists of Sentinel-3A, launched on 16 February 2016, and Sentinel-3B, launched on 25 April 2018, which orbit 180° out of phase of one another, essentially doubling temporal coverage for a given location. Additional observations over a timeseries present the opportunity to observe added, potentially more extreme water quality events and therefore may bias results compared to trend assessments leveraging a single satellite platform. Here, we used data from the Cyanobacteria Assessment Network (CyAN), to assess the statistical implications of the inclusion of additional satellite platforms on long-term trend analyses. CyAN leverages Sentinel-3 data to estimate cyanobacteria abundance for over 2,000 large inland lakes across the United States. Shapefiles of Sentinel-3B swaths were retrieved and used to mask observations collected after its 2018 launch. Spatial coverage with and without the inclusion of Sentinel-3B was assessed across latitudes for the contiguous United States. Then, the non-parametric seasonal Mann-Kendall test for trend and associated Thiel-Sen slope were applied to timeseries of monthly CyAN data spanning 2016-2022, both with and without additional observations collected by Sentinel-3B. Our results demonstrate the impact of additional satellite observations on long-term trend analyses and suggest best practices for statistical assessments leveraging multi-platform satellite missions. Findings are also relevant for the Copernicus Program's Sentinel-2 satellite series, which includes Sentinel-2A, launched on 23 June 2015, and Sentinel-2B, launched on 7 March 2017. Trend analyses conducted with the Sentinel-2 satellite series should consider statistical recommendations made here for the Sentinel-3 satellite series.

Seagrass scenarios driven with satellite derived bio-optical inputs across Tangier Sound.

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Seagrass meadows provide a variety of ecosystem and environmental services, including a habitat for marine organisms, shoreline stabilization, carbon sequestration, and improved ecosystem productivity. Historically the seagrass in Chesapeake Bay decreased due to human impacts on the bay ecosystem, but since the 1980's seagrass extent has increased as a variety of projects have increased ecosystem health. Seagrass extent is also used as a measure of bay restoration; however, in 2022 seagrass extent was only at 59% of the Chesapeake Bay Program's 2025 restoration goal. Seagrass extent fluctuates yearly, driven by anthropogenic and climatic factors, such as water temperature and light availability. The goal of this project is to map the potential extent of seagrass in Tangier Sound, a sub-estuary in the eastern part of Chesapeake Bay. The bio-optical model *GrassLight* was used to model the seagrass leaf area index, which was applied to a digital elevation model to predict the distribution and density of seagrass. Model inputs included a matrix of climate and water quality target scenarios. Satellite derived sea surface temperature, turbidity, colored dissolved organic carbon, and chlorophyll-a concentrations were applied as baseline conditions. Model results reveal that seagrass has the potential to cover 178 km^2 (16%) of Tangier Sound (1130 km^2) with expansion and contraction given various climate and water quality combinations.

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Chlorophyll and Primary productivity variations of the Indian Ocean using model simulations and observations

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Monitoring of the ocean using Satellite remote sensing plays a major role in the global climate change studies. Ocean color sensors provide an opportunity to investigate variations of surface chlorophyll on a wide range of spatial and temporal scales. The Phytoplankton containing chlorophyll are the primary producers in the oceans. The biological processes responsible for fixation of carbon dioxide (Photosynthesis) are mainly controlled by the amount of chlorophyll in the euphotic zone. Since long time series observations on marine ecosystem variables are very few in the Indian Ocean, use of mathematical models along with satellite observations would help us to improve our ability to understand the marine ecosystem. The Arabian Sea is one of the highly productive oceanic regions of the world oceans compared to Bay of Bengal. It is well known that there are significant seasonal and interannual variations of Chlorophyll and Primary Productivity in the euphotic zone of the Indian Ocean. To study the spatial and temporal variations of the chlorophyll and Primary productivity of the Indian Ocean at different scales, we have used Ocean Color data derived for the years 2000 to 2018 from the merged ocean color data (OC-CCI) and from model simulations (MOM5 with coupled with biogeochemical cycles). To validate the physical-biological-chemical coupled model simulation results, we have divided the Indian Ocean into ten regions based on biogeochemical regimes and used the satellite data on Chlorophyll and primary productivity derived from different algorithms. This study illustrates the significance of physical processes in the Indian Ocean on seasonal and interannual variabilities of the chlorophyll and primary productivity.

Satellite-Based Primary Production during a Phaeocystis sp. Bloom in the Labrador Sea

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A large bloom of phaeocystis sp., a dimethylsulfide-producing, colony-forming flagellate, occurred in 2022 in the Labrador Sea (LS) as revealed by taxonomic identification and pigment signature collected during the Fisheries and Oceans Canada Atlantic Zone Off-shelf Monitoring Program . Photosynthetic parameters were also derived at selected stations though ^{14}C incubation of water samples. Phytoplankton pigment distribution and environmental properties collected between 2014 and 2022 in the LS were used to identify four oceanic regimes: 1) Shelf dominated by diatoms, 2) Basin with oligotrophic conditions, 3) blooming conditions with a mixed phytoplankton population, and 4) phaeocystis sp. dominated. Each regime showed a particular set of photosynthetic parameters, which was accounted for in a satellite-based primary production model (SBPPM). The SBPPM is spectrally and vertically resolved and uses regional bio-optical models to derive light attenuation and phytoplankton absorption. Validation of the model with in situ measurements show a good agreement with a slope of 0.76 and a correlation coefficient of 0.67. We show that phaeocystis bloom had a significant impact on the Labrador Sea compared to “normal” years with implications for the biological carbon pump.

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Exploring the satellite-derived lakes variables for climate studies: impact of fires on water quality and trends of bio-physical in shallow lakes

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Lakes are crucial sources of freshwater and significant indicators of environmental change on a global level. They are reacting quickly to climate change, and it is expected that in coming decades global warming will have an even more pronounced impact on biodiversity, nutrient cycling, and hydrology. To support the comprehension of this topic at global scale as well as for understanding the complicated behavior of lakes in a changing environment, satellite technologies provide a unique source of data. In such a context, Lakes_cci project recently provided the most complete collection of consistent satellite observations water level, water extent, lake surface water temperature, water-leaving reflectance and related chlorophyll-a concentration and turbidity and ice cover. The products span from 1992 to 2020 and quantifies over 2000 relatively large lakes, which represent a small fraction of the number of lakes worldwide but a significant fraction of global freshwater surface. To illustrate the project's scientific contribution, two use-cases are described in this study. The first use-case is motivated by the increased risk of wildfire driven by high temperatures, low precipitation, and dry vegetation can have a substantial hydro-geomorphological effect on watersheds: post-fire precipitation can lead erosion and transport mechanisms potentially affecting water quality. The use-case investigates the response, if any, of chlorophyll-a and turbidity to fire effects via terrestrial pathway; it is conducted across a variety of geographic regions and fire regimes. The second use-case focuses on shallow lakes distributed globally as, in comparison to deeper lakes, they have received less attention the climate change context. The use-cases hence investigate long-term timeseries of bio-physical parameters, as chlorophyll-a, turbidity and water temperature, in view of understanding possible causes of their trends.

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Using Ocean color data for understanding the shrimp farms water discharge in the coastal ecosystems of the Gulf of California

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Abstract

Along the coastal areas of the Gulf of California, anthropogenic activities have been increasing for the last 30 years in this region. A massive shrimp farm industry coexists with agricultural districts, pig farms, urban settlements, and the mining industry, this can impact marine ecosystems, there has been reported for example that agricultural nitrogen runoff of the Yaqui irrigation district can contribute to influencing phytoplankton blooms extending 75 km within the Gulf of California. Exclusive Shrimp farms in the east of the Gulf of California have grown exponentially over the last twenty-two years, going from 17,000 ha in the year 2000 to more than 125,000 ha in 2022. There are few studies that use color ocean sensors that allow us to understand whether there is an influence on water exchange from shrimp farms in the coastal zone.

To better understand this influence, we analyzed the daily KD 490 product images of the Ocean Color CCI 1 km database from 2000 to 2022 for 17 sampling zones of approximately 10 km including control zones, oceanic control zones, shrimp farm influence zones, and shrimp farm-agro influence zones. As a result of the analysis, we found lower water clarity around the shrimp farms, while the higher clarity of coastal zone water corresponds to where there are no agricultural or shrimp farm zones. which indicates that shrimp farm inputs could be generating a change within the optical properties of the water column.

Enhancing Seagrass Monitoring: Multiscale multispectral comparison of seagrass mapping methods

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Seagrasses face global threats stemming from anthropogenic pressures and escalating climate change impacts. These mounting challenges highlight the need to incorporate advanced ocean color sensors with enhanced spatial, temporal, and spectral resolutions, into routine monitoring efforts. Though conventional monitoring programs usually rely on the use of aerial imagery to map seasonal or annual changes in seagrass coverage, targeted drone data and commercial satellite images can provide additional higher spatial and temporal resolution images for shallow coastal areas. For this study, we conducted a comparative analysis of multispectral drone data (sub-meter resolution) and PlanetScope multispectral satellite (3-5m resolution) data to determine the spatiotemporal distribution of seagrasses in Lido Key, Florida. We utilize in situ underwater photo quadrat images in order to assess the accuracy of satellite-based versus drone-based mapping. This study underscores the importance of integrating multisource data – from field observations to commercial satellites – to validate ocean color products in coastal areas from forthcoming satellite missions such as PACE and SBG.

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Assessing submerged aquatic vegetation blue carbon in The Chesapeake Bay from high resolution satellite imagery

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Blue Carbon emphasizes the role of aquatic plants in the carbon cycle. However, the global importance of submerged aquatic vegetation (SAV) is highly uncertain, as <10% of this resource has been mapped. Satellite technology now provides daily coverage of the global coastal environment at 3 m resolution, enabling the mapping of Blue Carbon system dynamics at spatial and temporal scales not previously attainable. We employed satellite imagery from the Planet/Dove constellation to quantify the monthly dynamics of SAV Blue Carbon potential at five locations in the Chesapeake Bay ranging from the upper Bay dominated by freshwater SAV to the oceanic coastal lagoons exclusively vegetated by eelgrass (*Zostera marina* L.). We employed machine learning to classify the images and a physics-based model of reflectance to quantify Blue Carbon abundance. Since 2018, the SAV meadows occupying the oceanic coastal lagoons were temporally stable, supporting a mean above-ground biomass of 40 g C m^{-2}. Meadows in the polyhaline lower Bay supported less biomass (~34 g C m^{-2}) with a seasonal amplitude characterized by winter declines and summer re-growth. SAV meadows covered extensive mudflats in the freshwater uppermost portion of the Bay at extremely high density (>40 g C m^{-2}) in summer but disappear almost completely during winter. Our efforts to quantify the seasonal dynamics of SAV from satellite imagery will improve the assessment of Blue Carbon in the Chesapeake Bay and provide an automated workflow environment that can be scaled to routine assessment of SAV dynamics across the globe.

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Dominant Timescales of Variability in Global Satellite Chl and SST revealed with a MOving Standard deviation Saturation (MOSS) approach

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Marine ecosystems are both defined by the general abundance of primary producers and the frequency of hotspots and blooms which generates high spatial and temporal variability in phytoplankton biomass. Satellite-derived proxies for Chlorophyll and POC provide unprecedented coverage in time and space to better estimate this variability on different scales but data gaps due to factors such as clouds, sun angle, or sun glint obfuscate the satellite's view of the ocean. The erroneous data are also not evenly distributed, showing a patchiness that reflects the effect of synoptic weather systems. Consequently, on average only 20% of the derived satellite fields are useful. Such sparse and unevenly distributed datasets create a major challenge for common time-series analysis tools, such as Fourier analysis or Empirical Orthogonal Functions (EOFs), thus hindering efforts to understand the frequency distribution of the data.

To better meet the specific challenges with time series analysis of sparse satellite derived properties, we suggest a new method to estimate dominating timescales of variability. The approach is similar to semi-variograms of spatial patchiness, but describes temporal variability rather than spatial autocorrelation. The technique is based on calculating the standard deviation of the time series data over moving windows of a set time interval, and repeating for different time-interval windows.

Our results show that the method has the ability to assess dominating timescales in time series where data coverage is sparse. Analysis of synthetic data sets suggests a threshold where estimated timescales start diverge from actual ones is at about 10% coverage. The main consequences of sparse data is MOSS curves with too gentle slopes, which would exaggerate the dominant timescales. We compensate for this problem by scaling all K_M differently for different coverage in the original data sets. The scaling further allows us to interpreted the resulting values as timescales of variability.

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Satellite ocean colour to inform Essential Biodiversity Variables (EVB) in the context of climate change

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Increasing pressure on nature due to anthropogenic drivers is leading to a reduction of global biodiversity and its associated benefits at the planetary scale. In coastal and open ocean ecosystems, the primary direct factors contributing to biodiversity loss include fishing, shipping, spatial competition, pollution, and their interplay with climate change.. These drivers have accelerated in the last 50 years (IPBES, 2019) and they are predicted to continue (Leclère et al, 2020), despite international efforts in the last decades (Convention on Biodiversity, CBD, Aichi targets) and renewed efforts (Kunming-Montreal Global Biodiversity Framework). To guide further action, it is therefore urgent and vital to develop "fit-for-purpose" observation tools from existing remote sensing platforms to guide needed actions to achieve these objectives. These observations should be capable of assessing and monitoring how the community structure and function of coastal ecosystems will respond to the anthropogenic and natural drivers in a changing climate. We present progress on two projects supported by the European Space Agency (ESA): Biodiversity in the Open Ocean: Mapping, Monitoring and Modelling (BOOMS, https://www.booms-project.org/) and Biodiversity of the Coastal Ocean: Monitoring with Earth Observation (BiCOME, https://www.bicome.info/). These projects explore satellite ocean colour observations to derive a wide range of Essential Biodiversity Variables (EBV) in intertidal, subtidal and pelagic (coastal and oceanic) ecosystems. The approach is to test conventional and advanced Earth Observation algorithms to assess their ability to retrieve EBV at community and ecosystem level. This includes the exploration of its use for achieving the Biodiversity Beyond National Jurisdiction treaty objectives of protecting 30% of the open sea areas by 2030 (BBNJ 30x30). In coastal intertidal environments the development of seagrass algorithms and their application to explore taxonomic class specific phenology. The results will feed into a roadmap informing the Space Agencies about future algorithms and datasets development needs.

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No. 94

Testing a hyperspectral, bio-optical approach for identification of phytoplankton groups in the Chesapeake Bay estuary

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Satellite-based identification of phytoplankton diversity is among the new capabilities anticipated from next-generation hyperspectral ocean color sensors. In this work the bio-optical Phytoplankton Detection with Optics (PHYDOTax) approach for deriving taxonomic (class-level) phytoplankton community composition (PCC, e.g. diatoms, dinoflagellates) from hyperspectral information is evaluated in the Chesapeake Bay estuary on the U.S. East Coast. PHYDOTax is among relatively few regionally customizable PCC differentiation approaches available for optically complex waters, but it has not yet been evaluated beyond the California coastal regime where it was initially developed. Study goals include: 1) regional parameterization, including novel incorporation of colored dissolved organic matter (CDOM) and non-algal particles (NAP), and 2) performance and sensitivity assessments using field and synthetic data. Using field data, statistical performance was typically robust for cryptophyte or cyanophyte phytoplankton groups but not conclusive for diatoms or dinoflagellates. Small, and sometimes significant, improvements were observed in algorithm output when tested on field data with and without added CDOM and NAP. Performance was typically robust for all phytoplankton groups using synthetic mixtures. Algorithm sensitivity to hyperspectral-relevant spectral resolutions (1nm, 5nm, 10nm) was low for both field and synthetic datasets. PHYDOTax can identify some phytoplankton groups in the turbid Chesapeake estuary using field data, but more evaluation-quality datasets are needed to test performance across broader temporospatial scales in the region. Work supports proof-of-concept in optically complex waters. This approach merits further testing and development in the Chesapeake and similar regions where sufficient data are available.

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No. 95

Evaluation of ocean color remote sensing as a tool to investigate ocean biogeochemistry response to episodic aerosol deposition events

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Abstract:

Terrestrial aerosols are thought to influence ocean biogeochemistry by stimulating phytoplankton growth in regions of the global oceans by providing limiting nutrients. The deposition of these aerosols is inherently episodic (e.g. volcanic eruptions, dust storms, and wildfires), making it logistically challenging to sample in the field during a deposition event. Consequently, ocean color remote sensing has become an increasingly popular tool to investigate the biological and biogeochemical response following an aerosol deposition event. To date, most of these studies have used the standard ocean color algorithm for chlorophyll-a concentration (chl-a) as a phytoplankton biomass proxy. But the presence of volcanic ash in the ocean and atmosphere affects standard ocean color satellite algorithms: the water's optical properties are altered by the addition of ash, and ash particles in the atmosphere act as strong light-absorbing aerosols that are not fully removed in the standard ocean color atmospheric correction algorithms. Both of these effects result in an enhanced water-leaving signal that translates to an augmented chl-a signal that is not a true biological response. The question remains: are artificial changes to the chl-a estimations from ocean color remote sensing in the presence of atmospheric aerosols significant enough to mask any biological response? Here, we present data showing changes to in-water optical properties in the presence of volcanic and wildfire ashes, and how these artificially increase the estimation of chl-a using the standard remote sensing algorithm. We also present a method to improve atmospheric correction during a deposition event, reducing the erroneous chl-a signal. Combining these observations, we will present the applicability and limitations of ocean color remote sensing to study the response of ocean biogeochemistry due to aerosol deposition events.

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Intercomparison and sensitivity assessment of primary production models for lake remote sensing

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In this sensitivity study of aquatic primary production models, we aim to provide an intercomparison of existing models, evaluate the importance of input parameters using Sobol indices, and offer recommendations for model improvement and application in lakes.

While marine primary production is extensively studied due to its impact on climate through the biological carbon pump, knowledge on primary production in lakes is more scarce but crucial as eutrophication can threaten access to drinking water, irrigation, fisheries, and recreational areas. Utilizing bio-optical primary production models, which run on remotely sensed data, is an essential tool for studying marine primary production, and various approaches were developed. However, applying these bio-optical models to lakes is challenging due to the complexity of lake inherent optical properties, the increased uncertainty in atmospheric correction, and the propagation of resulting errors.

This study compares four common marine primary production models and one freshwater model, outlining light availability in the water column and the efficiency of algae in absorbing photons and assimilating carbon. These models approximate these bio-physical processes using remotely sensed input parameters. We examined the implementation of these processes in the five models, the assumptions and parameterizations made, and estimated input parameter importance using Sobol indices to determine which processes warrant further model complexity and input parameter retrieval efforts.

Consistent with established results from the marine community, we found input parameters, especially those related to light attenuation, pigment absorption, and quantum yield, to be more crucial than model differences. By unifying model descriptions and identifying key processes, we hope to support further primary production model applications in lakes.

MODIS-Aqua chlorophyll and phytoplankton size class distribution in the northern Gulf of Mexico

Arnab Paul[1], Bingqing Liu[2], Eurico D'Sa[1]

Phytoplankton play a vital role in marine food webs and biogeochemical cycling, especially in the highly productive river-dominated coastal regions. Given the scarcity of extensive, and long-term monitoring of phytoplankton community composition, the present study focuses on algorithm development of chlorophyll a (Chl a) and phytoplankton size class (PSC) in the optically-complex estuarine-coastal waters influenced by the Mississippi-Atchafalaya River system in the northern Gulf of Mexico (nGoM) using Aqua-MODIS data. This study leverages MODIS data to study the spatial and temporal variability of Chl a and PSC (micro-, nano- and pico-phytoplankton) distribution in the nGoM. An existing adaptive atmospheric correction (AD-ATCOR) is employed to retrieve more accurate surface remote sensing reflectance in the turbid estuarine to ocean continuum. Subsequently, an optimized empirical red/green band ratio algorithm is applied to the atmospherically corrected images for the estimation of Chl a in the study region; each Chl a image is then converted to 301 (400-700 nm; 1 nm interval) hyperspectral absorption images based on a regionally-tuned 3rd order polynomial regression model. Lastly, PSC images are obtained using singular value decomposition and a non-negative least square method, respectively. The results of this study will used to elucidate trends in phytoplankton size structure following extreme weather events in the nGoM.

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No. 98

Seasonality and correlations of Colored Detrital Matter to Chlorophyll-a and Sea Surface Temperature on the Southeast Brazilian Continental Shelf

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A 23-year time series of satellite ocean color data was utilized to analyze the variability of light absorption by colored dissolved organic matter and detritus (CDM, m-1) along the continental shelf of southeastern Brazil (22° - 28° S) between 1998 and 2021. Monthly means, anomalies, and correlations involving CDM, chlorophyll-a, sea surface temperature, and dissolved organic carbon (DOC) calculated from data obtained from the Copernicus Marine Service Data Store (CMEMS) are presented along a meridional section. The previously described seasonal chlorophyll meridional gradient in the area was also observed for CDM, driven by the annual dispersion of the La Plata River plume (Ppw) and the position of the subtropical shelf front, exhibiting significant seasonal and inter-annual variability. After removing the seasonal signal from the time series, CDM presented a negative and positive correlation with temperature and chlorophyll, respectively. Nonetheless, the correlation coefficients varied with latitude. The upwelling of South Atlantic Central Water (SACW) was identified as a source of DOC for the region near the shelf break during late spring and early summer. An estimate of DOC flux using satellite CDM suggests a DOC transport ranging from 0,01 to 0,04 (kg/m²-s), illustrating the complexity and variability of oceanographic parameters in the continental shelf.

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Remote Detection of Floating Algae and Other Floating Matters in Global Oceans and Lakes

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Abstract (300 words)

Surface floating macroalgae and microalgae have been reported in many regions around the globe. Outbreaks of floating algae blooms can have negative effects on ocean ecosystems, local economies, and human health. The use of satellite remote sensing has shown great potentials in the detection of floating algae blooms and analysis of their long-term trends. However, because of their typically small size and because of many different types of floating algae and non-algae matters, timely detection in global oceans and lakes is technically challenging.

The NOAA Ocean Color Team is dedicated to developing traditional and new ocean color data products as well as to using these data products to address earth science questions. One of such topics is remote detection of floating algae and other floating matters in global oceans and lakes. This is through three technical steps: 1) Use of a multi-sensor OCView online tool to search for suspicious image features; 2) Use of multi-band spectral analysis to discriminate the floating matter type of the image features (e.g., macroalgae, microalgae scums, and non-algae floating matters); 3) Use of long-term, multi-sensor data to study trends in floating algae blooms in specific regions to understand their responses to climate change and human activities.

The research not only led to the development of the online near real-time monitoring tool, but also resulted in several findings on floating algae blooms. For example, the expansions of *Sargassum horneri* and *Ulva prolifea* blooms in the East China Sea and Yellow Sea, respectively, are attributed to ocean warming and human activities. The occurrence and distribution of *Trichodesmium* blooms around Australia is attributed to ocean temperature as well as to dust and fire events. While this research is still ongoing, we expect to a better understanding of the mechanisms behind floating algae blooms.

"Species-Specific Satellite-Based Monitoring of Harmful Algal Blooms in the Indian Ocean for Operational Services"

Premkumar Rameshkumar*, Alakes Samanta[1], Sk Baliarsingh[1], Sudheer Joseph[1] & TM Balakrishnan Nair[1]

Abstract

Harmful algal blooms (HAB's) in the Indian Ocean region pose substantial threats to marine ecosystems, fisheries, aquaculture, and public health due to toxin production and water quality deterioration. To address these complexities, this research concentrates on the identification and monitoring of prevalent multiple HAB species in the Indian Ocean. In response to these challenges, regional stakeholders are actively pursuing comprehensive monitoring solutions at both spatial scales and temporal resolutions. So, this study focus on data derived from the ocean color imagery of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Sentinel-3 satellites, to effectively monitor HABs across the Indian Ocean region. Multiple band ratio algorithms and spectral signatures of phytoplankton pigments and cellular properties are employed to differentiate between algal blooms species, including Green Noctiluca, dinoflagellates, diatoms, cyanobacteria, and mixed species blooms. These algorithms leverage distinct spectral characteristics with chlorophyll-a concentration to identify different phytoplankton groups. The cross-validated done with in situ phytoplankton data and reported events which shows a good correlation. In this study, a comprehensive understanding of the distinct hyperspectral reflectance characteristics exhibited by different types of algal blooms. These algorithms relied on the normalized remote-sensing reflectance values (Rrs) at specific wavelengths (488 nm, 531 nm, and 667 nm) that align with the MODIS spectral bands. The validation of green Noctiluca presence in the Indian ocean region was well matched with r*ameshkumar et. al., 2023*. The developed algorithms exhibited commendable performance when applied to MODIS data, successfully discriminating green Noctiluca blooms from other phytoplankton blooms. Furthermore, these algorithms provided valuable insights into the dynamics of algal blooms. These algorithms play a pivotal role in environmental monitoring efforts. The output of this work will be helpful to predict HAB transport and expert interpretation to generate HAB risk alert bulletins, which proved invaluable for fisherman and stakeholders across the aquaculture industry.

Keyword: Satellite Data, Chlorophyll-a, Spectral Signature, Harmful Algal Blooms

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No. 101

Machine Learning for Water Optical Properties Using Satellite Imagery

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Oceans occupy about 70 percent of the surface of the earth and support innumerable living organisms. Despite its vast spatial extent and the invaluable role it plays, the precious resource is continually threatened by both anthropogenic and natural factors. Pollution and climate change are the key threats to water quality (WQ). Satellite imageries have the capability of detecting and extracting various parameters which assist in evaluating, predicting and monitoring changes in ocean colour. We will present on the work we are conducting in validating the use of satellite remote sensing using in-situ data for water optical properties. In this study, we are utilising free satellite imageries of Landsat 8 and 9 together with Sentinel 2 and 3 to determine the water optical properties in a unique bay in the west coast of Ireland. The study analyses the variation of chlorophyll concentration with respect to changes to its environment. This is to provide an understanding of the various factors influencing the fluctuations. Machine learning is used to support the analysis by providing insights into the complex association between various elements to improve on accuracy. Additionally, it is used to support WQ prediction for monitoring in order to support in realisation of the sustainable development goal (SDG) 14 on conservation of the oceans.

Keywords: chlorophyll, machine learning, remote sensing, water optical properties

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Drivers of phytoplankton biomass trends in Arctic marine waters.

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An increase in satellite-derived phytoplankton chlorophyll (Chl) concentration and productivity have been observed in the Arctic. However, it has been shown that the mechanisms driving these trends have changed since 2008, although these mechanisms have not yet been fully identified. Here we combine satellite remote sensing estimates and field data to understand what has driven the changes in phytoplankton biomass in the Arctic. We use the OC-CCI merged product (1997 and 2022) to analyze the trends in phytoplankton carbon using different satellite-derived proxies (i.e. backscattering, phytoplankton absorption, Chl). The use of the different proxies will allow to understand whether algorithms are consistent between each other. Next, we use the Arctic Ocean Physics Reanalysis (Copernicus) to understand how these changes correlate to changes in the mixed layer depth and stratification. We find significant increases in phytoplankton biomass in the inflow regions, however the mechanisms driving these increases vary. Despite a decrease in stratification (resulting in an increased nutrient supply), this is not always the main driver of phytoplankton biomass increase. This is because phytoplankton are not always nutrient-limited. We discuss the interaction between resource limitation, changes in light and nutrients, and the effects of using the different optical proxies, particularly in regions where phytoplankton are light-limited.

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Chlorophyll-a concerning Environmental Factors in the Bay of Bengal using Remote sensing and in-situ data

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This study determined the spatial, and temporal distributions of Chlorophyll-a concerning environmental factors in the Bay of Bengal during 2003-2020. Three regions of interest (A, B, and C) were selected by considering a 2.5° × 2.5° grid for each in the BoB. The study showed that Chlorophyll-a ranged from 1.34 ± 2.23 mg/m^3 to 0.12 ± 0.02 mg/m^3 whereas the coastal area comprised higher Chlorophyll-a irrespective of the month, season, and year. The post-monsoon period showed the highest concentrations (1.19 ± 2.12 mg/m^3) of Chlorophyll-a while the pre-monsoon period showed the lowest concentrations (0.66 ± 1.12 mg/m^3) of that in the coastal area. Chlorophyll-a showed a rising, and falling trend during the study period; however, Bay of Bengal showed a rising trend of Chlorophyll-a at a rate of 0.02 mg/m^3 per decade. Chlorophyll-a and SST showed a significant ($p<0.05$) negative relation, and for each additional SST, Chlorophyll-a showed a declination of 0.035 mg/m^3 in the BoB. Chlorophyll-a showed a positive relationship with POC, NPP, SSHA, River Discharge, and Nutrients (silicate, nitrate, phosphate) whereas wind speed showed no significant relationship with Chlorophyll-a in the study area. Regression analysis showed that for each additional POC, NPP, SSHA, Nitrate, Silicate, Phosphate, River Discharge, Chlorophyll-a increased by 0.006 mg/m^3, 0.001 mg/m^3, 0.531 mg/m^3, 0.140 µg/l, 0.078 µg/l, 1.448 µg/l, 0.00001 mg/m^3 respectively in the BoB. Moreover, Nitrate had a great influence (45.65%) on Chlorophyll-a (µg/l) than Phosphate (37.57%) and Silicate (16.78%) in the BoB. Northern BoB is mostly comprised of a warm-core eddy that founds in the eastern, and western boundary mostly. Except for the pre-monsoon season (except March), the eddy was observed during all other seasons; thus, productivity was high during all those seasons. Satellite-derived Chlorophyll-a data showed a correlation coefficient r = 0.75 (n=58, R2 = 0.56), and the RMSE 2.54% with WOD-derived Chl.

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Bio-optical and biogeochemical parameterization of IOP-traceable, hyperspectral R_{rs} datasets for transitional water applications

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The diversity of phytoplankton communities is not well characterized in the context of observed shifts in plant, amphibian, and fish populations in many of South Africa's highly dynamic optically complex coastal and inland water bodies. Reduced phytoplankton diversity is hypothesized to impact upon ecosystem function at higher trophic levels, but in these seasonally eutrophic water bodies the robustness of ecosystem stability over annual and interannual time scales has not been assessed. Extensive optical & biogeochemical field measurements in support of the NASA hyperspectral imaging campaign in the Greater Cape Floristic Region of the Western Cape (i.e. BioSCAPE) form the basis for parameterization of a comprehensive synthetic IOP-traceable R_{rs} and TOA radiance dataset representing these environments, towards improving and optimizing sensor-agnostic satellite data exploitation for both current and future satellite missions. A hyperspectral radiometric buoy deployed at selected inland and coastal sites provides continuous optical measurements, characterizing daily and diurnal optical variability, while historical satellite datasets contextualize seasonal and interannual variability, and long-term trends in water quality, eutrophication, and vegetation cover. The synthetic dataset, developed as part of the Hyperspectral Capabilities across Atmospheric, Aquatic and Terrestrial Domains (HyperCAAT) project, is used to identify tipping points in R_{rs} signal change with respect to algal biomass (eutrophication indicators), and to evaluate signal sensitivity requirements in terms of distinguishing algal types as well as differentiation from suspended non-algal particulate, aquatic vegetation, and bottom effects. Indicators developed will ultimately be applied to a variety of intact and transformed aquatic ecosystems to identify ecosystems at risk and facilitate targeted management interventions.

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Spatial and temporal variability of SPM in the European coastal waters using OLCI satellite images

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The monitoring of the coastal water quality at large spatial and temporal scales is mandatory in the frame of the EU "Marine Strategy" directive. One tool to do that is remote sensing, that provides a synoptic view of the oceans. With the goal of defining the quality of the coastal waters, studying the spatial and temporal variation of the ocean color is a powerful tool that provides information about the biogeochemical parameters of the seawater. Here, spatio-temporal patterns of Suspended Particulate Matter (SPM) concentration have been assessed from the Ocean and Land Color Instrument (OLCI) on Sentinel-3 over the whole European coastal waters from 2016 to 2023. The semi-analytical algorithm of Han et al. (2016) has been used for SPM estimation and validated using the recent extensive dataset of in-situ measurements GLORIA. An SPM climatology has been generated at the scale of Europe, and the temporal patterns (seasonal variability, long-term trend, and irregular component) have been described using the Census X-11 time series decomposition method as well as the long-term trend using the Sen's slope. We found a significant rate of change in SPM concentration in the North Sea, the English Channel, the Black Sea, and in the North of the Baltic Sea.

No. 106

Later start of the accumulation season: 25-year trends in phytoplankton phenology in the marginal ice zone west of the Antarctic Peninsula

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Shifts in phenology, the timing of annually occurring biological events, are being altered in the global ocean with climate change. We examined phenological changes in the phytoplankton accumulation season in a polar region using long-term patterns in satellite-derived chlorophyll-a concentration. A merged multi-sensor cloud-filled remote sensing dataset was analyzed to determine shifts in the phenology of the phytoplankton growing season from 1997-2021 for the West Antarctic Peninsula, which is rapidly warming. Over the continental slope and shelf, the phytoplankton growing season is beginning later in the season over time, initiating up to 3 weeks later in recent years compared to the late 1990s. In northern coastal waters, the seasonality of the air-sea CO_2 flux has also shifted, showing evidence of a longer-lasting CO_2 sink extending later into the fall. Possible mechanisms include changes in winds and decreased ice-associated early season water column stability. Mechanisms were tested using coupled physical-biogeochemical modeling experiments, using an ice-ocean-ecosystem model and an advanced data-assimilative ocean biogeochemistry model. Modeling experiments suggest that increased wind speed is one likely mechanism for the observed changes. Phenology results will be discussed in the context of potential changes in absorption and backscattering caused by different phytoplankton groups, since coastal waters show a seasonal succession of large spring diatoms, summer cryptophytes, and late-season smaller diatoms. Future work will explore satellite-derived Chl-a algorithms and assess the potential to distinguish phytoplankton group using an *in situ* optical dataset collected in 2021, with concurrent IFCB imaging, HPLC pigments, QFT-ICAM hyperspectral absorption spectra, and above-water hyperspectral reflectance spectra. These data will improve understanding of the optical characteristics that make Antarctic phytoplankton unique in the global ocean. Observed shifts in phytoplankton phenology will have important implications for carbon cycling and food web dynamics.

Assessing the spatio-temporal development of submerged aquatic vegetation cover in the Baltic Sea low transparency waters with Sentinel-2 data.

Vahtmäe, Ele[1]; Toming, Kaire[2]; Argus, Laura[3]; Ligi, Martin[4]; Kutser, Tiit[5]

Alterations in submerged aquatic vegetation (SAV) distribution patterns indicate changes in marine environment and need to be monitored. Vegetation percent cover (%cover) is recognized as one of the key parameters in SAV monitoring. The current study investigates the suitability of multispectral Sentinel-2 (S2) for SAV %cover mapping in the low transparency Baltic Sea waters, which are turbid and contain high amount of CDOM. These factors significantly reduce the water depth, where benthic parameters can be detected with remote sensing.

Two approaches were tested for the SAV %cover mapping - empirical and physics-based. Physics-based radiative transfer inversion model IDA was able to produce comparable and even higher accuracy %cover predictions than those achieved by empirically tuned models. Physics-based models do not require an extensive set of simultaneously collected training data for model calibration. Therefore, they have more potential to be applicable in regions and time periods, when ground truth data are not available, enabling retrospective time series analysis across multi-temporal images.

Physics-based approach was implemented to archived S2 data to reconstruct spatio-temporal dynamics of SAV %cover across seasons and over successive years. S2 captured significant changes in SAV %cover patterns across seasons - the extent of low cover areas reduced and high cover areas increased during the growing period. This is because summer is the period of most rapid SAV growth in the Baltic Sea region. The inter-annual variability in SAV %cover patterns was greater at the beginning of the vegetation period. Strong natural disturbances, such as wave action and ice scouring may affect the dynamics of benthic communities during winter and the strength of those disturbances determine the SAV %cover patterns at the beginning of the vegetation period. At the peak of the vegetation period, low, intermediate and high cover areas showed generally similar areal extents over the years 2016-2021.

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No. 108

Chlorophyll-specific absorption coefficient of phytoplankton in world oceans: seasonal and regional variability

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Seasonal and regional variations of chlorophyll-specific absorption coefficient of phytoplankton (a^*_{ph}(443)) are evaluated based on satellite observations over global oceans. First, a^*_{ph}(443) shows a decreasing gradient from the open ocean toward the coastal environment, with considerable spatial variance. Second, seasonal variations are prominent over most oceans, resulting in substantial deviations from the climatological means. We fit a sinusoidal model to the monthly time series data to describe the spatial/temporal variability. Our results show that the amplitudes and the phases of the satellite monthly data are latitudinally dependent. The occurrence times of the maximum a^*_{ph}(443) values are six months out of phase between the northern and southern hemispheres. The global mean relationship for a^*_{ph}(443) and chlorophyll-a (Chl-a) is comparable with those obtained from global in situ measurements. Our analyses further indicate that the dependency of a^*_{ph}(443) on Chl-a concentration varies considerably with seasons and regions, resulting in significant departures from a global relationship. Based on our observations, we propose a hypothesis that a^*_{ph}(443) can be predicted as a function of geolocation and time. Preliminary comparison with the in situ matchup data suggests that this new method is a promising alternative to the traditional approaches requiring Chl-a as input. Despite its exploratory nature, the present study contributes to understanding phytoplankton biogeography and facilitates future efforts to improve bio-optical modeling and primary production estimation.

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Variability and trends of the major phytoplankton functional types in the Fram Strait (Arctic Ocean) from two-decade satellite observations

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Phytoplankton in the sunlit layer of the ocean act as the base of the marine food web, and also regulate key biogeochemical processes such as exporting carbon to the deep ocean. Phytoplankton composition structure varies in ocean biomes and phytoplankton functional types (PFTs) drive differently the marine ecosystem and biogeochemical cycles. In the Arctic Ocean, phytoplankton are highly influenced by sea ice conditions and brine release, and their dynamics are influenced by the extent of stratification as this determines the timing of nutrient and light dependent biological production. Fram Strait (located between Svalbard and Greenland) as an important gateway to the Arctic, is a region where the cold ice-covered Arctic water exits from the western side and the warm Atlantic water enters the Arctic Ocean through the eastern side of the Strait. The two contrasting water masses interact in the central Fram Strait leading to complex phytoplankton dynamics especially under a rapidly changing Arctic climate.

Within the framework of Copernicus Marine Service Evolution Program, we have established a complete and systematic approach for a consistent long-term monitoring of surface ocean PFTs of the global oceans. The two-decade observations enable us to study the inter-annual variation and analyze the trend of the surface phytoplankton community structure on different scales. Focusing on the Fram Strait, PFT observations from satellites will be evaluated with in situ time series from AWI established LTER (Long-Term Ecological Research) Observatory HAUSGARTEN area, that include data sets of bio-optical properties, pigment composition, phytoplankton taxonomic data from expeditions in the past years. We further investigate the trend and current state of the major PFTs; present and interpret their phenological patterns, inter-annual changes and the potential connections between the PFT shifts/trends and climate drivers in the Fram Strait.

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No. 110

Pelagic *Sargassum* in the Sargasso Sea as observed from satellites

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The Sargasso Sea was named after the pelagic brown macroalgae *Sargassum* spp., which serves as a critical habitat for a range of marine organisms (e.g., crabs, fish, shrimps, and sea turtles) and may have profound impacts on nutrient remineralization and primary productivity. However, despite the wealthy literature on its spatial distributions and temporal changes, our knowledge is still incomplete. For example, where and when can it be found in the Sargasso Sea, and in what abundance? In this study, long-term (2000–2023) satellite observations of *Sargassum* areal density were used to characterize the spatial distributions and temporal changes of pelagic *Sargassum* in the Sargasso Sea as well as in the adjacent ocean waters. Additionally, multiple environmental variables, including ocean surface currents, winds, and mixed layer depth, were investigated to gain insights into the mechanisms influencing the formation and variability of *Sargassum* blooms in this distinctive marine ecosystem. Our results unveil strong seasonal and inter-annual fluctuations in both the density and spatial distributions of pelagic *Sargassum* in the Sargasso Sea and beyond. Changes in winds, ocean currents, and mixed layer depth were found to significantly contribute to such seasonality and inter-annual fluctuations.

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Societal value & impacts of ocean colour

Including economic valuations, linkages with other essential climate variables, value to industries, and impacts on sectors including fisheries, aquaculture, and coastal and marine pollution.

Spectral signatures & water sampling in Chile: Initial insights for enhancing desalination system efficacy and water supply precision with satellite data

Tomás Acuña-Ruz[1,2], Enzo Garcia-Bartolomei[2], Bryan Casanova[2], Cristian Mattar[1]

In the face of severe water scarcity in the Atacama desert, Chile is aggressively pushing for an expansion of desalination projects, with projections indicating a 350% increase by 2030, reaching a capacity of 38.766 l/s. However, seawater quality, often compromised by factors such as oil spills and algal blooms, poses significant OPEX challenges to the efficiency of these projects.

To address this, our study offers an integrated database, merging satellite data and in-situ spectral signatures together with plankton water sampling in front of the major desalination plant in South America (3000 l/s). Hyperspectral measurements from RAMSES TriOS instruments were collated using SBA method, presenting a comprehensive spectral of water types such as clear water, algal bloom and turbid ones. This was subsequently matched with PlanetScope and Sentinel-3 satellite imagery to bolster and calibrate remote sensing algorithms.

Preliminary insights reveal a correlation between RAMSES TriOS hyperspectral data and satellite spectral outputs, underscoring the potential for early warning in desalination source water monitoring. This database serves as an instrumental tool, facilitating a deeper comprehension of water quality variations, particularly those attributes pivotal to the desalination process and enabling forecasting of chemical treatment doses. To complement this, our biological assessments further enrich our understanding of water quality. The zooplankton qualitative analysis identified 77,244 individuals across 40 species, and the quantitative analysis detected 720 individuals over 35 species. Concurrently, the phytoplankton quantitative study recorded 2,168,387 individuals spanning 92 species, with the qualitative analysis reflecting varied abundance levels among these species.

Lastly, by collecting ground-based hyperspectral measurements with satellite data, we emphasize the critical role of remote sensing in ensuring continuous monitoring for efficiency of desalination projects and overall water security in Chile.

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Enhance water management in South Florida by combining satellite remote sensing and a numerical model: a case study of monitoring HAB in Lake Okeechobee and C43 Canal in South Florida.

Zhiqiang Chen[1], Liqiong Zhang[1], Chuanmin Hu[2], Cassondra Armstrong[1], Jennifer Cannizzaro[2], Yao Yao[2]

Harmful algal blooms (HABs) in South Florida water bodies can negatively impact fish, shellfish, and human health via the production of toxins and the degradation of water quality, which poses a great challenge to properly manage water resources during HAB occurrences. While the use of satellite remote sensing has proven to be a beneficial tool for resource management, remotely monitoring HABs in South Florida has been complicated by the absence of satellite imagery with adequate temporal and spatial resolutions. In this study, we combined Planet high resolution (3 meter) satellite imagery and the Hydrologic Engineering Center's River Analysis System (HEC-RAS) numerical model for better interpretation of HAB risk. Firstly, the HEC-RAS 2D model was calibrated and tuned through historical matching. Secondly, Planet high satellite imagery was processed with a machine learning algorithm to map the occurrence of HABs in Lake Okeechobee and its downstream C-43 canal. Finally, Planet satellite imagery was assimilated into the HEC-RAS model. The model's sediment transport component was used to simulate algal transport dynamics assuming no deposition or resuspension of particles. The verified HEC-RAS model was used to simulate different water release scenarios and assess potential HAB risk in the downstream. The synthetization of satellite observations and numeric model provides an improved monitoring of HABs with better temporal and spatial resolutions, thus enhances water management decision making in South Florida and similar other regions.

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Advanced training material and tools for the next generation of marine remote sensing experts

Hayley Evers-King[1], Benjamin Loveday[2], Juan Ignacio Gossn[1], Vinca Rosmorduc[3], Kevin Ruddick[4], Gary Corlett[1]

1. **EUMETSAT**
2. **Innoflair UG**
3. **CLS**
4. **RBINS**

To support the current and next generation of experts in the marine remote sensing community, EUMETSAT is facilitating the development of a range of advanced training material and tools. The material and tools cover a wide range of topics that can support current activities, and equip the next generation of experts with the knowledge and skills needed to access and process data, conduct validation activities, and more. Development of material and tools is taking place through collaboration with current scientific studies and community projects, as well as through collaboration with community members during our marine training courses. In this poster, examples of current materials are showcased including:

- Advanced data access tools using Python based clients and APIs to navigate and access collections of Sentinel-3 and Sentinel-6 data
- The exploitation of the ThoMaS (Tool to generate Matchups of OC products with Sentinel-3/OLCI) toolkit
- Demonstration models for learning about:
    - Ocean colour inversion and algorithm development
    - Applying altimetry corrections.
    - Cloud masking for sea surface temperature products

These tools are developed as Python-based Jupyter notebooks and, in the case of the demonstration models, will be accompanied by guidance on how to use them to both learn and train.
All material will be distributed via the EUMETSAT GitLab and made openly available for reuse by the community under open source licences. EUMETSAT seeks both feedback on existing material, and requirements for defining future developments. Experts who wish to contribute and collaborate on the development of this material are welcomed.

Poster Title

The IOCCG Task Force on Remote Sensing of Marine Litter and Debris

Authors

Shungu Garaba[1], Manuel Arias[2], Lauren Biermann[3], Paolo Corradi[4], Madeline Cowell[5], Laura Lorenzoni[6], Francois-Regis Martin-Lauzer[7], Victor Martinez-Vicente[8], Debashis Mitra[9], Hiroshi Murakami[10]

Abstract

The poster will provide an overview of the International Ocean Colour Coordinating Group Task Force focused on Remote Sensing of Marine Litter and Debris composed of experts from academia, industry, civil service and NGOs which is co-chaired by four Space Agencies (ESA, ISRO, JAXA, NASA). The Task Force has the overarching goal to coordinate the advancement of current and future remote sensing technologies and techniques that have potential to provide observations of natural and anthropogenic litter, mostly composed of plastic objects across aquatic environments. Considering all remote sensing technologies (with a special focus on techniques that stem from the ocean colour community), the Task Force aims to promote a unified interdisciplinary, international team of remote sensing experts that coordinate the development of traceable and transparent approaches and requirements for detecting, identifying, quantifying and tracking aggregated natural and anthropogenic litter patches composed of objects from a wide range of size classes. These requirements are being developed by four interlinked core topics that are the foundation pillars of the Task Force: (i) technologies, (ii) algorithms and applications, (iii) datasets and (iv) interdisciplinary aspects. The Task Force core topics are essential for creating a scientific roadmap relevant towards remote sensing of plastic litter in all aquatic environments. The Task Force also produces living guidelines on best practices in remote sensing of plastics, as well as promote Findability, Accessibility, Interoperability, and Reuse (FAIR policy) of relevant datasets and algorithms. The poster will also serve as a networking gathering point welcoming public entities, NGOs, industry, Earth Observation researchers, and all other stakeholders interested in remote sensing applications in monitoring strategies for aquatic plastic litter and debris.
https://ioccg.org/group/marine-litter-debris/

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Development of practical applications for maritime issues using multi-satellite data including Geostationary Ocean Color Imager

Hee-Jeong Han[1], Kum-Hui Oh[2], Jin-Wook Lim[3], Suk Yoon[1], Hyun Yang[4], Ki-Beon Ahn[5], Young-Je Park[1*]

Our research project aims to develop algorithms that can extract information on maritime issues from image data captured by the Geostationary Ocean Color Imager (GOCI), GOCI-II, and many other satellite sensors. We are exploring eight practical application areas: detection of floating macroalgae, marine fog, harmful algal blooms, fine aerosol particles, low salinity water on the sea surface, forecasting abnormal sea surface temperature, and derivation of ocean water quality parameters and primary production. We have devised a data analysis flow for each practical application and are working on several new practical candidate algorithms. The maritime issues service system is formulated modularly and designed to detect maritime issues and support the establishment of response strategies. This system comprises a system for collecting and processing data and a web-based GIS system for displaying and analyzing data. Evaluation standards have been proposed to perform accuracy evaluations using field data or other satellite data on the produced outputs on maritime issues. It is expected that this output will enable early detection of maritime issues.

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Sargassum Watch from Space – Monitoring and Tracking Pelagic *Sargassum* Using Multi-sensor Data and Numerical Models

Chuanmin Hu, Brian B. Barnes, Yuyuan Xie, Jennifer Cannizzaro, David English, Yingjun Zhang, Sarah Sullivan

University of South Florida, College of Marine Science, St. Petersburg, FL, USA

Pelagic *Sargassum* (a brown macroalgae) used to be abundant in the Sargasso Sea of the North Atlantic Ocean, but a new and recurrent *Sargassum* belt in the tropical Atlantic has been formed since 2011. Despite the ecological functions of *Sargassum* in the open ocean, excessive amounts of *Sargassum* in coastal waters and on beaches caused many environmental and economic problems in countries and regions around the Caribbean Sea, Gulf of Mexico, and west Africa. Here, based on multi-sensor satellite data and customized algorithms, a *Sargassum* Watch System (SaWS) has been developed and operated as a decision support tool to help managers and others to make informed decisions. The SaWS generates customized near real-time satellite imagery to monitor and track large mats of pelagic *Sargassum* in the Atlantic Ocean. Integration of surface currents in Google Earth makes it possible to forecast short-term *Sargassum* movement. Based on SaWS, monthly bulletins of current and future *Sargassum* outlooks are generated and distributed to various stakeholders. According to NASA's definition, such a decision support tool is at the Application Readiness Level 9: sustained operation and application to benefit many stakeholders. Future works will incorporate high-resolution satellite imagery with improved algorithms to "zoom in" local regions.

No. 117

From space to sea: Mapping the National Seagrass Extent in Seychelles Using PlanetScope NICFI Data

C. Benjamin Lee [1], Lucy Martin [2,3], Dimosthenis Traganos [1], Sylvanna Antat [4], Stacy K. Baez [5], Annabelle Cupidon [6], Annike Faure [7], Jérôme Harlay [4], Matthew Morgan [6], Jeanne A. Mortimer [6], Peter Reinartz [8] and Gwilym Rowlands [2]

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Seagrasses provide ecosystem services worth USD 2.28 trillion annually. However, their direct threats and our incomplete knowledge hamper our capabilities to protect and manage them. This study aims to evaluate if the NICFI Satellite Data Program basemaps could map Seychelles' extensive seagrass meadows. The NICFI basemaps are produced and calibrated for terrestrial forest monitoring. Owing to their current water buffer of about 10 km, the coastal waters have been included in their basemaps, which allowed us to attempt to map coastal waters. The Seychelles archipelago was divided into three geographical regions. Half-yearly basemaps from 2015 to 2020 were combined using an interval mean of the 10th percentile and median before land and deep water masking. Additional raster features were produced using the Depth Invariant Index, Normalised Differences, and segmentation. With 80% of the reference data, an initial Random Forest followed by a variable importance analysis was performed. Only the top ten contributing features were retained for a second classification, which was validated with the remaining 20%. The best overall accuracies across the three regions ranged between 69.7% and 75.7%. The biggest challenges for the NICFI basemaps are its four-band spectral resolution and uncertainties owing to sampling bias. As part of a nationwide seagrass extent and blue carbon mapping project, the estimates herein will be combined with ancillary satellite data and contribute to a full national estimate in a near-future report. However, the numbers reported showcase the broader potential for using NICFI basemaps for seagrass mapping at scale, and by extension coastal mapping.

Using Remote Sensing to Support Harmful Algal Bloom Monitoring and Recreational Health Advisories in a California Reservoir

Brittany N. Lopez Barreto[1], Erin L. Hestir[2], Christine M. Lee[3], and Marc W. Beutel[4]

Freshwater systems often have algal blooms that are a water quality concern such as cyanobacterial harmful algal blooms (cyanoHABs). CyanoHABs can threaten aquatic ecosystem health and can cause illness or in extreme cases, death, to people and animals if ingested. Cyanobacteria records and data are limited due to logistical and cost constraints, while chlorophyll-a (chl-a) is a more common water quality metric and has been shown to have a relationship with cyanobacteria. The World Health Organization (WHO) has recently updated their previous 1999 cyanoHAB guidance values (GVs) to be more practical by basing the GVs on chl-a concentration. This creates an opportunity for widespread monitoring of cyanoHABs based on chl-a, with remote sensing being a potentially powerful tool. This study assessed the comparability of remote sensing of chl-a for cyanotoxin public health advisories. We used Sentinel-2 and 3 to map chl-a and cyanobacteria, respectively, and classified the values according to WHO GVs. We then compared them to the existing cyanotoxin advisories set by the California Department of Water Resources (DWR) at San Luis Reservoir, the largest off-stream reservoir in the United States and a key piece of infrastructure in California's water system. We found that remote sensing-derived chl-a serves as an acceptable proxy to DWR advisories. Remote sensing chl-a advisories from Sentinel-2 overpredicted advisories 21-46 % and underpredicted 0-21% of the time, depending on the algorithm used. Remote sensing-based cyanobacteria advisories from Sentinel-3 overpredicted advisories 34% and unpredicted 18% of the time. Using remote sensing based chl-a GVs as an early indicator for possible exposure advisories and as a trigger for site sampling may be effective to improve public health warnings. Implementing both chl-a and cyanobacteria remote sensing data can help fill temporal data gaps and provide greater spatial information not available from using only in-situ measurements.

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Assessing Lake Water Quality Using Satellite Images to Explore Stakeholder-Driven Questions

Michael Moerk[1], Courtney A. Di Vittorio[2]

A significant challenge in developing water quality improvement plans and monitoring systems for inland lakes is the scarcity and consistency of in-situ data. This project aims to develop and validate methodologies for estimating key water quality parameters using satellite observations, in order to support nutrient planning efforts for impaired inland lakes. The study site of interest is High Rock Lake, North Carolina, which is classified as an impaired water body according to the North Carolina Department of Environmental Quality and serves as a pilot for improving state-wide nutrient management processes. Water quality parameters of the lake such as turbidity, total suspended sediment, and chlorophyll-a concentrations can be estimated by calibrating models that directly relate satellite reflectance to these parameters. Analysis of historical in-situ data, alongside concurrent satellite overpasses has been used to calibrate total suspended sediment and turbidity models, which report coefficients of determination of 0.71 and 0.67, and root mean squared errors of 4.80 mg/L and 33.37 NTU respectively. To date, 17 in-situ data collection campaigns have also been executed to complement historical data, and models estimating chlorophyll-a concentrations from Sentinel-2 imagery using these data are currently being developed. In the context of this model exploration, various alternative atmospheric correction procedures have been tested, comparing satellite derived chlorophyll-a concentrations alongside in-situ radiometric estimates, yielding a range of coefficients of determination from 0.13 to 0.70. The goal of this project is that High Rock Lake would serve as a pilot case for inland lake monitoring and that its application of incorporating satellite derived estimates would improve state-wide nutrient management processes. Engagement with High Rock Lake stakeholder groups that are involved in the nutrient management planning process, and discussion of how these satellite-derived water quality estimates can be applied is ongoing.

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Abstract for the fifth International Ocean Colour Science (IOCS) meeting 14-17 November 2023 in St. Petersburg, Florida, USA

Interannual trends in water clarity in Cape Cod recreational ponds: Assessment from medium-resolution satellite imagery

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This study demonstrates that imagery collected by medium-resolution (10-30 m) Earth-observing satellites, specifically/namely the Landsat and Sentinel-2 series, is a powerful and cost-effective tool for the quantitative assessment of water clarity in water bodies of small spatial scales (>1 ha). In this study, we utilized satellite imagery collected by Landsat-5/7/8/9 and Sentinel-2A/B satellites during 1984-2022 for approximately 200 ponds over the Cape Cod Peninsula, Massachusetts and compared them to water clarity measured by a Secchi Disk, an easy-to-use, reliable, repeatable, and low-cost tool. Satellite data were obtained from Google Earth Engine (GEE), a cloud-based geospatial processing platform coupled to a continuously growing archive of publicly available satellite imagery. The relationship between the Top-Of-Atmosphere reflectances measured by satellite sensors and the Secchi Disk Depths (SDD) established using Random-Forest Machine Learning Modeling Technology demonstrated high levels of similarity between the SDDs measured *in situ* and predicted from different satellite products. Multi-annual SDD averages in different ponds were loosely but significantly correlated with nutrients (phosphorus) discharged to the ponds with stormwater. In most ponds (especially large and deep), predicted water clarity (SDD) increased during the four decades of available satellite imagery. This result could not be obtained from *in situ* SDD measurements because of the absence of long, regular data series. Regular analysis of publicly available medium-resolution satellite imagery appears to be an effective method for routine assessment of water clarity in inland water bodies, including comparatively small recreational ponds.

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Tracking pelagic *Sargassum* in the Florida Keys and Bahamas using Sentinel-2 imagery and a Deep Learning model

Sarah Sullivan[1], Lin Qi[2], Yuyuan Xie[3], Brian Barnes[4], Jennifer Cannizzaro[5], Chuanmin Hu[6]

Pelagic *Sargassum* macroalgae has been accumulating over some of the vulnerable nearshore coral and seagrass ecosystems in the Caribbean Sea and Florida Keys since the initial 2011 large-scale bloom. Large amounts of decomposed *Sargassum* cause water quality declines, marine mortality events, toxic gas releases, and local environmental and economic problems. Satellite-based tracking of surface *Sargassum* mats has been vital to management efforts. However, when it comes to complex, nearshore environments, traditional, threshold-based *Sargassum* detection from medium-resolution satellite imagery is not sufficient. Here, we use Sentinel-2 high resolution satellite imagery (10-20 m resolution) together with a Res-UNet deep learning (DL) model to extract *Sargassum* features. After extensive training and evaluation using carefully prepared "ground truth" images, the DL model was able to detect *Sargassum* features with over 90% accuracy. Such detected features were linearly unmixed to estimate subpixel *Sargassum* coverage, then gridded to provide 4km monthly *Sargassum* density maps to facilitate visualization and time series analysis. Evaluation against concurrent and co-located medium-resolution MODIS images showed comparable results in total-estimated biomass, yet these high-resolution data provided more detailed information in nearshore environments in the Florida Keys and Bahamas, thus making them more useful for management purposes.

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Hyperspectral & polarimetric ocean observations from space! How the NASA PACE Mission will advance water resource management and advance societal applications

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The Plankton, Aerosol, Cloud, and Ocean Ecosystem (PACE) mission is NASA's next great investment in Earth Science, continuing NASA's legacy of over forty years of satellite ocean color measurements. PACE, expected to launch in January 2024, will advance our Earth-observing and monitoring capabilities through hyperspectral imaging and multi-angle polarimetric observations of ocean, atmosphere, and land ecosystems. PACE will give us an unprecedented view of our home planet and will support user-driven environmental applications through research and applied science to address societal challenges and inform decision-making. The PACE Applications program seeks to strengthen the ties between science and decision-making through programming such as the PACE Community of Practice, workshops and focus sessions, and information-sharing and co-production activities. Practical applications of PACE data include waterborne pathogen monitoring and prediction, harmful algal bloom species discrimination and early-detection, support for best-management practices for estuary and watershed health, as well as sustainable fishery and aquaculture practices. Hyperspectral and polarimetric PACE data will provide water resource managers and decision-makers with highly accurate ocean color and atmospheric observations that will directly improve their operational products and applied technologies, ultimately fulfilling real-world needs.

In this presentation, we will highlight the capabilities of the novel hyperspectral and multi-angular polarimetric instruments onboard the PACE observatory, showcasing PACE's ability to fill societal needs and enable decision-making in water quality and resource management from the perspective of the PACE Applications program. We will outline case studies and Early Adopter projects where PACE is enabling the continuation of heritage MODIS and VIIRS visible, near-infrared, and shortwave-infrared data products at 1 km resolution, as well as producing new hyperspectral and multi-angular polarimetric advanced data products not possible with MODIS and VIIRS due to their design and technological limits.

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NOAA CoastWatch: 25 Years of Satellite Ocean Color Data Products and Applications

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The National Oceanic and Atmospheric Administration (NOAA) CoastWatch/OceanWatch/PolarWatch Program ("CoastWatch") has a storied history at the forefront of operational satellite oceanography. From its establishment in 1991, CoastWatch sought to facilitate access to satellite ocean color products; though none would be acquired until 1998 with Chlorophyll-*a* and Kd490 products from SeaWiFS. These were the first operational ocean color products at NOAA. Since that historic initial commercial data-buy, CoastWatch has led NOAA's endeavors to produce, disseminate, and apply satellite ocean color data.

In 2000, CoastWatch began providing experimental Harmful Algal Bloom (HAB) Bulletins for the Gulf of Mexico in partnership with the National Ocean Service (NOS), using chlorophyll data from SeaWiFS. HAB Bulletins have since gone national, integrating several data products supplied by CoastWatch. These Bulletins are one of many applications stemming from the program.

Satellite ocean color products have diversified, as algorithms and use cases have become increasingly complex. CoastWatch now offers dozens of near-real time, blended, gap-filled, and science quality datasets from VIIRS, Sentinel, and OLCI, as well as historic data from SeaWiFS, MERIS, and MODIS. What the repository lacks is geostationary observations. Though the future of satellite ocean color is bright, as CoastWatch is involved in preparations for two upcoming missions: the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR), and NOAA's next generation GeoXO. Additionally, advanced polar-orbiting sensors are on the horizon, with the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) set for launch in 2024. CoastWatch is well-equipped to continue to lead the field developing and distributing satellite ocean color data products.

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CoastWatch's ShipWatch Service - providing near-real time ocean color data to NOAA's ship fleet

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Satellite data can provide useful environmental context during oceanographic cruises, indicating any nearby chlorophyll blooms, temperature fronts or eddies that might be of scientific interest. These data can be used to help make decisions about where to sample or to better understand the in situ data being collected. However, often scientists are not aware of the utility of satellite data in this context. In order to ensure that satellite data are readily available to NOAA scientists at sea, NOAA's CoastWatch program has started a ShipWatch service that automatically send maps of satellite chlorophyll, sea-surface temperature and sea-surface height for a 4° x 4° box around the ship's position to all 15 ships in the NOAA fleet. This ship's location is obtained by accessing the ship's underway data that is served on the ERDDAP jointly maintained by SWFSC/ERD and the West Coast Node of CoastWatch. The location data is used to construct images of satellite chlorophyll, sea-surface temperature and sea-surface height on a box centered on the ship's location. Maps, in .png format, are sent daily by email to the Survey Technician and the Operations Officer for each ship. The emails also contain links allowing users to interactively refine the color palette or spatial extent of the map to best fit their operational needs (as long as there is internet access). The first phase of this service started in September 2022.

Other research in ocean colour science

Continuous research that is not theme-specific

Estimating sediment mass concentration in a plume emanating from the West Florida Shelf induced by the passage of Hurricane Ian

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Before its catastrophic 9/28/2022 landfall near Sanibel Island, Florida, Hurricane *Ian* crossed the West Florida Shelf at approximately 25.6 N/-82.6 W, and proceeded northeastward to landfall. While over the shelf, *Ian* achieved Saffir-Simpson Category 5 storm strength.

On 9/30, two days after landfall, Moderate Resolution Imaging Spectroradiometer (MODIS) imagery showed highly reflective shelf waters with peak backscatter at ~480 nm. This bright "Maya Blue" (RGB - 115, 194, 251) color indicated suspension of fine carbonate ($CaCO_3$) sediments. *Ian's* windspeed and strike properties make it likely the water column was fully mixed to ~60 m.

MODIS imagery also showed formation of a dense plume of $CaCO_3$ mud slurry extending southwest from the Dry Tortugas and curving eastward in the Loop Current into the Straits of Florida. The composition and location of this feature provided a unique opportunity to test methods for estimating the suspended mass of $CaCO_3$ sediment.

A small number of previous attempts using remote sensing to estimate carbonate sediment mass in a storm-generated plume have been made; these attempts have not converged on a $CaCO_3$ sediment mass algorithm. In lieu of such, the Particulate Inorganic Carbon (PIC) standard product (based on the 'Chalk-Ex' release of diatomaceous chalk) provided by the NASA OBDAAC was examined. Due to optical similarity (particle size, mineralogy, reflectance properties) of suspended chalk and the *Ian*-induced plume, we used MODIS PIC data to estimate $CaCO_3$ mass concentration.

NASA Giovanni was used to examine 8-day data, and NASA Panoply processed Level 3 PIC data for 10/2/2022. The data indicate a maximum concentration of ~0.03 moles/m^3 in the central region of the plume. The resulting $CaCO_3$ mass concentration (~3 g/m^3) is comparable to the other rare estimates of sediment mass concentration for similar events, including likely the only *in situ* observations made by Neumann and Land in 1975.

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Latest atmospheric correction algorithm updates for the operational GOCI-II data processing system

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Atmospheric correction is a necessary process in ocean color remote sensing that estimates the water reflectance at the sea surface from the top-of-atmosphere. This study describes the updated features in the current atmospheric correction and its validation results for the second Geostationary Ocean Color Imager (GOCI-II). The GOCI-II atmospheric correction is theoretically based on the SeaWiFS method, then partially modified in terms of using the more direct aerosol reflectance estimation method and employing the more robust NIR water reflectance model for turbid waters. The current updates focus on the sensor's radiometric degradation correction and the vicarious calibration gains adjustment. The improved atmospheric correction is validated with in-situ radiometric data collected from several cruises and AERONET-OC sites. The updated atmospheric correction has been implemented in the GOCI-II Ground Segment since October 2023.

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No. 127

Ocean color mission reprocessing in the machine learning era: impacts of vicarious calibration updates on *Sargassum* retrievals

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Satellite ocean color measurements are a critical tool for monitoring and assessing oceanic and coastal environments. As such, enormous effort is dedicated to ensuring that the satellite-derived remote sensing reflectance (R_{rs}) dataset is stable (according to location, time, and viewing geometry) and accurate. Among these efforts, system vicarious calibration (SVC) involves scaling satellite-derived R_{rs} to match high-quality *in situ* measurements. SVC coefficients (termed 'gains') are updated as these matchups accumulate, and are applied to the entire mission datasets during major reprocessings, which NASA undertakes every ~4 years.

Most traditional ocean color algorithms are based on band ratios or band-subtraction, which primarily have linear responses to SVC gain changes. However, as machine learning (ML) approaches are becoming more common, the impacts of gain updates on derived products is much more unpredictable. Here, we demonstrate the practical effects of the R2022.0 reprocessing on a *Sargassum* detection and quantification algorithm, developed with ML using the R2018.0 dataset. Notably, the input dataset changes resulted in a decrease in algorithm sensitivity, and subsequent underestimation of *Sargassum* abundance. Direct retraining using the R2022.0 data did not satisfactorily restore results, necessitating an entirely new ML algorithm for *Sargassum* detection. Within development of this new algorithm, we also greatly increased the quantity of valid retrievals, thereby improving coverage and yielding more robust *Sargassum* abundance estimates.

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No. 128

Uncertainties propagation in HyperInSPACE Community Processor (HyperCP)

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HyperInSPACE Community Processor (HyperCP) is an open-source processing software for in situ above water radiometry. The current version of the processor is based on the development of Hyperspectral In Situ Support for PACE (HyperInSPACE) project initiated by NASA with new additions brought by a collaboration with the European Fiducial Reference Measurements for Satellite Ocean Colour (FRM4SOC) consortium supported by the Copernicus Programme and coordinated by EUMETSAT. The FRM4SOC team inputs include the integration of more commercially available instrument platforms, full instrument radiometric characterizations, and protocol-compliant end-to-end uncertainty budget. Uncertainties are propagated using Community Metrology Toolkit (CoMet) toolkit developed by NPL, which is an open-source software that provides a means to store and propagate uncertainty and error-correlation information. The Monte Carlo method of uncertainty propagation is selected for the in-depth study on error correlation between different uncertainty sources and different wavelengths. Depending on the level of information about an instrument calibration and characterisation uncertainties within HyperCP are handled differently. Correction factors for instrument related effects are used if an individual instrument was fully characterised and the residual uncertainties of that corrections are propagated. For the cases where that knowledge is not available the uncertainties are assigned to a given instrument class based on the results of intensive laboratory testing of several different radiometers from the same class. Uncertainties are evaluated first per measurement and per wavelength for all output products of the HyperCP and then they are combined and convoluted into spectral bands of a satellite of interest.

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BRDF correction of S3 OLCI water reflectance products

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Within EUMETSAT/Copernicus activities, the objective of the BRDF4OLCI study is to implement an operational Bidirectional Reflectance Distribution Function (BRDF) correction for computing Sentinel3/OLCI fully normalized L2 marine reflectance in clear and complex waters. The study has reviewed the BRDF correction models of Morel et al. (2002; denoted as M02), Park and Ruddick (2005; P05), Lee et al. (2011; L11), He et al. (2017; H17), and Twardowski and Tonizzo (2018; T18). Upon identifying limits in H17 and T18, the study has implemented M02, P05, and L11 in the OLCI L2 processor.
Diagnostic data for performance assessments include in situ water reflectances (OFS in-water data, Talone et al., 2018; JETTY above-water data, e.g., Pitarch et al., 2020), OLCI match-ups with AERONET-OC (Zibordi et al., 2021), MOBY (Voss et al., 2018) and BOUSSOLE (Antoine et al., 2008) measurements, and OLCI-A and B images in and outside the tandem phase. The capability of the BRDF correction schemes to reduce BRDF effects has been verified in all tested cases, with a noticeable dependency on the water type.
A similar performance of the BRDF correction methods was observed in Case 1 waters. Instead, an increase of the optical complexity leads to larger BRDF correction performance differences. This finding has been related to the BRDF correction design, and specifically to the phase function adopted by each BRDF model. On this basis, the BRDF4OLCI study is developing a new correction scheme. The model design will follow the formalism of L11, and it will be implemented relying on directional water reflectance simulated with Hydrolight for a broader range of IOPs compared to M02, P05, and L11.
The study benefits from synergies with the EUMETSAT activity on the standard atmospheric correction (OC-SAC) to ensure consistency between the current BRDF development and the other components of the L2 processing chain.

Assessing Diurnal Variability in Phytoplankton Chlorophyll-a Concentrations with Geostationary Satellite

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In recent years, advancements in satellite-based ocean color observations have significantly enriched our understanding of marine ecosystems and their responses to environmental changes. As the global climate continues to evolve, gaining insights into the diurnal dynamics of key oceanic constituents becomes imperative for comprehending the intricate interactions within aquatic ecosystems. The diurnal cycle plays a pivotal role in ocean biogeochemistry, governing the temporal fluctuations of critical elements and compounds, such as phytoplankton Chlorophyll-a (Chl-a) concentrations. Understanding this diurnal variability is paramount for informed decision-making in environmental management and sustainable resource utilization.

Satellite technology has emerged as a powerful tool in monitoring these diurnal processes in the oceans. However, there are still some limitations exist, for instance, low temporal resolution of polar-orbiting systems (Sentinel-3/OLCI) or inadequate bands on Meteosat Second Generation (MSG). These limitations have hindered our ability to capture the full spectrum of diurnal oceanic variability.

To bridge these gaps and prepare for the Meteosat Third Generation (MTG), we utilize Himawari-8. Its geostationary position offers high temporal and spatial resolution. Himawari-8 serves as a valuable testing ground, allowing us to refine data processing techniques and methodologies for monitoring diurnal Chl-a dynamics in fine detail. This preparation ensures that we can make the most of MTG's advanced capabilities when it becomes available. Our research leverages Himawari-8 data to uncover the significance of Chl-a variations. Through visual representations and statistical summaries, we showcase our findings, laying the foundation for improved ocean color observations with MTG. This approach optimizes satellite technology for informed environmental management and resource utilization.

Different Approaches to Uncertainty Estimation in HPLC Phytoplankton Pigments Measurements for Ocean Color Validation Support

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High-performance liquid chromatography (HPLC) measurements of phytoplankton pigments are widely recognized as the standard for calibrating and validating satellite-derived chlorophyll a concentrations. Estimating phytoplankton community composition and abundance often relies on chemotaxonomic analysis. To support the development of satellite algorithms and validate data products, it is crucial to evaluate the uncertainty associated with these measurements. As the condition of analysis, can change over time, the process of HPLC method validation and verification should be continuous to ensure the highest possible data quality.

In this study, we present two different approaches to uncertainty evaluation. One approach involves two laboratories that implemented the same analytical method using a dataset of 957 natural samples representing various water types. The dataset was collected over a period of five years (2012-2017), covering a wide range of chlorophyll a concentrations from 0.083 to 27.35 mg/m3. The second approach compares the two laboratories in the context of inter-calibration exercises, which included other laboratories that used different methods for pigment analysis and quantification. These inter-comparison exercises were organized over a period of eleven years (2010-2021) and included both natural samples collected in replicates and reference standards.

The comparison of the two laboratories revealed valuable insights into the consistency and reliability of HPLC measurements over time. The dataset's broad representativeness allowed for a comprehensive assessment of measurement uncertainties. Additionally, the inter-calibration exercises provided an opportunity to assess the compatibility of HPLC measurements with other analytical methods and their respective uncertainties.

We discuss the advantages and limitations of both approaches for uncertainty evaluation in HPLC phytoplankton pigment measurements. The findings contribute to our understanding of the robustness and reliability of HPLC measurements in various contexts, emphasizing the importance of continuous method validation and verification to ensure high data quality in satellite-derived chlorophyll a concentration assessments and phytoplankton community composition estimations.

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Mapping Intertidal Macrophytes in Fjords in Southwest Greenland Using Sentinel-2 Imagery

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Changes in the distribution of coastal macrophytes in Greenland, and elsewhere in the Arctic are difficult to quantify as the region remains challenging to access and monitor. Satellite imagery, in particular Sentinel-2 (S2), may enable large-scale monitoring of coastal areas in Greenland but its use is impacted by the optically complex environments and the scarcity of supporting data in the region. Additionally, the canopies of the dominant macrophyte species in Greenland do not extend to the sea surface, limiting the use of indices that exploit the reflection of near-infrared radiation by vegetation due to its absorption by seawater. Three hypotheses are tested: I) 10-m S2 imagery and commonly used detection methods can identify intertidal macrophytes that are exposed at low tide in an optically complex fjord system in Greenland impacted by marine and land terminating glaciers; II) detached and floating macrophytes accumulate in patches that are sufficiently large to be detected by 10-m S2 images; III) iceberg scour and/or turbid meltwater runoff shape the spatial distribution of intertidal macroalgae in fjord systems with marine-terminating glaciers. The NDVI produced the best results in optically complex fjord systems in Greenland. 12 km 2 of exposed intertidal macrophytes were identified in the study area at low tide. Floating mats of macrophytes ranged in area from 400 m 2 to 326,800 m 2 and were most common at the mouth of the fjord. Icebergs and turbidity appear to play a role in structuring the distribution of intertidal macrophytes and the retreat of marine terminating glaciers could allow macrophytes cover to expand. The challenges and solutions presented here apply to most fjords in Greenland and, therefore, the methodology may be extended to produce a Greenland-wide estimate of intertidal macrophytes.

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Seasonal variation in suspended particulate matter distribution and characteristics in two estuarine systems in the northern Gulf of Mexico

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Suspended particulate matter (SPM) is an important biogeochemical parameter in estuaries influencing water transparency, light field, and primary productivity, while also contributing to sediment and pollutant transport. SPM characteristics such as particle size distribution (PSD), a measure of size-specific particle concentrations in either volume or number, is also of interest as it can provide information on the aquatic ecosystem structure and modulate satellite remote sensing signals. PSD measurements with optical instruments such as the LISST (Laser In-Situ Scattering and Transmissometry) can provide information on particle size and have been used to characterize particle distributions in coastal waters. In this work, we examine the seasonal SPM concentration, PSD characteristics, and optical linkages in two estuaries in the northern Gulf of Mexico, namely, Apalachicola Bay (DOM-dominated) and Barataria Bay (particle-dominated) using field and satellite ocean color data. River discharge appeared to directly influence spatiotemporal SPM distribution in Apalachicola Bay, while river diversion and runoff including exchange with low salinity shelf waters influenced the SPM field in Barataria Bay. We examine the seasonal salinity field in conjunction with SPM and particle volume concentrations, which were an order of magnitude greater in Barataria Bay than in Apalachicola Bay. SPM as well as particle volume concentration were overall well correlated with beam attenuation for both the bays; however, deviations were observed due to relatively higher concentration of phytoplankton biomass during summer and high SPM during spring in Barataria Bay. Beam attenuation was observed to be most highly correlated to nano- and micro-sized particles and least to larger-sized particles. SPM maps obtained from backscattering coefficient using an adaptive semi-analytic algorithm and a relationship between backscattering and SPM indicated seasonal trends and highest values in low salinity river plume waters.

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Identification of the Spectral Pattern of Brown Algae in the southern area of Perú

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Brown algae (*Lessonia nigrescens, Lessonia trabeculata Lessonia nigrescens*), are considered of great commercial importance and for more than 20 years a rational extraction of these resources has been carried out, mainly in the southern area of Peru (from 12°S to 42°S). In order to obtain the spectral signatures of these algae, a study of *in situ* radiometric measurements was carried out in December 2019, using the RAMSES TriOS radiometer, which has a range from 320 to 920 nm.

The spectrum shows a fairly defined behavior, with a valley in the blue, green and part of the red areas, to register its maximum absorbance near 740 nm, where a jump in the R-spectrum occurs that goes from 0 to 0.2%. .

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Estimation of PAR at the ocean surface around Korean Peninsula using GOCI & GOCI-II

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Photosynthesis available radiation (PAR) has a key role for estimating primary production at the ocean. GOCI and GOCI-II were world's first geostationary ocean color satellite sensors and they observe ocean around Korean Peninsula successfully. However, they were not official PAR product from GOCI and GOCI-II. Here, we developed PAR algorithm for GOCI and GOCI-II. Then, evaluation of daily PAR data from GOCI and GOCI-II was carried out with in-situ measurement data and each sensor. Daily PAR from GOCI showed under 5% of root-means-square error (RMSE) and under -1% of mean-bias error (MBE) as in-situ measurement daily PAR. Daily PAR from GOCI-II showed under 5% of bias with GOCI daily PAR. GOCI and GOCI daily PAR were expected that help to understand primary production at the ocean around Korean Peninsula. At the further study, additional development of GOCI-II daily and hourly PAR data will be carried out.

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Sunglint mitigation strategy for upcoming multidisciplinary remote-sensing missions

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Abstract

The specular reflection (*i.e.,* sunglint) of direct sunlight on the air-water interface towards the satellite field of view may contaminate a significant portion of an image, which may hinder retrieval of useful information by the atmospheric correction processors. To circumvent that, ocean color missions employ a tilting strategy. The amount of tilt angle required hinges on factors, such as sun-sensor geometry and wind speed. This work presents a sunglint mitigation strategy by tilting the imaging instrument for typical geometry and wind speed. Firstly, through radiative transfer simulations, the impact of sunglint on top-of-atmosphere reflectance (ρ_t), radiance (L_t), and glint coefficient (L_{GN}) were assessed for four different orbits or Equatorial Crossing Times (ECT) – 10:15 AM, 10:45 AM, 11:15 AM and 11:30 AM, and three dates – summer solstice (June 21), fall equinox (September 21), and winter solstice (December 21). Intense sunglint effects were evident at the subsolar point (where Sun is at nadir/near-nadir) for the 11:15 AM and 11:30 AM ECT for all three dates. The sunglint mitigation was analyzed by tilting the imaging instrument westward with respect to the nadir. It is found that for the June 21, 11:30 AM ECT, 15° or more tilting will be required to diminish sunglint at the subsolar point ($\sim 25°N$), while ~7° tilt will significantly reduce the glint for 10:45 AM ECT. Sunglint is less intense for the winter solstice and fall equinox; and ~12° tilt minimizes the glint substantially for the 11:15 AM orbit. Analyses on change in useable signal indicate, without tilt, < 0.6x signal can be expected for 11:30 AM (June and September 21) with respect to 10:15 AM ECT, which increases by ~ 0.1x for every 5° westward tilt.

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Sea ice detection and monitoring using GOCI-II (Geostationary Ocean Color Imager – II)

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Sea ice affects the weather through surface energy exchange and economic activity such as fishery, transportation and oil exploration in the Bohai bay. Moreover, drifting sea ice can cause damage to port facilities and ships.

Therefore, many studies of sea ice detection have been conducted using synthetic aperture radar (SAR) and ocean color sensor, such as advanced very high-resolution radiometers (AVHRR) and moderate resolution imaging spectroradiometer (MODIS). Recently, more accurate and detailed sea ice detection is possible using Sentinel-2 and Landsat-8 in the Bohai bay. Although these satellites observed wide area with high spatial resolution, there are limitation to sea ice monitoring due to the its revisit period.

In this study, we developed sea ice detection algorithms (threshold algorithm, deep learning algorithm) in Bohai bay using Rayleigh-corrected reflectance (Rrc) data of Geostationary Ocean Color Imager-II (GOCI-II). We proposed a threshold-based algorithm to sea ice detection using Rrc at 680 and 865 nm bands for GOCI-II. Threshold of the ratio of Rrc at two bands and standard deviation method allows the classification of sea ice, clouds and sea water. Additionally, we developed Multi-Layer Perceptron (MLP) algorithm using Rrc at 12 bands for GOCI-II. Training data set used the threshold-based algorithm classification data. The algorithm results were validated against detected sea ice using Sentinel-2 data. The results showed that the both algorithms using GOCI-II is suitable for sea ice detection. Furthermore, GOCI-II, which has good temporal resolution, can be used sea ice monitoring for short-term variability and the movement of drifting sea ice by tidal current.

No. 138

On-orbit Radiometric Calibration of GOCI-II Solar Diffuser with Improved Bidirectional Transmittance Distribution Function

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On-orbit radiometric calibration is a crucial process to ensure the accuracy of satellite data and acquire reliability for various ocean color products. This study will present the update of GOCI-II radiative correction algorithm to ensure the continuous quality and accuracy of the Geostationary Ocean Color Imager-II (GOCI-II) products. The GOCI-II has utilized an on-board calibration device monitoring system using a Solar Diffuser (SD) and Diffuser Aging Monitoring Devices (DAMD) to continuously produce the absolute radiometric gain parameters derived from the Sun. The time series of the SD gain data (K1) exhibits an increasing tendency to possible sensor degradation as well as seasonal variability. To remove the sensor degradation effects on ocean color products, we improved the radiative correction algorithm to consider the SD/DAMD measurements. The improved radiative correction algorithm includes Bidirectional Transmittance Distribution Function (BTDF) correction and sensor degradation model, which collectively operate to compensate for the observed seasonal fluctuation and estimate degradation trend in radiometric gain values. The results demonstrate the impact of BTDF correction and sensor degradation model on the spectrum of Top of Atmosphere (TOA) radiance, confirming the capability for improving the long-term stability of GOCI-II data.

No. 139

SeaDAS: NASA Software for the Analysis of Earth-Viewing Satellite Data

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SeaDAS (Sea, Earth and Atmosphere Data Analysis System) is a comprehensive software package developed by NASA OBPG (Ocean Biology Processing Group) for the processing, visualization, analysis, and quality control of remote-sensing Earth data. The SeaDAS science processors OCSSW (Ocean Color Science Software) apply the OBPG algorithms to generate the level-2 and level-3 Earth science data for the NASA EOSDIS (Earth Observing System Data and Information System) OB.DAAC (Ocean Biology Distributed Active Archive Center). SeaDAS fully supports over 20 U.S. and international satellite missions, some of which are: MODIS (Aqua, Terra), VIIRS (Suomi NPP, NOAA20, NOAA21), OLCI (Sentinel 3A, Sentinel 3B), MSI (Sentinel 2A, Sentinel 2B), OLI (Landsat 8, Landsat 9), SeaWiFS, MERIS, GOCI, HICO, CZCS and HawkEye. When PACE launches, SeaDAS will support the PACE sensors: OCI, HARP2 and SPEXone. SeaDAS provides users the ability to conveniently view, analyze and process satellite data using OBPG default settings. Users can fine-tune any of the SeaDAS processing options to generate level-2 and level-3 files specific to their unique scientific analysis needs, requirements, and quality acceptance thresholds. SeaDAS is free open source software and can be downloaded from the NASA OB.DAAC.

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No. 140

Bio-optical feedback as a mechanism for stability of primary production in the mixed layer

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Critical Depth Theory is arguably one of the longest standing bio-physical theories in oceanography and is the earliest mathematically formulated theory aimed at explaining the process of phytoplankton blooms. It relies on the assumption of there being a depth horizon, termed the critical depth, and if the mixed layer extends below this critical depth average light levels in the mixed layer get so diminished that photosynthesis no longer surpasses losses. A similar horizon in case of week mixing is the compensation depth, where the rate of photosynthesis matches the loss rate. In this work the Critical Depth Theory is developed further by in depth analyses of the effect of self shading, which creates a bio-optical feedback in the mathematical model. A new differential equation is derived for the time evolution of the compensation depth. Using this equation it is demonstrated that the light intensities at both the compensation depth and the critical depth are constants of motion. The standard assumption of zero biomass below the mixed layer is derived as a consequence of the bio-optical feedback in the mixed layer. Exact solutions for average and total mixed layer biomass at steady state are derived and their stability properties analysed. It is demonstrated that the system has a trivial and a non-trivial steady state. An existence of a bio-optical bifurcation is shown, in which the mixed layer depth acts as bifurcation parameter. The critical depth is identified as the bifurcation point at which the trivial and the non-trivial steady state exchange stability properties. Transients between steady states are also explored and it is shown that the relation between the initial condition and the final steady state is paramount in deciding whether the biomass response to mixed layer shallowing or deepening will be a rise or a decline in biomass over time.

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No. 141

Uncertainty estimates for satellite-based computations of marine primary production

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In their latest report, the IPCC expressed low confidence in satellite-based estimates of trends in marine primary production, citing the insufficient length of the time series as well as the lack of independent validation methods. Independent validation of basin-scale primary production estimates is compromised since all available *in situ* data from photosynthesis-irradiance measurements and all remotely-sensed data on chlorophyll concentration and available light are used for the modelling of primary production. Independent, concurrent, *in situ*, daily, water-column primary production measurements are not sufficient in numbers or in geographic distribution, for a global validation. Moreover, indirect methods of validation, such as the comparison with bulk property estimates, are compromised by incompatibility of time scales and representation of different components of primary production. In this study, we address the uncertainty in satellite-based primary production estimates by assessing the errors inherent to the calculation, in which each element of the calculation is considered separately. This method closely follows the validation approach described in the Guide to the expression of Uncertainty in Measurement (GUM). We assess the error in each of the input quantities to the primary production model (biomass, photosynthetic parameters and light) and propagate the errors through the model to obtain the uncertainty in primary production. By doing this on a pixel-by-pixel basis, we can address the uncertainties in primary production at regional scales and pinpoint regions where more *in situ* and remote-sensing data are needed to improve the confidence in satellite-based estimates of trends in marine primary production.

Deep neural network-based derivation of ocean-color products

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This study introduces an algorithm that derives inherent optical properties (IOP) based on a deep neural network (DNN) using R_{rs} data from 9 wavelengths. Previous studies proposed a neural network-based algorithm structure, whereas this study developed an algorithm that leverages the DNN model. Furthermore, we aimed to enhance the algorithm's performance by adjusting the activation function and optimization techniques. In contrast to the existing algorithm structure, which calculates IOP in three stages using a neural network, we present an algorithm that directly applies a DNN for IOP derivation. The input and output data for this study utilized a synthetic dataset provided by the International Ocean Color Coordinating Group Report 5. Subsequently, we compared the performance of the algorithm proposed in this study with the results of the quasi-analytical algorithm (QAA). The findings show that by employing a DNN-based algorithm, IOP can be accurately estimated (with an R^2 of 0.9 or higher), outperforming the QAA. This result is attributed to the DNN model's capacity to effectively handle nonlinearity between components through data patterns within the dataset used in this study. However, it remains essential to identify the strengths and weaknesses of empirical, semi-analytical, and neural network-based algorithms and apply them judiciously for deriving ocean-color products.

Development of NO_2 absorption correction model for GOCI-II based on radiative transfer model

Kyeong-Sang Lee[1], Myung-Sook Park[1], Jae-Hyun Ahn[1*]

The Geostationary Ocean Color Imager (GOCI)-II employs a four-step atmospheric correction algorithm, comprising gas absorption correction, Rayleigh reflectance correction, aerosol reflectance correction, and turbid water and bidirectional reflectance distribution function (BRDF) correction. This research primarily focuses on the gas absorption correction step, specifically targeting nitrogen dioxide (NO_2) absorption. NO_2 in the atmosphere absorbs solar radiation in the blue and green wavelengths, and the extent of this absorption varies depending on factors like sun-surface-satellite angles and NO2 concentrations. It's well-established that NO_2 absorption significantly affects the accuracy of primary ocean color products such as Chlorophyll-a concentration, total suspended material, and remote sensing reflectance. Therefore, including NO_2 absorption correction is crucial for precise ocean color product generation. Notably, the current atmospheric correction process for GOCI-II lacks NO2 absorption correction. This study introduces a finely-tuned NO_2 absorption correction model tailored to GOCI-II specifics. Traditional Beer's Law isn't suitable for NO_2 absorption correction due to high concentrations near the Earth's surface, where multiple scattering phenomena occur. As a result, our study involves the construction of a comprehensive Look-Up Table (LUT) for NO2 absorption correction. We employ the vector version of the linearized discrete ordinate radiative transfer (VLIDORT) model and conduct an in-depth analysis to assess each variable's sensitivity.

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No. 144

Estimation of microphytobenthos biomass using *in situ* and airborne WaterSat Imaging Spectrometer Experiment (WISE) hyperspectral imagery

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Tidal flats are colonized by photosynthetic microorganisms grouped under the generic term of microphytobenthos (MPB), one of the coastal ecosystem's major primary producing groups. These microbial assemblages form transient biofilms at the sediment surface and have important ecosystem functions. The MPB component has been studied for decades in temperate waters elsewhere in the world, many of them using hyperspectral remote sensing. Combining *in situ* data (photosynthetic pigments, absorption, granulometry, and hyperspectral reflectance) and hyperspectral imagery acquired over a cold temperate tidal flat, this study aims to document the composition of the MPB assemblage and its biomass at the sediment surface. We are presenting the results of three fieldwork campaigns (2019, 2022) conducted in the Manicouagan Peninsula (Québec, Canada) as part of a multidisciplinary research project. Airborne hyperspectral images were acquired at low tide by the WaterSat Imaging Spectrometer Experiment (WISE) by the National Research Council (NRC) sensor on August 20th, 2019. In addition to being geometrically and atmospherically corrected, the images were georeferenced and radiometrically calibrated by the NRC. A water column correction was performed based on the semi-analytical algorithm of Albert and Mobley (2003) using *in situ* data. For the spectra collected, it is possible to distinguish a red absorption band (between 676 nm and 683 nm) for an MPB biomass above 2 µg cm^{-3}. Different published spectral indices based on spectral shape of bottom reflectance between 495 to 673 nm were tested to estimate the biomass of MPB using *in situ* and hyperspectral imagery spectra. We observe poor relationships between those indices and the biomass measured (r^2 between 0.16 and 0.48) both on the *in situ* and the water column corrected WISE images. Based on the results from different published spectral indices, we proposed the development of regional algorithms adapted to map MPB biomass and assemblage over the study area.

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No. 145

Global daily gap-free ocean color products derived from multi-satellite measurements using the DINEOF method

Xiaoming Liu[1] and Menghua Wang[2]

Abstract

Satellite ocean color products derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) and NOAA-20, and the Ocean and Land Colour Instrument (OLCI) on the Sentinel-3A (S3A) and Sentinel-3B (S3B) have been widely used for surveillance of the ocean environment and research on ocean physical, biological, biogeochemical, and ecological processes. However, either VIIRS or OLCI daily ocean color images are often incomplete in spatial coverage due to cloud cover, contamination of high sun glint, narrow swath width, high sensor-zenith angle, high solar-zenith angle, and/or other unfavorable retrieval conditions. Although merging daily ocean color images from multiple satellite sensors can help reduce the number of invalid pixels, gap-filling methods such as the Data Interpolating Empirical Orthogonal Function (DINEOF) are often used to reconstruct invalid pixels and generate gap-free data coverage. In this study, multi-sensor derived global daily gap-free ocean color data, including chlorophyll-a (Chl-a) concentrations, water diffuse attenuation coefficient at the wavelength of 490 nm ($K_d(490)$), and suspended particulate matter (SPM) concentrations will be presented. Daily global gap-free ocean color data of 2-km and 9-km spatial resolutions are routinely produced, and can be accessed from NOAA/CoastWatch. Recently, to capture fine features in ocean color products, especially in coastal regions, high-resolution gap-free data of 1-km and 0.5-km spatial resolution are also developed and tested. The performance of gap-free data in different spatial resolutions will be compared and discussed.

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OCROC: Ocean Color Radiometry for the assessment of the particulate and dissolved Organic Carbon over both open and coastal waters.

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Carbon monitoring from space is critical for the reporting and verification of carbon stocks and changes in both coastal and open ocean waters. In the frame of the OCROC project, funded by the Copernicus 2 – 1st Service Evolution Call for Tenders (2022-2024), we focus on the particulate (*POC*) and dissolved (*DOC*) organic carbon of surface oceanic and coastal waters, which represent the two components of the total organic carbon (*TOC*) pool in the ocean. Due to their different role in the carbon cycle, as well as their different carbon export pathways toward the deep ocean, the spatio-temporal distribution of *POC* and *DOC* as well as their relative contributions to *TOC* have to be characterized over the global ocean. While surface *POC* spatio-temporal patterns are now relatively well described over open ocean waters thanks to the availability of ocean color radiometry (OCR) algorithms, *POC* over coastal waters and *DOC* over open and coastal waters are still not well described. Knowing that *DOC* represents about 90% of *TOC* in open ocean waters, it is crucial to assess its spatio-temporal variability from remote sensing, especially to bring new insights to the carbon modeling community. Different *POC* and *DOC* algorithms, based on diverse approaches and input parameters (OCR but also sea surface temperature and mixed layer depth ancillary data) have been selected based on extensive match-up exercises using Copernicus products. To better account for the bio-optical complexity of marine (coastal and oceanic) waters, and to better address the transition between coastal and open ocean waters these different algorithms have been combined using an Optical Water Class approach. The main advances of this project will be presented.

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No. 147

The importance of temporal variability or seasonality in the relationship between Line Height Absorption and chlorophyll concentration: a case study from the Northern Gulf of Alaska.

Benjamin Lowin[1], Suzanne Strom[2], Will Burt[3], Thomas Kelly[4] and Sara Rivero-Calle[5]

As autonomous instruments are becoming typical tools to explore the ocean's chlorophyll variability, scientists are adopting common-practice methods to cross-calibrate and validate different chlorophyll concentration estimates. Using absorption to estimate chlorophyll can be done using remote sensing and *in situ* measurements. Roesler and Barnard's Line Height Absorption (LHA) method, developed in 2013, is a popular method used to estimate chlorophyll concentrations from high frequency absorption measurements. The slope of the relationship between absorption and chlorophyll concentration is known as the chlorophyll-specific absorption line height (a_{LH}*). The a_{LH}* varies with phytoplankton community composition and pigment packaging. Most users understand the importance of regional tuning, however, the effect of seasonality on a_{LH}* is not accounted for. The following evaluates the impact of temporal or seasonal variability on the LHA. The study was carried out in the Northern Gulf of Alaska (NGA), which is intensely seasonal. It was found that the a_{LH}* for the NGA ranged between 0.0108 and 0.0136, with the highest values occurring in summer and the lowest in spring. This translates into a non-negligible 26% variability in chlorophyll estimates. The size fractionated chlorophyll data strongly suggests that a shift in the phytoplankton size is a major driver of the a_{LH}* variability between spring and summer. Given these results, we encourage others to consider the seasonality factor when using the LHA method to obtain chlorophyll estimates from absorption measurements.

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Global ocean study from space lidars: CALIPSO and ICESat-2

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The CALIPSO mission has 17th year of very successful operation, providing the first ever multi-year global record of high-resolution profiles of aerosols and clouds in the Earth's atmosphere (Winker et al. 2010), which are critically important for Earth radiation budget estimation and climate model improvements. Although CALIPSO was not designed for ocean subsurface applications, its measurements over the Earth's oceans now provide a wealth of unanticipated opportunities for ocean biology and biogeochemistry studies (Behrenfeld et al., 2019, 2016, 2013; Churnside et al., 2013; Dionisi et al., 2020; Lu et al., 2016, 2014), which fill observation gaps in the passive remote sensing of ocean biology (e.g., MODIS ocean color) that occur when sensors are obscured by optically thin cloud and/or sea ice and during all nighttime observations.

We will present the global ocean biology results during both daytime and nighttime observed from CALIOP lidar and its comparison with ICESat-2 lidar and passive ocean color results. The global scale and high vertical resolution profiles from CALIPSO and ICESat-2 provide new and unique information that augment the existing ocean color records acquired by passive remote sensors. This pioneering use of space lidars to retrieve ocean subsurface properties will provide a meaningful satellite lidar record to the ocean science community and an important preparatory data for the upcoming Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission.

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Using Ocean Color Data for Estimation of Spatiotemporal Biogeochemical Model Parameters

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Ocean biogeochemical (BGC) models are a primary tool for investigating ocean biogeochemistry and the global carbon cycle. These models contain many uncertain parameters whose values are not precisely known. Uncertainty in the parameter values translates into uncertainty in the model outputs. The value of ocean BGC parameters depends on the physical and biogeochemical context of the marine environment. However, they are used as constant values across space and time in the model simulations. This study assimilates satellite ocean color data into the ocean BGC model Regulated Ecosystem Model 2 (REcoM2) to estimate spatially and temporally varying parameters in a global model setup. We applied an ensemble Kalman filter provided by the Parallel Data Assimilation Framework (PDAF) to simultaneously estimate selected uncertain parameters and the BGC model states and quantify the spatiotemporal uncertainties regarding the parameter estimation and the prediction uncertainties induced by those parameters. The uncertain parameters were selected based on a sensitivity analysis. We further assess the performance of estimated spatially and temporal varying parameters. We show that ocean color-derived surface chlorophyll-a concentration can effectively constrain error in the BGC model parameters. The parameters converge in less than a year and reduce the BGC parameter uncertainty. The chlorophyll concentration simulations of the model with the estimated spatially varying parameters are closer to the observations than the reference simulation using uniform values of the parameters with a 48% reduction of Root Mean Square Error.

Recent advances on Sentinel-3 OLCI Ocean Colour Standard Atmospheric Correction (OC-SAC)

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We will present recent advances in the EUMETSAT Ocean Colour Standard Atmospheric Correction (OC-SAC), which is a candidate algorithm for the next Copernicus Programme S3 OLCI L2 reprocessing in 2024 (Collection 4). The multi-spectral aerosol identification has been revised to speed up the algorithm and match the CPU constraints for operations. In parallel, a new formulation of the aerosol reflectance has been developed to further reduce the Look-up table size and minimize the memory usage, specifically critical with the new set of 108 aerosol models (2 families of weakly and strongly absorbing models, mixing fine and coarse modes for 9 fractions and a size distribution indexed on 6 values of relative humidity), tabulated at 3 mean altitudes. The new Aerosol Layer Height (ALH) module, using the OLCI O2 absorbing channels, is validated against Sentinel-5P data and its impact assessed against match-ups. The strongly-absorbing aerosol detection (flagging) and correction has also been tuned and is compared to current standard algorithm and the alternative Spectral matching Atmospheric Correction algorithm (SACSO). Updates on the Bright Pixel Correction (BPC), now formally part of the OC-SAC module, is shown to also improve retrieval in complex situations. We will report validation results at Level-2 and Level-3 scales, based on a data set shared with the Ocean Colour community.

Sign me up! Inventory of current ocean colour mission validation activities

Lachlan McKinna[1,2,*] and Jeremy Werdell[1]

This poster is an extension of Breakout Workshop 3. It is intended to provide an additional opportunity for engagement with IOCS delegates. As the collective international ocean color community has not met in-person for several years, our objective is to take an inventory of current global validation activities to identify potential gaps/opportunities and learn how we might assist each other. There are multiple international ocean color missions on-orbit and in-formulation (e.g., GCOM-C, Senitel-3A/B, VIIRS, PACE). Each mission has its own dedicated validation program to ascertain data product quality and provide confidence to the user community. Successful validation programs are key to determine if prescribed mission requirements are met. There are currently multiple validation programs run concurrently throughout the global ocean with data stored in various data repositories.

We intend to take stock of activities occurring in the near-term with a focus on biogeochemical measurements (e.g., HPLC, POC, PIC), apparent optical properties (AOPs, K_d), and inherent optical properties (IOPs). We hope to identify: (i) gaps in validation campaigns, (ii) geographic domains being sampled, (iii) new technologies, (iv) innovative sampling strategies, and (v) areas where we can collaborate and/or share resources to achieve collective objectives.

We invite IOCS delegates to 'sign up' at our poster to share details of data collection activities relevant to ocean color validation. This information will be used to assist in formulating our workshop report to the IOCCG. We are interested to hear about the types of measurements you collect, the geographic region where you sample, and any challenges you face. For example, there may be measurements or instruments you are lacking that could be resolved by a collaboration. We are also interested to learn about novel technologies and non-traditional approaches that may lend themselves well to validation, however, the capabilities and benefits may not be broadly familiar.

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Verification of uncertainty estimates of autonomous field measurements of marine reflectance using simultaneous observations

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Remote sensing reflectance R_{RS} data are at the basis of almost all ocean-color applications. Quantifying their uncertainties is thus key to the creation of comprehensive uncertainty budgets for ocean color products. Estimating satellite R_{RS} uncertainties has largely relied on validation with field measurements but this process is solid only if these measurements are in turn fully characterized. Uncertainty budgets have therefore been defined for the observations collected by the Ocean Color component of the Aerosol Robotic Network (AERONET-OC). The contemporaneous deployment of two autonomous systems for 5.5 years on the Acqua Alta Oceanographic Tower (AAOT, northern Adriatic Sea) led to the collection of a large body of coincident observations (collected within a time window of 10 minutes) that can be used to verify reported uncertainty values. The comparison of matched pairs showed a good agreement for R_{RS} (with differences of typically 2-3% between 412 and 560 nm) and for the aerosol optical thickness τ_a (3-6%). Differences between data from the two systems appear generally consistent with their stated uncertainties, indicating that they are metrologically compatible and that reported uncertainties are trustworthy. Using uncertainty cone diagrams, this result holds across the range of uncertainty values with few exceptions. Independent uncertainty estimates associated with non-systematic error contributions were obtained using a collocation framework allowing for error correlation between measurements from the two systems. The resulting uncertainties appeared comparable with the values reported for τ_a and R_{RS}. The related mathematical development also showed that the centered root-mean-square difference between data collected by two systems is a conservative estimate of the uncertainty associated with these data (excluding systematic contributions) if these data show a good agreement (expressed by a slope of method II regression close to 1) and if their uncertainties can be assumed similar with errors moderately correlated (typically lower than 0.5).

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Validation of GOCI-II Rrs Product using above- and in-water radiometry measurements

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Geostationary Ocean Color Imager-II (GOCI-II) is the follow-up ocean color sensor launched after the world's first geostationary ocean color sensor, GOCI. It was successfully launched on Feb 2020 and has completed a six-month on-orbit test period. It is currently observing Northeast Asian waters 10 times from 8 am to 5 pm every day. Totally 26 products processed using GOCI-II data are now provided to the advanced and end users by National Ocean Satellite Center (NOSC) at Korea Hydrographic and Oceanographic Agency (KHOA) and are used in many application fields. Since the remote sensing reflectance, Rrs, is primarily used for other products calculation, it is a major product of satellite ocean color data and requires a lot of effort to maintain high accuracy.

Due to this necessity, in this study, GOCI-II Rrs data was verified using various in-situ measurements. For the verification of GOCI-II Rrs, we implemented several field campaigns to obtain the hyperspectral radiometry measurements using RAMSES hyperspectral radiance and irradiance sensors / TriOS for above-water radiometry and HyperPro-II / Sea-Bird Scientific for in-water radiometry. And we also used the AERONET-OC (Aerosol Robotic Network-Ocean Color) observations installed at the Sochongcho Ocean Research Station in Korea. The field measurements were conducted in two ways: using a fixed observing station and using moving vehicles. In-situ measurements at fixed observing stations were implemented at Sochongcho Ocean Research Station located at northern part of the Yellow Sea of Korea. Other in-situ measurements using moving vehicles were implemented at the Yellow Sea and East Sea of Korea showing the typical Case-II and Case-I water optical characteristics, respectively.

The Rrs calculations for in-situ measurements were applied differently depending on the method of field observation. For the in-water radiometry data, the sky radiance reflection was corrected as a function of the solar elevation(θ_s) and sun-sensor relative azimuth angle(φ_s). Totally 40 match-up data obtained for the above-water measurements and 26 match-up data were acquired for the in-water measurements. The overall statistical results were shown for the correlation coefficient of 0.90 and the mean relative errors of 29.26%. Using the methodology obtained from this study, we plan to build an autonomous observation system for hyperspectral above-water radiometry, and this system will also continue to be used to calibrate GOCI-II and other ocean color sensors. This autonomous hyperspectral radiometry observing system will also be more helpful for the evaluate and validate the next-generation hyperspectral sensors like as PACE, GLIMR, SBG.

No. 154

Investigating atmospheric correction details of ocean color imagery over an extremely turbid lake

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It is well known though that there are atmospheric correction (AC) problems in turbid waters, including coastal marine and inland lake systems, resulting in degraded remote sensing products. Contemporaneous field measurements with satellite overpasses are critical for validation efforts and improving the image quality resulting from imperfect AC. In this work, we assembled an image set from the Sentinel-3A satellite over Lake Okeechobee during a time period when a SeaPRISM was active (2018 and 2019) and conditions were totally cloud-free over the lake (N=44). Lake Okeechoobee, located in South Central Florida, is a shallow lake (mean depth of 3m and 1700 km^2), and is considered extremely turbid. We assessed the performance of several widely used AC schemes with this matchup data set with comparisons of remote sensing reflectance and aerosol products. We also used SeaPRISM data directly injected into the processing codes to further investigate the dynamics between aerosol and bio-optical models in coupled air-water schemes. This evaluation enabled isolation and evaluation the two components with the aim of improving AC schemes over turbid waters.

Assessing semi-analytical models across freshwater and marine environments

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Remotely sensed ocean color products have been key to providing repeated coverage and detailed views for regions of interest, to better understand biogeochemical dynamics. Current bio-optical inversion models are dependent on the relationship between remote sensing reflectance (Rrs) and inherent optical properties (IOPs) to estimate bio-physical products and additional optical properties, such as chlorophyll (chl-a) concentrations and phytoplankton absorption. Phytoplankton absorption (a_{ph}) greatly influences ocean color and is dependent on multiple factors such as species composition, cell size, pigmentation, and physiology. Current bio-optical inversion schemes (such as NASA's GIOP) use a_{ph} models that incorporate these factors, and a_{ph} models can heavily influence the algorithm inversion outputs and following interpretations. A recently developed forward model by Zaneveld-Twardowski-Tonizzo (ZTT), incorporates the volume scattering function (VSF) and bidirectional reflectance distribution function (BRDF), and is set up such that viewing geometries and optical properties are set as explicit parameters.

For this research, phytoplankton absorption measurements from freshwater and marine environments at varying trophic stages (and extreme cyanobacteria blooms in lakes), were obtained. Multiple a_{ph} models were applied to three different types of systems and error statistics were calculated to determine best regional models. In-situ optical properties have been collected for an additional study site of interest, the Indian River Lagoon (IRL), with the intent of running multiple ZTT inversion configurations. This poster will present preliminary inverse ZTT configuration and error results. The obtained preliminary results can make way for future incorporation and testing of semi analytical models, and further use and adaptation for hyperspectral inversions for upcoming NASA's Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) mission.

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Spatio-Temporal Variations of Bio-Optical Properties in Coastal Arctic Waters

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Abstract

We present here results from our analysis of spatial and temporal variations in the concentrations, composition, and optical properties of constituents in coastal Beaufort Sea waters along the North Slope of Alaska. The goal of the study was to investigate variations in biophysical and bio-optical properties along the North Slope coast that could be potentially linked to any differences in the type of materials transported by four rivers that drain into the Beaufort Sea near the Prudhoe Bay area – the Colville, Kuparuk, Sagavanirktok, and Canning Rivers. The dataset collected over a two-year period includes a mix of coastal and offshore stations. We measured concentrations of total and size-fractionated chlorophyll-*a*, suspended particulate matter, colored dissolved organic matter, particulate organic carbon, and dissolved organic carbon, absorption and scattering of light through the water column, at-surface radiometry, and airborne hyperspectral imagery. In general, nearshore stations shows distinct differ3ences from offshore stations, though there were exceptions. One offshore station, in particular, exhibited characteristics more similar to nearshore stations than nearby offshore stations, raising questions about the potential role of wind-driven eddies and circulation patterns. The barrier islands had a significant effect on the bio-optical properties, as revealed by distinct differences between stations inside and outside the region encompassed by the barrier islands. The data reveal distinct differences in optical and biophysical properties between stations north and south of the barrier islands around Prudhoe Bay, thus demonstrating the influence of the barrier islands on the biophysical properties of coastal Arctic waters. We also show results from applying various algorithms for retrieving concentrations of chlorophyll-*a*, particulate organic carbon, and suspended particulate matter.

An assessment of the global ocean Particulate Organic Carbon sequestration flux from BioGeoChemical-Argo floats and ocean colour remote sensing

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Sinking Particulate Organic Carbon (POC) is said to be sequestered when it reaches the bottom of the ocean twilight zone (1000 m) where it remains stored out of contact with the atmosphere for 100 years or more. This so-called POC sequestration flux is assessed in this study at the global scale using BioGeoChemical-Argo floats and ocean colour remote sensing. We exploited observations from 176 BGC-Argo floats that measured the particulate backscattering coefficient, b_{bp}, continuously while parked at 1000 m depth. From these high-resolution time series of deep b_{bp}, we quantified the concentration of large particles at 1000 m from b_{bp} spikes. Using a subset of BGC-Argo floats additionally equipped with a beam transmissometer, which acted as an Optical Sediment Trap (OST) at parking depth, we set up a relationship between deep b_{bp} spikes and OST-derived large particle POC flux, $FPOC_l$. We set up monthly climatologies of $FPOC_l$ for 11 biogeochemical provinces, examined seasonal variability in $FPOC_l$, and compared our results to a recently established compilation of POC flux observations from sediment traps. Next, we set up a relationship between ocean colour satellite products (b_{bp} and phytoplankton size indicators) and $FPOC_l$ to estimate $FPOC_l$ for the global ocean. We found a sequestration flux of 0.70 Pg C year^{-1}, indicating that about 11% of the gravitationally sinking POC flux survives its transit through the twilight zone, assuming a total export of the gravitational pump of 6.5 Pg C year^{-1}.

Deep learning for remote sensing-based estimation of water quality parameters

Dinesh Neupane[1], Stephanie Rogers[2]

Abstract

Monitoring and assessing the characteristics of inland surface water is critical for managing and improving its quality. Although currently used *in situ* measurement techniques are accurate, they lack spatial and temporal coverage, and are difficult and costly to obtain. Remote sensing data, specifically satellite imagery, has the potential to provide an invaluable complementary source of information at multiple scales of analysis. Incorporating *in situ* measurements with satellite imagery provides a way to estimate water quality parameters at broader scales and with greater temporal frequency. Previous studies on machine learning methods for predicting water quality parameters often overlooked the complex non-linear relationship between satellite and *in situ* data, leading to low accuracy. To address this, there is a need for a high-performance deep learning technique capable of capturing higher-order statistical relationships between surface reflectance values and water quality parameters. This is particularly crucial given the challenges posed by the frequency and volume of satellite imagery, making it imperative to efficiently process and synthesize vast amounts of data for timely water quality assessments. This research proposes a new and cost-effective technique coupling Sentinel-2 imagery and Deep Neural Network (DNN), a deep learning technique to estimate two water quality parameters: Chlorophyll-a and Turbidity in three water bodies in Florida (St Johns River, Lake George, and Lake Okeechobee). Surface reflectance values from satellite images will be used as a proxy to predict the water quality parameters based on *in situ* datasets. The developed deep learning model will be evaluated against general machine learning approach; Support Vector Machines based regression and ensemble method: Random Forest Regression. The results of this study could provide water resource managers with a means to monitor water quality at the regional scale in a more streamlined manner, allowing for a more targeted approach to site sampling selection.

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A Web-Based Robust Quality Monitoring Tool for Ocean Color Products at NOAA CoastWatch

Authors: S. Ramachandran [1,2]

IOCS Abstract:

NOAA (National Oceanic and Atmospheric Administration) CoastWatch processes and serves satellite data products with global and regional spatial coverage for ocean, coastal and inland water applications. VIIRS ocean color products are used in NOAA operational missions such as monitoring harmful algal blooms and ecosystem-based management for commercial fish stocks and protected marine species. An Eutrophication Indicator developed for the United Nations Environment Program in support of global Sustainable Development Goals relies on a daily chlorophyll anomaly product. To meet the user requirements for data quality and availability, CoastWatch has developed a robust and automated methodology for quality assessment. For ocean color products, an intercomparison of observations from VIIRS and from OLCI sensors are used to flag changes in trends to catch calibration or processing errors. The method uses a near term 30 day running average of Level 3 product values as a benchmark against which to look for abrupt changes. Three primary benefits of this method are 1) good sensitivity to small changes; 2) no dependency on long term climatology products (useful for new products); and 3) both product and sensor agnostic in its implementation. Results with examples from this analysis for ocean color products using VIIRS and OLCI sensors will be presented.

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No. 160

NOMAD v3.0: supporting PACE mission for validation and algorithm development.

Violeta Sanjuan Calzado[1], Chris Proctor[2], Jeremy Werdell[3].

PACE, Plankton, Aerosol, Cloud, ocean Ecosystem is a new NASA ocean color mission scheduled for launch in 2024. PACE science goals are to extend key systematic ocean color, aerosol, and cloud data records for Earth system and climate studies, and to address new and emerging science questions using its advanced instruments, surpassing the capabilities of previous and current missions. As such, a new stream of science data requirements is being developed in support of PACE mission following its technical definition.

The NASA bio-Optical Marine Algorithm Dataset, NOMAD, is a global, high quality in situ bio-optical dataset for use in ocean color algorithm development and satellite data product validation activities. Data products include coincident observations of water-leaving radiances and chlorophyll a concentrations, along with relevant metadata. Other products include Inherent optical properties (IOPs; e.g., spectral absorption and backscattering coefficients). A binary flagging system describes database characteristics on available data, instrument description and data processing.

As science data requirements evolve with the development of new ocean color satellite missions, NOMAD v3.0 will provide the required science data support for PACE technical definition. NOMAD v3.0 aims to expand its wavelength coverage at the defined wavelengths of the OCI instrument for the required ocean color data products, water leaving reflectances and other ocean color products derived from water-leaving reflectances; chlorophyll-a concentration, diffuse attenuation coefficient, non-algal particle absorption, dissolved organic matter absorption, particulate backscattering coefficient. When available, such products report uncertainties associated with the data product. Other advanced data products generated for PACE will be added in time. The database structure is modified accordingly to accommodate the expanded information included on the new release. The binary flagging system is expanded to include stations covering a variety of optical conditions for algorithm development.

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Mapping and tracing *Sargassum* distribution and origin in the Yellow Sea and East China Sea using Sentinel-2 and GOCI data

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Macroalgal blooming or seaweed tide has determined effects on coastal ecosystem and local economy. 'Golden tide' caused by *Sargassum* occurred globally. *Sargassum horneri* is only a species causing outbreaks in northwestern Pacific and largest supply of floating patches are introduced into the Yellow Sea (YS) and East China Sea (EC). The annual pattern of *Sargassum* bloom is not well known due to changing air-sea interaction conditions. To determine the spatio-temporal distribution and variation of the golden tide in the YS and ECS, the multi-satellite sensor data (e.g. Sentinel-2 and GOCI) was used to detect the floating macroalgae patch using the Alternative Floating Algae Index and mapped over the study area using a 15-year data. The floating patches detected by both satellite data were overlapped to make the annual pattern maps.

The *Sargassum* blooms were generally found on spring in the YS and ECS. The *Sargassum* blooms was proceeded in the waters near the Yangtze River and Zhejiang Province, China and then floating into the east and north-east ward influenced by the Tsushima warm current or Kuroshio. The *Sargassum* blooms were build-up in the middle of the ECS and pile-up in the coast of Korea from March to May. Recently, the *Sargassum* blooms were temporally expanded from to May from 2019 to 2022 and spatially raised in the YS and ECS.

From the annual pattern maps of the golden tide blooms, we suggested two origins with tracing the temporal and spatial distribution and development. The first blooms were onset on fall around the Bohai Bay and/or Shandong Peninsula and southward controlled by the local wind and sea surface temperature condition on winter. The second blooms were initiated on winter near the Zhejiang Province, China and east- and northward affected by the local current and wind condition.

Satellite Ocean Color: Multi-platform Data Visualization and Access

Michael Soracco[1,2], Veronica Lance[2,3]

NOAA (National Oceanic and Atmospheric Administration) CoastWatch serves satellite data products with global and regional spatial coverage for ocean, coastal and inland water applications. The NOAA CoastWatch Data Portal map viewer provides access to data from the Visible Infrared Imaging Radiometer Suite (VIIRS), Ocean and Land Color Instrument (OLCI), and MultiSpectral Instrument (MSI) sensors along with other datasets. The viewer leverages daily true color image tiles produced by the NOAA/STAR Ocean Color Science Team, NOAA CoastWatch Geostationary Operational Environmental Satellite (GOES) 10 minute geocolor tiles, and NOAA CoastWatch services for datafile access and visualization.

Ocean color products such as normalized water leaving radiances, chlorophyll, suspended particulate material, and attenuation coefficients are available as data layers. An 'Active Layers' feature allows data to be promoted to a category independent of calendar input which provides the ability to compare timesteps such as the onset of an algal bloom. The viewer can be used in additional ways to support color researchers: data coverage, cruise planning, and *in situ* match-ups. Satellite orbital paths (VIIRS, OLCI, MSI) can be layered and compared simultaneously to quickly determine coverage including preview images and links to the underlying Level-1/-2 NetCDF data. A spatial-temporal search is built-in to locate data for a specific location over time, returning either a text list of data Uniform Resource Locators (URLs) or preview thumbnails and shopping cart feature to identify and obtain only cloud-free data. The researcher can export waypoints to conduct sampling, plot prior cruise stations or match-up points by dragging and dropping a Comma Separated Value (CSV) file onto the map view.

The NOAA CoastWatch Data Portal map viewer (https://coastwatch.noaa.gov/cw_html/cwViewer.html) is a versatile online application that can aid in the exploration and access to ocean color remote sensing data.

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Examining the OLCI 709 nm Water Vapor Correction on Chlorophyll Algorithms

Richard P. Stumpf[1] and Andrew Meredith[2]

Coastal and inland waters often contain non-algal pigments that absorb blue light, with chlorophyll concentrations exceeding 2-3 µg L^{-1}, often reaching 100 µg L^{-1}. Red and "red-edge" (infrared) wavelengths, including the OLCI 709 nm band, are increasingly used for chlorophyll algorithms in these waters. However, variations in water vapor may influence 709 nm, as this band lies on the shoulder of a water vapor absorption band. The update of NASA's SeaDAS for their 2022 reprocessing (R2022) added a correction for transmission losses due to water vapor (Twv). This includes adjustment of the calibration, as the calibration and atmospheric correction are inherently coupled. We examined the influence of this change on a few key algorithms, including the "red edge" chlorophyll based on a ratio of 709 to 665 nm. Prior to the change (using the U.S. Middle Atlantic Bight and the eastern Gulf of Mexico), chlorophyll concentration changed with seasonal changes in water vapor. However, the R2022 updated SeaDAS also produced seasonal and regional changes with water vapor that indicate that Twv is too strong, and the associated band vicarious calibration may be too low. A reduction of Twv by 50% and a small (1.7%) adjustment upward in the 709 nm calibration appears to generate consistent products between low and high water vapor. Twv is much smaller in the other bands, with 885 and 510 nm bands the next most influenced. We checked the impact on OC4 chlorophyll of changing Twv by 50% for all bands. Only 510 nm showed an impact. Changing Twv for 510 nm, without changing the 510 calibration, increased OC4 against the standard R2022 for high chlorophyll concentrations. We recommend that NASA adjust the Twv and the associated 709 nm calibration, and consider adjusting Twv and calibration of the other bands accordingly.

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Estimation of various carbon fractions in coastal waters by remote sensing to support large-scale carbon cycle studies.

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Our seas and coastlines are vital ecosystems that strongly support and maintain natural diversity and play crucial roles in the stability and sustainability of larger ecosystems. Traversing European Coastlines (TREC) is a unique two-year research project coordinated by the European Molecular Biology Laboratory that studies human impact on Europe's seas and coastal areas. TREC also collaborates with many national research institutes. The Tara Europa (TARA) is the at-sea part of the TREC. During the project, a large variety of data including soil, sediment, aerosol, and water samples, as well as numerous environmental data, will be collected at 120 coastal sampling sites across 46 regions in 22 European countries in 2023-2024.

The TREC expedition will cover each of the sites once. Meaning that it will not be possible to study seasonal cycles in the carbon processing between land and coastal waters. Therefore, we carried out bio-optical measurements between the last TREC sampling point on land and the closest TARA sampling point at sea and did this four times during the ice-free season (April, May, June and September in 2023) simultaneously with the Sentinel-2 MSI overflight. All three TREC sites located in Estonian coastal waters in the eastern part of the Baltic Sea were selected for this experiment. *In situ* measurements included hyperspectral absorption, attenuation, scattering and multispectral backscattering coefficient, and water reflectance, as well as measurements with underwater fluorometers (Chl-a, CDOM, phycocyanin), CO_2, pH and turbidity sensors. Additionally, water samples for laboratory analyses of Chl-a, CDOM, TSS, various carbon fractions, and phytoplankton species composition were collected.

The main aim is to study how the carbon fractions in coastal water are related to the carbon in soils in different environments (urban, agricultural, and forested coasts) and whether we can detect changes in different carbon fractions using hyperspectral (field radiometer) and satellite (Sentinel-2 MSI) data. If successful, then we will be able to study carbon processing in near-coastal waters using satellite imagery.

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Remote sensing assessment of water quality in Qatar coastal waters between 2002 and 2022

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For many reasons, little information is available on the long-term trend of water quality around Qatar, although seawater is the most important source of water for local people. Here, we use remote sensing to fill this knowledge gap through analyzing spatiotemporal variations of water quality in Qatar coastal waters (24-27°N, 50-53°E). These include sea surface temperature (SST), chlorophyll-a concentration (Chla), turbidity (Turb), and water clarity (SDD) from 1-km resolution MODIS/Aqua observations from 2002 to 2022, and floating algae scums from 20-m resolution MSI observations from 2016 to the present. To avoid algorithm uncertainties, a customized shallow-water mask is developed to mask low-quality data. The long-term trends are determined using the modified Mann-Kendall test.

Over the past 20 years, Qatari waters have warmed faster (0.64 °C/decade) than the Gulf waters and much faster than the global oceans. Both Chla and Turb decreased slightly, with SDD increased slightly. Strong nearshore-offshore gradients have been found in all water quality parameters (Chla ~ 0.6 – 3 mg m^{-3}; SDD ~ 5 – 12 m). A northwest-southeast turbid belt was observed with an area ~7650 km^2. The 12-nautical mile (12NM) zone of the Qatar Peninsula was mainly affected by resuspended sediment, while the Exclusive Economic Zone (EEZ) was also affected by algal blooms. Substantial algae scums were found in April 2016 and June 2017, and these algae scums were due to green *Noctiluca scintillans* in winter months and *Trichodesmium* in spring and summer months.

The case study shows that, even in the absence of field measurements, long-term multi-sensor satellite data can still be used to assess water quality in coastal environments as long as the sensors are well calibrated and tailored algorithms are used.

Important contributions of water-leaving irradiance to the parametrization of ocean surface albedo

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Abstract：

Water-leaving albedo (α_w), defined as the ratio of the water-leaving irradiance to the downwelling irradiance just above the sea surface, is a major component of the ocean surface albedo (α), but has long been ignored or underrepresented. A semi-analytical scheme based on inherent optical properties (IOPs), termed IOPs-α_w, is proposed in this effort to estimate α_w from ocean color measurements. Evaluations with numerical simulations of radiative transfer show that IOPs-α_w outperforms the conventional scheme based on chlorophyll-a (Chl) concentration, where the estimated broadband α_w in the visible domain by IOPs-α_w could be over 50% greater than that by the Chl-based scheme in most oceanic waters. More importantly, this study concludes that α_w has strong spatial-temporal variability and could contribute up to 20% to α in oceanic waters and over 60% in extremely turbid waters under low solar-zenith angles. Thus, it is recommended to incorporate IOPs-α_w into current parametrizations of α in the coupled ocean-atmosphere and climate models.

No. 167

Error covariance in MODIS R_{rs} retrievals

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Spectral remote sensing reflectance, R_{rs}, is fundamental to deriving a host of bio-optical and biogeochemical properties of the water column from satellite ocean color measurements. Estimation of uncertainty in those derived geophysical products is therefore dependent on uncertainty in R_{rs}. Furthermore, since the associated algorithms require R_{rs} at multiple spectral bands, the spectral error covariance in R_{rs} is needed to accurately estimate the uncertainty in those derived properties. A derivative-based approach is established for propagating instrument random noise, instrument systematic uncertainty, and forward model uncertainty into R_{rs}, as retrieved using NASA's multiple-scattering epsilon (MSEPS) atmospheric correction algorithm, to generate pixel-level error covariance in R_{rs}. The approach is applied to measurements from MODIS-Aqua and verified using Monte Carlo analysis. The spectral error covariance in R_{rs} is also used to calculate uncertainty in phytoplankton pigment chlorophyll-a concentration (chl_a). While accounting for the error covariance in R_{rs} generally reduces the estimated relative uncertainty in chl_a by ~1-2% (absolute value) in waters with $chl_a < 0.25$ mg/m^3 where the color index algorithm is used and by ~5-10% in waters with $chl_a > 0.35$ mg/m^3 where the blue-green ratio algorithm is used, it can be higher than 30% in some regions. The error covariance in R_{rs} is further verified through forward-calculating chl_a from MODIS-retrieved and in situ R_{rs} and comparing estimated uncertainty with observed differences. An 8-day global composite of propagated uncertainty shows that the goal of 35% uncertainty in chl_a can be achieved over deep ocean waters ($chl_a \leq 0.1$ mg/m^3). While the derivative-based approach generates reasonable error covariance in R_{rs}, some assumptions should be updated as our knowledge improves. These include the inter-band error correlation in top-of-atmosphere reflectance, and uncertainties in the calibration of MODIS 869 nm band, in ancillary data, and in the in situ data used for system vicarious calibration.

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