International Ocean Colour Science Meeting 2019

SUBMITTED ABSTRACTS - Alphabetical Order

Current status of GOCI-II atmospheric correction algorithm for turbid waters

Jae-Hyun Ahn[1], Young-je Park[2]

The atmospheric correction algorithms based on the black pixel assumption (BPA) tend to overcorrect aerosol reflectance in turbid waters because of the considerable NIR water reflectance by relatively strong backscattering of in-water suspended sediments. An iterative solution to separate NIR water reflectance from the observation based on the NIR water reflectance model has been widely used. We describe the NIR water reflectance model for the second Geostationary Ocean Color Imager (GOCI-II) which will be following the GOCI mission. The use of the 620 and 709 nm bands added to GOCI-II can improve the accuracy of NIR water reflectance model for turbid waters compare to the current GOCI mission. We use spectral relationships of water reflectance or inherent optical properties between red and NIR wavelengths to estimate NIR water reflectance. The reflectance model is validated by both simulations and in-situ Rrs data. Accuracy of the NIR water reflectance model for GOCI-II is increased by ~19% at 745 nm and ~9% at 865 nm.

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No. 2

Classifying colour of natural water using Forel-Ule colour comparator index and CPA's concentration of monoculture and integrated multi-trophic aquaculture in Salut Mengkabong Lagoon

Nurzaliah Ali[1]*, Madihah Jafar Sidik[1], Saiyidah Munirah Mohd. Shazali and Abentin Estim

Forel-Ule (FU) color comparator scale is a traditional method that has been used to classify the colour of natural water since the end of the 19th century. In this study, Forel -Ule colour comparator scale was used as an alternative method to classify colour of coastal water in aquaculture area as it was quite difficult to obtain good satellite data near the land area as well as the frequent cloudiness in the equator. The aquaculture industry has been developing rapidly since the 1920s and various methods have been used to provide sustainable aquaculture with an optimal culture model in Malaysia. The aim of this study is to classify the water colour changes in three different areas of cultural practice; i) monoculture oyster (MO), ii) monoculture fish (MF), iii) integrated multi -trophic aquaculture (IMTA) (fish, green mussel and seaweed) and coastal area (CO) as a control in Salut-Mengkabong Lagoon. The samplings were conducted from May to December 2018 and the water samples were collected for colour producing agent's concentration and nutrient analyses. The colour of coastal water was classified using Forel-Ule index using EyeOnWater mobile application. The result showed Forel-Ule index higher in MO area (FUI 14 to FUI 16) with mean (FUI 15 ± 1), followed by IMTA (FUI 11 ± 3) and MF (FUI 11 ± 2) with Forel-Ule index (FUI 8 to FUI 15) and (FUI 7 to FUI 15) respectively, while Forel-Ule index was lower at CO area with bigger range of Forel-Ule index (FUI 5 to FUI 11) with mean (FUI 7 ± 2). Colour-producing agents concentration are higher in MO area with (SPM=25.2 mg/L ± 7.0, Chl-a=0.144 µg/L ± 7.3, and CDOM=0.7 m^{-1} ± 0.2) and lower at CO (SPM=15.2 mg/L ± 7.4, Chl-a=0.012 µg/L ± 0.6, and CDOM=0.2 m^{-1} ± 0.1). For nutrient analyses, MO area has higher nutrient concentration (Nitrite=0.005 mg/L ± 0.002, Nitrate=0.008 mg/L ± 0.004, Ammonia=0.080 mg/L ± 0.037 and total Phosphorus=0.004 mg/L ± 0.003) and lower concentration of nutrient at CO area (Nitrite=0.003 mg/L ± 0.001, Nitrate=0.003 mg/L ± 0.001, Ammonia=0.003 mg/L ± 0.001 and total Phosphorus=0.000 mg/L ± 0.000). In conclusion, aquaculture stations alters the composition of water constituent and gives effect to water colour in Salut-Mengkabong Lagoon compared to coastal area. The monoculture of oyster area has higher Forel -Ule index recorded, colour producing agents and nutrient concentration, followed by monoculture of fish, integrated multi-trophic aquaculture and the lowest was in the coastal area. FUI value and all parameter measured in the study area can be used to developing a regional algorithm to classify water quality based on colour of the water.

Keywords: *Forel-Ule Index, suspended particulate matter, colour dissolved organic matter, chlorophyll, integrated multi-trophic aquaculture, monoculture*

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No. 3

Retrieving CDOM, CDOM Spectral Slope, and DOC

Dirk Aurin[1], Antonio Mannino[2]

A Global Ocean Carbon Algorithm Database (GOCAD) has been developed from over 500 oceanographic field campaigns conducted worldwide over the past 30 years including in situ reflectances and coincident satellite imagery, multi- and hyperspectral Chromophoric Dissolved Organic Matter (CDOM) absorption coefficients from 245–715 nm, CDOM spectral slopes in eight visible and ultraviolet wavebands, dissolved and particulate organic carbon (DOC and POC, respectively), and inherent optical, physical, and biogeochemical properties. From field optical and radiometric data and satellite measurements, several semi-analytical, empirical, and machine learning algorithms for retrieving global DOC, CDOM, and CDOM slope were developed, optimized for global retrieval, and validated. Global climatologies of satellite-retrieved CDOM absorption coefficient and spectral slope based on the most robust of these algorithms lag seasonal patterns of phytoplankton biomass belying Case 1 assumptions, and track terrestrial runoff on ocean basin scales. Variability in satellite retrievals of CDOM absorption and spectral slope anomalies are tightly coupled to changes in atmospheric and oceanographic conditions associated with El Niño Southern Oscillation (ENSO), strongly covary with the multivariate ENSO index in a large region of the tropical Pacific, and provide insights into the potential evolution and feedbacks related to sea surface dissolved carbon in a warming climate. Further validation of the DOC algorithm developed here is warranted to better characterize its limitations, particularly in mid-ocean gyres and the southern oceans.

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Developments of algorithm to estimate chlorophyll-a concentration in the Saemangeum based on low-altitude remote sensing observations

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For a long time, various attempts have been made to estimate chlorophyll concentration, which are based on both direct and indirect observations. The direct observation is to measure the chlorophyll concentration in water mass analysis in the area, but it is not possible to estimate chlorophyll concentration in a broad area. Meantime, indirect observation is to estimate the chlorophyll concentration in plankton using remote sensing observations. The indirect observation based on remote sensing enables us to obtain information for a broad area at the same time, but there is limited use in coastal areas due to high spatial and temporal variability. Therefore, we use 'Helikite,' low-altitude remote sensing system to observe the chlorophyll concentration in coastal regions. 'Helikite' is a system that complements the satellites' shortcomings for limited use in coastal areas and can be used to observe a wide range of high-resolution images. The system is also equipped with a multi-spectral camera and GPS/IMU. Thus, the study was conducted in the saemangeum dike, South Korea. We used three observations. First, the multi-spectral camera images from Helikite low altitude remote sensing system at 1.5 km above sea surface. Second, the quantitative light intensity which was measured by the hyper- spectral sensor. Third, in-situ chlorophyll concentration which was measured through the water sampling during the cruise. Therefore, we combined these data to examine relationship between the observed light intensity, the digital number of the multi-spectral camera image, and in situ chlorophyll concentration measurements. In this presentation, we illustrate how the chlorophyll concentration can be estimated from the multi-spectral camera image.

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Satellite-based estimation of carbon fluxes along key interfaces in marginal seas

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Abstract: The oceans are the largest reservoir for the active carbon in the earth, which play a key role in regulating earth's ecosystems and global climate change. Due to lacking of observation data in both of the spatial and temporal resolutions, it is inevitable that the estimation of marine carbon budgets and fluxes by in-situ measurements have large certainty. While, satellite remote sensing has unique advantage with large area coverage and long-term observing capacity, which has shown its great values and progress in marine carbon cycle research with decadal data accumulation. Here, we overview our recent progresses on the satellite-based estimations of carbon fluxes along key interfaces in marginal seas, including: 1) the mechanistic-based semi-analytical remote sensing algorithm (MeSAA) of the aquatic pCO2 and the estimation of the air-sea CO2 fluxes; 2) estimations of the organic carbon fluxes from larger rivers (e.g. Changjiang River) to the estuaries based on high-spatial resolution satellite data of Landsat and the high temporal resolution satellite data of GOCI; 3) estimation of the organic carbon inventory in the ocean upper layer based on the satellite-derived surface water organic carbon concentration and the empirical profile models; 4) estimations of the lateral organic carbon transport from the shelf to open ocean by combing the satellite-derived organic carbon concentrations and numerical model simulated currents; 5) estimation of the vertical export flux of the particulate organic carbon from the upper layer to deep layer based on the food-web models. Overall, in the past few years, significant progresses have been achieved on satellite remote sensing of the marine carbon cycle, which are benefit from interdisciplinary collaborations.

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No. 6

Vicarious calibration of the near infrared band for satellite ocean color sensors

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Abstract : Vicarious calibration of satellite ocean color sensors is critical to accurate retrievals of remote sensing reflectance (R_{rs}, sr^{-1}) and other geophysical parameters, as well as to minimizing cross-sensor differences. Current vicarious calibration procedures forgo calibration of the long-wave near infrared (NIR_L) band, partially due to previous simulations indicating that accuracy in the retrieved R_{rs} is insensitive to changes in the NIR_L vicarious gain (*g*). In this study, however, we find substantial variations in MODIS/A-derived R_{rs}(547) seasonality within ocean gyres resulting from changes in *g*(869). Particularly, time-series derived from ~1.4 million gain configurations indicated differences in overall mean R_{rs}(547) and seasonal patterns (harmonic shape, phase, and amplitude), as well as residual noise. Of the gain configurations tested, only those with *g*(869) ~ 1.025 lead to R_{rs}(547) patterns which best satisfy *a priori* assumptions about gyre seasonal patterns and noise distribution. The *g*(869) derived using this approach is stable with only a few years of satellite data, and thereby provides a robust mechanism by which to determine the otherwise elusive g(NIR_L). Applied to the full MODIS/A time series and other satellite instruments, these results may potentially minimize cross-sensor differences to improve multi-sensor continuity toward more effective monitoring of oceanic systems and assessment of long-term trends.

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Machine Learning for Remote Sensing Complex Waters

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Complex aquatic environments, such as coastal and inland waters have been experiencing deterioration in water quality due to increased anthropogenic impact and climate change. There is an increased demand to have reliable, fast and continuously available techniques to monitor these waters.

Advances in remote sensing technology provides the possibility to retrieve information about the water quality of complex waters. The Ocean and Land Color Instruments (OLCI) onboard the Sentinel 3 satellites acquire high spatial, spectral and temporal resolution data of the world's waters. Moreover, the data collected by OLCI is used to retrieve water quality parameters in complex waters by utilizing a machine learning Neural Net (NN).

However, validations have shown that the NN complex water algorithm fails to estimate water quality parameters, when it is applied to local aquatic environments.

In this work, we present an alternative machine learning approach, which is tuned locally for a complex inland shallow water, Lake Balaton (Blix et al., 2018).

Lake Balaton shows unique optical characteristics: a significant trophic gradient, including both hyper-eutrophic and oligotrophic conditions and turbid and clear waters. This allows to establish a flexible model that can retrieve water quality parameters from data acquired by OLCI in a wide range of water complexity.

The model we propose in this work, might be generalized, and hence applied to other complex aquatic environments, such as coastal and Arctic waters. This could open the possibility to use a unified algorithm for water quality monitoring.

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Blix et al., 2018:
Blix, K.; Pálffy, K.; R. Tóth, V.; Eltoft, T. Remote Sensing of Water Quality Parameters over Lake Balaton by Using Sentinel-3 OLCI. Water 2018, 10, 1428.

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Detection of oil spills and look-alikes in Sentinel-1 SAR imagery of the Great Barrier Reef, Australia using an artificial neural network: Towards the use of complementary optical information from Sentinel-2 MSI.

David Blondeau-Patissier[1], Foivos Diakogiannis[2], Thomas Schroeder[3], Paul Irving [4], Christian Witte [5]

The timely detection of oil floating on the ocean's surface, and particularly in protected marine parks, is critical for the monitoring and protection of coastal environments. Oil slicks are best detected from Synthetic Aperture Radar (SAR) satellite sensors, such as ESA's Sentinel-1 SAR (S-1 SAR), which provide imagery at high resolution (20 m), day or night and in any weather. The surface slicks, whether actual oil spills or "look-alikes" caused by wind features for instance, appear as low backscattering, dark areas in the grey-scaled SAR images, which contrast with the surrounding waters that often appear brighter. To distinguish oil spills from look-alikes in S-1 SAR imagery, we developed a convolutional neural network-based deep learning classifier trained on a dataset of 4,000, single-band chips subsampled from downscaled S-1 SAR imagery of past events. Features identified in the training set were manually labelled as "no oil", "oil" and "other" independently of the radar incidence angle acquisitions, sea state or wind stress. The classifier was applied to a sample dataset of S-1 SAR imagery of the Great Barrier Reef (GBR), Australia for the detection and mapping of potential oil spills in the marine park. Using image pyramids, full resolution S-1 SAR Level-1 Ground Range Detected (GRD) images, processed with the software SNAP, were downsized for faster processing and used as input into the neural network. The results obtained will allow us to assess the performance of the classifier to detect possible oil spills in the GBR. We are considering integrating ancillary data to increase the classifier's performance, thus further identifying false positives from actual oil slicks. Future work entails the processing of the entire S-1 SAR image archive for the GBR since launch (April 2014) to further assess if the effect wind speed or incidence angle ranges are limiting the identification of oil slicks in the GBR. The use of additional, coincident optical information acquired by Sentinel-2 MSI is also explored.

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No. 8

Bio-optical relationships of extreme Case-2 coastal waters in tropical Northern Australia

Blondeau-Patissier, David[1], Thomas Schroeder[2], Lesley Clementson[3], Vittorio Brando[4], Diane Purcell[5], Phillip Ford[6], David K. Williams[7], David Doxaran[8], Janet Anstee[9], Nandika Thapar[10], Miguel Tovar-Valencia[11]

This study focuses on the seasonal and spatial characterization of optical properties and biogeochemical concentrations in the Van Diemen Gulf and Darwin Harbour, two neighbouring tropical, complex coastal environments of Northern Australia that exhibit shallow depths (~20 m), large tides (> 5 m) and a monsoonal climate. A total of 63 stations were sampled during three dedicated field campaigns between the wet season of 2012 (March) and the dry season of 2013 (September). Our results revealed that most parameters showed distinct spatial and seasonal differences. The absorption budget of the two coastal systems are mostly driven by non-algal particles (~0.36 m^{-1}; aNAP) during the dry season and coloured dissolved organic matter (~0.18 m^{-1}, aCDOM) during the wet season. No differences in Chlorophyll (~1 mg.m-3) or phytoplankton absorption (0.06 m^{-1}; aphy(440)) were found between seasons or locations. The major processes explaining this seasonal variability are resuspension from strong south-easterly trade winds in combination with the tidal energy during the dry season months (May-October), and terrestrial river runoff during the monsoon (November-April). The scattering coefficient, bp(555), was found to contribute significantly (>80%) to light attenuation c(555). Spatially, the waters of the Van Diemen Gulf were found to have higher total suspended sediment concentrations (TSS), higher CDOM, higher nutrient concentrations and larger phytoplankton cells than Darwin Harbour. Key bio-optical relationships derived from this comprehensive set of parameters were used for a region-specific seasonal parameterization of a Linear Matrix Inversion-based ocean color algorithm.

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No. 9

Continuous data sets on phytoplankton composition in the water column across the Atlantic Ocean from optical sensors mounted to a ship-towed vertical undulator

A. Bracher, H. Xi, Dinter T., S. Wiegmann

Different types of phytoplankton dominate the ocean biomes and by that drive differently the marine food web, the biogeochemical cycling in the ocean, and the exchange mechanisms with the atmosphere. During the Polarstern cruise PS113 (May-June 2018) we transected the Atlantic Ocean from Patagonian Shelf to the English Channel and measured within different Longhurst provinces (Longhurst 2010) phytoplankton composition and underwater light at discrete stations. In addition, measurements of the underwater light field were obtained continuously in the profiles at 5-hour to 2-day transects during the cruise from radiometers mounted to a vertical undulator platform towed behind the ship. The method by Bracher et al. (2015) was adapted to obtain predictions of the major phytoplankton groups from the spectral irradiance transmission data via empirical orthogonal function analysis using the HPLC surface and profile data information. Using a high number of subsampling for model testing and validation, our cross validation results verify the high robustness of our estimates. This is also in line with previous point observations from various cruises by other research groups. The in-situ observational data on phytoplankton diversity shall be used in future to validate satellite derived phytoplankton functional type products, e.g., obtained from OLCI (Xi et al., this conference) and high spectrally resolved sensors, such as SCIAMACHY (Bracher et al. 2009), TROPOMI on Sentinel-5, and products synergized from high spatiotemporal and high spectrally resolved data sets (e.g. Losa et a. 2017).

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No. 10

Modeling inherent optical properties (IOPs) in different water types: heating rates, air-sea fluxes and phytoplankton community structure

Bronwyn Cahill[1], Bennet Juhls[1], Lena Kritten[1], Rene Preusker[1], Jürgen Fischer[1], John Wilkin[2], John Warner[3] and Neil Ganju[3]

Heating rates induced by optically active water constituents (OACs), i.e. phytoplankton, CDOM and inorganic suspended sediments, may contribute to the seasonal modulation of thermal energy fluxes across the ocean-atmosphere interface in coastal and regional shelf seas. We explore the contribution of OACs to energy fluxes in the upper ocean using a coupled bio-optical-ocean-atmosphere model. Our aim is to understand how heterogeneity in OACs in shelf seas affects the characteristics of sub-mesoscale vertical mixing and advective fluxes, through feedbacks with upper ocean heating rates and water density. We consider selected shelf sea regions (New York / New Jersey Sea Bight, western Baltic Sea and Laptev Sea) characterised by different freshwater and nutrient regimes, and complex bio-optical and hydrodynamic processes. We spectrally resolve the underwater light field in a dynamic ocean and model the inherent optical properties of the different water constituents under varying environmental conditions. The relative contributions of water constituents to the divergence of the heat flux and heating rates are estimated. These heating rates are evaluated with more rigorous co-located heating rate calculations provided by an atmosphere-ocean radiative transfer model and satellite observations.

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GLAUCUS, Smart Fishing and Route Planning System using SENTINEL 3 ocean data

Mario Castro de Lera , Pablo Ruiz Sánchez
Deep Blue Globe UG

GLAUCUS is an end-to-end system to help fisheries to optimise their navigation routes and identify the best fishing grounds, dynamically updated to know where it would be more convenient to fish them during the fishing trip. The system will allow fishermen not only to locate the fishing grounds and the best time to fish in them over time but will also provide the optimal route to navigate through the seas, between fishing grounds and/or to the ports.

Fisheries are the biggest contributors to the ocean-based industries, with an estimated work force of almost 11 million persons which is expected to increase severely in the upcoming decades. GLAUCUS is an artificial intelligence solution based on deep learning techniques that can help fishermen to increase their productivity by 15% by reducing the navigation time and selecting the best fishing grounds.

The proposed service provide a solution addressing two different but related problems:

- The need to minimise the navigation time between fishing grounds and/or ports.
- Identification of the best ground fisheries.

In addition to the obvious operational benefits of addressing those problems, GLAUCUS is also aligned with new regulations affecting fisheries operations, like the ones issued by IMO regarding the fuel consumption and carbon emission footprint and the legal conditions to operate in a fishing ground.

GLAUCUS project was born from the direct interest of Navales Pombo, a Spanish fishery that operates in the Atlantic Ocean travelling from the North of Spain to the coasts of South America and Africa during months, and their needs to maximise the fishing time over the navigation time.

The solution is taking advantages of a different set of Sentinel 3 data, Sea Surface Temperature, Plankton Concentration, Ocean Current and Marine Weather, essential to determine the optimal route and best fishing grounds, Satellite Navigation, for accurate positioning of the vessel and route planning, transmitted between GLAUCUS service platform and the vessel.

GLAUCUS is a project fully aligned with Deep Blue Globe roadmap and current activities, which are focused on the development of artificial intelligence solutions for the maritime industry based on Earth Observation data and satellite services.

Sentinel3-A/B OLCI Ocean Colour Product Validation with *in-situ* Measurements

Ilaria Cazzaniga[1], Ewa Kwiatkowska[1], Malcolm Taberner[1], Estelle Obligis[1]

Continuous monitoring and validation activities covering Ocean Colour products from the European Commission's Copernicus Sentinel-3 (S3) OLCI sensors are required in order to give users information on the accuracy and limitations of the published data. To achieve this, comparative analyses with *in-situ* measurements are performed concurrently product delivery.

In order to systematically monitor the accuracy of the products, a Matchups Database (MDB) tool was developed and implemented for S3A OLCI. This tool is used to provide information on the accuracy of Remote Sensing Reflectance (Rrs), chlorophyll-a concentration (chl-a), and diffuse attenuation coefficient at 490 nm ($K_d(490)$) products. Since the launch of S3B, in 2018, analyses have also been carried out from that OLCI sensor, in particular for Rrs products.

The analyses were carried out using radiometric measurements provided by NOAA's MOBY (Marine Optical BuoY) (Clark et al., 1997) and JRC/NASA's AERONET-Ocean Colour (Zibordi et al., 2004) network, as well as some chl-a and K_d measurements, derived from data provided in NASA's SeaBASS Database (Werdell et al., 2003).

The highest quality levels for the radiometric measurements were selected: AERONET-OC level 2.0 was used for S3A OLCI Rrs validation while only quality level 1.5 was available for the period after S3B launch. With SeaBASS data, quality assessment criteria, mainly based on Werdell et al. (2005), were applied.

This presentation will provide S3A and S3B OLCI *in-situ* validation results. It will also introduce user services from the *In-Situ* Database and MDB product validation facility. The *In-Situ* Database, which is currently under development, is where Sentinel-3 Validation Team members and other contributors will be encouraged to share their *in-situ* measurements, useful for Ocean Colour product validation and performance monitoring, in different types of water. The services will provide user access to quality assessed measurements used in operational validation activities.

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No. 13

In situ measurement of particulate organic carbon: developing uncertainty budgets and performance metrics for ocean color validation.

Joaquín E. Chaves[1, 2], Michael G. Novak[1, 2], Ivona Cetinić[1, 3] & Antonio Mannino[1]

Particulate organic carbon **(**POC) is a standard NASA ocean color data product estimated by means of a blue-to-green band ratio of remote-sensing reflectances. Error inherent to the *in situ* POC measurements that have been used to tune these algorithms has not been assessed. Different approaches, particularly with regard to sampling, filtration, and blank corrections, are known to introduce biases and errors in the magnitude measured. Lack of a uniformed consensus protocol precludes a complete assessment of algorithm uncertainty and the accuracy of satellite data products. NASA's responsibility to collect and distribute *in situ* data of the highest possible quality to support satellite algorithm development and data product validation activities requires that those field measurements be generated with a documented uncertainty in keeping with established performance metrics for producing climate-quality data records. For example, average precision in the determination of chlorophyll *a* (Chl-a) in field samples at NASA's HPLC analytical facility is on average below 4%. Ideally, POC measurements should meet the same benchmarks achieved for Chl-a. Here we present preliminary results of an ongoing effort to develop standardized protocols and performance metrics for the *in situ* measurement of POC intended for calibration and validation of ocean color sensors. We measured near-surface POC (< 200 m) during the 2018 P06 GO-SHIP campaign across the very clear waters of the South Pacific Gyre and into the Chile Upwelling region to develop method limit-of-quantitation and precision metrics for POC. Sample processing was carried out using an in-line filtration system to reduce contamination from atmospheric particles. Two sequential in-line filter holders were used per sample replicate to collect a filtrate blank for each individual replicate. To evaluate method precision and evaluate different approaches for filtrate blank correction, between 3 and 6 replicates were collected for each sample. We found average precision ~10% for sample replicates. Precision values are affected by filtrate correction strategies and sample concentration. Results from this investigation will help improve uncertainty estimates for POC estimates from ocean color data, and guide their assimilation into ecological and climate models, and time series records.

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Estimating ocean attenuation coefficient profiles using airborne lidar measurements

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In recent years, airborne lidar has shown a wide range of oceanic applications, including measuring bathymetry and optical properties of water column, and detecting plankton scattering layers, bubbles, internal waves, and schools of fish. However, this technique has not yet been extensively applied to Chinese seas. In particular, there are no studies on measuring optical properties of water column in the South China Sea (SCS) using airborne lidar. In this study, we investigated the applicability of this technique to profile ocean attenuation coefficient in the SCS. A flight experiment with nine tracks was conducted in the water near Wuzhizhou Island on September 30, 2017. Shipboard synchronous measurements were carried out to validate the lidar measurements. A slope method was applied to obtain lidar attenuation coefficient; then, water optical properties' profiles were derived based on a bio-optical model. There was a consistent relationship between lidar retrieved c compared with shipborne in-situ measurements. The mean relative error percentage of lidar retrieved c was within 10%. Subsequently, the profile distribution of lidar-derived results along nine flight tracks were mapped. Primary results showed that our airborne lidar has the potential for providing subsurface vertical structure information in relatively clear water, which will enhance our understanding of biogeochemical processes in these optically complex aquatic systems.

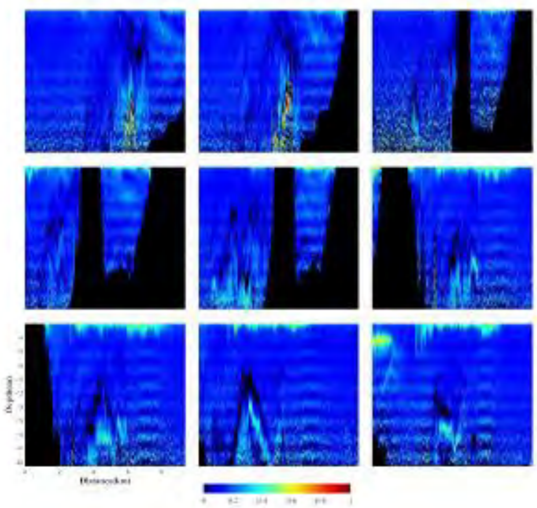

Fig. 1. Lidar retrieved c profiles mapped as a function of depth and distances along the nine flight tracks according to the color scale at the bottom. Attenuation coefficient ranges from Blue = 0.0 m-1 to Red = 1 m-1.

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Development of Daily PAR from GOCI and Comparison with PARs from Other Satellite Sensors

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Abstract: Phytoplankton carbon in marine environment is one of the important factors for ecosystem and climate change. Using satellite-based primary production, which is mainly influenced by the sun light energy, especially photosynthetically available radiation (PAR), phytoplankton carbon at the ocean surface can be estimated. Thus estimating PAR at the ocean surface accurately is important to understand the marine ecological environment. Here, daily PAR from Geostationary Ocean Colour Imager (GOCI) was estimated and validated in terms of a comparison with in-situ measurements from ocean research station, Socheong-cho station located in turbid water condition and Ieodo station in clear water condition. GOCI daily PAR had shown a constant value of difference with the in-situ measurements, which was corrected using the in-situ measurements obtained on the days of clear-sky conditions. After the corrections, GOCI daily PAR showed overall good agreements with in-situ measurements. Validations were made with sufficient in-situ data, although they were from only two locations, which indicating a relatively high level of reliabilities. GOCI-derived daily PAR was also compared with the ones from MODIS and Himawari, the Japanese weather satellite system. It seems that around the Korean peninsula GOCI showed good agreements with MODIS or Himawari, but near the edges of the GOCI boundaries there were some disagreements and relatively big differences at some spots. Thus, more in-situ data collected at various locations within GOCI coverage are needed to improve the accuracies and reliabilities of GOCI-derived daily PAR.

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EFFECT OF PHYTOPLANKTON BLOOM ON DOWNWELLING RADIANCE

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Effect of phytoplankton blooms on the intensity and spectral features of downwelling radiance in the coastal waters of the Crimea during the summer period was assessed. Increase in the bloom intensity leads to a decrease in the water transparency and in narrowing of the euphotic zone. In coastal waters mixed intensively down to the bottom the narrowing of the photosynthesis zone resulted in decrease in light intensity for phytoplankton mixed within the water layer. Narrowing of the euphotic layer in the case of coccolithophore bloom was less than the bloom was associated with other taxa. It was due to significantly (almost by an order of magnitude) higher values of phytoplankton light absorption coefficients compared with the coefficients of particulate backscattering.

The spectral features of downwelling radiance (at the same optical depth) varied depending on the taxon blooming. The increase in bloom intensity lead to a shift of penetrating radiation to a longer wavelength spectrum domain, which was more pronounced in the case of diatom/ dinoflagellate bloom than in the case coccolithophores bloom. This difference was caused by differences in both the spectrum shape and coefficient values of absorption and backscattering of light by phytoplankton. The shift to the longer wavelength spectrum domain increased with the bloom intensity raise.

It was obtained that the spectral features of downwelling radiance effected on spectrally weighted chlorophyll a specific absorption coefficient of phytoplankton, which could effect photosynthesis and primary productivity of coastal waters.

It was shown that in the case of coccolithophore bloom the change in water transparency leading to a narrowing of the euphotic layer was the main factor effecting the photosynthetic capasity of phytoplankton, while in the case of bloom of the other taxa (dinoflagellate/diatom), the change in the spectral features of downwelling radiance should also be taken into account.

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Policy-driven changes in enclosure fisheries of large lakes in the Yangtze Plain: Evidence from satellite imagery

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Abstract: Enclosure fisheries have accommodated the widespread expansion of aquaculture in many lakes throughout the Yangtze Plain (YP), China, for over four decades. Such practices have increased food provision but have also triggered various detrimental environmental consequences. To restore ecosystem functions, the Chinese government has recently implemented specific regulations to remove enclosure fences from lakes throughout the YP. However, little information is available on the spatial and temporal distributions of the enclosure fences, particularly in relation to the enforcement of recent policy changes. Using Synthetic Aperture Radar (SAR) satellite images taken between 2002 and 2018, we conducted the first comprehensive assessment of the interannual changes in enclosure fences for 17 large lakes throughout the YP. Consistent decreases in fence density were found after 2015 for most lakes; 15 lakes had >50% of their fences removed, while 9 lakes had >90% removed. Timing and implementation of enclosure fisheries development, and destruction, were related to government policy: before 2015, regional dynamics in enclosure fisheries were attributed to provincial policies, whereas the nearly ubiquitous fence demolition after 2015 appeared to be a response to national policy. This study represents the first remotely sensed evidence demonstrating the importance of both local and national environmental policies and their effectiveness in mitigating ongoing human impacts on vulnerable and invaluable natural resources.

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The Australian Shallow Water Ecosystem Substratum Spectral Library: Lessons Learnt

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Australia's extensive continental coastline and offshore territories are difficult to monitor and assess using in situ data. National and international requirements for comprehensive monitoring are increasing with reporting for State-of-Environment reporting, Sustainable Development Goals and the System of Economic and Environmental Accounting needing timely delivery of spatial and temporal information. Combining satellite images with a curated spectral library may enable systematic mapping of shallow water seabed features. We assessed spectral libraries from government and academic institutes to capture seabed spectral features within coral reef, coastal and estuarine waters. This inventory contains ~4000 spectra, covering habitats from temperate to tropical inlets, estuaries, rocky and coral reefs along Australia's continental coastline.

We recommend establishing a national spectral library for aquatic ecosystems, harmonised measurement protocols and development of a spectral library template for the use of validation, parametrisation, and research into intra-and inter-species and substratum type variability. A globally accessible substratum spectral library will support the aquatic community to collate, publish, share and discover and re-use existing spectra and facilitate the capture of new datasets with DOI's.

The existing spectra are of variable usefulness as many spectral laboratory-based or field campaigns were carried out on an ad-hoc basis and essential metadata for other purposes were not collected. If standardised protocols had been in place many of these spectra would be more valuable for e.g. the parametrisation and validation of products from the Landsat and Sentinel-2 archives of shallow water ecosystems. A rough calculation indicates that each, well measured, spectrum costs about AUD 1000 (taking into account all costs associated with instrumentation, logistics, lab costs etc.). Thus these ~ 4000 spectra represent 4 million AUD of R&D investment, yet incomplete metadata prevents some of these data being re-used. Some examples of missing meta-data information were: GPS locations, size and homogeneity of the patch and field photographs of the target material: with a few minutes of extra work per spectrum all this essential metadata could have been registered! We recommend future spectral data collection to incorporate all future uses of the spectral data rather than just the specific research purposes. Adopting a metadata standard and sampling protocols will ensure longevity, fitness for re-use, and foster collaboration and development of more effective community standard and protocols.

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No. 19

Evaluation of remotely sensed Vibrio parahaemolyticus prediction and forecast models for Chesapeake Bay

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Over the last decade, an increase of gastrointestinal illness due to the consumption of raw or undercooked shellfish containing high concentrations of the naturally occurring bacterium Vibrio parahaemolyticus has been reported. Studies mainly attribute this increase to rising sea surface temperatures and prolonged warm seasons in the mid-latitudes. Being able to predict high concentrations of Vibrio parahaemolyticus in estuarine waters is important because it can indicate to shellfish harvesters that they should implement post-harvesting interventions that can lower the risk of illness in consumers. Historically, sea surface temperature and salinity have been the main environmental determinants used to predict Vibrio parahaemolyticus presence and abundance. However, several studies using in situ sampling campaigns have shown that additional environmental parameters may be useful in predicting when and where Vibrio parahaemolyticus is likely to be in concentrations that pose a risk to public health. The time and cost of obtaining in situ samples for each shellfish harvesting site at a high enough temporal resolution is impractical, and the laboratory measurements needed for some measurements make the data unavailable in real time. Our study evaluates several versions of classification and regression models that predict Vibrio parahaemolyticus presence and abundance in the Chesapeake Bay. The models use ocean color remote sensing products from near-daily overpass of the Moderate Resolution Imaging Spectroradiometer (MODIS) as inputs, which provides the potential for a real-time warning system. In addition to sea surface temperature and salinity, we include several other ocean color products and remote sensing reflectances in the models to determine whether additional information can improve predictions. We also evaluate the utility of MODIS ocean color products in forecasting Vibrio parahaemolyticus one week in advance.

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Introduction to Chinese Ocean Color and Temperature Scanner on-board HY-1C Satellite as well as its preliminary evaluations

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HY-1C satellite has been launched successfully on 7th September, 2018, in China, which is the succeeding one of the Chinese HY-1 satellite series. HY-1C is designed to monitor routinely global ocean color variations as well as the environment of Chinese coastal zones. Besides that, it could also contribute to the detection of marine disasters such as red-tides, green-tides and oil spill, etc. It operates on the sun-synchronous orbit at 782km altitude and the local time is 10:30am at the descending point. Compared with HY-1A and HY-1B which had only two sensors, there are five sensors on-board HY-1C which may also display much better performance in remote sensing and detection abilities both for open oceans and coastal zones. The Chinese Ocean Color and Temperature Scanner (COCTS) is one of the main sensors with 10 bands on-board HY-1C. There are 6 visible bands and 2 near-infrared bands for ocean color remote sensing, as well as 2 thermal infrared bands for sea surface temperature (SST) detection. The swath width of COCTS is 2900km with the spatial resolution is 1.1km*1.1km at nadir. The results of preliminary evaluations on in-orbit satellite data together with pre-launch laboratory measurements, show that the main technical parameters including signal-to-noise ratio (SNR), polarization sensitivity, the control of stray light, etc., could be much better than that of HY-1A and HY-1B. At the same time the sensor has higher dynamic domains in visible and near-infrared bands than traditional ocean color sensors. Once commissioned in orbit routinely, it could provide global chlorophyll concentration and SST distribution every day. HY-1D satellite with the same payloads and platform designs operating in ascending mode will follow in 2020 which could achieve satellite constellation with HY-1C in descending mode.

Key words: HY-1C satellite, global ocean color remote sensing, SST, preliminary evaluations

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No. 21

Satellite detection of a dredging plume by the spectral slope (S_{cdpm}) of Coloured Dissolved plus Non-Algal Particle absorption

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Abstract: Dredging activities in shallow estuaries can affect the environment in different ways, including removal or smothering of subtidal benthic species and communities, possible release of organic matter, nutrients and or contaminants, and modification of light availability in the water column. The latter is mainly controlled by coloured dissolved and non-algal particulate matter (CDOM and NAP) concentrations in highly turbid waters. While dredging activities can often be inferred from increased NAP or CDOM concentrations, the spectral slope of CDOM and NAP absorption from dredging activities has not previously been investigated but offers evidence of the different nature and origin of dissolved and particulate matter. From mid-May until the end of October 2016 an unusually intense and extensive (~150 Km long) dredging plume was detected in the upper Río de la Plata (Rdp) estuary (Argentina) using remote sensing imagery. A conspicuous plume, brighter and more yellow comparing to the adjacent waters, was observed in RGB ocean colour composites images from different sensors at both high (Sentinel-2/MSI, Landsat-8/OLI) and moderate spatial resolution (SNPP/VIIRS, and MODIS/A). Bio-optical data collected in and close to the dredging plume on September 25 2016 in the upper estuary showed that samples collected inside the plume had turbidity (T) values ten times higher (T~500 FNU), smaller median particle size and a distinct reflectance spectral shape, *i.e.* a flattened spectra, than the surrounding waters. Using a simplified first order reflectance model (QSSA: quasi single scattering) assuming $a >> b_b$, and a_w, b_{bw} and a_{phy} to be negligible in the blue part of the spectrum (*i.e.* 400-500 nm), plausible conditions in these highly turbid waters, an algorithm was developed to derive the CDOM+NAP absorption spectral slope (S_{cdpm}) using two bands in the blue, e.g. 443 and 490 nm. Applying this algorithm to the field measured reflectance data showed unusual low S_{cdpm} values (~0.005 nm^{-1}) inside compared to outside the plume (~0.008 nm^{-1}) and to typical values for CDOM and NAP absorption spectral slopes ranges reported in the literature (0.008-0.038 for S_{cdom} and 0.007-0.02 for S_{nap} and average values of 0.0176 and 0.0123 nm^{-1}, respectively). Similar results were found when applied to Sentinel-2 and Landsat-8 imagery during the 2016 dredging plume event, even though some difference in the absolute values were found. Hydrolight simulations (CoastColor Round Robin data set) were used to validate the algorithm and to assess the uncertainty due to increasing chlorophyll-*a* concentration and different satellites spectral response functions.

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No. 22

Optical-biogeochemical properties of hurricane impacted estuarine-coastal systems using optimized semi-analytic and inversion algorithms for VIIRS, MODIS and Sentinel-3 OLCI ocean color imagery

Eurico J. D'Sa[1], Ishan D. Joshi[1], Bingqing Liu[1]

During summer/fall 2017 and 2018, the northern Gulf of Mexico was impacted by two major hurricanes, namely, Hurricane Harvey and Hurricane Michael with contrasting impacts on the estuaries and shelf waters of the impacted coastal systems. Hurricane Harvey (25-29 August 2017) after making landfall on the Texas coast, deposited unprecedented rainfall (>500 mm) in the highly industrialized Houston Metropolitan and surrounding areas that resulted in a large pulse of discharge into Galveston Bay and the shelf waters. We used field and satellite ocean color observations (NPP-VIIRS, Sentinel-3 OLCI) combined with tuned semi-analytic (QAA-V) and inversion IOP/NNLS algorithms to examine the optical (CDOM/phytoplankton absorption and backscattering coefficients) and biogeochemical (dissolved and suspended particulate matter e.g., DOC, POC, phytoplankton taxonomy and pigment composition) properties in Galveston Bay and surrounding coastal ocean following the hurricane passage. Hurricane Michael, which made landfall just west of Apalachicola Bay on 10 October 2018, in contrast, was a fast moving major hurricane (winds 250 km/h) that caused widespread damage due to strong winds and flooding associated with a large storm surge. We applied optimized semi-analytic (QAA-VM) and inversion algorithms to MODIS and Sentinel-3 OLCI imagery to examine the biogeochemical response in Apalachicola Bay and the west Florida shelf following Hurricane Michael. Results of these novel applications of semi-analytical and inversion optical approaches to estuarine/coastal system will be presented.

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EUMETSAT Copernicus Marine Training and User Support

Hayley Evers-King[1], Ben Loveday[1], Sally Wannop[2], Christine Traeger-Chatterjee[2]

EUMETSAT provides user support and training for all users of the Copernicus Marine Data Stream (CMDS). The CMDS refers to all the level 1 and level 2 marine data from sensors on the Sentinel-3 and Jason-3 satellites, including ocean colour, sea surface temperature, and surface topography data. Details on the products and processing methodologies are available through handbooks, product notices, and a number of services including a help desk, and forum. The training service aims to support all users wishing to explore potential applications of the CMDS. The service is primarily based around the delivery of two week, blended courses with both an online and classroom component. The online component is hosted on a Moodle platform and uses a variety of prepared resources including short articles, videos, software installation, and basic software tutorials; supported by discussion forums, to prepare participants for the classroom phase. The classroom phase is focused on practical work, with no lectures given. Participants are led through examples of workflows using SNAP and Jupyter Notebooks/Python, and are then given one-on-one/small group trainer support to work for 3 days on personal projects that they defined during the online phase. The training service has also run a variety of collaborative courses with community led initiatives, and proposes to develop online courses and resources in response to community needs. This poster will provide the opportunity for feedback and requests from the ocean colour community.

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Estimating the fraction of PAR absorbed by live phytoplankton from satellite data

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Primary production, *PP*, or the quantity of organic matter synthesized by phytoplankton per unit of surface and time, depends on the fraction of photo-synthetically available radiation absorbed by live phytoplankton, *APAR*. Computing *APAR* requires knowledge of the absorption coefficient of live phytoplankton and the total absorption coefficient, quantities that are difficult to retrieve accurately from satellite ocean-color data. In the proposed approach, *APAR* is obtained directly from a linear combination of water reflectance in the *PAR* spectral range. Feasibility is demonstrated theoretically from simulations for realistic conditions, and experimentally using data collected at bio-optical stations in various regions. Improvements in *APAR* accuracy are quantified in comparisons with estimates obtained from absorption coefficients or chlorophyll concentration determined from retrieved water reflectance via standard satellite algorithms. The linear combination of water reflectance is fairly robust to atmospheric correction errors. Due to the linear nature of the algorithm, the impact of those errors may be further reduced when using space- or time-averaged water reflectance. The methodology is applied to actual MODIS imagery, uncertainty is attached to the *APAR* values, and variability in the resulting *APAR* field is analyzed. The study suggests that determining *APAR* directly from water reflectance has the potential to improve *PP* estimates from space.

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No. 25

Atmospheric correction for coastal waters based on multi-angle polarimetric observations

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Atmospheric correction is an essential procedure of ocean color remote sensing, which obtains water-leaving signals from satellite or airborne sensors. Due to the small percentage of the water leaving signals in the total measurement, atmospheric correction requires precise evaluation of the radiometric contributions from the aerosol and ocean surface. It is often challenging over coastal waters when absorbing aerosols are present and when water leaving signals in the near infrared spectral region are non-negligible. In this work, we report on a joint retrieval algorithm that determines aerosol and ocean optical properties using the polarimetric measurements based on a coupled atmosphere and ocean radiative transfer model. Two bio-optical models are designed for ocean water properties. One model parameterizes the open ocean optical properties in terms of the concentration of chlorophyll a. The other is a generalized bio-optical model for coastal waters that describes the absorption and scattering by phytoplankton, colored dissolved organic matter and non-algal particles using multiple parameters. We applied the algorithm to the airborne Research Scanning Polarimeter (RSP) measurements acquired over both open and coastal ocean waters. Through the comparisons with in situ ocean color measurements, the flexibility and accuracy of the retrieval algorithm in retrieving aerosol and water leaving radiance properties are demonstrated under various aerosol and ocean water conditions.

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Remote sensing of floating plastics in the aquatic environment

Shungu Garaba[1]

Abstract : Plastics in marine litter are becoming a nuisance in the environment and as a result there has been a dire need to synoptically detect, track, characterise and quantify them in the ocean. I present findings from collaborative scientific evidence-based studies and datasets-of-opportunity demonstrating the potential application of optical sensors on airborne and satellite platforms in remote sensing of floating plastics from the open ocean to estuarine systems. Very fine geo-spatial resolution satellite and airborne imagery was captured in the Great Pacific Garbage Patch and nearshore waters of Greece in the visible to shortwave infrared spectrum. I also evaluate the performance of these optical sensors in terms of the 'detect, track, characterise and quantify' requirements which also depends on the size distribution of the target aquatic plastics floating or slightly submerged. Optical sensor characteristics were also investigated in terms of temporal, spectral, geospatial coverage and resolution. The measured spectral properties of the target floating plastics were compared to open-access spectral libraries to best predict polymer types present. Additional work was aimed at determining ways to estimate the abundance of plastic debris in target areas. Implications of successful remote detection, tracking and quantification of plastic debris will be towards operational validation of field measurements over large areas and at repeated time intervals in different aquatic environments.

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Total and polarized radiance from the ocean surface from hyperspectral polarimetric imager and polarization camera

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We present results of measurements of total and polarized radiances from the water surface by a state-of-the-art snapshot hyperspectral imager, which simultaneously acquires spectra with 4nm spectral resolution in the wavelength range of 450-950nm with a 40° field-of-view (FOV) for 20°-60° viewing angles. The imager does not require any along track movement and allows the continuous collection of data from stationary structures or slow moving platforms such as ships or helicopters. A computer controlled filter wheel is installed in front of the imager allowing division-of-time Stokes vector images from the ocean surface.

Several sets of measurements were acquired from ocean platforms in the New York City area and Duck, NC, as well as from shipborne observations in the Gulf of Mexico and along the Florida coast. Imager measurements are in good agreement with vector radiative transfer simulations based on measured IOPs. Pixel-to-pixel variability was analyzed for the total and polarized above-water radiance, sky radiance, and derived water-leaving radiance for viewing angles ranging from 20° to 60° and various wind conditions. This allowed estimating spectrally resolved measurement uncertainties for polarized and un-polarized radiances for the whole spectral range, thus setting requirements for the quality of polarized measurements.

In addition, first measurements of total and polarized radiance are presented, as measured by a novel polarized polarization camera (Teledyne DALSA), where each pixel contains four subpixels bearing built-in linear polarizers oriented at the 0, 45, 90 and -45 degrees. Radiances are recorded in a FOV similar to the FOV of the hyperspectral imager. The camera is equipped with a filter wheel containing five band-pass filters in the range of 400-900 nm, thus providing multi-spectral data in the same wavelength range as the hyperspectral imager.

The combination of these two instruments allows to observe spectral and polarization properties of the wind-roughened ocean at high spatial and temporal resolution, with the goal of advancing our understanding of air-water interface and in-water light propagation, related uncertainties and their influence of on the retrieval of in water particulates.

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No. 130

The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)

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The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) is an interdisciplinary investigation to improve understanding of Earth's ocean ecosystem-aerosol-cloud system. Specific overarching science objectives for NAAMES are to (1) characterize plankton ecosystem properties during primary phases of the annual cycle and their dependence on environmental forcings, (2) determine how these phases interact to recreate each year the conditions for an annual plankton bloom, and (3) resolve how remote marine aerosols and boundary layer clouds are influenced by plankton ecosystems. Four NAAMES field campaigns were conducted in the western subarctic Atlantic between November 2015 and April 2018, with each campaign targeting specific seasonal events in the annual plankton cycle. A broad diversity of measurements were collected during each campaign, including ship, aircraft, autonomous float and drifter, and satellite observations. Here, we present an overview of NAAMES science motives, approach to accomplishing the science objectives, and highlight early results and observations from this multidisciplinary project.

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From satellite ocean colour data to information and applications: NOAA Coastwatch /Oceanwatch / Polarwatch

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Abstract

The purpose of the NOAA CoastWatch/OceanWatchPolarWatch Program (a.k.a. "CoastWatch") is to improve decision outcomes by facilitating the use of ocean satellite data in applications and research.

NOAA CoastWatch has existed since 1987 when the primary focus was on distributing sea surface temperature data for continental US regions. With time and in response to the continual development of ocean observations from space, our scope has expanded to customize, serve and monitor ocean satellite data products from any satellite missions (NOAA and/or non-NOAA) along with supporting in situ data covering multiple environmental parameters across space and time to a broad audience of users across sectors (government, commercial, academic, public). Organized with our "hub" having the primary processing responsibilities and co-located with the ocean satellite environmental data record (EDR, i.e., Level 2) producers and our "spokes" being regional Nodes distributed geographically and across NOAA mission line offices, CoastWatch is well-positioned to bridge upstream ocean EDR producers with downstream user needs. The new interactive data portal enables search and discovery, multi-product visualization and customizable data downloading. "Power users" can use command-line scripts to automate their access. The OceanWatch Monitor enables the assessment of data products over time and in comparison with reference datasets. CoastWatch teaches training courses, develops tutorials and maintains a helpdesk all for our efforts of educating and guiding users from novice to expert. Coastwatch also develops and distributes CoastWatch Utilities, a software package, to help users analyze and visualize satellite data products. Ocean Color data products available through CoastWatch feature NOAA VIIRS SNPP and NOAA-20 as well as OLCI Sentinel 3A/B from Copernicus, and soon SGLI from JAXA's GCOM-C. Some examples of data products, discovery and access pathways, tutorials and several user applications will be presented.

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On identification of appropriate sites in the South China Sea for ocean color System Vicarious Calibration with time-series data analysis

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Abstract: The prerequisite for operational Ocean Color (OC) is to retrieve required quantities (i.e., water-leaving radiance) within a predefined uncertainty level, and to assure data consistency among different missions in decadal or even a longer scale. For example, SeaWiFS project suggested accuracy goal in clear waters for spectral reflectance and chlorophyll concentration are 5% and 35% in clear ocean waters, respectively. This target has also been accepted by follow-on sensors (e.g., MODIS, VIIRS, OLCI, etc.). As commonly used methodology, the System Vicarious Calibration (SVC) technique is the best practice to assure ocean color sensors meeting those uncertainty requirements, especially to characterize uncertainties in the sensor calibration and the atmospheric-correction algorithm on mission-long scale. SVC treats the sensor and the atmospheric-correction algorithm as a coupled system, which is accomplished by applying gain correction to pre-launch calibration coefficients of ocean color sensors. Practical instructions have been proposed by many researchers (e.g., Gordon, 1998; Eplee et al., 2001; Franz et al., 2007; Zibordi et al., 2015). There have been several OC SVC sites worldwide, either operational (e.g., the North Pacific Ocean, the Mediterranean Sea) or virtual (e.g., the South Pacific Gyre).

The aim of this work is to identify potential sites for OC SVC in the South China Sea (SCS). The SCS is the largest semi-enclosed marginal sea in the tropical-subtropical area in the northwest Pacific, which is characterized with mean depth of 1350m and maximum depth of over 5000m, and its surface circulation in the SCS is predominantly controlled by the seasonally changed East Asian Monsoon. Because of its large area (~3.5*106 km2) and basin-scale gyres' isolating interior water from the influence of land-runoffs (Wong et al., 2007), SCS is characterized by oligotrophic properties even though terrestrial inputs from several rivers (Gong et al., 1992).

Inspired by the work of Zibordi and Mélin (2017), we analyzed the seasonal/annual variability of bio-optical and meteorological quantities in SCS, and also their spatial homogeneity in the defined geographic area. Over 10 years of remote sensing data has been collected and analyzed, including bio-optical (chlorophyll a concentration, remote-sensing reflectance), atmosphere optical (aerosol optical thickness) and meteorological (wind) parameters. Constrained by several requirements (e.g., homogeneity, trophic state, surface roughness, cloud cover, etc.), several sites are identified as potential SVC sites in the SCS, which could serve current and future OC sensors. This work is supported by ocean color satellites project of China.

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Data services and user supports of GOCI-II Ground Segment (G2GS)

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Geostationary Ocean Color Imager–II (GOCI-II), which is the successor of GOCI, will monitor in local area and full disk area in real-time. GOCI-II Ground Segment (G2GS) will generate huge datasets such as GOCI-II Level 1B dataset (geometrically corrected radiance), GOCI-II Level 2 dataset (26 products related to ocean color, optical properties, ocean phenomena observing, atmospheric monitoring, land change monitoring). Data Service Environment (DSE) of G2GS will provide all datasets via various ways. In order to ensure usability, we have provided a data retrieval and user support environment using a standardized framework (SNAP). The DSE distributed satellite data through the GOCI Library, to retrieve only necessary data in the interested area of slot, and to retrieve data from Lucene search engine and OPeNDAP / THREDDS. In addition, it is also possible to search for filename, date of creation and metadata in the NetCDF file format. We plan to complete the system implementation and integration test before launching the satellite and evaluate whether we meet the operation requirements by in-orbit test (IOT) after launching the satellite.

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Preliminary results on cross-calibration and atmospheric correction of HY-1C/COCTS data

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Abstract：As the successor of the Chinese HY-1A and HY-1B ocean color missions, HY-1C is the third ocean color satellite launched by China on 7 September 2018. Compared to the limit abroad observation of the HY-1A and HY-1B, HY-1C has the capacity of daily global coverage. The Chinese Ocean Color and Temperature Scanner (COCTS) is one of the three major payloads onboard the HY-1C satellite, which has eight VIS/NIR bands like the SeaWiFS with band center wavelengths at 412nm, 443nm, 490nm, 520nm, 565nm, 670nm, 750nm and 865nm. The spatial resolution of the COCTS is 1.1km at nadir with swath width around 2900km. In this study, the preliminary results of the on-orbit performance of the HY-1C/COCTS were provided. First, the atmospheric correction algorithm was developed for the HY-1B/COCTS by using the look-up tables of the Rayleigh-scattering radiance, the ratio of the atmosphere path radiance to Rayleigh-scattering radiance, and the atmosphere diffuse transmittance. These look-up tables were generated by the vector radiative transfer model for the coupled ocean-atmosphere system (PCOART). The validations based on the simulated radiance at the top-of-atmosphere showed that the established atmospheric correction algorithm can retrieve the water-leaving reflectance accurately. Second, the cross-calibration was carried out for the HY-1C/COCTS by taking the Aqua/MODIS-derived remote sensing reflectance as reference values. The results showed that the determination coefficients of the linear relationship between the simulated radiance the TOA and the original HY-1C/COCTS measured radiance were all larger than 0.98, indicating the good linear response performance of the HY-1C/COCTS. However, our results revealed that the correction of the 412nm was more than 10%, and it was about 5% for the next three bands (443nm, 490nm, 520nm). In addition, the estimated polarization sensitivity (including other non-linear factors) based on the cross-calibration data were up to 5.1%, 2.38%, 2.44%, 4.55%, 2.8% and 1.57% for the first six bands of the HY-1C/COTS. Based on the developed atmospheric correction algorithm and calibration coefficients (including derived polarization responses), the HY-1C/COCTS Level-1 data from Jan. 1-16, 2019 were proceeded to derived the daily global normalized water-leaving radiance (Lwn) and the chlorophyll concentration (Chl), and the corresponding 8-days composited products. The results showed that both the Lwn and Chla derived by HY-1C/COCTS were consistent with the results from Aqua/MODIS and SNPP/VIIRS, indicating that HY-1C/COCTS has good performance to observe global ocean color information.

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Evolution of the versatile ocean colour algorithm ONNS

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The ocean colour algorithm ONNS (OLCI Neural Network Swarm) is specially designed to process data of the Ocean and Land Colour Instrument on board the Sentinel-3 satellites [Hieronymi et al., 2017]. The aim of the development is to provide one algorithm that is suitable to all natural waters, from clearest oceanic (Case-1) waters to very turbid coastal or highly absorbing inland waters (Extreme Case-2 waters). For this purpose, a fuzzy logic optical water type (OWT) classification is applied in conjunction with a set of specific neural networks. Input to the algorithm are normalized remote sensing reflectances at 11 OLCI bands, i.e. atmospheric corrected satellite data. The algorithm calculates concentrations of chlorophyll (*Chl*) and suspended matter (*ISM*), various inherent optical properties, such as CDOM absorption at 440 nm ($a_{cdom}440$) or particulate backscattering at 510 nm ($b_{bp}510$), and other useful ocean colour parameters, such as down-welling diffuse attenuation coefficient at 490 nm (K_d490). These products are delivered with an algorithm-inherent uncertainty estimate. Moreover, due to continuous development, new products are provided based on the previous parameters: 1) total absorption and scattering coefficients at 440 nm (*a440*, *b440*), 2) optical dominance of water constituents at 440 nm, 3) dissolved organic carbon (*DOC*), and 4) particulate organic carbon (*POC*).

By means of newly designed “band adapters”, it is now also possible to process atmospherically corrected data from other ocean colour sensors like SeaWiFS, MODIS, MERIS, OCM-2, VIIRS, SGLI, GOCI-2, EnMAP, and PACE/OCI (examples will be provided). The performance of the band adapters is evaluated in view of diverse optical water types. In the spectral range between 400 and 600 nm, the mean percentage retrieval error is mostly <5 %. This is less uncertainty compared to usual differences due to application of various atmospheric correction models. Thus, the band adaptation is a tool for cross-mission Earth observation and uncertainty estimate, as well as for extended possibilities of algorithm validation.

As it is the case for all ocean colour algorithms, results of ONNS depend on the quality of input, i.e. atmospheric corrections. ONNS results are water-type-wise compared to different atmospheric correction algorithms, to standard ocean colour products (e.g. OLCI Chl_OC4ME and Chl_NN) and set into context with in situ observations.

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Lidar depolarization ratio measurements: linking diffuse attenuation and beam attenuation

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Abstract: Multiple scattering causes depolarization of lidar backscatter. If the lidar footprint is large enough, effective attenuation of the laser light gradually reduces from beam attenuation to diffuse attenuation. Based on Monte Carlo simulation of laser light propagation in the atmosphere and ocean, we found that lidar depolarization ratio measurements are a function of the ratio of diffuse and beam attenuation (we call it "multiple scattering factor"). Such a relation has been verified with CALIPSO's atmospheric measurements (clouds and aerosols) and enabled new applications in atmospheric remote sensing (e.g., cloud thermodynamic phase discrimination, aerosol properties above clouds). This presentation examines the validity of the lidar depolarization – multiple scatter factor relation of light propagation in the ocean.

During the NAAMES field campaigns, the NASA LaRC airborne HSRL lidar made both diffuse attenuation and depolarization ratio measurements. Beam attenuation coefficients were derived from the HSRL lidar measurements for three different seasons. The beam attenuation coefficients derived from HSRL Kd and depolarization measurements compared reasonably well with ship-based beam attenuation measurements. This finding suggests that it is possible to measure the beam attenuation coefficient together with Kd, Bbp and their vertical profiles from HSRL lidar. The upcoming NASA's A-CCP mission could provide an opportunity to make these measurements globally.

Self-shadow correction of SBA measurements under controlled laboratory conditions

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Abstract: It is an important goal to obtain accurate measurement of water-leaving radiance (Lw) in ocean optics and ocean color remote sensing. Among the various approaches that have been proposed and implemented, the skylight-blocked approach (SBA) is a scheme to measure Lw directly in the field with high precision. However, due to the setup of the instrument and measurement strategy, it is inevitably that Lw measured by SBA contains some effects of self-shading, and a processing algorithm based on numerical simulations has been developed to correct this self-shading effect. Here, under controlled experiments, we evaluate such a scheme using measurements from both SBA and the above-surface method. We compare the effects of different solar zenith angles, different water body optical characteristics, and different size of the blocking cones on the SBA self-shadowing effects. For wavelengths of ~400 – 700 nm and absorption coefficient > 0.3 m^{-1}, we found that the normalized root-mean-square difference (NRMSD) between the corrected and reference Lw in a range of ~5% – 15%. These results provide support of SBA to get highly precise and accurate Lw in the field.

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Subsurface plankton layers observed from an airborne lidar in Sanya Bay, South China Sea

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In recent years, airborne lidar has a wide range of oceanic applications, including detecting bathymetry, bubbles, internal waves and schools of fish. However, it has not yet been extensively applied in Chinese seas. There are no studies to detect subsurface plankton layers in the South China Sea (SCS) by airborne lidar before. In this study, we investigated the applicability of this technology to identify subsurface plankton layers in Sanya Bay, SCS. A total of three airborne lidar flight experiments were carried on in March 2018 and September 2017. Shipboard synchronous measurements were carried out in March 2018 to validate the lidar measurements. A method to detect subsurface plankton layer which characterized by depth, thickness and intensity was presented. Compared with chlorophyll-a profile synchronously measured by shipborne fluorometer, there was a quite consistent relationship. The subsurface plankton layer depth error was less than *0.7 m*. Then the spatial distribution and seasonal variation of lidar measured subsurface plankton layers in Sanya Bay, SCS was analyzed. The results showed that airborne lidar has the potential for detecting subsurface plankton layer within 50 meters deep in relatively clear water, which will enhance our understanding of biogeochemical processes in these optically complex aquatic systems.

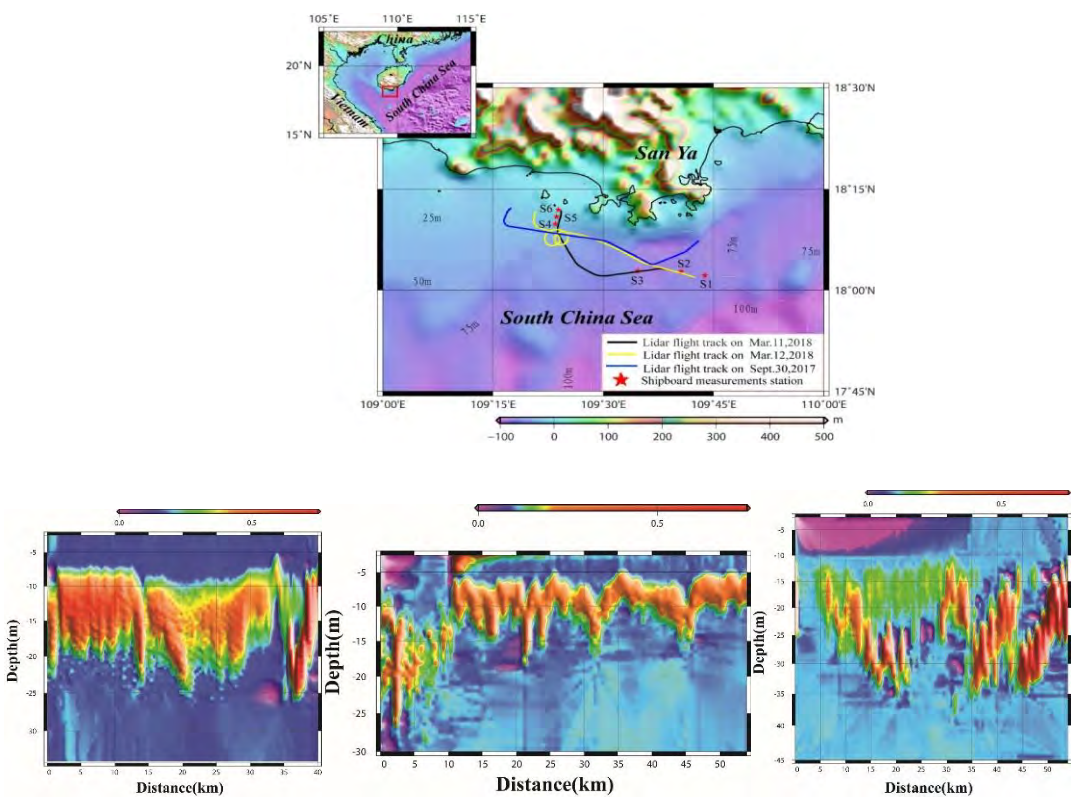

Fig. 1. Vertical slice of lidar measured subsurface plankton layers.

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Creation of merged ocean color products on the basis of MODIS, VIIRS, GOCI, OLCI and SGLI radiometers in the optical complex waters of the Peter the Great Bay

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Peter the Great Bay is situated in the west part of the Sea of Japan (East Sea). This bay has wide range of different optical cases: waters which are significant influenced by rivers flow, anthropogenic load, high bioproductive waters, open clean waters. There are observed zones of wind upwelling and internal waves. Primorsky current (Liman current) passes on the south border of Bay. Sea eddies regularly reach the central part of Bay. Data of continuous observations are important for regular sea surface monitoring and researching oceanography processes in time.

Last advantages of satellite ocean color allow to get about 10 images of the Bay area every day from the following scanners: geostationary GOCI-COMS [1,2] 500 m; MODIS-Aqua [1,3] 1100-2000 m; MODIS-Terra [1,3] 1100-2000 m; VIIRS-SNPP [1] 700-1500 m; VIIRS-JPSS1 [1] 700-1500 m; and two scanners of new generation OLCI-Sentinel-3A [4] 300 m and SGLI-GCOM-C [5] 250 m. Last two scanners have the best spatial resolution and additional spectral channels in UV-Blue: 400 nm on OLCI [6] and 380 nm on SGLI [7]. It can be used for the better retrieval of atmosphere aerosol and colored dissolved organic matter. So, it is possible to create combined data for researching diurnal dynamics, composite products for improvement of the daily spatial coverage of the water area, and combined spectra of sea color of extended spectral range and improved spectral resolution.

The main aim of this work is an optimal combination of satellite ocean color data in the Peter the Great Bay taking into account regional optical characteristics in order to obtain diurnal time series of ocean color data, daily composite maps of measured parameters and common color spectra.

To achieve this goal, the regional grid was created with linear size of cells about 250 m which is matched with bathymetry of area, and the level-2 data of listed above satellite radiometers were used. Some satellite data have alternative processing with different atmosphere correction approach, e.g. GOCI [1,2] and MODIS [1,3]. There are common steps of whole procedure: Step 1. Satellite data of remote sensed reflectance (Rrs) and main biooptical characteristics from different scanners were individually interpolated on the grid points. Step 2. The data were cross-validated with each other and the data quality was estimated. Satellite data with various resolution and atmosphere processing get different quality weights. Step 3. Two-dimensional auto-correlation functions of the interpolated data and direction of correlation ellipses were calculated in the moving windows. Direction of correlation ellipses correspond to the observed oceanographic processes and could be used for additional filter the data and separate atmosphere influence. Step 4. Combined spectrum of Rrs were made which also used as additional indicator of interpolation quality. Step 5. The two-dimensional correlation functions were used for the optimal interpolation procedures in Step 1. The whole procedure was recursively repeated until the final results of interpolation don't stop to change. Stricter requirements were imposed on the quality of filtering to restore the whole spectra of Rrs, which can be used to apply quasi-analytical bio-optical algorithms.

MODIS-Aqua and -Terra are differed by a lower spatial resolution compared to other radiometers, which often does not distinguish some spatial features, therefore regional data processing [3] was also used, performed using the MUMM atmospheric correction algorithm and using 250 m bands for estimates of the parameters of light scattering in case-II waters. The quality of the regional processing of GOCI-COMS performed by KOSC [2] turned out to be better compared with the processing [1]. The data from the VIIRS-JPSS1 radiometer is geographically shifted to the west and most likely in the current version of the processing are inaccurate geo-referenced. The data of individual satellite images are often corrupted by artificial strips, and therefore it is not always possible to see the full distribution of analyzed parameter, so combining the data allows to solve this problem too.

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Multi-Band Atmospheric Correction Algorithm for Ocean Color Retrievals

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Abstract

NASA's current Atmospheric Correction (AC) algorithm for ocean color utilizes two bands and their ratio in the Near Infrared (NIR) to estimate aerosol reflectance and aerosol type. The algorithm then extrapolates the spectral dependence of aerosol reflectance to the visible wavelengths based on modeled spectral dependence of the identified aerosol type. Future advanced ocean color sensors, such as the Ocean Color Instrument (OCI) that will be carried on the Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) satellite, will be capable of measuring the hyperspectral radiance from 340 to 890 nm at 5-nm spectral resolution and at 7 discrete Short-wave Infrared (SWIR) channels: 940, 1038, 1250, 1378, 1615, 2130, and 2260 nm. To optimally employ this unprecedented instrument capability, we propose an improved AC algorithm that utilizes all atmospheric-window channels in the NIR to SWIR spectral range to reduce the uncertainty in the AC process. A theoretical uncertainty analysis of this , namely Multi-Band AC (MBAC) indicates that the algorithm can reduce the uncertainty in remote sensing reflectance (R_{rs}) retrievals of the ocean caused by sensor random noise. Furthermore, in optically complex waters, where the NIR signal is affected by contributions from highly-reflective turbid waters the MBAC algorithm can be adaptively weighted to the strongly-absorbing SWIR channels to enable improved ocean color retrievals in coastal waters. We provide here a description of the algorithm and demonstrate the improved performance in ocean color retrievals, relative to the current NASA standard AC algorithm, through comparison with field measurements and assessment of propagated uncertainties in applying the MBAC algorithm to MODIS, VIIRS, and simulated PACE OCI data.

Keywords: Ocean Color$_1$, Atmospheric Correction$_2$, PACE$_3$, Aerosol$_4$, Turbid waters$_5$.

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Using the new features of OLCI / Sentinel-3A and SGLI / GCOM-C to determine the concentration of colored dissolved organic matter and chlorophyll-a in the optically complex waters of the Amur Bay

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The Amur Bay, located near the Vladivostok-city, is a complex object for conducting quality satellite monitoring of seawater bio-optical characteristics. First of all, the bay has small linear dimensions (65 km length, 9-20 km width) and depths don't exceed 22 meters. Secondly, the waters of the bay are influenced by the rivers' flows and a significant anthropogenic load: the wastewater discharge, active navigation, recreational activities, etc. Also, bottom macroalgae are actively grow in some parts of the bay. One of the most effective methods for monitoring the state of the bay is sea color satellite sensing, from which you can get the distribution information of optically active water components (OAC), the main of which are chlorophyll-a (chl-a), colored dissolved organic matter (CDOM) and suspended matter (SM). However, to obtain representative satellite information results, it is necessary to take into account the influence of the atmosphere, the ratios inconstancy of the OAC contributions to the sea color, the influence of signals reflected from the bottom or from macroalgae. Standard atmospheric and bio-optical algorithms work correctly for case-I waters, but they fail in the case-II waters, which are the optically complex waters of the Amur Bay with a high content of CDOM and SM.

The aim of the work is to identify the mechanisms for sea color forming in the Amur Bay and to test the capabilities of new optical satellite scanners OLCI and SGLI to measure the concentration of CDOM (D) and chl-a (C). To achieve the goal, sub-satellite shipboard measurements of the hyperspectral remote-sensed reflectance (Rrs), main biooptical and hydrological parameters were carried out and an array of sea-color satellite scanners data (Level-2) was assembled: MODIS (Aqua, Terra), VIIRS SNPP, GOCI, OLCI and SGLI, received from their main distribution web-portals with standard processing procedures, and data from the Satellite Monitoring Center of the Far Eastern Branch of the Russian Academy of Sciences (SMC), where MODIS Aqua and Terra data are streamed for Peter the Great Bay using the MUMM atmospheric correction. And additionally GOCI data processed by Korean Ocean Satellite Center (KOSC) were used.

According to multiyear sub-satellite observations, it was revealed that the Amur Bay waters have a two-layer structure with a pycnocline at about 10-15 meters in the summer. The upper part is influenced by river flow (salinity is 25-30 psu), contains high D_{ship} (<20 µg/l) and turbidity (<10 FTU) and low C_{ship} (<1-2 µg/l). In the lower part, relatively clean sea water is observed with salinities at about 33 psu, D_{ship} <5 µg/l, turbidity of about 1 FTU, C_{ship} <5 µg/l, depending on the season. Thus, the array of sub-satellite observations contains cases with different ratios of chl-a and CDOM. On the basis of data on the relationship between the light attenuation coefficients and the content of chl-a and CDOM, it was founded that the distribution of the OAC in the upper 10-meter layer of water makes 95-97% of the contribution to the remote sensed sea color, and 3-5 % are determined by the OAC in the 10-15 m layer. The optical characteristics of waters below 15 m do not affect the formation of the sea color, as well as the radiation reflected from the bottom or macroalgae.

Comparison of satellite and contact data showed that satellite scanners typically overestimate up to two times the visible C_{sat} due to the additional influence of terrigenous CDOM. In addition, incorrect satellite data atmospheric correction can lead to differences in C_{sat} estimates up to 10 times; e.g. estimates by different scanners from 3 to 30 µg/l were observed. The best results in the bay were shown by the data processed in SMC and KOSC by atmospheric correction algorithms adapted for case-II water. Therefore, only those OLCI and SGLI data that were in good agreement with this data were used for research. The pixel size of about 300 m for OLCI and SGLI made it possible to describe better the boundaries, where reflection from the bottom or macroalgae begins to affect sea color. In addition, a quasi-analytical GIOP model with regional settings obtained from shipborne measurements was used for these scanners, the use of which with the new 380 nm and 400 nm satellite channels made it possible to better separate the contributions from chl-a and CDOM. This is estimated by calculating the standard deviation of the corresponding scatterplots D_{ship} – C_{ship} and D_{sat} – C_{sat}.

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REMOTE SENSING OBSERVATIONS OF OCEAN COLOUR USING THE TRADITIONAL FOREL-ULE SCALE

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ABSTRACT : We test a method for calculating the colour of the sea, as measured on the traditional Forel-Ule (FU) scale, from satellite remote sensing measurements of reflectance. Forel-Ule colour scale numbers are calculated from 46 in situ radiometer profiles in the Mozambique channel and Irish Sea and compared to direct measurements of water colour made with the FU scale. There is generally good agreement (R^2=0.79, RMS difference=2.7) between observed and calculated values over the range FU2 (blue)-FU18 (greenish brown). The method is applied to map the colour, on the FU scale, of the Irish Sea using 242 in situ radiometer measurements. MODIS satellite data is used to calculate the long-term (2003-2014) average and seasonal variation of sea colour. The colour of the Irish Sea, from both in situ and satellite radiometry, shows patterns which are consistent with the known distribution and seasonal variation of suspended particles. A Forel-Ule colour scale map of western European waters shows that the most coloured waters are found in north-west European seas which are coloured by suspended sediments rather than phytoplankton blooms.

Keywords: Forel-Ule colour comparator scale, ocean color, traditional method, MODIS satellite data, suspended sediments, phytoplankton

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Evaluation of Five Atmospheric Correction Algorithms over French Optically-Complex Waters for the Sentinel-3A OLCI Ocean Color Sensor

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The Sentinel-3A satellite has been launched on February 16, 2016 with on-board the Ocean and Land Colour Instrument (OLCI) for the study of the ocean color. The accuracy of ocean color parameters depend on the atmospheric correction algorithm (AC). This processing consists in removing the contribution of the atmosphere from the total measured signal by the remote sensor at the top of the atmosphere. Five ACs: the Baseline AC, the Case2 Regional CoastColour Neural Network AC and its alternative version, the Polymer AC and the Standard NASA AC, are inter-compared over two bio-optical contrasted French coastal waters. The retrieved water-leaving reflectances are compared with in-situ ocean color radiometric measurements collected using an ASD FielSpec4 spectrometer. Statistical and spectral analysis were performed to assess the best performing AC through individual (Relative error (RE) at 412 nm ranging between 23.43 and 57.31%; Root mean square error (RMSE) at 412 nm ranging between 0.0077 and 0.0188) and common (RE(412 nm) = 24.15-50.07%; RMSE(412 nm)=0.0081- 0.0132) match-ups. The results suggest that the most efficient schemes are the alternative version of the Case2 Regional CoastColour Neural Network AC with RE(412 nm)=33.52% and RMSE(412 nm)=0.0101 for the individual and Polymer with RE(412 nm)=24.15% and RMSE(412 nm)=0.0081 for the common ACs match-ups. Sensitivity studies were performed to assess the limitations of the AC and the errors of retrievals showed no trends when compared to the turbidity and CDOM.

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Extraction of Sea Surface Current derived from Optical Image Observed by Low-Altitude Remote Sensing

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Surface ocean currents are an important external factor affecting on the energy transport and the change of coastal areas. Also, surface ocean currents play a significant role in social and industrial aspects, such as contributing significantly to forecasting the extent and scope of the disaster in the event of a marine catastrophe. There are direct observations and indirect estimations of surface ocean currents. The direct observations are a method using a flow rate measuring instrument such as ADCP (Acoustic Doppler current profiler), and the indirect measurement is a method of calculating and estimating current vectors using images from satellite sensors. However, in the case of direct observations, they have spatial limitations and takes considerable time and cost to compensate these limiting factors. Indirect measurement methods are relatively low in cost compared to the direct observations, and long-term monitoring is possible over a wide range which can complement the shortcomings of the direct observations. In this study, we use Helikite, a low - altitude remote sensing equipment, to acquire images to extract the surface ocean currents. On April 20, 2018, images with a resolution of about 10 cm per pixel are acquired in an area of 2 km or more through an optical camera mounted on the Helikite for the outside Saemangeum seawall. Then, the acquired images are georeferenced and analyzed for energy flow motion of temporally consecutive images by using Robust Optical flow approach (ROF). Additionally, surface ocean current vectors are compared nd verified with the flow data of the drift buoy.

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Algorithms Merging for the Determination of Chlorophyll-a Concentration in the Black Sea

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Blending solutions to improve the quality of ocean color products maps (e.g., [1]) are of main interest to the Copernicus program [2]. In the present work, estimates of Chlorophyll-a (Chl-a) concentration obtained with two different regional bio-optical algorithms for the Black Sea are merged as a function of the sea-water optical complexity [3]. The first data product (Chl-$a_{B/R}$) is determined with a band-ratio (B/R) polynomial regression as a function of the slope of Remote Sensing Reflectance (R_{RS}) values at 490 and 555 nm [4]. The second data product (Chl-a_{MLP}) is derived with a Multilayer Perceptron (MLP) neural net based on R_{RS} values at 490, 510 and 555 nm [5]. Both algorithms are based on the same set of BiOMaP field measurements [6] and the merging scheme is designed to compute Chl-a_{mrg} values benefitting from extrapolation properties of the B/R algorithm and the interpolation capabilities of the MLP neural net. Remote sensing data employed to demonstrate the merging results are L2 images acquired by the Ocean Land Colour Instrument (OLCI) on-board Sentinel-3A (reprocessing of January 2018) [2]. The data analysis includes comparison between regional results and OLCI standard products (Chl-a_{OC4} and Chl-a_{NN}). Results indicate that the application of the B/R algorithm only can lead to Chl-a overestimation especially in coastal areas under riverine influence. The exclusive use of the MLP neural net, instead, may suffer from a reduced coverage in areas where input R_{RS} spectra are out of the MLP applicability range. The merging scheme allows for slightly reducing the Chl-a overestimation of the B/R algorithm, whilst broadening the data product range with respect to that featured by the MLP alone. Both, the Chl-a_{OC4} overestimation tendency and the better performance of Chl-a_{NN} illustrated in this work, are confirmed by a validation study recently presented in literature [7]. As part of the activities of the Copernicus Marine Environment Monitoring Service, Chl-a_{mrg} maps have been included within the deliverables of Ocean Colour Thematic Assembly Centre relying on reprocessed input R_{RS} spectra time series (1997-2017) at 412, 443, 490, 510, 555 and 670 nm.

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Bayesian Modeling of Marine Inherent Optical Properties in Coastal Waters

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The advent of satellite oceanography has generated tremendous insight into marine biogeophysical processes by providing a global view of phytoplankton distribution dynamics, with measurable impact on various fields like ecology, fisheries, climate science. One of the principle obstacles in this endeavor is that the water's contribution to the sensed light field is dwarfed by that of the atmosphere. Some of this, like Rayleigh scattering, is straightforward to correct for. However, light redirected to the sensor by spatially and temporally variable aerosol distribution has so far been addressed by computing a modeled approximation. This approximation works well in the open ocean, but runs into trouble in coastal regions, where both marine and atmospheric layers are often optically complex, and as yet not well understood.

Here, we propose circumventing the atmospheric complexity of coastal areas, and use top-of-the atmosphere radiance, along with some additional ancillary input, to estimate phytoplankton absorption- a proxy for phytoplankton distribution. To this end, we develop and compare a series of linear and non-linear models using a Bayesian modeling framework. Bayesian formalism has a number of advantages. Among these are the inclusion of background information in models, built-in prediction uncertainty, and its compatibility with Information Theory for robust model evaluation and comparison.

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Estimation of sea surface salinity distribution from the Changjiang River outflow using deep neural network

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Abstract: The Sea Surface Salinity (SSS) variability due to the vast river plumes influences near the coastal water significantly. Especially, although Chang-Jiang River mouth is off coast of south-east China, this plume influences not only the East China Sea but also Korean coastal regions including around the Jeju Island. The problem is that it is hard to measure the in-situ SSS due to that the freshwater from the original region is the water in the foreign territory. Therefore, measuring SSS from satellites is one of the important tasks to analyze coastal water changes around Korea. However, there are no satellite observations to investigate coastal SSS variability. Therefore, many studies were conducted for estimating SSS using ocean color satellite data based on the fact that the low SSS presents high optical features around the river plume regions. To estimate SSS, Geostationary Ocean Color Imager (GOCI) and Soil Moisture Active Passive (SMAP) satellite data were analyzed using Deep Neural Network (DNN) algorithm for the Chang-jiang River plume regions in this study. The correlation coefficient between predicted SSS and SMAP SSS of validate dataset is 0.91 and Root Mean Square Error (RMSE) is 0.97 psu. The RMSE was relatively high in river mouth region where SSS variability was high. This research is in progress.

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Analysis of application changes according to concept change of GOCI Data Service

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Korea Ocean Satellite Center (KOSC) of Korea Institute of Ocean Science & Technology (KIOST) is main operation station of Geostationary Ocean Color Imager (GOCI) which was launched in 2010. The distribution of GOCI data was started in April, 2011. KOSC provides radiometric/geometric calibrated (Level 1B) data and ocean products (Level 2) data for public user using our web site and off line.

Recently, demand for the operational application of GOCI data explosively increased. Therefore, the concept for operation for GOCI changed from support the research to operational application service. KOSC provides the results of analysis of various national issues such as not only oceanic phenomena (red tide, green tide, brown algae, low salinity water, sea fog, sea ice, coastal upwelling, and so on) but also land/atmospheric phenomena (typhoon, forest fire, aerosol, and so on) to related organizations using FTP and e-mail/official document.

As a result, the number of GOCI data download was increased rapidly from 70,000 (2014~2015) to 1,000,000 (2016~2018) per year. The number of related organizations increased to 33. There is a continuing request from the unincluded organizations.

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Development of Atmospheric Corrected GK-2A True Color RGB Images

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True color RGB imagery can express variety of atmospheric phenomenon intuitively for example, cloud, yellow dust, fog, and volcanic ash. We applied true color RGB using the GEO-KOMPSAT-2A (GK-2A) launched in December, 2018, which improved observational performance compared with Communication, Ocean, and Meteorological Satellite (COMS) in terms of spatial, temporal, and spectral resolution.

The sensor measured reflectance is reduced by atmospheric scattering. Rayleigh scattering effect is inversely proportional to wavelength so visible channels needed to be corrected. Without reduction, we constructed a look-up table (LUT) considering geometric conditions and atmospheric conditions using Second Simulation of the Satellite Signal in the Solar Spectrum (6S) Radiative Transfer Model (RTM) to correct atmospheric effect in visible channels.

Inspection of created LUT showed that atmospheric correction coefficients dramatic increased over 70 degrees of solar zenith angle and viewing zenith angle. As a results, reflectance near limb area occurred over correction values. To mitigate reflectance, we applied limb correction by fixing angles.

GK-2A green channel wavelength (0.51 ㎛) is different from the green grass vegetation (0.55 ㎛) from NASA's Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) spectral database. One of alternative way is hybrid green method which combined with near infrared band (0.87 ㎛) to mimic green grass vegetation. We applied hybrid green instead of original green band.

True color RGB imagery applied atmospheric correction showed dark. Supplement method is histogram equalization. This method is aimed to more brighten image by expanding narrow color distribution. True color RGB imagery is useful to prompt detection and analysis.

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Deep Convolutional Neural Network for Spatial Red Tide Detection

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It is important to detect promptly red tide blooms in a vast ocean for protecting marine ecosystem. In this study, we proposed a deep convolutional neural network (CNN) for automatic spatial red tide detection. In order to train the CNN, we constructed training data with GOCI images between 2011 and 2018 and other environmental factors such as sea surface temperature (SST) and photosynthetically active radiation (PAR). The CNN can learn the spectral features and the correlation related to the occurrence of red tides from GOCI spectral images and the environmental factors. The spectral GOCI images are taken hourly over Northeast Asian region at 8 times a day with spatial resolution of 500 m. The daily SST and PAR data come from MODIS and GHRSST. Three spatial data have different spatial resolution, thus we did pre-processing to match the resolution over the interested region. As ground truth indicating where the red tides were occurred, we considered a red tide index map generated by a decision tree and real measurements provided from National Fisheries Research & Development Institute. The trained CNN gave well-matched red tide index maps to ground truth.

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Feasibility of the satellite-sensed surface chlorophyll concentration maps for the submesoscale process studies

Sung Yong Kim[1] , Eun Ae Lee[1]

The regional variability and turbulent characteristics of submesoscale surface chlorophyll concentrations are examined with hourly maps of geostationary ocean color imagery-derived chlorophyll concentrations at a 0.5-km resolution for a period of five years (2011 to 2015) over the East/Japan Sea with concurrent mesoscale and submesoscale observations. Two seasonal blooms occur in the spring and fall within 250 km off the coast that are associated with constructive combinations of light exposure, nutrients, and vertical stratification. Another bloom occurs in the summer and is closely related to regional wind-driven upwelling events. The spring and fall blooms are more significant near the coast (within 40 km from the coast) than offshore because of the more energetic submesoscale horizontal shear and vortical phenomena onshore as well as their propagation in the cross-shore direction. In addition, the regional spring bloom starts offshore and migrate onshore with a time delay of one month, which may result from the onshore propagation of geostrophic currents, the deepening of the mixed layer, and favorable nutrient fluxes from the subsurface. The wavenumber-domain energy spectra of chlorophyll concentrations exhibit anisotropy, which may be closely related to bathymetric effects and regional circulations. The spectral decay slopes change from k-5/3 to k-1 at the O(10) km scales and from k-1 to k≤-3 at the O(1) km scales and have weak seasonality. These results are consistent with the two-dimensional quasi-geostrophic turbulence theory and can be interpreted with the baroclinic instability energized from the moderate seasonal mixed layer under mesoscale regional circulations.

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Factors Influencing Water Color Development in Masan Bay, Korea

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Slack-tide sampling was carried out for the surface and bottom waters of 7 stations in the summer (7, 8, 9) and fall (10) of 2016 in order to identify the factors of the water color development in Masan bay. The measured data were analyzed by spatial variation analysis and Pearson correlation analysis. The unfiltered and filtered samples showed a large difference in the HZCU (Hazen Color Unit, TCU) for the surface and bottom waters of all the stations. The HZCU of the filtered sample showed almost 0~5 TCU. As a result, HZCU of both surface and bottom water was simply generated by the particulate matters.
In summer, the HZCU of the surface water at the uppermost station (ST1) where the large amounts of stream water were flowed into showed a high level, due to the high turbidity (TURB) concentration. The HZCUs of the surface waters at the upper (ST2~4) and the middle (ST5) stations showed high levels and increased in almost the same pattern as the chlorophyll-a (Chl-a), suspended solid (SS) and total organic carbon (TOC), due to eutrophication. The HZCU and Fe content in SS ((Fe)SS) of the surface water at each station changed to almost exactly the same pattern. Also, the SS and (Fe)SS changed in approximately the same pattern. The HZCU of the bottom water at ST1 showed a high level, due to the high TURB and then decreased in the same pattern as H2S according to moving to the entrance of the bay, after increasing with H2S at ST2. Eutrophication did not have any effect on the HZCU of the bottom water.
In summer, there were strong positive correlations between HZCU and TURB ($r=0.508$, $p<0.05$) and between HZCU and TOC ($r=0.803$, $p<0.01$), and a strong negative correlation between HZCU and dissolved inorganic phosporus (DIP) ($r=-0.631$, $p<0.01$) for the surface water. And there were strong positive correlations between HZCU and (Fe)SS ($r=0.844$, $p<0.01$), between SS and (Fe)SS ($r=0.857$, $p<0.01$) and between SS and TOC ($r = 0.792$, $p<0.05$) for the surface water. There were strong positive correlations between HZCU and TURB ($r=0.682$, $p<0.01$) and between HZCU and TOC ($r=0.566$, $p<0.01$) for the bottom water. Therefore, the HZCU of the surface water resulted from TURB and the amplification by combining (Fe)SS with the SS containing TOC (algae growth and humic substances). The HZCU of the bottom water resulted from TURB and the TOC due to the elution of contaminated sediments. In fall, the HZCU of the surface and bottom waters showed a variation of the almost same pattern as the TURB, and eutrophication, H2S and TOC did not have any effect on the HZCU.
In summer, the apparent color observed for the surface water was very dark and cause an aesthetic problem, but in fall, the apparent color was clear and did not cause an aesthetic problem.

Keywords: spatial variation analysis, Pearson correlation analysis, HZCU, TURB, Chl-a, SS, TOC, $(Fe)_{SS}$, eutrophication, elution of contaminated sediments

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Development of a Joint MISR/MODIS Ocean Color Atmospheric Correction algorithm

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We recently started development of a new algorithm that combines observations from MISR and MODIS (both on the NASA Terra spacecraft) to provide improved atmospheric correction and coverage for ocean color data products. This algorithm will utilize information rich, multi-angle observations from MISR for atmospheric correction (including angles that observe reflected sun glint), and apply this correction to MODIS spectral channels. We will therefore produce atmospherically corrected Remote Sensing Reflectance as a research evaluation product, with enhanced coverage (in typically glint screened regions) and accuracy, for input to downstream bio-optical ocean parameter retrieval algorithms.

This algorithm utilizes the resources of the Ocean Biology Processing Group (OBPG) at the NASA Goddard Space Flight Center. Thus far, we have ingested MISR data into the data processing system at the OBPG, and started initial atmospheric correction tests. This includes the generation of atmospheric correction Lookup Tables (LUT's) which will be used to derive surface wind speed in addition to aerosol parameters required for atmospheric correction. We are also developing an information content assessment tool, which will ultimately guide the atmospheric parameterization scheme we will use in our retrieval. Additionally, we are investigating the first application of ocean color instrument vicarious calibration techniques to the MISR instrument. The status of these activities will be described here.

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

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

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Towards Close-Range Ocean Colour Investigations with Aerial Drone-based Hyperspectral Imaging Technology

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Advancements in hyperspectral sensors and aerial drone technologies have opened the potential for more comprehensive ocean colour and shallow benthos measurements to aid in the understanding of ocean and coastal ecosystems. Instead of being constrained to orbiting schedules of remote sensing satellites, coupling compact hyperspectral imaging sensors onto small commercial aerial drones allows for hyperspectral data to be collected on demand. The spatial resolution of the collected data from the low altitude platform is significantly higher than that of satellite systems – between 5 cm and 50 cm per pixel as compared to between 250 m and 1 km per pixel. Though the very high-resolution output from aerial drone systems is advantageous, its area coverage, however, is limited to the flight endurance capacity of the aerial drone and other uncontrollable variables (e.g., cloud, sunlight, winds, tides). Therefore, undertaking successful field campaigns that produce usable and high-quality data requires informed planning and cross-disciplinary experience. This paper proposes a framework for undertaking successful campaigns to collect high-quality, ground-truthed and map-ready hyperspectral data using aerial drone systems in open waters and reef systems. The methods have been developed and trialled at Davies Reef, central Great Barrier Reef, Australia. After the data collection campaign, orthorectification and radiometric calibrations were implemented, producing a standardised georeferenced hyperspectral data cube. Deterministic annealing was used to cluster materials according to their spectral reflectance properties. The resulting analysis, validated against existing in situ data, provided valuable insights into the reef composition that can be used to understand benthic habitats and to document events such as coral bleaching and flood plumes. The high spectral and spatial resolutions produced by the airborne system offers a new compelling tool for mapping and monitoring shallow water reef habitats. Besides coral reefs, close-range hyperspectral imaging can also contribute to other fields of ocean colour, such as satellite calibration, modelling water quality, seagrass meadows, phytoplankton blooms, oil slicks and coral spawn slicks.

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Retrieval of Size-Partitioned Phytoplankton Carbon Via the Particle Size Distribution Using Coated Spheres Modeling

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The KSM09 algorithm (Kostadinov et al., 2009) retrieves the parameters of an assumed power-law particle size distribution (PSD) using the magnitude and spectral shape of the particulate backscattering coefficient. Under certain assumptions, the retrieved PSD can then be used to estimate the size-partitioned bio-volume (Kostadinov et al., 2010). Applying published allometric relationships, absolute and relative size-partitioned phytoplankton carbon concentrations (i.e. carbon-based phytoplankton size-classes or functional types (PSCs/PFTs)), as well as total POC, can be retrieved (Kostadinov et al., 2016). The look up tables (LUTs) used by KSM09 are constructed using a homogeneous sphere Mie scattering model. Achieving realistic values for absolute POC and phytoplankton carbon that validate well against in-situ POC measurements and are comparable to other retrievals and CMIP5 models requires the use of an empirical correction factor for the PSD scaling parameter (Kostadinov et al., 2016). This factor is derived from validation of the PSD retrievals against limited in-situ measurements. Previous studies indicate that the backscattering coefficient is heavily influenced by the structural heterogeneity and compositional complexity of phytoplankton cells, more so than other IOPs. Achieving better closure and PSD/C-based PFT retrievals based on backscattering will require relaxation of the homogeneous sphere assumption and better treatment of the complex index of refraction. Organelli et al. (2018) recently concluded that a coated sphere Mie scattering model reproduced realistic oceanic surface backscattering coefficients much better than a homogeneous sphere model, achieving better closure for both backscattering and beam attenuation. The above considerations indicate that an update to the KSM09 model is recommended. Here, I present initial results of application of a coated spheres Mie scattering model used to generate updated LUTs for the retrieval of the PSD. The coated-spheres LUTs are compared to the KSM09 LUTs. The KSM09 PSD and total and size-partitioned phytoplankton carbon retrievals are compared to the new retrievals based on coated spheres, for a test image. Monte Carlo simulations are used to assess uncertainty arising from variability of the Mie code input parameters, namely the relative complex indices of refraction of the particle core and coat, the coat thickness, and the maximum particle diameter. The cumulative modeled backscattering coefficient is investigated as a function of diameter for polydispersions in order to ascertain what size range of particles contributes the most to the backscattering signal in the coated spheres case.

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NOAA 2019 update: in situ validation activities for satellite ocean color products and related ocean science research

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Abstract: The National Oceanic and Atmospheric Administration (NOAA), Center for Satellite Applications and Research, Ocean Color team takes an "end-to-end" approach to the production of near real time and delayed mode high quality satellite ocean color products that support research and applications by all NOAA Line Offices, as well as external users in the government, academic, commercial and general public sectors. In situ validation of satellite data is essential to the process. In May 2019, the fifth annual NOAA research cruise dedicated to the primary objective of ocean color calibration and validation (Cal/Val) for the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) will be conducted with ship time awarded by the NOAA Office of Marine and Aviation Operations. On these cruises, In situ radiometric observations are made of apparent optical properties (e.g., remote sensing reflectance) and inherent optical properties (e.g., absorption and backscattering coefficients) along with other optical, biological and biogeochemical parameters. Cruise activities are documented in NOAA Technical Reports: November 2014 (Report #146, https://dx.doi.org/10.7289/V52B8W0Z); December 2015 (Report #148, https://dx.doi.org/10.7289/V5/TR-NESDIS-148); October 2016 (Report #151, https://doi.org/10.7289/V5/TR-NESDIS-151). The technical report for the May 2018 cruise is currently in progress. NOAA CoastWatch/OceanWatch is developing a database for in situ observations in support of satellite validation. Datasets from NOAA Cal/Val cruises are in the process of being archived and will be publically accessible through NOAA National Centers for Environmental Information. The NOAA Ocean Color Cal/Val team, composed of NOAA and external academic principal investigators, also collaborates with other investigators and field programs to leverage in situ observations for satellite validation and for algorithm development. The NOAA optical sensor calibration laboratory with NIST traceable materials is operated in College Park. NOAA also supports the operation of four AERONET-OC sites in US coastal and inland waters.

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Evaluation of GOCI R_{rs} data retrieved from GOCI Level 1B data using the correction of inter-slot radiometric discrepancy

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Abstract: GOCI image has a radiometric stray light, called as inter-slot radiometric discrepancy (ISRD), which means radiometric inconsistency between the adjacent slots. The Correction of Inter-slot radiometric Discrepancy Using the Minimum noise fraction transform, namely CIDUM, is in effect to reduce ISRD in the GOCI Level 1B.

This research evaluates for reduction of horizontal ISRD in remote sensing reflectance (R_{rs}) data, which is retrieved from GOCI Level 1B data corrected by CIDUM. Atmospheric correction is performed by GOCI Data Processing System (GDPS) V.2.0. For the evaluation the bottom image in ISRD area where northern and southern images are overlapped is assumed as reference data. The horizontal discrepancy is mitigated in all ISRD area and the differences between upper- and bottom- slots becomes close to 0. But it doesn't work for blue bands effectively.

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An Empirical Model for the Evaluation of Chlorophyll-a and Trophic Status of Lake Victoria from MODIS Aqua Satellite Imagery

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Abstract

With a surface area of about 68,000km2, Lake Victoria is Africa's largest and the world's second largest freshwater lake. It is a transboundary lake shared by Uganda, Kenya and Tanzania. The lake supports more than 20 million people within its basin with water for domestic, agricultural and industrial activities on top of contributing to economic development and being an important part of the ecosystem. Human activities within the basin coupled with climate change have affected the water quality resulting in increased eutrophication. Because of its adverse effects, monitoring and communication of the level of eutrophication is of paramount interest. This is done by measuring among others chlorophyll-a (Chl-a), a phyto-pigment present in all algae groups. Chl-a is then used to derive the trophic status of the water body which is used to communicate to practitioners on the quality therein. Conventionally, Chl-a is determined using in situ and laboratory methods, however these are time consuming, cumbersome and limited in space and time. These limitations inspired the exploration of space based techniques as an alternative. Using Standard algorithms, Chl-a has been evaluated from satellite imagery, however these algorithms have been seen to overestimate Chl-a in Lake Victoria. Therefore this research sought to improve the modeling of Chl-a for the evaluation of the trophic status of Lake Victoria from MODIS Aqua satellite imagery.

Sampling was performed in two excursions to Lake Victoria on November 26th 2014 (Chl-a data) and July 27th 2015 (Chl-a and spectral reflectance from handheld field spectrometer). Using the July dataset, a linear model was developed to quantify in situ Chl-a from in situ reflectance (R2 0.71). Whereas there was a strong correlation, when this model was applied to the MODIS image obtained on the same date, it performed poorly for Chl-a retrievals (R2 0.071). This was attributed to the difference in atmospheric conditions at the sensors and sensor bandwidth. Using data from both excursions, in situ Chl-a was then modelled from MODIS derived reflectance, using every other match-up for model development and the residual data for validation. The results showed that the resultant linear model (R2 0.901) when validated was suitable for the quantification of Chl-a over the study period (R2 0.877). This model was applied onto monthly binned MODIS satellite images collected between November 2014 and July 2015. The results showed that for the study duration, Lake Victoria was generally oligotrophic inshore with eutrophic hotspots most notably in areas close to Kampala-Uganda, Kisumu-Kenya and Mwanza-Tanzania.

This research provides an operational tool for the retrieval of Chl-a from MODIS satellite imagery that can be utilized by various stakeholders such as the national environmental, fisheries, water and sewerage organisations. It emphasizes the strength of a specified model for Chl-a retrieval on Lake Victoria. In order to further improve this model, the use of an extensive in situ data set captured across a larger geographic area and in different seasons is recommended for calibration purposes.

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ProVal: A profiling float dedicated to radiometric measurements

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In-situ high quality measurements of radiometric quantities are mandatory to enable a "system vicarious calibration" (SVC) of satellite sensors dedicated to Ocean Color Radiometry (OCR) as well as to validate their derived products. These data are especially needed for remote areas poorly covered by oceanographic cruises, areas where atmospheric properties are poorly constrained and in areas with known bio-optical anomalies. This necessity is particularly critical during the early stages of an OCR satellite activity. Autonomous profiling floats have revolutionized oceanography by massively increasing the number of profiles; we argue here that dedicated floats could provide a strong foundation for global SVC.

The ProVal float measures downward irradiance and upwelling radiance at seven wavelengths on two arms that allow radiometer redundancy and shading mitigation. We analyzed more than 500 profiles sampled in the Southern Ocean, Mediterranean Sea, and Ionian Sea to date. We find that 45% and 85% of data in the surface layer exhibit tilts lower than 10° in the Southern Ocean and Mediterranean Sea respectively. From comparison between the redundant sensors the maximal relative drift is estimated by less than 0.2% per month over a year. Floats deployed in the Mediterranean Sea were recovered allowing post-deployment calibrations of radiometers that confirmed the low sensor drift. In addition, platform shading, estimated from the difference between the two radiometers, shows good agreement with Monte-Carlo simulations. Finally, comparisons of Remote Sensing Reflectance with VIIRS and the OLCI sensor (Sentinel-3A) show results in agreement with other sources of *in-situ* data but with extended coverage capabilities.

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No. 59

Trophic state assessment of global lakes and reservoirs using a MODIS-derived Forel-Ule index

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Abstract: The eutrophication of lakes and reservoirs is a serious global environmental problem. Remote sensing technologies can be used to assess the trophic state of lakes and reservoirs by retrieving water quality parameters like chlorophyll-a; however, they usually suffer from regional and temporal limitations due to the complex optical properties of lakes and reservoirs. In this study, we developed a new method to assess the trophic states of lakes and reservoirs using Moderate Resolution Imaging Spectroradiometer (MODIS) images to identify the Forel-Ule idex (FUI). We applied this method to assess the trophic states of 1423 large-and medium-sized lakes and reservoirs that distributed around the world in the austral and boreal summers of 2012. The results showed that the overall accuracy of the FUI-based trophic state assessment method is 77.8%;furthermore, the assessment accuracy for eutrophic assessment reached 90.0%. Of the 1423 water bodies considered, 38.2% were found to be eutrophic, 55.5% were mesotrophic, and 6.3% were oligotrophic. Oligotrophic to slightly mesotrophic water bodies were found to be concentrated in northern North America, southern South America and central Asia, while eutrophic water bodies concentrated in eastern and southern Asia, eastern Africa, and southeast North America. Factor analysis showed that anthropogenic variables have a significant correlation with eutrophication, while meteorological factors and the geographical position of lakes and reservoirs also play a role.

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Spectral characteristics analysis and retrieval of Chlorophyll α and CDOM in Liao River Estuary

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Monitoring of estuary water quality is complicated but significant due to the complex optical properties of water body. Hyperspectral technology is a powerful tool to recognize spectral characteristics of water quality parameters according to previous studies. Based on 53 sets of synchronous measurements of Chlorophyll α, CDOM concentration and spectral reflectance of Liao River Estuary, China, this study aimed to make accurate identification of spectral characteristics of Chlorophyll α and CDOM using correlation analysis between water quality indexes and transformed spectral reflectance including band difference, band ratio, principal component analysis (PCA) and first derivative in 400~850nm bands. Then the four kinds of characteristic spectral bands were selected to develop linear regression models for retrieval of Chlorophyll α and CDOM concentration which were subsequently validated by 10-fold cross validation. The results showed that compared to original reflectance, the above-mentioned four methods improved relevance between water quality indexes and characteristic spectrum to a similar degree (R increased from 0.6 to 0.8). The characteristic spectrum of Chlorophyll α appeared at 678~689nm, and the band ratio model (R_{688}/R_{678}) had best performance (R^2=0.75, P value < 0.001). The characteristic spectrum of CDOM located in 738nm and 770~783nm, and the band difference model (R_{738}-R_{781}) showed the best fit (R^2=0.68, P value < 0.001). The fist derivative model performed well both for Chlorophyll α and CDOM, with R^2 reached to 0.74 and 0.63, respectively. However, PCA model showed relatively low but acceptable performance with R^2 equal to 0.65 and 0.56. A stratified sampling which were executed on the optimal models showed that a stable model can be built with ~35 samples for estimation of Chlorophyll α and CDOM concentration.

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E-MOBY: a new candidate infrastructure for Copernicus Ocean Colour Vicarious Calibration: Preliminary Results.

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Copernicus/EUMETSAT funded activities aimed to produce a preliminary design of the Copernicus Infrastructure dedicated to Ocean Colour Satellite Vicarious Calibration (OC-SVC) are here considered. A comprehensive vision is firstly presented to establish a reference for the Design phase of the OC-SVC infrastructure. OC-SVC scientific and operational requirements are then evaluated accounting for a wide range of components related to Ocean Colour science and Vicarious Calibration. These include: in situ infrastructures, measurements, and protocols; metrology applied to field radiometry; marine field operations; Ocean Colour operational processing chain; Ocean Colour modelling error sources; radiative transfer modelling and in situ data processing.

The design and the project planning components are undertaken accounting for requirements for the OC-SVC Infrastructure defined in a previous study. A specific emphasis is given to solutions addressed to attain short- and long-term goals of Copernicus OC-SVC infrastructure.

The design proposed for the Copernicus OC-SVC Infrastructure is based on the recently developed MOBY-NET system based on MOBY, this being a successful technology build upon more than 30-year experience capable of offering a technologically proven system within a timeframe in line with Copernicus SVC requirement. The devised Copernicus OC-SVC Infrastructure, called E-MOBY (European Marine Optical BuoY), is conceived to support vicarious calibration for Copernicus current missions (Sentinel-3/-2 A, B,C,D), Third Party ocean colour missions, and Copernicus Ocean Colour data services. The System specification is designed to ensure the value of European contribution to OC-SVC global assets.

Starting from the MOBY-NET concept, the study investigates E-MOBY adaptions to best fit the specificities and the marine optical properties of the European site. To this aim, E-MOBY will be designed to ensure operational and sustainable measurements of water-leaving radiance, the key quantity in the vicarious process, which are SI traceable and meet application requirements. The design approach is committed to the highest radiometry standards and operational readiness.

The Ground Segment will be scoped to acquire and archive E-MOBY measurements, as well as to derive and distribute data products for computing Vicarious Calibration Gains and related uncertainties. A modular structure of the overall system is adopted to be able to update independently individual subsystems (field and ground) without the need to reconsider the whole system architecture.

To meet the objectives and OC-SVC infrastructure requirements, the study includes the following tasks:

1. investigate the optimal location for the E-MOBY deployment by considering a detailed characterization of different candidates.;
2. design the field segment accounting for the surface buoy and optical system, deployment structure as well as associated activities including radiometric characterizations and calibrations;
3. design the ground segment by ensuring reliable solutions for data acquisition, data processing, data products and data services;
4. devise the operations for the field segment (operation procedure for servicing, rotation in the field, refurbishment and replacements) and ground segment (data acquisition scheduling, operational data transmission, data processing, archive and dissemination, maintenance);
5. deliver data products accounting for all the components that contributes to the total uncertainty budget;
6. prepare an Infrastructure Project Plan which will encompass the OC-SVC design with technical specification, development phase, the infrastructure set up and the early operations as well as the cross-institutional cooperation framework;
7. detail the estimated cost of the infrastructure.

The prosed baseline is to deploy the E-MOBY near Lampedusa Island, a small and flat island in the central Mediterranean Sea surrounded by blue waters with very low chlorophyll concertation and no source of sediments. Since 90's, Lampedusa hosts the Climate Observatory collecting in situ measurements for the detailed characterization of the atmospheric structure and composition, and more recently oceanographic properties. Historical measurements at the site are used, together with ocean color field measurements acquired during oceanographic cruises cruise and satellite data, to perform a detailed site characterization. The study is furthermore aimed to evaluate additional deployment sites, namely: Madeira Island in the Atlantic and Antikithera Island, north of Crete. Past and recent sites characterizations presented in the literature shall be included in the analysis.

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Possibilities of Satellite Ocean Color Sensing to Determine Amplitudes of Internal Waves and Corresponded Chlorophyll-A Vertical Profiles

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This paper investigates the possibility of detecting the signs of internal waves (IW) in the satellite ocean color images, and to estimate IW amplitudes and simulate corresponded vertical distribution of chlorophyll-a (chl-a) with additional using of oceanographic modeled data and in-situ measurements.

IW have a significant effect on the vertical stratification of waters and turbulent mixing, which in turn leads to a change in the vertical distribution of temperature, salinity and optically active components (OAC), the content of which forms the color of the ocean.

Based on the analysis of the spectral remote sensed reflectance (Rrs) of the sea in the visible range outside the solar highlight, information on the IW amplitude can be obtained due to the recorded ocean color variations associated with changes in the stratification of the main OAC of sea water: phytoplankton, colored dissolved organic matter (CDOM) and suspended matter.

To study the possibility of detecting IW in the Rrs spectra of the sea, hourly sub-satellite CTD profile measurements of the hydrological and biooptical parameters of sea water were carried out in Peter the Great Bay during the IW generation. Also satellite data of the mid-spatial resolution from the geostationary ocean color scanner GOCI-COMS, from the MODIS family scanners and VIIRS-SNPP were used for the Sea of Japan (East Sea). The data of the 2nd level of processing were used, which passed the standard procedures of atmospheric correction [https://oceancolor.gsfc.nasa.gov/]. For additional filtering, a quality flag was applied to the image pixels corresponding to the selection of data for level 3. This made it possible to exclude «boundary» cases with possible processing errors that could lead to false identification of IW. Also, areas of the image were filtered or marked, in which the wind speed was such that traces of internal waves could be significant in the sea waves data, which in turn could affect the estimates of the light reflection coefficients and thus have possible influence on the estimation of the OAC content "visible" from space.

The task of direct comparison of sub-satellite and satellite ocean color measurements during IW propagation is not easy, since a number of conditions must be the same: such generation of IW, which causes significant changes in the OAC stratification; sufficient content of OAC in sea water; the presence of clear weather to obtain the correct satellite optical data of the desired resolution; high quality satellite data passed through listed above filtration procedure. Unfortunately, it was not possible to obtain direct comparisons in the presented work. Therefore, from the sub-satellite in-situ data obtained during the IW generation, we calculated the Rrs spectra, which would have been observed remotely. Peculiarities of changes in the vertical distribution of chl-a and DOM during the passage of IW were also determined. The variability of the modeled Rrs spectra and characteristic changes in the spectral shape were estimated.

IW were detected in the MODIS-Aqua estimations of chl-a in the central part of Japan (East) Sea in September 2003. Interpolation along the propagation direction of waves with a step of 0.1 km using the nearest neighbor and cubic splines algorithms were performed. The magnitude of the variations chl-a was about 0.03–0.05 mg/m^3 (7–12%) and the oscillation period was about 2–3 km (1–2 pixels per peak). Observed chl-a variations could be associated with changes in the depth of the main mass of phytoplankton cells. IW with a similar manifestation on sub-satellite in-situ data had an amplitude of about 3 meters.

The manifestations of IW on the GOCI data found by the authors of [Pan et al, 2015] in the southern part of the Japan (East) Sea in August 2013 were also analyzed. Here the amplitudes of explosives were additionally estimated based on the methods of [Shuleikin V.V. 1968, Apel et al., 1985]. As the difference in estimates of IW phase velocities from changes in water density in the pycnocline zone according to HYCOM data [https://www.hycom.org/] (0.68 m/s) and from neighboring GOCI images (1.38 m/s), the wave amplitude was calculated - 20.34 m. The distance between the crests was about 8 km. Variations of chl-a amounted to about 10% of 0.27 mg/m^3. In this area, comparisons were made of satellite measurements of the Rrs spectra and the results of direct modeling of Rrs with different possible OAC stratifications based on the HYCOM density profiles. A range of solutions is obtained that satisfies observations made from a satellite.

On the basis of the obtained results, it can be concluded that with the help of sea-color scanners it is possible to detect some types of IW when a number of conditions coincide, and these data can provide useful information for estimating the amplitude of IW and modeling corresponded vertical structure of phytoplankton cell distribution.

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Satellite estimation of particulate organic carbon flux from Changjiang River to the Estuary

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Abstract: Rivers link land and ocean ecosystems, the two largest active carbon reservoirs in the world, and transport tremendous amounts of particulate organic carbon (POC) into marginal seas annually. Due to high spatiotemporal variations, estimations of riverine POC flux into the sea can be relatively inexact when based on field measurement only. In this study, remote sensing algorithms of riverine POC flux through the Xuliujing hydrological station in the Changjiang River Estuary (CRE) were developed using satellite data with hourly resolution from the Geostationary Ocean Color Imager (GOCI). Based on data collected during four seasonal cruises in the CRE from 2014 to 2016, POC concentration showed a significant linear relationship to total suspended matter (TSM) ($N = 426$, $R^2 = 0.97$, $p < 0.01$). Thus, surface POC concentration was calculated by satellite-derived TSM. From the *in-situ* data, the vertical POC concentration profile at Xuliujing showed an exponentially increasing curve ($p < 0.01$), but a linear decrease ($p < 0.01$) for the water flow profile from the surface to the bottom. Combining the GOCI-derived surface POC concentration and vertical profiles of POC and water flow, we estimated monthly riverine POC fluxes to the CRE. Results showed that monthly POC flux at Xuliujing (0.071 ± 0.022 Tg C) was 22.64% higher, on average, than the commonly used value at the non-tidal Datong hydrological station. Moreover, under human activity pressures, the influences of POC input from the Changjiang River on POC concentration at Xuliujing have weakened in recent years. Monthly and diurnal POC variations in the CRE were mainly impacted by wind speed and tidal processes, respectively. Thus, satellite monitoring with high spatiotemporal resolution has great significance for accurately estimating riverine POC flux to estuary.

Keywords: Vertical profile; particulate organic carbon flux; Changjiang River; satellite remote sensing; Geostationary Ocean Color Imager (GOCI)

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Importance of the parallel polarization radiance for estimating inorganic particle concentrations in turbid waters based on radiative transfer simulations

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Abstract: Contemporary ocean color radiometers and inversion algorithms to derive optical properties and oceanic constituents rely only on the scalar treatment of water-leaving radiance (Lw). However, Lw polarization components, which contain embedded hydrosol information, have been largely neglected. Here, we examine Lw polarization characteristics, based on vector radiative transfer (RT) simulation, for determining suspended particulate matter in highly turbid waters. The RT simulations show that parallel polarization radiance (PPR) can improve the retrieval of Lw, with a higher relative fraction of ocean color signal to total radiance (Ioc/It) than the total intensity (I). Moreover, the remote-sensing reflectance for PPR ($R_{rs\text{-}P}$), compared with that for I, is more sensitive to inorganic particle concentration (IPC) variations, particularly those in the red and NIR bands. Additionally, $R_{rs\text{-}P}$ displays significantly directional and spectral variations with respect to geometrical conditions, and the maximum $R_{rs\text{-}P}$ is highly peaked at 555 nm (6%) in the solar plane. Furthermore, the relationship between $R_{rs\text{-}P}$ and IPC, based on the back propagation neural network, is established with a very high coefficient of determination (R^2=0.99999). Significant improvements in inversion accuracy are observed for PPR with a lower relative deviation (0.901%) than I (3.74%). This study highlights that PPR might be used as an alternative approach to retrieve Lw and thus to derive biogeochemical parameters, particularly in optically complex coastal waters.

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Uncertainty in optical remote estimation of biomass of *Ulva prolifera* macroalgae using MODIS imagery in the Yellow Sea

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Abstract: Annual blooms of *Ulva prolifera* since 2008 has been posing a significant threat to marine ecosystem in the Yellow Sea. Although spatial-temporal coverage of floating *Ulva prolifera* could be figured out by MODIS imagery, total biomass is essential for salvaging and cleaning up. Laboratory experiment was employed to obtain floating algae index (FAI) of floating *Ulva prolifera* corresponding to various Biomass per area (BP A). A piecewise empirical model (including linear and exponential functions) could be adopted to fit the statistical relationships between BPA and FAI, corresponding to FAI ≤ 0.2 (BPA ≤ 1.81kg/m^2) and FAI > 0.2 (BPA > 1.81kg/m^2) respectively. According to spectral mixing-derived results in this study, linear relationships between FAI and BPA are maintained when the BPA of endmember is less than 1.81kg/m^2. However, when the BPA of endmember is greater than 1.81kg/m^2, uncertainty in optical remote estimation of biomass will be displayed obviously Although MODIS-derived FAI of *Ulva prolifera* is often less than 0.2, it's really hard to identify the low FAI is from low BPA (≤ 1.81kg/m^2) of endmembers, or the low area ratio of high BPA(> 1.81kg/m^2) of endmembers due to pixel mixing. In this study, four MODIS imageries were used to show the uncertainty in biomass estimation of *Ulva prolifera* in the similar phonological period (i.e., June, summer in the yellow sea). Although we don't know the unit biomass distribution of pure endmembers, it could be assumed according to standard Gaussian distribution. Therefore, the uncertainty in optical remote estimation of biomass of *Ulva prolifera* would be given as follow. It would generate about ~36% uncertainty in total biomass estimation, and ~43% of the uncertainty is contributed by a few pixels (10% of total pixels) with high FAI (> 0.05). The uncertainty in BPA caused by a high-FAI (> 0.05) pixel is about 7.2 times as that of a low-FAI (≤ 0.05) pixel. In future, spatial distribution characteristics of FAI of pure endmembers should pay more attention to, which could be collected from high-spatial resolution images to improve the accuracy of optical remote estimation of floating *Ulva prolifera* macroalgae.

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Optical interpretation of oil emulsions in the ocean – From laboratory measurements to remote sensing applications

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Abstract: Optical identification and quantification of spilled oils in the ocean play an important role in oil spill monitoring and assessment as well as in mitigation. Through weathering processes, oil may become emulsified in two forms of oil-water mixture: water in oil (WO) and oil in water (OW). These two forms of oil emulsion are significantly different in their volume concentrations, physical properties (viscosity, density, thickness), and optical properties (remote sensing reflectance (Rrs(λ), sr-1), and spectral absorption (a(λ), m-1)). The optical properties of both types of oil emulsion, with different volumetric concentrations, are determined from carefully prepared oil emulsion samples, with the aim of helping to interpret optical remote sensing imagery. The concentrations of stable WO and OW emulsions range from 45-95% and from 0.025-3%, respectively. They exhibit different Rrs spectral shapes in the near-infrared (NIR) and shortwave-infrared (SWIR) bands, with five "-CH" molecular bonds evident in the WO emulsion spectra. The difference between the Rrs spectral shapes of OW and WO emulsions, as well as the statistical relationships between volume concentrations and Rrs (NIR-SWIR) and between oil thickness and Rrs (NIR-SWIR), provide the basis for developing optical models to classify oil types and for quantifying oil volume from remote sensing imagery. Using simulations and AVIRIS and Landsat observations, we show that false color RGB composite images from Landsat-like sensors (R: 1677 nm, G: 839 nm, B: 660 nm) are effective in differentiating WO and OW emulsions as they show reddish and greenish colors, respectively, in such composite images. Based on image statistics, a decision tree method is developed to classify oil type and quantify oil concentration for each type, with results partially validated through spectral analysis and spatial coherence test. The mixing experiment using AVIRIS pixels further indicates that the SWIR bands might be used to develop linear unmixing models in the future.

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Super typhoon Mangkhut-induced sea surface chlorophyll-a enhancement in different areas along the track

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Abstract: Typhoon can impact on the quantity and distribution of chlorophyll-a through physical processes including upwelling, vertical mixing and entrainment, which depend on the intensity, translational speed of typhoon, and pre-typhoon conditions. Generated on September 7, 2018 and dissipated on September 17, 2018, super typhoon Mangkhut passed through the northwest Pacific ocean (NWPO) and northern South China Sea (NSCS), caused chlorophyll-a enhancement in three regions along its track. The differences of upper ocean responses and sea surface biological responses to Mangkhut among these three regions were compared via the variations of water temperature, salinity, sea level anomaly (SLA), eddy kinetic energy (EKE) and chlorophyll-a concentration before and after typhoon at first, and then the water temperature and salinity vertical sections were used to study the relationship between upper ocean response to typhoon and chlorophyll-a enhancement. Linear-regression analysis was conducted based on sea surface chlorophyll-a concentration change with the changes of sea surface temperature (SST), sea surface salinity, SLA and EKE.

Results show that: 1) Obvious chlorophyll-a enhancement happened in NSCS, where tropical storm Barijat passed by just before Mangkhut. 2) A severe decrease of chlorophyll-a concentration appeared around Pearl River Estuary (PRE) due to vertical mixing, temperature reduction and rainfall dilution. 3) Besides typhoon structure, flows also contributed to the asymmetry of chlorophyll-a distribution. 4) The chlorophyll-a enhancement region in open ocean showed significant negative correlations between chlorophyll-a concentration change and changes of SST, SLA with Pearson correlation coefficients of -0.48, -0.47 respectively.

Key words: Typhoon Mangkhut; Chlorophyll-a enhancement; NWPO; NSCS;

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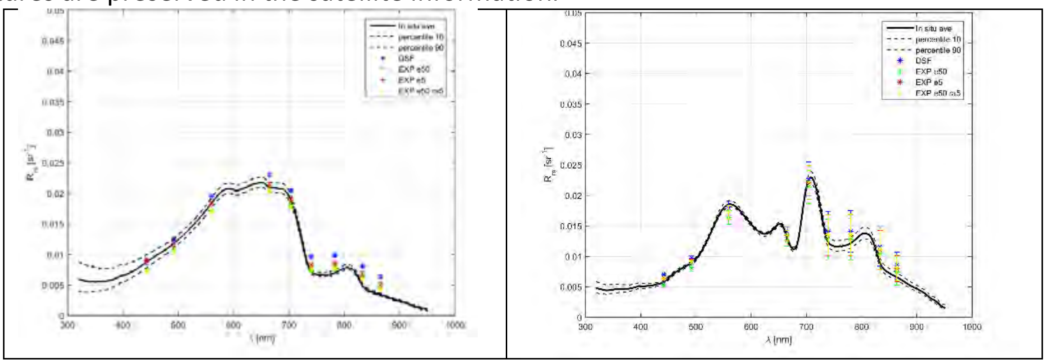
Evaluation of satellite spectral signatures to retrieve water quality parameters using different atmospheric corrections in the Rio de la Plata turbid waters

Fernanda Maciel[1] and Francisco Pedocchi[1]

Remote sensing of coastal turbid waters is challenging due to its optically complex waters in comparison with the open ocean. This work focuses in the northern coast of the estuary Rio de la Plata, located in South America between Argentina and Uruguay. The study period includes the southern hemisphere Spring-Summer 2018-2019. The data available are: 1) remote sensing information from Landsat-8 and Sentinel 2 (A and B); 2) above water reflectance obtained using Ramses-Trios hyperspectral radiometers, matching the time of satellite images (+/- 2 hours); 3) in situ data of turbidity and fluorescence of chlorophyll-a and phycocyanin. Firstly, data from 1) and 2) are compared to evaluate the performance of different atmospheric correction (AC) methods. The software Acolite (version 20181210.0) is used, and the recently available Dark Spectrum Fit (DSF, Vanhellemont & Ruddick 2018) is compared to the aerosol exponential model using SWIR bands (Vanhellemont & Ruddick 2015). For the latter, fixed 50th and 5th percentile ε are evaluated, as well as fixed 5th percentile aerosol reflectance (with 50th percentile ε). Two examples of in situ and satellite reflectance spectra are shown below (left: moderate turbidity and low phytoplankton concentration, right: low turbidity and cyanobacterial bloom). Considering the available data so far (more data will be available by the end of Summer.), the best fit is obtained using exponential SWIR AC with fixed ε, with relative error around 30%, and RMSE of 2.4×10^{-3} and 3.7×10^{-3} sr^{-1} for the 5th and 50th percentile ε respectively. The RMSE is similar for the fixed aerosol reflectance AC, but the relative error increases to 50%, while for the DSF method the relative error is over 80%. Except for the 50th percentile ε, all the methods present a global positive bias. When results are considered independently for each wavelength band, DSF presents a good performance for the visible bands, but highly overestimate the NIR region. A similar behavior is observed for the fixed ε and fixed aerosol reflectance method, while the fixed ε methods present a good to moderate performance for all the bands. It is important to highlight that all the methods give very similar spectrum shapes. Furthermore, data from 3) will be used to identify spectrum features for different water quality conditions, including the presence of blooms, and whether these features are preserved in the satellite information.



In figures satellite data is referred to each band center-wavelength. For AC evaluation in situ spectra is averaged for each bandwidth.

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No. 69

Arctic-COLORS (Arctic-COastal Land Ocean inteRactionS) Field Campaign Scoping Study Update and Plans

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The realization that changes within the Arctic have profound impacts on ecosystems and human populations across the globe has motivated greater attention. Yet major gaps remain in our understanding of the feedbacks, response, and resilience of coastal Arctic ecosystems, communities, and natural resources to current and future pressures. Most importantly, the Arctic coastal zone, a vulnerable and complex contiguous landscape of lakes, streams, wetlands, permafrost, rivers, lagoons, estuaries, and coastal seas—all modified by snow and ice—remains poorly understood. To improve our mechanistic understanding and prediction capabilities of land-ice-ocean interactions in the rapidly changing Arctic coastal zone, our team proposed a Field Campaign Scoping Study called Arctic-COLORS (Arctic-COastal Land Ocean inteRactionS) to NASA's Ocean Biology and Biogeochemistry Program. Arctic-COLORS aims to quantify the response of the Arctic coastal environment to global change and anthropogenic disturbances – an imperative for developing mitigation and adaptation strategies for the region. Arctic-COLORS is unprecedented, as it represents the first attempt to study the nearshore coastal Arctic (from riverine deltas and estuaries out to the coastal sea) as an integrated land-ocean atmosphere-biosphere system. The overarching objective of Arctic-COLORS is to quantify the coupled biogeochemical/ecological response of the Arctic nearshore system to rapidly changing terrestrial fluxes and ice conditions, in the context of environmental (short-term) and climate (long-term) change. The science of our field campaign will focus on three key science themes and several overarching science questions per theme:

(1) Effect of land on nearshore Arctic biogeochemistry
(2) Effect of ice on nearshore Arctic biogeochemistry
(3) Effects of future change (warming land and melting ice) on nearshore Arctic biogeochemistry

This field campaign will be composed of an integrative measurement approach utilizing a broad range of proven sampling approaches from a multitude of platforms including autonomous vehicles to achieve sufficient seasonal and spatial coverage to resolve the science questions proposed by the Arctic-COLORS team as well as remote sensing and development of coupled physical-biogeochemical models. While NASA's efforts on Arctic-COLORS focus on the coastal Arctic between Norton Sound, Alaska and the Gulf of Amundsen, Canada, our hope is that international funding agencies will adopt similar research goals to enable a Pan-Arctic investigation.

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Arctic-COLORS Team

Introduction of HY-1C satellite mission and ocean color productions

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China has launched the first ocean color satellite (HY-1A) on 15 May 2002, and the second (HY-1B) on 11 April 2007, and the third (HY-1C) on September 15, 2018. The satellites carry two payloads: the Chinese Ocean Color and Temperature Scanner (COCTS) and the Coastal Zone Imager (CZI). COCTS has eight visible bands for ocean color remote sensing and two infrared bands for sea surface temperature. A data processing system (HYDPS) has been developed to be used to generate some standard products from the HY-1C remote sensing data. Some examples of the products are introduced and compared with similar images from other satellites. The accuracy of the products has been evaluated on some in-situ measurements. The products will be distributed around the ocean color community. We hope to obtain many suggestions to improve the data quality of HY-1C.

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No. 71

Underwater hyperspectral light availability in fjordal ecosystems along coasts of Norway and Greenland

Veloisa J. Mascarenhas and Oliver Zielinski

Sunlight penetration underwater and its interaction with water optical constituents is an important physical phenomenon in the ocean that governs light availability underwater and determines the signature of ocean color. With an aim to study underwater light availability, radiometric profiles were measured along fjord transects along the coasts of Norway and Greenland. In concurrence, water samples were collected and analyzed via methods of spectrophotometry, fluorometry and gravimetry to quantify water optically active constituents (OACs). We present here hyperspectral one percent irradiance curves derived from in situ measured downwelling irradiance along fjordal transects. Three characteristic spectral types are identified:

(i) Type 1: V-shaped, with ~ 500 nm travelling deepest in the water column
(ii) Type 2: U-shaped, with ~ 500 – 560 nm travelling deepest in the water column
(iii) Type 3: V-shaped, with ~ 560 nm travelling deepest in the water column

Analysis reveals type 1 spectra to be characteristic of fjord sections with low concentrations of OACs, type 2 characteristic of fjord sections with intermediate concentrations while type 3 of high OAC concentrations. Investigation also reveals the fact that bio-optical variability in fjordal ecosystems is strongly influenced by meltwater composition upstream. In contrast to fjordal systems along the coast of Norway, meltwater influenced stations in fjordal systems along coast of Greenland exhibit type 1 spectral behavior.

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No. 72

Shallow-water Satellite-based Benthic Habitat Mapping and Classification of Special Fishery Conservation Areas, Jamaica

Ava Maxam[1], Renee Babb[2]

Abstracts: Benthic habitat classes were created of Jamaica's Special Fishery Conservation Areas (SFCAs) as a baseline to support the government's policy decisions for marine planning and management in building climate change resilience. Multi-spectral, 8-band, 2-m resolution satellite imagery from the WorldView-2 satellite sensor were processed across 4 SFCAs covering 47 km2 (4,700 ha) to produce benthic classes including: hard coral, rubble, sparse seagrass, dense seagrass, pavements, sand, mud and mangrove. The bands used for analysis included: blue, green, yellow, coastal blue, red, red edge, near-infrared 1 and near-infrared 2. Atmospheric correction, mosaicing, and water column correction were performed to remove water interference in analysing these submerged aquatic habitats. The radiometric approach was used in the analysis of the coastal marine ecosystem. A hybrid classification technique was employed comprised of unsupervised classification, followed by field validation and then refinement by supervised classification incorporating field data. Agreement of expected (classification results) and observed (field samples) were found acceptable for the SFCAs at: 90 % overall accuracy for Galleon Harbour, 80 % for Three Bays, 78 % for Bluefields Bay and 73 % for Whitehouse Bay (Matthew's Correlation Coefficient range: 0.65 > MCC > 0.88). This imaging with classification technique therefore worked well for identifying shallow-water benthic classes across all the SFCAs. Along with this acceptance, agreement of the classes correlated strongly with decreasing habitat richness (Pearson's r for agreement vs richness = -0.9913). This was expected as the more homogeneous the cover, the more predictable its characterisation. Galleon Harbour SFCA, for example, was significantly lowest in benthic richness and so displayed the most significant agreement between expected and observed classes.

Keywords: benthic habitat mapping, multi-spectral satellite imagery, Jamaica, Fisheries, conservation

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Springtime Coupling Between Arctic Sea Ice Export and Phytoplankton Blooms in the Greenland Sea

Nicolas Mayot[1], P. Matrai[1], A. Arjona[1,2], C. Marchese[3], T. Jaegler[3], S. Bélanger[3]

Over the pan-Arctic domain, the phytoplankton spring production is the major annual primary production event, playing a crucial role in marine food webs and biogeochemical cycles. In the Greenland Sea, located in the subarctic Atlantic region, the open-ocean area is a highly dynamic environment, influenced by both deep water convection and sea ice. Our objective is to address the influences of the exported Arctic sea ice on open-ocean phytoplankton spring bloom patterns observed in the Greenland Sea. We use almost 16 years of satellite-based chlorophyll concentration observations, interpolated to generate a dataset with a high spatiotemporal resolution. A light-photosynthesis model, specifically tuned for the Arctic Ocean, is then applied to derive net phytoplankton production estimates. The Arctic sea ice export and distribution are quantified with satellite microwave and true color imagery. Finally, the water column mixing (stratification) regime is studied with in-situ hydrological profiles from Argo floats. Results reveal spatial modes of variability of the phytoplankton spring bloom in the Greenland Sea, associated with freshwater stratification from sea ice melting. In fact, unusually high (low) exported Arctic sea ice in April lead to an early (delayed) phytoplankton spring production within a large open-ocean area of the Greenland Sea deep basin.

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Uncertainty assessment of MERIS and OLCI marine products

Constant Mazeran*

Assessing the uncertainty of satellite Ocean Colour Radiometry (OCR) and other marine products is a pre-requisite for their proper use in scientific and operational applications. It is particularly crucial for demonstrating the consistency of long-term data series built by a succession of satellite missions. IOCCG has recommended a "*better quantification of uncertainties in derived products, including an in-depth analysis of error sources and their propagation, with the quality of R_{rs} playing a critical role in the accuracy of retrieved Inherent Optical Properties*" (IOCCG, 2006). Within the International Network for Sensor Inter-comparison and Uncertainty Assessment for Ocean Color Radiometry (INSITU OCR; Zibordi *et al*. 2012), the Committee on Earth Observation Satellites (CEOS) and its contributing space agencies, guided by IOCCG, have further identified the need to "*enforce quantification of uncertainties on a pixel-by-pixel basis in satellite OCR [Ocean Colour Radiometry] and derived products*".

The Level-2 processors of ESA (both MERIS and OLCI) are made of successive steps, from ingestion of the Level-1 calibrated radiometry to the production of Level-2 marine reflectance and bio-optical products. It is a mission requirement to associate to each OLCI Level-2 products a pixel-by-pixel uncertainty (Donlon, 2011) and ideally this should be done for MERIS as well. To do so, an uncertainty budget shall be derived for each step of the Level-2 processor and be propagated from the Level-1 input radiometry to the Level-2 outputs. The atmospheric correction is a major contribution in the uncertainty propagation of instrumental radiometric noise, and also induces its own uncertainty through the aerosol retrieval in the NIR. Understanding the uncertainties of upstream steps is crucial in this propagation. Downstream steps, such as BRDF correction producing normalised reflectance, are also of much importance in the uncertainty of bio-optical product. These aspects are currently not handled in the ESA Level-2 processors.

The present work, conducted in the frame of ESA Sensor Performance, Products and Algorithms (SPPA, IDEAS+ consortium), reviews in detail the uncertainty budget of the end-to-end Level-2 ocean processor (baseline atmospheric correction branch in MERIS and OLCI) up to marine reflectance and chlorophyll concentration. Our methodology builds notably on the Quality Assurance Framework for Earth Observation (QA4EO). We deal with the various sources of uncertainty on a pixel-by-pixel basis: radiometric (instrumental and Level-1), ancillary (e.g. wind speed in glint correction, pressure in atmospheric correction) and model (e.g. LUTs in gaseous correction and atmospheric correction). This work gives a framework to derive the end-to-end and pixel-by-pixel uncertainty budget of the complete ocean colour processing. This analysis suggests some evolutions in the MERIS and OLCI processing chain to better handle the uncertainties and improve data quality.

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No. 75

Validation of satellite radiometric products from multiple missions: synthesis and analysis

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After 20 years of operational global ocean color missions and 16 years of activity by the ocean color component of the Aerosol Robotic Network (AERONET-OC), it is possible to take stock of validation results and draw general conclusions about the behavior of a standard atmospheric correction applied to SeaWiFS, MERIS, MODIS (A/T) and VIIRS. This study makes use of AERONET-OC radiometry data covering a large range of optical properties and collected at 5 coastal sites, in the northern Adriatic, Baltic (2 sites) and western Black (2) seas. For each site and satellite mission, the number of satellite match-ups is numbering tens to hundreds. Across missions and sites, the spectrum of RMS differences between satellite and field values of remote sensing reflectance most often shows a decrease with wavelength, with values in the blue generally between 0.0008 and 0.0025 sr^{-1}. Usually, the distribution of differences shows an approximately normal shape, which allows a statistical interpretation of the associated RMS differences. Average relative differences (in %) display a large variability, with values nearing 10% in the middle range of wavelengths and increasing in a typical horseshoe shape towards the blue and red bands. Differences appear to be well correlated across the spectrum. Furthermore, using match-ups common to several missions, some differences appear significantly correlated across missions, implying that part of the differences is not random. Considering the issue of representativeness and the uncertainties associated with field measurements, the interpretation of the observed differences in terms of uncertainty estimates is discussed.

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No. 76

A comparative study on optical characteristics on the West Coast of California and the sea waters around Korea

Jee-Eun Min[1] and Liane Guild[2]

Studying the light field of sea water is important in Ocean Color Remote Sensing (OCRS) because it brings immense information concerning the ocean environmental properties. This magnitude of the Apparent Optical Properties (AOPs) emerges from the sea-surface after incidence light energy has been absorbed and scattered by sea water constituents. The understanding of Inherent Optical Properties (IOPs) is very important in OCRS, especially in the bio-optical modeling, algorithm developments, water quality monitoring, and so on. In this study, we would like to describe the optical properties of the West Coast of California (WCC). To identify the optical characteristics for the WCC, we collected the IOPs (absorption and backscattering coefficients) and AOPs (in- and above-water radiometric measurements) for the chlorophyll (Chl), suspended particulate matter (SPM) and colored dissolved organic material (CDOM) from SeaWiFS Bio-optical Archive and Storage System (SeaBASS). We analyzed about 500 sets of the optical properties on the WCC and compared the results with observations in the waters around Korea.

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No. 77

Using GOCI to monitor suspended sediment concentration along Taiwan north coast affected by typhoon Soudelor

Pham Minh Chau[1,*], Wang Chi-Kuei [1], Ante Huang[1]

Abstract: This poster discusses using high spatial-temporal resolution satellite images to monitor the variation of suspended sediment (SS) concentration along Taiwan north coastal areas affected by a typhoon Soudelor. Satellite images derived from the Geostationary Ocean Color Imager (GOCI) are collected and then processed by applying an empirical algorithm to generate hourly maps, daily maps in both pre-typhoon and post-typhoon. These maps are created by a binning algorithm and to retrieve an average map of SS concentration including 3-day average image before the typhoon, 3-day average image after the typhoon and (10-12)-day average image after the typhoon. Results based on the histogram of these average maps shows that 3-day before the typhoon SS concentration from 0-5g/m3 was dominated about 97% while SS 5-15g/m3 were the lowest about 3%. However, 3-day after the typhoon the SS concentration 0-5g/m3 decreased from 97% to about 84% while SS 5-15g/m3 increased significantly approximate 16%, which was followed by decreasing to 4% (10-12)-day after the typhoon. This means that spatial-temporal variation of SS concentration was a significant increase to a peak in 3-day after the typhoon, and then it tends to return to its original status as before the typhoon after 10 to 12 days. Moreover, there were four profiles located in the three largest river plumes namely Langyang, Tamsui and Daan and Taiwan Strait used in order to analyze the spatial and temporal variation of SS before and after the typhoon. These profiles will be highlighted the relationship of SS before and after typhoon by scatter plots and profile plots. Results based on these profiles show that after the typhoon landed into Taiwan the SS concentration at three river plumes increased about 2-3 times compared to it before typhoon. The Tamsui river plume had variation of SS more complicated than that ain Daan and Lanyang river plume. Overall, the SS high concentration distributed at three river plumes and along the coastal water was higher than that in Taiwan Strait, East China See and Pacific Ocean.

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No. 78

Classifying the water colour of an estuary using Forel-Ule Colour Comparator scale and its correlation with water constituent.

Saiyidah Munirah Mohd Shazali[1]*, Madihah Jafar Sidik[1], and Nurzaliah Ali

The colour of natural water such as river, estuary, lake and ocean which range from indigo blue to cola brown is majorly attributed by the concentration of Colour-producing Agents (CPAs) which comprises of Chromophoric Dissolved Organic Matter (CDOM), Total Suspended Matter (TSM) in the water column. The concentration of CPAs were not only affecting the clarity of water, they also inhibit light penetration for primary production within water column. There are two main objectives of this study: 1) to classify the water colour of an estuary using Forel-Ule colour comparator scale and 2) to investigate the spatial variation of Color Producing Agents (CPAs) and its correlations between Forel-Ule Index and CPAs in study area. Likas estuary is a semi-enclosed with estimated 5 km in length estuary that located in urban area of Kota Kinabalu, Sabah with the presence of residential area and mangrove ecosystem along the rivers. Previous studies showed that Likas estuary was considered to be heavily polluted due to development, concentrated housing area, industrial effluent in-flow and marine debris problem that occurred in the area. In this study, Forel-Ule color comparator scale was used as a tool to classify the water colour of Likas estuary from upper stream (brackish water with salinity ranged between 0.1 ppt to 16.6 ppt) to coastal area (saline water with salinity ranged between 28 ppt to 31.8 ppt). The surface waters were collected at 19 sampling points monthly during spring tide from June 2018 until December 2018 to determine the concentration of CPAs. The study area was categorized into four groups based on salinity range which were Group A (0 ppt to 10 ppt), B (11 ppt to 20 ppt), C (21 ppt to 29 ppt) and D (salinity is more than 30 ppt). The result showed that the spatial variability of FUI scale was significantly decreasing from upperstream (FUI16 ± 1) to coastal area (FUI 11 ± 2). The spatial variability of CPAs showed that the concentration of SPM was the highest in Group A (upperstream) with 21.84 ± 11.14 mg/L, while the concentration of CDOM increased in group B (middle stream) with 0.88 ± 0.41 m^{-1} and the concentration of chlorophyll A was the highest in Group C (near river mouth) with 11.24 ± 16.4 mgm^{-3}. The results of correlation showed that FUI has significant correlations with CDOM, chlorophyll A, salinity, secchi depth, and vertical attenuation coefficient. Thus, it proved that the FUI can be a good proxy to determine the changes of the constituents and properties of natural water in the coastal water. \

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First look at a lake-configured SeaPRISM for remote sensing applications

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In the summer of 2017, a SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM) instrument was deployed in western Lake Erie and integrated into the AERONET-OC network. This is a new 12-channel version that includes bands in the red/NIR region, as well as traditional bands in the blue/green region. The main purposes of the instrument are to characterize radiance uncertainties for a variety of satellite sensors, and to provide a continuous stream of radiance measurements for harmful algal bloom (HAB) monitoring. The data collected reveal interesting optical dynamics that relate to cyanobacteria ecology, as well as co-measurements for satellite matchup validation. In this poster, these facets are examined from the first year's data stream. The instrument is maintained by the U.S. National Oceanic and Atmosphere Administration (NOAA).

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Remote Sensing Retrieval of Colored Dissolved Organic Matter (CDOM) Absorption Using Sentinel-2 in Liao River Estuary

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Colored dissolved organic matter (CDOM), the key component in aquatic environment, plays an important role in biogeochemical processing. The aim of the study was to develop an empirical model to derive $a_{CDOM}(400)$ that could be directly apply to Sentinel-2 image and to analyze the spatial variation characteristics of CDOM in Liao River Estuary, China. The data were collected on 25 August 2018 from the estuarine area of the Liao River. Through the analysis of field measurement, we found that the range of sampled CDOM valule ($a_{CDOM}(400)$) was wide (0.39 to 2.51m^{-1}) with a mean value of 1.12m^{-1}. The Sentinel-2 images used were collected on 25 August 2018. The atmospheric correction of Sentinel-2 images were carried out in Cen2Cor, freely available in the SNAP software. We divided all data into modeling data and validation data according to the rules. Through the correlation analysis between the single band and band combination value of remote sensing reflectance (Rrs)and $a_{CDOM}(400)$, the band 5/ band 1 ratio showed a good Pearson correlation. Therefore, band 5/ band 1 ratio and $a_{CDOM}(400)$ were selected for modeling and analysis. In this study, linear relation, quadratic polynomial, exponent and power function were used to build the model respectively, it was found that the quadratic polynomial model has the highest accuracy. The determination coefficient of calibration model was 0.9, and the root-mean-square errors(RMSE) of validation model was 2.1m^{-1}. According to the verification results, it can be found that the retrieved $a_{CDOM}(400)$ were well distributed near the 1:1 line. These results showed that Sentinel-2 will be a valuable tool for monitoring and the CDOM in the Estuary. The optimal model was applied to the whole image. The result showed that the $a_{CDOM}(400)$ decreased gradually from River course to coast due to the dilution of river.

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No. 82

Analysis of the spatial and temporal variability of suspended particulate matter concentration (SPM) in a highly-turbid macrotidal estuary using a 6-year-long remotely sensed data archive at high resolution

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Abstract: Hydro-sedimentary dynamics controls in part the good ecological state of estuarine environments. Improve knowledge about these physical processes is of key importance to anticipate hydrological and sediment transport regime changes related to the increase in anthropogenic pressures and uncontrolled climate change. The fluvio-estuarine system of the Gironde estuary is a prototypical study case of highly-turbid macrotidal environments. Numerous modeling studies and empirical works, based on *in situ* and remote sensed observations, have been conducted in recent years to better understand the hydro-sedimentary functioning of this system. In this presentation, we propose an original description of the spatial and temporal variability of surface suspended particulate matter concentration (SPM) that brings new and complementary knowledge to the previous studies. A large dataset (N=41) of high resolution multispectral satellite images, acquired by the Landsat-8 and Sentinel-2 space missions over the 2013-2018 period, is used to conduct the study. Environmental forcings (tide, river inflow, wind) are representative of the different hydrological and meteorological conditions that can occur. Results highlight very clearly the control of the lateral and along-channel gradients in bathymetry on the heterogeneous distribution of surface residual sediment transport and trapping along the fluvio-estuarine system. Environmental forcings lead to modulate the residual turbidity signal for time scales less than or equal to the season.

Keywords: Gironde Estuary, Landsat-8/OLI, Sentinel-2/MSI, hydrodynamics, remote sensing, SPM

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Seasonal and Interannual Variability of Satellite Chlorophyllu a in Malacca Strait

Susanna Nurdjaman[1], Age Hidayat[1]

Thirteen years of Aqua MODIS ocean color data are used to characterize variability of chlorophyll-a concentration over seasonal to interannual timescale in Malacca Strait and to assess the effect of the ENSO phenomenon (El Niño Southern Oscillation) and IOD (Indian Ocean Dipole). The results show dominant period in the strait are 6 month, 12g month and 3.5 years periods that is dominantly by Asian Monsoon. The average chlorophyllg-a concentration high November-February (the northeast monsoon) and lower in the April-June (the southwest monsoon). The average chlorophyllg-a highest in January, which reached 5 mg / m^3, while the average chlorophyllg-a concentration lowest in June ie 0.15 mg / m^3. High chlorophyll-a concentration in northeast monsoon closely associated with nutrients as a result from river discharged that is correlated with heavy rainfall. In general, chlorophyll-a in the northern region of the Strait of Malacca (0.46 mg / m^3) tends to below concentration than southern part of strait (3.3 mg / m^3). The influence of ENSO and IOD phenomenon in the Malacca Strait is low correlation with chlorophyll-a.

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No. 132

Spectral decomposition of visible multispectral and hyperspectral images: An alternative method to characterize optical constituents in aquatic systems

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Cyanobacterial and Harmful Algal Blooms (CyanoHABs) are a growing concern in coastal and inland waters. But, spectral interference from multiple constituents in optically complex waters can hamper application of remote sensing using traditional image processing methods. The Kent State University (KSU) spectral decomposition method can be applied to multispectral and hyperspectral remote sensing images to partition and identify signals related to cyanobacteria, algae, pigment degradation products and suspended sediment in each pixel. This information can be validated with laboratory and/or *in situ* sensors, which capture spatial or time series of information at discrete points within remote sensing images. This approach provides the complete spatial pattern of various water quality constituents. As proof of concept, we compare results from work in Lake Erie to quantify the Microcystis CyanoHAB and from the Indian River Lagoon, Florida to quantify the Brown tide resulting from *A. lagunesnsis*. The results document that hyperspectral sensors extract more information than multispectral ones, but more information can be extracted from Multispectral tool with this approach than traditional band ratio approaches. The spectral decomposition method is capable of enhancing the signal to noise ratio (SNR) of the NASA Glenn, second-generation hyperspectral imager by a factor of 7x to 20x, with a reproducibility of+/-3%. Field operations in the Western Basin of Lake Erie, using a bbe Fluoroprobe to collect vertical profiles and horizontal tows along a transect from the Toledo Lighthouse to the Detroit Lighthouse during coincident satellite overpasses. Extraction of pixel values from the MODIS Aqua sensor yields agreement between *in situ* field and lab-based measures of cyanobacterial, cryptophyte, diatoms and green algae, suspended sediment and pigment degradation products with r^2 >0.8. The spectral decomposition method, when compared against existing remote sensing monitoring methods exhibits both greater specificity and a lower detection limit.

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Long-term Trend of Satellite-Observed Chlorophyll-a Concentration and Relation to Change in Physical Environment in the East Sea (Japan Sea)

Ji-Eun Park [1], and Kyung-Ae Park[2]

A study on spatial and temporal changes of chlorophyll-a (chl-a) concentration in the East Sea using MODIS (Moderate Resolution Imaging Spectroradiometer) data for 13 years from 2003 to 2015 showed that ocean warming signal was associated with low-level of marine ecosystem and how they affect. Chl-a errors with extremely high concentration values were removed by applying an error elimination algorithm to each satellite path image. The chl-a data was composited as a monthly grid image using weighted average method. The missing pixels by the cloud coverage were objectively filled by 3 dimensional optimal interpolation. Empirical Orthogonal Function (EOF) analysis was applied to decompose the principal component of the chl-a variance. The first EOF mode of the monthly chl-a data accounted for 14% of the total variation and showed a higher variation pattern in the eastern part of the East Sea. In the first EOF mode, the time series of chl-a concentration fluctuations showed inter-annual variation, and tended to increase with time especially in spring. The long-term trend of chl-a showed a difference between the southwestern part and northeastern part of the East Sea, which was clearly appeared in March and April. The eastern coast of Korea showed an increasing trend in August. This study emphasized and discussed the role of physical environment changes such as sea surface wind, mixed-layer depth and stratification of sea water on long-term changes of chl-a concentration in the East Sea.

Keywords chlorophyll-a concentration, MODIS, the East Sea (Japan Sea), variability, trend

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Red Tide Detection from High-Resolution Optical Satellite Image based on Deep Learning Method

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Red tides often impact coastal environments and fishery (or human society) on a local scale, but the occurrence is highly global. Satellite imagery has a great potential to be an effective tool for the research of red tide and for devising proactive strategies to minimize its impact on coastal fishery. However, previous satellite-based studies on this topic were mostly conducted on a shorter time scale focused on a specific area with coarse spatial resolution to monitor coastal area. We applied previously developed algorithms for red tide detection to Landsat OLI data and investigated availability in this study. The previous algorithms were not properly applied to Korean water or Landsat OLI. We developed an algorithm to be applicable to the high-resolution optical satellite data for red tide detection. For this, we conducted in-situ measurements when red tides occurred in coastal water in South Korea between 2013-2015 and elucidated the spectral characteristics of red tides, red tide density, and its dominant species. The sea water shows different spectral shape by its component (red tide density, chlorophyll-a concentration, suspended particulate matter). Red tides have bimodal peaks over visible wavelengths. However, high-resolution satellites have limitation on presenting the spectral characteristics of red tide due to the lack of observing channels. Using deep learning method, we trained an algorithm with input data selected based on in-situ spectral characteristics of red tide. The results of the algorithm were validated with the in-situ red tide report map (National Institute of Fishery Science). These works have made it possible to monitor red tides with high-spatial resolution and provide a predictive tool to minimize the socioecological impact of red tide.

Keyword: Red tide, Deep learning, Landsat OLI

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Diurnal changes of cyanobacteria blooms in Taihu Lake as derived from GOCI observations

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Using frequent and long-term measurements (8 times per day, 2011 - present) from a geostationary satellite sensor (GOCI), this study investigates diurnal changes of cyanobacterium *Microcystis aeruginosa* blooms (surface scums) in Taihu Lake, from which vertical migration patterns can be inferred. After proper atmospheric correction, an cyanobacterial index algorithm is used to quantify equivalent surface cyanobacterial density (σ, 0% – 100%) at both pixel and synoptic scales from each cloud-free image, followed by analysis of diurnal changing patterns of σ at both scales. Three typical diurnal changing patterns are identified from all images, which show distinctive and different seasonality from the long-term statistics. Spatial distributions of the "hotspot" regions where diurnal changes are most often observed have also been established. While the seasonality of the three patterns appears to be a result of seasonality in both temperature and light availability, large blooms only occur one day after major wind events. Based on several lines of evidence, we hypothesize that the diurnal changes of such observed surface bloom patterns are likely a result of vertical migration rather than horizontal dissipation/aggregation of cyanobacteria. The mean migration speeds inferred from either a simple model or a radiative transfer model (<0.03 cm s^{-1} or <1 m h^{-1}) are consistent with those reported earlier from laboratory measurements for certain cyanobacteria colony sizes. Complete understanding of the three types of diurnal patterns and direct validation of the hypothesis, however, require further investigations from field measurements.

Keywords: Cyanobacteria, *Microcystis aeruginosa*, vertical migration, diurnal change, remote sensing, GOCI, Taihu Lake

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No. 87

Temporal and spatial variation of carbon dioxide concentration and its exchange fluxes in Lake Chaohu

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Abstract: In order to understand the temporal and spatial variation of carbon dioxide concentration (cCO_2) and its influencing factors in the surface water of Lake Chaohu, the physicochemical parameters, biological parameters, and cCO_2 of surface (15-30cm) water samples collected in February, April, August and November in 2017 in Lake Chaohu, representing different seasons, were measured. The surface water-air flux of CO_2 was then calculated based on gradient method as well. The results showed that the cCO_2 ranged from 13.31-55.47μmol L^{-1}. The average annual cCO_2 was 26.27μmol L^{-1}. The cCO_2 was higher in the west lake zone than that in the central and east sub-lake zones; The surface water of Lake Chaohu had a lower cCO_2 in the warm season (summer) than in cool and cold seasons (spring, autumn and winter). cCO_2 was positively correlated with dissolved organic carbon (DOC) concentration (r=0.37, p<0.01) and negatively correlated with chlorophyll-a (Chla) concentration (r=-0.59, p<0.01), suggesting that photosynthesis and decomposition of organic matter plays an important role in the biochemical cycle of CO_2. Due to the serious pollution of inflowing rivers surrounding Lake Chaohu, DOC input from the watershed supplied substrates for CO_2 production. Lake Chaohu was a relatively small source for atmosphere CO_2 compared to others studies. Lake Chaohu shifted from a CO_2 source to a sink in cold seasons.

Keywords: Lake Chaohu; carbon dioxide concentration; carbon dioxide diffusion flux; spatial-temporal variation; influencing factors

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No. 88

SeaHawk: First Ocean Color CubeSat

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CubeSats are revolutionizing the way we make Earth Observations. These low-cost mini satellites (a.k.a. nanosatellites) are described as cube-shaped spacecrafts with units of 1U =10X10x10cm. SeaHawk, with a total weight of 5kg, is the first 3U CubeSat specifically designed to hold an ocean color instrument payload (HawkEye). As this is a proof-of-concept mission, HawkEye's specifications are similar to SeaWiFS (one of the most successful ocean color mission to date) in that it is an 8-band multispectral ocean color sensor, except band 7 was modified to improve atmospheric correction and the SNR is >50% that of SeaWiFS. However, HawkEye was designed to fit a 1U cube, it has ~100m spatial resolution, it does not saturate over land, and was built with low-cost, off-the-shelf materials. SeaHawk follows a sun-synchronous Low Earth Orbit at a nominal height of 575km, orbiting 15 times a day, with a swath of 216 x 480km and a repeat time of about 9 days. SeaHawk-1 is one of two identical CubeSats that was launched in December 2018 as part of SpaceX first ride-share mission; SeaHawk-2 will be launched within the next year. Once SeaHawk-1 is fully commissioned, data will be available at no cost through NASA's OBPG (https://oceancolor.gsfc.nasa.gov)and UNCW (https://uncw.edu/socon/mission.html). The ocean color community will also be able to submit requests for image acquisition (e.g. for field support) through UNCW (https://uncw.edu/socon/requests2.html). This project was possible thanks to the Gordon and Betty Moore Foundation and a Space Act Agreement between NASA and UNCW.

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Results of field intercomparison experiment, calibration plan and 2019 expansion plan for the WATERHYPERNET, a Network of Hyperspectral Radiometers for Multi-satellite Water Reflectance Validation

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A network of hyperspectral radiometers is being developed for radiometric validation of satellite missions. This network follows closely the AERONET-OC federation concept [Zibordi et al, 2009] but uses the TRIOS/RAMSES hyperspectral radiometer and a more extensive multi-look pointing scenario. The instrument system consists of one radiance and one irradiance sensor on a pointing robot, controlled by a microprocessor and supplemented with GPS, inclinometer and video camera data feeds. The measurement protocol is based on the abovewater method of [Mobley, 1999 and 2015], but includes additional scenarios for different viewing zenith and azimuth configurations. The system is being deployed initially in Belgian coastal and inland waters, then at sites in Argentina and France before full international expansion. The network will provide water reflectance data for the radiometric validation of all visible and near infrared bands of all optical missions, including Sentinel-2A&B, Sentinel-3A&B, PROBA-V, MODIS-AQUA&TERRA, VIIRS, Landsat-8, Pléiades, CHRIS-PROBA, MSG-SEVIRI, PlanetDove … PRISMA, ENMAP, PACE, MTG and ... any future optical missions, including nanosatellites. This presentation will provide results from prototype testing on Aqua Alta Oceanographic Tower in July 2018, including a comparison with a conventional manually-operated TRIOS/RAMSES system and the automated AERONET-OC data from this site. Lessons learned and prototype improvements will be outlined in preparation for multi-site deployments in 2019. Research in progress on the abovewater measurement protocol and the operational plan for characterisation of all radiometers will also be outlined.

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The classification of the north-western Pacific and Eastern Arctic waters based on multi-sensor optical satellite and ship-borne data

Salyuk Pavel, Permyakov Mikhail, Kleshcheva Tatiana

The functional types of phytoplankton communities in the marginal seas of the northwestern Pacific Ocean and in the Eastern sector of the Arctic based on the study of the spatial and temporal variability of hydrological and hydro-optical parameters measured from satellites and from ships are analyzed in the presented work.

A statistical analysis of the fields of hydrological and hydro-optical parameters was carried out, and stable statistical structures were selected based on an analysis of the ratios of the parameters determined by the content of chlorophyll-a and dissolved organic matter, temperature and salinity. Additionally, wavespectra of the chlorophyll concentration and the sea surface temperature were calculated, which made it possible to analyze and separate the hydrological and hydro-optical processes in the upper ocean layer. The phytoplankton communities functioning in the selected stable statistical structures are classified.

As data for analysis, the results of continuous measurements of hydrological and hydro-optical parameters from moving ships, measurements of the sea surface color from satellite scanners, and reanalysis of hydro-physical and meteorological parameters were used.

Ship data includes flow measurements of seawater temperature and salinity, performed at intervals of 10–60 sec., fluorimetric measurements of chlorophyll-a and dissolved organic matter at intervals of 20–120 sec., optical measurements of the potential efficiency of photosynthesis at intervals of 300 seconds.

Third-level data from SeaWiFS, MODIS, VIIRS and GOCI optical scanners were used as satellite data: brightness of the upwelling sea color on 8 spectral channels in the range of 400-700 nm, chlorophyll-a concentration, light absorption coefficient of detritus and gelbstoff matter (adg), coefficient backscattered light by suspended particles (bbp), sun-induced chlorophyll-a fluorescence (flh), primary production (PP).

Reanalysis data include models HyCOM, OSCAR, WW3, GFS. The main parameters that were additionally taken into account: the depth of the mixed layer, the temperature of sea water, salinity, sea currents, sea waves. The data were used to filter extreme weather events and gradient regions of hydrophysical parameters, to take into account the depth of the mixed layer in the assessment of the depth of phytoplankton communities, to identify stationary regions of hydrophysical parameters.

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Landsat 8 Remote Sensing of Boston Harbor Water Quality

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The Boston Harbor Project is among the most expensive and extensive estuarine recoveries in the world, resulting from a $3.8 billion lawsuit against the Metropolitan District Commission for violating the Clean Water Act. The Massachusetts Water Resource Authority (MWRA) have conducted an extensive water quality monitoring program over the last 25 years and so offers a unique opportunity to validate historical remote sensing imagery. A subset of the water quality data coincides with acquisitions of the Thematic Mapper (TM) onboard Landsat 5, the Enhanced Thematic Mapper Plus (ETM+) onboard Landsat 7, and the Medium Resolution Imaging Spectrometer (MERIS) onboard Envisat. Preliminary ocean color (OC) products: chlorophyll a (Chl a), total suspended solids (TSS), diffuse attenuation (Kd) and particle backscatter (bbp) derived from MERIS, TM, and ETM+ are examined from 1994- 2013, documenting changes of “the dirtiest harbor in America” to the present day Boston Harbor Islands National & State Park. Product comparisons between MERIS, TM, and EMT+ for Rrs(482), Rrs(561), Rrs(655) are presented. Optimized OC3 coefficients for Boston Harbor using *in situ* validation of the Operational Land Imager (OLI) onboard Landsat 8 are offered along with buoy and cruise data collected during the 2015-2017 field season. 250 discrete samples have been analyzed for CDOM fluorescence, CDOM absorption, Chl a fluorescence and TSS matching OLI acquisitions and *in situ* radiometry over 13 field campaigns. The main goal of this poster is to show the capabilities and limitations for satellite monitoring of water quality in Boston Harbor.

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Determination of the Downwelling Diffuse Attenuation Coefficient of Lake Water with the Sentinel-3A OLCI

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Abstract: The Ocean and Land Color Imager (OLCI) on the Sentinel-3A satellite, which was launched by the European Space Agency in 2016, is a new-generation water color sensor with a spatial resolution of 300 m and 21 bands in the range of 400–1020 nm. The OLCI is important to the expansion of remote sensing monitoring of inland waters using water color satellite data. In this study, we developed a dual band ratio algorithm for the downwelling diffuse attenuation coefficient at 490 nm (K_d(490)) for the waters of Lake Taihu, a large shallow lake in China, based on data measured during seven surveys conducted between 2008 and 2017 in combination with Sentinel-3A-OLCI data. The results show that: (1) Compared to the available K_d(490) estimation algorithms, the dual band ratio (681 nm/560 nm and 754 nm/560 nm) algorithm developed in this study had a higher estimation accuracy (N = 26, coefficient of determination (R^2) = 0.81, root-mean-square error (RMSE) = 0.99 m^{-1} and mean absolute percentage error (MAPE) = 19.55%) and validation accuracy (N = 14, R^2 = 0.83, RMSE = 1.06 m^{-1} and MAPE = 27.30%), making it more suitable for turbid inland waters; (2) A comparison of the OLCI K_d(490) product and a similar Moderate Resolution Imaging Spectroradiometer (MODIS) product reveals a high consistency between the OLCI and MODIS products in terms of the spatial distribution of K_d(490). However, the OLCI product has a smoother spatial distribution and finer textural characteristics than the MODIS product and contains notably higher-quality data; (3) The K_d(490) values for Lake Taihu exhibit notable spatial and temporal variations. K_d(490) is higher in seasons with relatively high wind speeds and in open waters that are prone to wind- and wave-induced sediment resuspension. Finally, the Sentinel-3A-OLCI has a higher spatial resolution and is equipped with a relatively wide dynamic range of spectral bands suitable for inland waters. The Sentinel-3B satellite will be launched soon and, together with the Sentinel-3A satellite, will form a two-satellite network with the ability to make observations twice every three days. This satellite network will have a wider range of application and play an important role in the monitoring of inland waters with complex optical properties.

Keywords: diffuse attenuation coefficient; Sentinel-3A OLCI; Lake Taihu; remote sensing

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No. 93

A CIE color purity algorithm to detect black and odorous water in urban rivers

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Abstract: Urban black and odorous water (BOW) is a serious global environmental problem. In China, BOW is identified as water exhibiting at least one of the following four characteristics: Secchi depth < 25 cm, dissolved oxygen < 2.0 g•m−3, oxidation–reduction potential < 50 mv, and ammonia nitrogen > 8 g•m−3. These waters are often narrow rivers or small ponds, so detection of BOW waters using traditional satellite data and algorithms is limited both by lack of spatial resolution and by imperfect retrieval algorithms. Several problems need to be solved: (1) Defining a spectral index that can differentiate BOW from ordinary water using the broad bands of multi-spectral remote sensing data; (2) Making operational atmospheric corrections in the absence of a short wave infrared band; (3) Accounting for the adjacency effects of river banks. In this paper, we used the Chinese high resolution remote sensing satellite Gaofen-2 (GF-2, 0.8 m). Atmospheric correction using the multivariate alteration detection (MAD) method showed that the mean absolute percentage error of the derived remote sensing reflectance (Rrs) in visible bands is 25.19%. We first measured Rrs spectra of two classes of BOW (BOW with high concentrations of iron (II) sulfide, BOW1; BOW with high concentrations of total suspended matter, BOW2) and ordinary water in Shenyang City. Then, in-situ Rrs data were converted into Rrs corresponding to the wide GF-2 bands using the spectral response functions. We used the converted Rrs data to calculate several band combinations, including the baseline height, (Rrs(green)-Rrs(red))/(Rrs(green)+Rrs(red)), and the color purity in a Commission Internationale de L'Eclairage (CIE) chromaticity diagram. The color purity was found to be the best index to extract BOW from ordinary water. Then, Rrs (645) was applied to categorize BOW into BOW1 and BOW2. We applied the algorithm to two synchronous GF-2 images. The recognition accuracy of BOW2, and ordinary water are 100% and 100% respectively. Two BOW1 samples were in the shade of trees and were not used for evaluating the RA. The extracted river water type near Weishanhu Road was BOW1, which agreed well with ground truth. The algorithm was further applied to other GF-2 data of Shenyang and Beijing city.

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Determining AVIRIS spectral groups to distinguish oil emulsions from Sargassum over the Gulf of Mexico

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Abstract: Spilled oils can form various types of oil pollution, such as non-emulsified oil slicks and oil emulsions, during the weathering of marine-spilled oils. The remote detection, classification and quantification of various spilled oils is important in marine environmental monitoring. Although multispectral images can be used to observe various spilled oils, due to confusion between the multispectral backscattered signals, distinguishing spilled oils from floating algae in the same image is challenging. The spectral features of carbon-hydrogen (-C-H) and oxygen-hydrogen (-O-H) groups, and pigments, are diagnostic absorption features and are different from the backscattering signal. These spectral features have not been used to improve detection independently. In this study, the spectral features of the groups were clearly interpreted using reflectance spectra collected from an airborne visible infrared imaging spectrometer (AVIRIS). A reflectance peak-trough detection method to characterize the different spectral groups was used to determine the spectral features of Deepwater Horizon (DWH) oil emulsions and floating Sargassum in the Gulf of Mexico. The results show that the spilled oils and floating Sargassum can be clearly identified, and the various spilled oils (i.e., different oil emulsions and non-emulsified oil slicks) could also be determined from the differences in the spectral features of the above groups. Finally, we discuss the spectral requirements for the identification of these groups and we conclude that optical remote sensing, including imaging spectrometers, will play an increasingly important role in assessing marine oil spills.

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Characterization of the Global Turbid Coastal and Inland Waters from VIIRS Satellite Ocean Color Observations

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In coastal and inland waters, the complex features of the water and the limitation of the visible-based satellite ocean color remote sensing make it difficult to produce high-quality ocean color products in order to study the water biological and biogeochemical variability. This presentation shows that remote-sensing reflectance model in the turbid waters can be significantly simplified at the near-infrared (NIR) wavelengths, thus water inherent optical property (IOP) and particle size related products such as particle backscattering coefficient ($b_{bp}(\lambda)$), phytoplankton absorption coefficient ($a_{ph}(\lambda)$), dissolved and detrital absorption coefficient ($a_{dg}(\lambda)$), power law slopes of the particle size distribution (PSD) can be derived using the normalized water-leaving radiance spectra $nL_w(\lambda)$ at the NIR wavelengths, derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP). Using the HYDROLIGHT simulated normalized water-leaving radiance spectra, we demonstrate that the $b_{bp}(\lambda)$, $a_{ph}(\lambda)$, and $a_{dg}(\lambda)$ values derived using the NIR-based IOP algorithm generally match well with true values in turbid coastal and inland waters. We show that the dynamics of global highly turbid waters such as in the China's east coastal region, La Plata River Estuary, and Amazon River Estuary can be well characterized and quantified with VIIRS-derived products of $b_{bp}(\lambda)$, $a_{ph}(\lambda)$, $a_{dg}(\lambda)$, and PSDs.

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Using of satellite data on ocean color and SST to study the changes of the near-bottom water hypoxia formation conditions in the Amur Bay and the adjacent area (Japan/East Sea)

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Based on the satellite ocean color sensors data from MODIS-Aqua for 2010-2014 and OLCI-Sentinel-3 for 2018 it was studied the change in distributions of the phytoplankton, organic matter, suspension content indicators in the Amur Bay (AB) and the adjacent area under the influence of hydrometeorological conditions caused by wind speed and direction, continental runoff at different level of precipitation, convective mixing of water at its cooling. The above mentioned distributions are compared with literary information based on field observations about hypoxia cases in the consideration area.

Data from the MODIS-Aqua of level 1 and from the OLCI/SLSTR-Sentinel-3 of level 2 for cloudless situations, respectively, from sites - http://oceancolor.gsfc.nasa.gov and http://coda.eumetsat.int were used in this work. To process these data, the SeaDAS software of versions 7.4 and 7.5 was used. At that for the data from the MODIS-Aqua, the MUMM-atmospheric correction recommended for turbid coastal waters was applied. Obtained by us the data of level 2 included the following bioproduction and biogeochemical characteristics: the chlorophyll-a concentration and fluorescence (chl_OC3 and Fchl), coefficients of light absorption by the detritus and yellow substance (adg (443)_QAA) and light backscattering by the suspended particles of mineral and biological origin (bbp(443)_QAA), and also the sea surface temperature (SST). Data from the OLCI/SLSTR-Sentinel-3 included the chlorophyll-a concentration (chl_OC4me, chl_NN), adg (443) _NN, total suspended matter concentration (tsm_NN), SST. To study the relative seasonal and interannual changes of these characteristics, their time course in the separated points and on the sections located near sources of nutrients, organic and suspended matter was constructed. Data on the wind speed and direction, the quantity of atmospheric precipitation from the hydrometeorological station "Vladivostok were also used in this work. These data we obtained from the site - http://rp5.ru.

According to the mentioned above distributions of bioproduction and biogeochemical characteristics for the AB, four scenarios were identified. These scenarios indicate on the following processes: 1) inflow of seawater to the northern part of AB (2014) and 2) formation of front separating areas of high and low parameters - at the southern the winds; 3) spread of the Razdolnaya River waters along the western coast of AB and the adjacent area; 4) spread of waters with elevated values of parameters from the eastern to the western coast of AB after repeated precipitations with a total number above 200 mm/month (2013). It is noted, that in the case 1 the formation of water hypoxia is most likely in the estuarine zone of the Razdolnaya River, the case 3 at weak mixing of water may lead to a reduced oxygen content along the western coast of the AB and the adjacent area; in the case 4 the area of reduced oxygen content may be shift toward smaller depth of northern, northeastern AB part. Starting from approximately the late August - the late September, depending on the year, a sharp increase of the phytoplankton and colored dissolved organic matter indicators throughout almost the entire AB area indicates on the wind and convective mixing of water and gradual destruction of the near-bottom hypoxia.

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No. 97

Estimated the concentration of the total suspended matter in the Sea of Azov in 2013–2014 by using the simulation results and Ocean Color imagery

Tatiana Shul'ga[1], Vyacheslav V. Suslin[1]

The work demonstrates that appropriate data-assimilation schemes make numerical modeling a suitable and reliable tool for filling the gaps arising due to satellite imagery unavailability and/or cloud covering. In this research we apply the Princeton Ocean Model (POM) to the Sea of Azov, assimilating bio-optical indexes index34 = RRS(531)/RRS(488) and bbp(555) from MODIS L2 products. The results focus on the ability of the method to provide spatial maps that overcome the general issues related to Ocean Color imagery (e.g., cloud cover) and on the comparison between the assimilating and the non-assimilating runs. Numerical algorithms and the new complex of applied programs are of considerable practical importance. They are useful for satellite data assimilation, help to identify concentration fields more precisely and are cost- effective. Modeling results make it possible to compare calculations with operating environment based on the satellite images and lead to sound conclusions when forecasting the consequences of pollution propagation. The present paper is a continuation of earlier studies, however this report presents new results obtained using improved methods of assimilation. The satellite images MODIS-Aqua scanner used in assimilation in the case of partial or complete absence of images were supplemented with the data from the MODIS-Terra scanner. Another modification of the assimilation algorithm was the assignment of information in the model about the distribution of suspended matter in the surface layer and the deep sea. The selected study area the Sea of Azov is a shallow sea basin is linked by the narrow Strait of Kerch to the Black Sea. The scale of pollution becomes threatening to the ecosystem of this region. The study area is entirely included in the color image downloaded from the NASA's Ocean Color web site (http://oceancolor.gsfc.nasa.gov) for the period from 2013 to 2014.

The methodology is includes three main stages: (1) the analysis of satellite information, (2) the 3D model simulation POM using prognostic wind from the SKIRON/Eta model (http://forecast.uoa.gr), and (3) assimilation procedure of satellite data. The process of data assimilation was accomplished through a variety of schemes. Scheme I – without subsequent assimilation of the MODIS data (assimilation was made only initially). Scheme II – with subsequent regular assimilation at the time points when the satellite data are available (every 24 or 48 h). The MODIS data were used to derive the remote-sensing reflectance with central wavelengths of bands 438, 531 and 555 nm. The first parameter (index34, dimensionless) is a relation of the remote-sensing reflectance RRS(λ) at λ wavelength in two bands. The second parameter is a coefficient of backscattering by suspended matter particles at 555 nm wavelength (bbp (555), m–1), which allows one to observe peculiarities of light scattering in the water upper layer. These parameters set the suspended matter field of neutral buoyancy in the near-surface layer and in the deeper layers of the Sea of Azov.

The study of fluctuations in the total content of the suspension at different depths of the sea is done. A standard satellite product was used – diffuse light attenuation at a wavelength of 490 nm Kd(490). Interestingly, the suspended matter concentration during 2014 rapidly decreased with the depth, going below zero lower then 5–6 m deep. It should be noted that the data derived from only the surface layer have more than 62% discrepancies in the determination of the common concentration of the suspended matter in the Sea of Azov.

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Impacts of cyclonic eddies on phytoplankton biomass and phenology in the Kuroshio Extension region

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Two-decade ocean color chlorophyll-a concentration (CHL, a metric of phytoplankton biomass) data from 1997 to 2017 were used to comprehend the impact of cyclonic eddies on phytoplankton biomass and phenology in the Kuroshio Extension region (KE) of the western North Pacific Ocean. The CHL data have 4-km and 8-day spatiotemporal resolution and were acquired from the ESA Ocean Colour-Climate Change Initiative (http://www.esa-oceancolour-cci.org/). Prior to defining spring bloom onset, spatiotemporal gaps in CHL data were filled by applying empirical orthogonal function-based interpolation. The analysis was mainly focused on the winter season (January-March) as oceanographic conditions during the winter largely control phytoplankton spring bloom in terms of both magnitude and onset. Based on winter sea surface height anomaly (SSHa), cyclonic eddies (negative SSHa) were dominant mainly within the periods from 1998 to 2001 and from 2005 to 2009, whereas anti-cyclonic eddies (positive SSHa) were dominant mainly within the periods from 2002 to 2004 and from 2011 to 2015. Based on datasets from all seasons, the concurrences of negative SSHa and positive phytoplankton chlorophyll anomaly (CHLa) were observed, albeit not always. This indicates an eddy-induced upwelling supplies nutrients to the near-surface layer. Upwelled nutrients eventually promote phytoplankton growth. Such a concurrence of low SSHa and high CHLa was less obvious during the winter indicating that another factor (such as intense winter vertical mixing) also non-trivially controlled nutrient input to the surface layer, and hence CHLa variability. Overall temporal mean indeed showed that the active cyclonic eddy area (approximately south of the Kuroshio Current main axis) was characterized by high CHLa, low SSHa, and shoaled mixed layer. In this study, a Cumulative Sum method was applied to find phytoplankton spring bloom onset. Correlation between SSHa and spring bloom onset time was investigated, and it was found that approximately over the active cyclonic eddy area, positive correlation between winter/late winter SSHa and time of spring bloom onset was observed. Such a positive correlation indicates that cyclonic eddies during the winter likely tended to advance phytoplankton spring bloom onset.

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Enhancing Chlorophyll-a Retrievals from Multispectral Observations via Machine Learning

Brandon Smith[1,2,3], Nima Pahlevan[2,3] and Sundarabalan V Balasubramanian[2,4]

Determination of water column constituents from remote sensing reflectance measurements, especially of inherent and apparent optical properties (IOPs & AOPs), is a subject which has received much scrutiny in literature. For any given constituent (or set of constituents), there are a wide variety of algorithms available, which tend to work in isolation of any other constituent(s). While these algorithms can approximate quantities surprisingly well in some cases, there is nevertheless a restriction on the range of environments to which any given algorithm can actually be applied; algorithms which can be applied in more wide-ranging environments have a tendency to underperform relative to their more specific counterparts. Contrary to this, we posit that the inclusion of all available constituents into a single algorithm can improve estimates as a whole, and allow for a consistent performance within *any* environment. To achieve this goal, we examine a modified Mixture Density Network which is capable of learning correlations between all target variables, and outputs a probability density for constituent magnitudes. The primary goal of this study is to enhance retrievals of chlorophyll-a in nearshore coastal and inland waters. We show that our proposed model allows not only accurate estimation in previously unavailable situations, but also improves upon the state-of-the-art estimates for specialized retrieval algorithms - in some cases, achieving up to 50% reduction in error rates.

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Assessing the quality of bio-optical products from Ocean and Land Colour Instrument (OLCI) imagery on board Sentinel-3 over the East Coast of Australia

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OLCI Imagery on board Sentinel-3 was launched in 2016 for continuous water quality monitoring. The reprocessed OLCI level-2 full-resolution products for open-ocean waters have been validated against *in situ* data from the east coast of Australia, collected in September 2017 onboard of R/V Investigator. The study region is strongly influenced by the Eastern Australian Current which forms eddies that stimulate phytoplankton growth and enhance primary production. Although oligotrophic open-ocean waters are usually dominated by small-sized phytoplankton, mesoscale features such as cyclonic eddies can generate seasonally favourable conditions for the growth of large phytoplankton cells. Based on radiometric, HPLC and other bio-optical data, we quantified relative sources of error in satellite products. The OLCI water-leaving reflectance gave good agreement with *in situ* reflectance in cyclonic eddies, where euphotic depth was around 50 m. In anticyclonic eddies, where euphotic zone reached even 100 m, the reflectance was overestimated, mostly in the blue part of the spectrum. Results showed that even though reflectance show good agreement in the region of cyclonic eddies, the satellite chl-*a* estimation was underestimated in the higher chl-*a* concentrations. Region of cyclonic eddies is characterised by increased primary production and domination of large-sized phytoplankton. The large cells, that have a greater package effect, are less visible to the bands used in the chlorophyll algorithm. The *in situ* values of chl-*a* were on average 2 times higher than OLCI values.

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No. 101

Comparison of GOCI and VIIRS Ocean Color Products in the Western Pacific Region

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Abstract: The first geostationary ocean color satellite sensor, Korean Geostationary Ocean Color Imager (GOCI), which has eight spectral bands from the blue to the near-infrared (NIR) wavelengths, has the unique capability with hourly measurements during daytime to provide short- and long-term environmental monitoring such as water optical, biological, and biogeochemical variability in the marine ecosystem. GOCI measurements cover the western Pacific region, including the Bohai Sea, Yellow Sea, and East China Sea, which are one of the most turbid regions in the world. It has been shown that GOCI ocean color products such as normalized water-leaving radiance spectra derived using an iterative NIR-corrected atmospheric correction algorithm are significantly improved compared with the original GOCI products and have a comparable data quality as MODIS-Aqua in this region.

In this presentation, we show more results of GOCI ocean color products from March 2011 to December 2018 derived from the Multi-Sensor Level-1 to Level-2 (MSL12) ocean color data processing system to characterize diurnal, seasonal, and interannual variations in water optical, biological, and biogeochemical properties. In addition, GOCI ocean color products are compared with those of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) using the NIR and shortwave infrared (SWIR) combined atmospheric correction algorithm. GOCI and VIIRS ocean color products are also compared with the in situ measurements from the two AERONET-OC sites (Ieodo and Socheongcho) located in the Yellow Sea. It will be shown that VIIRS ocean color products are quite accurate and highly stable in open oceans, and much improved in highly turbid coastal and inland waters. Furthermore, GOCI measurements are important to provide diurnal information that the polar sensor cannot provide. Some detailed data analyses and discussions for GOCI and VIIRS results will be provided.

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No. 102

Evaluation of Polymer atmospheric correction algorithm applied to HICO images over coastal waters

Mariana A. Soppa[1], Brenner Silva[1], Francois Steinmetz[2] and Astrid Bracher[1,3]

Satellite imaging spectrometry can significantly contribute to the monitoring of inland, coastal and oceanic waters with the fine spectral resolution and sampling. The vast information provided by hyperspectral sensors allows to better explore the upwelling spectral radiance distribution from the water and the retrieval of geo-biophysical parameters. The applications cover a wide range as detection of phytoplankton types and harmful algal blooms, benthic habitat mapping and fluorescence retrievals. Past, current and future hyperspectral sensors with potential application in ocean colour studies include HICO (2009-2014), SCIAMACHY (2002-2012), CHRIS-PROBA (2001-), OMI (2004-), TROPOMI (2017-), DESIS (2019-), HyspIRI, EnMAP, HISUI, PRISMA and PACE. In this work, we evaluate the Polymer atmospheric correction algorithm (v.4.10, Steinmetz et al. 2011) applied on Hyperspectral Imager for the Coastal Ocean (HICO) data. Polymer is an AC algorithm based on an optimization technique in which atmospheric and oceanic signals are obtained simultaneously. We present results of the validation of HICO-Polymer against multispectral radiometric measurements at AERosol RObotic NETwork - Ocean Colour coastal stations and the comparison with HICO images processed by L2gen (level 2 generator distributed in the SeaWiFS Data Analysis System software package - SeaDAS) and MERIS products processed by Polymer. Further, we present coupled atmosphere-ocean radiation transfer simulations of top-of-atmosphere and water-leaving-radiance by the radiative transfer model SCIATRAN (Rozanov et al., 2017) that will be used for sensitivity studies and uncertainty estimation of Polymer applied to hyperspectral data.

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Evaluation of Sentinel-2 and Sentinel-3 Ocean Colour products processed by Polymer

François Steinmetz[1], Didier Ramon[1]

With now two Sentinel-2 and two Sentinel-3 satellites in operation, there is an unprecedented monitoring potential of the Global Ocean, coastal zones and inland waters at medium and high spatial resolutions. The Polymer atmospheric correction algorithm for Ocean Colour uses the full available spectrum to discriminate the water reflectance from the atmospheric and surface signal, using an iterative optimization scheme and relying on analytical models. With its generic design, its robustness to the aerosol contamination, partial cloud and haze contamination, adjacency effects and the ability to process the sun glint contaminated observations, this algorithm maximizes the usefulness of these observations. We are demonstrating the extended observation capability obtained with the combination of these sensors, in particular the global coverage from OLCI-A and OLCI-B. We are also presenting validation results of the Polymer products from OLCI and MSI using in-situ data from Aeronet-OC.

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No. 104

Near Real Time satellite detection and drift forecast of Sargassum algae in the Equatorial Atlantic

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Unprecedented massive landings of sargassum floating algae have been observed since 2011 along the shorelines of a huge area encompassing the Gulf of Mexico and the Caribbean Sea. The phenomenon is highly reported in West Indies (Guadeloupe, Martinique, Barbados ...), Dominican Republic, Mexico, Costa Rica, Texas, etc. Algae arrive from the open sea as large rafts (tens of km) after having drifted over long distances, probably from Brazil or the Gulf of Guinea. This issue has tremendous negative impacts over local communities, marine environment and industry. The tourism and fishing sectors are particularly drastically affected.

Pioneering work by Gower et al. (2006), and Hu (2009) has demonstrated the capacity of ocean colour satellites to detect sargassum rafts.

Our solution to this issue consists in (1) detecting sargassum algae using a synergy of satellite sensors (MODIS/Aqua, OLI/Landsat-8, Sentinel-3/OLCI, Sentinel-2/MSI), (2) running a drift model to estimate the sargassum trajectories and their potential landings on the coasts using environmental data coming from the Copernicus Marine Service, (3) providing dedicated bulletins to the end-users through a secured web platform to help them in their decision-making processes in all impacted sectors. This poster will put emphasis on the satellite data processing needed for sargassum detection.

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No. 105

Preliminary study on satellite data quality analysis of solar band based on simulation over ocean

Ling SUN[1], Lei GAO[2], Dan-Yang CAO[3]

The satellite data quality is one of the prerequisites of successful quantitative remote sensing applications. Using traditional methods, such as site calibration, cross calibration, stable target calibration, the radiometric quality of satellite data can only be reflected under limited conditions. In order to evaluate the data quality of reflective solar band more comprehensively, a data quality evaluation method based on the top-of-the-atmosphere earth observation simulation over global ocean using the mainstream radiative transfer model and double difference analysis is proposed. The method is applied to the visible bands of FY-3B MERSI and the radiometric error characteristics relative to MODIS are obtained. It reveals that although the simulated TOA reflectance tends to be underestimated due to the impact from stray light. Compared with the result of MODIS, the observed reflectance of MERSI using vicarious calibration is much higher than simulated value, which indicates the systematic bias. The double difference characteristics of scanning direction also reveals the problem in polarization dependence. Compared with the traditional calibration and validation methods, this method can provide global samples covering various geometries, and reveal the quality defects in spatial distribution, scanning and polarization dependence.

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Correction of the chlorophyll-a concentration profile in the Black Sea: *in situ* measurements and measurements from bio-argo floats

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The concentration of the photosynthetic pigment chlorophyll a concentration restored by regional algorithm in the Black Sea [Suslin V. and Churilova T., 2016] based on remote sensing ocean color data set in the visible spectrum [NASA Goddard Space Flight Center] describes an average value that characterizes only the upper layer of the sea on the order of the inverse value of the diffuse attenuation coefficient for downwelling irradiance. However, this is not enough for a number of scientific and practical applications. Using the current available data on chlorophyll-a concentration profiles, including in situ expedition measurements and measurements from bio-argo floats, correlations between the chlorophyll-a concentration in the upper layer of the Black Sea and its profile with a depth obtained earlier from the results of a summary of multi-year expeditionary data set [Finenko et al., 2005] have been calculated. A comparative statistical analysis of the old and the new approach showed the advantage of the new connections [Suslin et al., 2018]. The greatest progress has made in the profile description during the cold period from the second half of October to first half of April.

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Studying Ocean Color From Space: outreach and education in the junior classes

Natalia Suslina[1]

The high school club “Seeker” was formed on the city base of the young technicians In 1964. In the future, this club was renamed the Sevastopol territorial Department of the small Academy of Sciences “Seeker”, operating on the basis of the Center of scientific and technical creativity until 2011. On August 18, 2014, the government of Sevastopol signed Resolution No. 215 on the establishment of the state budget educational institution “Center for additional education of children “Small Academy of Sciences of the city of Sevastopol” (http://sevman.edusev.ru/). During existence of “Small Academy of Sciences” a great among of children were prepared for active scientific activity. Attending classes of “Small Academy of Sciences” helped children to achieve self-determination and chose their future profession.
The popularisation of science within pupils is the first preparation aim of personnel training for the Marine hydrophysical Institute (http://mhi-ras.ru/en/) and the Institute of Marine Biological research (http://imbr-ras.ru). Both institutes develop in different directions, one of them is Remote Sensing.

Basic scientific directions are:
• Experimental and analytical research of physical processes on the sea surface and in a near-surface sea layer with the purpose of development of marine environment remote sensing methods in microwave, infra-red and visible bands.
• Development of elements of the Azov-Black Sea basin operational monitoring system.

The overall aim for me is to enlight the modern scientific achievements to senior pupils in an accessible form, particularly, Ocean Color From Space (http://oceancolor.gsfc.nasa.gov/outreach/). This material is planned to be summarized though your conference.

Reference: SeaWIFS Project, Studying Ocean Color From Space, Teacher’s Guide with Activities http://oceancolor.gsfc.nasa.gov/SeaWIFS/LIVING_OCEAN/
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Estuary classification using satellite observations and forcing variables

Jing Tao[1], Paul S. Hill[2]

Abstract: This study examines the links between estuarine dynamics and remotely sensed longitudinal distribution of reflectance in estuaries. Surface reflectance at 655 nm from Landsatl 8 correlates with in-situ measurements of surface turbidity (R^2 = 0.96). Images collected from 2013-2018 are used to investigate the spatial and temporal characteristics of estuarine turbidity maxima (ETM) in six selected estuaries with different dynamics. The results show that the magnitude (C_{max}) and location (X_{max}) of the observed ETM are functions of two major forcing variables, the freshwater discharge and tidal stage. Salt wedge estuaries (i.e., the Fraser River, Connecticut River and Columbia River estuary) are affected strongly by river discharge and are less affected by tidal forcing. In salt wedge estuaries, the C_{max} values of the ETM along the river channel are strongly correlated with river discharge, while the X_{max} values of the ETM are weakly correlated with river discharge. In strain-induced periodic stratification (SIPS) estuaries (i.e., Delaware River) and nearly welll mixed SIPS estuaries (i.e., Gironde estuary), the X_{max} values of the ETM strongly correlate with river discharge, while the C_{max} values of the ETM do not correlate with river discharge. Well-mixed (i.e., Merrimack River estuary) and nearly well mixed SIPS estuaries (i.e., Gironde estuary) are strongly affected by tidal forcing. In these estuaries, the C_{max} values of the ETM are correlated with tidal stage, but the X_{max} values are not. C_{max} values decrease on flood tides and increase on ebb tides. Overall, the results demonstrate that remote sensing observations of ocean color can be used to infer subsurface estuarine processes.

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No. 109

An unmanned surface vehicle for ocean color remote sensing field investigation: a case in Honghu Lake, China

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Abstract: Integrated and intelligent on-site observation is an important fundamental support for remote sensing dynamic monitoring of water environment in the world. For the requirements of ocean color remote sensing field investigations, we developed an ocean color unmanned surface vehicle (OC-USV) and conducted test experiments in Honghu Lake, China. The OC-USV consists of an unmanned surface vehicle platform with data acquisition and transmission modules, a floating optical buoy (FOBY) for water remote sensing reflectance (R_{rs}) collection using the skylight-blocked approach (SBA), ocean color constituents observation system for chlorophyll, turbidity, and colored dissolved organic matter(CDOM), water sample auto-collection system, meteorological sensors for wind speed, wind direction, air pressure, temperature detection, and a portable control station etc. OC-USV has remote controlling, status monitoring, automatic obstacle avoidance, one-button return, data acquisition, transmission and processing functions. OC-USV conducted a six-day field investigation during March 23-28, 2018 in Honghu Lake (118°110'-118°52'E, 33°06'-33° 40'N), China. Compared with spectra from PSR 3500+ spectroradiometer based on the traditional above-water method, the uncertainty of R_{rs} obtained by the SBA-based FOBY onboard OC-USV is ≤ 5%. Regressions between results from in-lab analysis and OC-USV resulted in R^2s of 0.71 and 0.77 for chlorophyll and turbidity, respectively. This demonstrates the feasibility and practicability of OC-USV for automated in-situ observations of water optical properties. It would be a good option to conduct field investigations for ocean color remote sensing, and also provide an alternative for high-risk water areas with high pollution and/or with shallow depth where large ships are difficult to reach.

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Uncertainty in optical remote estimation of biomass of *Ulva prolifera* macroalgae using MODIS imagery in the Yellow Sea

Ting Lu[1], Yingcheng Lu[1,*], and Lianbo Hu[2]

Abstract: Annual blooms of *Ulva prolifera* since 2008 has been posing a significant threat to marine ecosystem in the Yellow Sea. Although spatial-temporal coverage of floating *Ulva prolifera* could be figured out by MODIS imagery, total biomass is essential for salvaging and cleaning up. Laboratory experiment was employed to obtain floating algae index (FAI) of floating *Ulva prolifera* corresponding to various Biomass per area (BP A). A piecewise empirical model (including linear and exponential functions) could be adopted to fit the statistical relationships between BPA and FAI, corresponding to FAI ≤ 0.2 (BPA ≤ 1.81kg/m^2) and FAI > 0.2 (BPA > 1.81kg/m^2) respectively. According to spectral mixing-derived results in this study, linear relationships between FAI and BPA are maintained when the BPA of endmember is less than 1.81kg/m^2. However, when the BPA of endmember is greater than 1.81kg/m^2, uncertainty in optical remote estimation of biomass will be displayed obviously Although MODIS-derived FAI of *Ulva prolifera* is often less than 0.2, it's really hard to identify the low FAI is from low BPA (≤ 1.81kg/m^2) of endmembers, or the low area ratio of high BPA(> 1.81kg/m^2) of endmembers due to pixel mixing. In this study, four MODIS imageries were used to show the uncertainty in biomass estimation of *Ulva prolifera* in the similar phonological period (i.e., June, summer in the yellow sea). Although we don't know the unit biomass distribution of pure endmembers, it could be assumed according to standard Gaussian distribution. Therefore, the uncertainty in optical remote estimation of biomass of *Ulva prolifera* would be given as follow. It would generate about ~36% uncertainty in total biomass estimation, and ~43% of the uncertainty is contributed by a few pixels (10% of total pixels) with high FAI (> 0.05). The uncertainty in BPA caused by a high-FAI (> 0.05) pixel is about 7.2 times as that of a low-FAI (≤ 0.05) pixel. In future, spatial distribution characteristics of FAI of pure endmembers should pay more attention to, which could be collected from high-spatial resolution images to improve the accuracy of optical remote estimation of floating *Ulva prolifera* macroalgae.

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No. 111

Consensus on aquatic primary productivity field protocols for satellite validation and model synthesis

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The NASA PACE project, in conjunction with the IOCCG, EUMETSAT, and JAXA, have initiated an Aquatic Primary Productivity working group, with the aim to develop community consensus on multiple methods for measuring aquatic primary productivity used for satellite validation and model synthesis. A workshop to commence the working group efforts was held December 05-07, 2018 at the University Space Research Association headquarters in Columbia, MD U.S.A., bringing together 26 active researchers from 16 institutions. The group discussed the primary differences, nuances, scales, uncertainties, definitions, and best practices for measurements of primary productivity derived from in situ/on-deck/laboratory radio/stable isotope incubations, dissolved oxygen concentrations (from incubations or autonomous platforms such as floats or gliders), oxygen-argon ratios, triple oxygen isotope, natural fluorescence, and FRRF/ETR/kinetic analysis. These discussions highlighted the necessity to move the community forward towards the establishment of climate-quality primary productivity measurements that follow uniform protocols, which is imperative to ensure that existing and future measurements can be compared, assimilated, and their uncertainties determined for model development and validation. The specific deliverable resulting from of this activity will be a protocol document, published in coordination with the IOCCG. This presentation will discuss the findings of the meeting, and address future activities of the working group.

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Mediterranean ocean colour Level 3 operational multi-sensor processing

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The Mediterranean near-real-time multi-sensor processing chain has been set up and is operational in the framework of the Copernicus Marine Environment Monitoring Service (CMEMS). This work describes the main steps operationally performed to enable single ocean colour sensors to enter the multi-sensor processing applied to the Mediterranean Sea by the Ocean Colour Thematic Assembly Centre within CMEMS. Here, the multi-sensor chain takes care of reducing the inter-sensor bias before data from different sensors are merged together. A basin-scale in situ bio- optical dataset is used both to fine tune the algorithms for the retrieval of phytoplankton chlorophyll and the attenuation coefficient of light, Kd, and to assess the uncertainty associated with them. The satellite multi-sensor remote sensing reflectance spectra agree better with the in situ observations than those of the single sensors. Here, we demonstrate that the operational multi-sensor processing chain compares sufficiently well with the historical in situ datasets to also confidently be used for reprocessing the full data time series.

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No. 113

A Scheme to Improve Atmospheric Correction Based on VIIRS Multi-angle observation

Junwei Wang[1], Zhongping Lee[2], Jianwei Wei[2]

Robust atmospheric correction to obtain accurate ocean color remote sensing reflectance (R_{rs}) from satellite measurements is still a big challenge, especially for coastal waters and/or there are absorbing aerosols. Here we represent a novel retrieval algorithm that determine atmospheric and ocean optical properties using VIIRS measurements from two different geometrical angles, with resulted R_{rs} compared with in situ measurements made in the Massachusetts Bay. The atmospheric model is the POLYMER based approach, where the power coefficient used to describe the spectral variation from aerosol scattering is varying instead of the default value of 1.0. The ocean reflectance model was revised by adopting an IOP-based R_{rs} instead of the chlorophyll-concentration based model. The performance of this novel algorithm is demonstrated using VIIRS measurements from two occasions centered on the Massachusetts Bay, with the results showing high potential of this method for atmospheric correction in coastal waters.

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Ocean Color Products Derived from VIIRS SNPP and NOAA-20

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Abstract: In this presentation, we provide an overview of the progress on producing accurate global ocean color products from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) and NOAA-20 satellites. VIIRS global ocean color products include normalized water-leaving radiance spectra nL_w(l) at the VIIRS six spectral bands, chlorophyll-a (Chl-a) concentration, water diffuse attenuation coefficients at the wavelength of 490 nm, K_d(490), and at the domain of photosynthetically available radiation (PAR), K_d(PAR), as well as QA Score for indication of ocean color data quality. However, VIIRS-derived daily ocean color images on either SNPP or NOAA-20 have some limitations in ocean coverage due to its swath width, high sensor-zenith angle, sun glint, and cloud, etc. Merging VIIRS ocean color products derived from the SNPP and NOAA-20 significantly increases the spatial coverage of daily data images. The two VIIRS sensors on the SNPP and NOAA-20 have similar sensor characteristics, and global ocean color products are generated using the same Multi-Sensor Level-1 to Level-2 (MSL12) ocean color data processing system. Therefore, the merged VIIRS ocean color data from the two sensors have high data quality with consistent statistical property and accuracy globally. We describe the data merging methodology from multiple satellite ocean color sensors, as well as an approach to remove data gaps of missing pixels using the Data Interpolating Empirical Orthogonal Functions (DINEOF). Some applications using the new complete global data coverage of daily ocean color product are also presented and discussed.

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Remote identification of biomass-burning smoke from clouds at multiple altitudes over ocean surface using MODIS data

Qing Wang[a, b], Yingcheng Lu[b*], Zhenke Zhang[a*], Minwei Zhang[c], and Junnan Jiao[b]

Biomass-burning smoke could contribute many non-negligible hazardous substance and carbon to atmosphere, such as generated in significant forest fire in Sierra Nevada near to the west coast of the United States, would be blown to the ocean surface and eventually settle into the ocean. In this study, MODIS imageries were collected to map the concentration of this smoke over ocean surface in 8th-11th November 2018. Although the biomass-burning smoke and various clouds could product strong backscattering signal in near infrared and short wave infrared wavelenghth (NIR-SWIR), how to identify smoke from various clouds is still a challenge. Moreover, two other key differences between smoke and clouds could be given as follow. (1) Spectral absorption features of water vapor are different, clouds are mainly composed by little water droplets or little ice crystals, but smoke is not. (2) Different clouds (i.e., cirrus and cumulus clouds) floating at two different heights over ocean surface, and therefore have a significant thermal difference. A decision tree method was designed to identify smoke, and include the following key steps. MODIS apparent reflectance of 936 nm (at the top of atmosphere) was used to detect all clouds and smoke; MODIS-derived brightness temperature from 9730 nm can distinguish high-altitude cirrus clouds (low temperature) from low-level cumulus clouds and smoke; and then a water-absorbed depth index (WADI, composed by 859, 936, and 1240 nm) was employed to identify cumulus clouds from smoke. According to the backscattering signal of MODIS 859 nm, the normalized concentration of satellite observed smoke was figured out. Spatial distribution and concentration of MODIS-derived smoke was accurately verified by spaceborne Lidar data over the same area (The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, CALIPSO) obtained on the same day. Remote identification and quantification of biomass-burning smoke over ocean surface play an important role in assessing the impact of them to marine environment and carbon cycle.

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No. 116

Deriving inherent optical properties from classical water color measurements : Forel-Ule index and Secchi disk depth

Shenglei Wang[1], Zhongping Lee[2], Shaoling Shang[3], Junsheng Li[4], Bing Zhang[5]

Long before the development of modern optical-electronic instruments for water's optical properties, Secchi disk depth (Z_{SD}) and Forel-Ule index (FUI) are the two oldest and easiest measurements of water's optical properties based on visual determinations, and there are records of such measurements of world's water bodies for more than a century. FUI divides natural water color into 21 classes from dark blue to yellowish-brown based on the Forel-Ule water color scale, while Z_{SD} provides a measure of water clarity based on the depth when a Secchi disk disappears from the sight of human eyes. These historical measurements, due to its qualitative nature (especially FUI), make it difficult to evaluate the change of water properties from its historical state. In this article, with an overarching objective to obtain water's inherent optical properties from such historical measurements, a model is presented to relate remote-sensing reflectance (R_{rs}) with FUI and Z_{SD}. Further, because both R_{rs} and Z_{SD} are functions of water's total absorption (a) and backscattering (b_b) coefficients, a system to convert FUI and Z_{SD} to absorption and backscattering coefficients (FZ2ab) is developed. The FZ2ab system was first tested with data generated by Hydrolight simulations, where promising results were obtained (R^2 = 0.95, mean absolute relative difference (MARD) = 10.5% for a and R^2 = 0.78, MARD = 28.0% for b_b, N = 500). The algorithm was further tested with in situ measurements and it was found that the FZ2ab system derived a at the transparent window agreed well with measurements from water samples (R^2 = 0.88, MARD = 26.0%, N = 195). These results demonstrate that we may quite confidently extend our knowledge of water's inherent optical properties of global seas and lakes to at least a century ago with the combination of FUI and Z_{SD}, which further opens the door to obtain more accurate estimation of chlorophyll concentration or suspended sediments than that from Z_{SD} or FUI alone.

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No. 117

Wind vector retrieval algorithm from spaceborne lidar data

Tianyu WANG[1,*], Delu PAN[1], Xianqiang HE[1], Difeng WANG[1]

The principal purpose of this paper is to extract entire sea surface wind's information from spaceborne lidar, and particularly to utilize a appropriate algorithm for removing the interference information due to whitecaps and subsurface water. Wind speeds are obtained through empirical relationship with sea surface mean square slopes. Wind directions are derived from relationship between wind speeds and wind directions implied in CMOD5n geophysical models function (GMF). Whitecaps backscattering signals were distinguished with the help of lidar depolarization ratio measurements and rectified by whitecaps coverage equation. Subsurface water backscattering signals were corrected by means of inverse distance weighted (IDW) from neighborhood non-singular data with optimal subsurface water backscattering calibration parameters. To verify the algorithm reliably, it selected NDBC's TAO buoy-laying area as survey region in camparison with buoys' wind field data and METOP satellite ASCAT of 25 km single orbit wind field data after temporal-spatial matching. Validation results showed that the retrieval algorithm works well in terms of root mean square error (RMSE) less than 2m/s and wind direction's RMSE less than 21 degree.

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No. 118

Deriving bottom depths and optical properties in Coral Reef Area from Ocean Color Sensor data

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Abstract: Coral reef ecosystem is a complex tropical marine ecosystem with high ecological, economic and social value. Fast and effective acquisition of underwater topography and optical properties of coral reefs is an important basic research content. Compared with other ocean satellites, Landsat 8 (30m) and Sentinel 2 (10m) data have higher spatial resolution. Combining hyperspectral remote sensing reflection model and quasi-analytical algorithm (QAA), a data processing method for fast determination of clear water depth using ocean color sensor data is proposed. The method is applied to visible band data of Landsat 8 and Sentinel 2 to obtain underwater topography and optical properties of coral reef ecosystem in Qilianyu waters of Xisha Islands. By comparing the water depth data and tidal data obtained at different time, it can be concluded that the method is robust and reliable in the application of Landsat 8 and Sentinel 2 data. It can be predicted that this method has great application value in shallow water depth measurement and shallow water ecological research, especially in functional areas such as coral reef ecosystem.

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No. 119

Derivation of phytoplankton, CDOM and detritus absorption coefficients from the Landsat 8/OLI reflectance in coastal waters

Jianwei Wei[1], Zhongping Lee[1], Shaoling Shang[2], and Xiaolong Yu[1]

The Operational Land Imager (OLI) onboard Landsat 8 has potential for mapping the water bio-optical properties with high spatial resolution. Landsat 8/OLI generates the remote sensing reflectance (R_{rs}) product at four visible bands ($\lambda_{1\text{-}4}$ = 443, 482, 561, and 655 nm), and is lack of a 412 nm band. This spectral configuration has limited the use of Landsat 8/OLI reflectance product for derivation of light absorption coefficients of phytoplankton, colored dissolved organic matter (CDOM), and detritus. In this study, we proposed a hybrid approach to facilitate such derivation from Landsat 8 data. First, we developed the virtual-band estimator to estimate the reflectance in a virtual band centered at λ_0 = 412 nm from the OLI reflectance spectra $R_{rs}(\lambda_{1\text{-}4})$. Both the modeled $R_{rs}(\lambda_0)$ and measured $R_{rs}(\lambda_{1\text{-}4})$ by Landsat 8/OLI were then used together to retrieve the water component absorption coefficients with existing algorithms including the quasi-analytical algorithm (QAA). We assessed the model performance with *in situ* measurements representative of a wide range of waters. The analyses showed that this novel approach could generate the component absorption coefficients with acceptable accuracy over the global waters.

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No. 120

Using HSV color segmentation to quantify marine oil emulsions based on reflectance spectral differences

Yansha Wen[1], Yingcheng Lu[1,*] and Jing Shi[1]

Abstract: Crude spilled oils in the ocean surface can form different types of pollutions (i.e., non-emulsion oil slicks and various oil emulsions) during oil weathering processes. Two different emulsions (Water in oil, WO; Oil in water, OW) are the most hazardous floating spilled oils and have various concentrations and show distinguished hyperspectral features. These made optical remote sensing of oil emulsions possible in detecting and quantifying works. However, spectral mixing is a significant challenge for quantification of oil emulsions with multispectral remote sensing. In this study, the lab- based spectral reflectance of WO and OW emulsions were used to simulate Landsat observed spectral features. The modeled results show that it is difficult to identify and estimate oil concentrations just using reflectance of bands. Relationship between characterized bands of mixing emulsions was another important reference for quantification of oil emulsions concentration. Hue-Saturation-Value (HSV) color model can take into account both reflectance and relationship between different bands of mixing oil emulsions. It was employed to determine the dominant oil emulsion in a mixing pixel, and HSV-derived segmentation could promote multispectral quantification of oil emulsions concentration. Landsat imageries with strong or weak sunglint over the BP oil spill in Gulf of Mexico were used to test this HSV segmentation. The results indicate the major emulsion dominant in a Landsat pixel could be identified based on hue and saturation of color model. Moreover, the normalized oil concentration of oil emulsions can be given. This test also indicates the multispectral remotely sensed data could be used to estimate oil emulsions volume in the future.

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Empirical formulas for estimating selected sea water inherent optical properties from the remote-sensing reflectance in Baltic Sea conditions and examples of their application

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Abstract: We present empirical formulas for estimating selected seawater inherent optical properties from the remote-sensing reflectance spectra, $R_{rs}(\lambda)$. Among them is the formula for estimating the backscattering coefficient $b_b(620)$ directly from the magnitude of R_{rs} at the red part of the visible light spectrum, as well as the formula for estimating the absorption coefficient $a(440)$ from the hue angle α, which is single parameter representing the colour of water perceived by the human eye, and which can be calculated from the shape of R_{rs} spectrum. Our formulas were originally developed on the basis of data obtained in a specific, optically-complex environment of the Baltic Sea, but, as we have documented, similar variants of formulas also seem to work when we have expanded our set with additional data representing different regions of global oceans, taken from NASA bio-Optical Marine Algorithm Data set (NOMAD). In the work we point to selected reasons for which one can observe these simple empirical dependencies (between $b_b(620)$ and $R_{rs}(620)$, and between $a(440)$ and)α, and also confront them with the results that can be achieved by carrying out simple modelling. Possible applications of developed empirical formulas are also described. We give examples of simple quasi-analytical algorithms that allow to estimate seawater backscattering and absorption coefficients in the entire visible spectral range. These algorithms do not require any additional *a priori* assumptions regarding the spectral shape of absorption coefficients by dissolved and suspended seawater constituents.

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No. 122

A Global Retrieval Algorithm of Phytoplankton Functional Types (PFTs): Toward the Applications to OLCI and GlobColour Merged Products

Hongyan Xi[1], Svetlana N. Losa[1], Antoine Mangin[3], Mariana A. Soppa[1], Philippe Garnesson[3], Julien Demaria[3], Odile Hembise Fanton d'Andon[3], Astrid Bracher[1,2]

Abstract: In the present study we focus on the approach for globally retrieving phytoplankton function types that are then applied to Sentinel-3A (S3) OLCI data and merged OC products from CMEMS GlobColour archive. The main retrieved PFTs include diatoms, haptophytes, dinoflagellates, green algae and prokaryotic phytoplankton (e.g., *Prochlorococcus* and other cyanobacteria). A previously proposed retrieval method, based on empirical orthogonal functions (EOF), is investigated and adapted using extensive data sets of *in situ* measurements, matchups between *in situ* and satellite data, and satellite OC products. Performance of the EOF-based approach is assessed statistically and cross-validated. The retrieved PFTs are compared with that derived from diagnostic pigment analysis (DPA) based on HPLC measurements, with results showing that the approach can well predict the chlorophyll-a concentrations for most of the mentioned PFTs. The performance of the algorithm is, however, less accurate for prokaryotes due to their general low concentration resulting in weak signal reflected in the spectra and EOF modes. Finally, the EOF modes derived from remote sensing reflectance (Rrs) at 9 bands and 11 bands are applied to the GlobColour merged data and OLCI products, respectively. Climatological characteristics of the PFTs are also evaluated based on 17 years of OC products (2002–2018). This study is to eventually develop the global satellite PFT products for long-term observation, updated timely with more available OC data in the future, and intercompared to the results with other existing PFT products (e.g. PhytoDOAS, OC-PFT, SynSenPFT, and PHYSAT).

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No. 123

Lessons from Spring 2018 Asian dust event: Source, Transport, and Implication for iron hypothesis

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Abstract

The supply of atmospheric mineral dust aerosols (i.e., bioavailable iron) to oceans could stimulate phytoplankton growth and have significant implications for the ocean carbon cycle. Here, we present the results of source, transport, and implication for the iron hypothesis of the spring Asian dust event occurred during 26 March to 5 April 2018 using multi-satellites data of Visible Infrared Imaging Radiometer Suite (VIIRS), Ozone Mapping and Profiler Suite (OMPS), Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) with the NOAA Hybrid Single Particles Lagrangian Integrated Trajectory (HYSPLIT) model. The distribution of Aerosol index (AI) values indicated that the Asian dust occurred in the Gobi and Taklamakan deserts on 26–27 March, and then moved northeastward through the northern East/Japan Sea into the Bering Sea over five days. This transport pathway was also consistent with visual inspection of VIIRS true-color imagery and backward trajectories provided by HYSPLIT model. Furthermore, CALIOP data, which enable to identify aerosol types such as mineral dust, polluted dust, smoke, showed that mineral dust aerosols were dominant in the altitudes of 2–7km in the Gobi desert, and then moved to the North Pacific Ocean ascending to 4–12 km altitudes. Chlorophyll-a concentrations have increased three times (from ~0.5 to ~1.5 mg m^{-3}) with the lag times of ~10–15 days since the dust passed through the western North Pacific, suggesting that the Asian dust event has a huge potential for enhancing ocean biological pump by supplying bioavailable iron to the North pacific ocean.

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Spatial distribution of chlorophyll a concentration and relationship to environment factors in the offshore waters of South China Sea

Jie Yu[1]

South China Sea (SCS) is a marginal sea of Pacific, with average water depth of 1212 m. SCS waters is oligotrophic, especially in the offshore waters. The annual chlorophyll a concentration (Chl-a) changes from 0.50 mg m^{-3} to 0.57 mg m^{-3} from 2003 to 2014. The Chl-a differs from winter, autumn, summer, and spring with high to low. The Highest monthly Chl-a is 0.83 mg m^{-3} at January, and the lowest monthly Chl-a is 0.37 mg m^{-3} at May. Spatial distribution of Chl-a show that higher value located at northeast and southwest of the SCS. Several Chl-a increase regions can be seen in the north continental shelf, northwest of Philippines coast, east of Vietnam coast, and surrounding waters of Dongsha Islands, Xisha Islands, Zhongsha Islands, and Nansha Islands. The spatial and temporal distribution of Chl-a are related to many environment factors. A seasonal correlation analyses between Chl-a and sea surface temperature (SST) and wind was done using SPSS. In spring, higher negative correlation between Chl-a and SST and positive correlation between Chl-a and wind are observed in the most region of SCS. The highest and lowest correlation between Chl-a and SST are located at northwest the Philippines and south of SCS. The highest correlation between Chl-a and wind are located in the northeast and south east of SCS. In summer, correlation between Chl-a and SST, Chl-a and wind show strong decrease in the north and west continental shelf. Higher correlation between Chl-a and SST distribute from Taiwan Island to southwest continental shelf. Higher correlation between Chl-a and wind are located at the south and east region of SCS. In autumn, the correlation factor in south SCS is lower than that in north SCS. The correlation factor increase compare to that in summer in the north continental shelf. In winter, there are weak correlation between Chl-a and SST almost in the whole SCS. While higher correlation between Chl-a and wind are observed at middle SCS with latitude from 14°N to 20°N.

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No. 125

An Empirical Algorithm to Seamlessly Retrieve Concentration of Suspended Particulate Matter from Water Color across Ocean to Turbid River Mouth

Xiaolong Yu[1], Zhongping Lee[1], Fang Shen[2], Menghua Wang[3], Jianwei Wei[1], Lide Jiang[3], Zhehai Shang[1]

Abstract: We propose a globally applicable algorithm (GAA$_{SPM}$) to seamlessly retrieve concentration of suspended particulate matter (C_{SPM}, in mg/L) from remote sensing reflectance ($R_{rs}(\lambda)$) of ocean and turbid river mouth waters without any arbitrary switching in its application. This GAA$_{SPM}$ is based on a calibrated relationship between C_{SPM} and a generalized index for SPM (GI_{SPM}) from water color. The GI_{SPM} is mainly composed of three $R_{rs}(\lambda)$ ratios (671, 745, and 862 nm over 551 nm, respectively), along with weighting factors assigned to each ratio. The weighting factors are introduced to ensure progressive application of $R_{rs}(\lambda)$ in the longer wavelengths for increasing turbidity. Calibration of GAA$_{SPM}$ employed data collected from multiple estuarine and coastal regions of Europe, China, Argentina, and the USA with measured C_{SPM} spanning from 0.2 to 2068.8 mg/L. Inter-comparison with several re-calibrated well-known C_{SPM} retrieval algorithms demonstrates that GAA$_{SPM}$ has the best retrieval accuracy over the entire C_{SPM} range with a relative mean absolute difference (rMAD) of 41.3% (N = 437). The uncertainty of GAA$_{SPM}$-derived C_{SPM} is mostly attributed to the retrievals from less turbid waters where C_{SPM} < 50 mg/L (rMAD = 50%, N = 214). GAA$_{SPM}$ was further applied to the Visible Infrared Imaging Radiometer Suite (VIIRS) images over prominent coastal areas and produced reliable C_{SPM} maps along with realistic spatial patterns. In contrast, applications of other C_{SPM} algorithms, which employ a hard-wired switching scheme, resulted in apparent discontinuities in C_{SPM} spatial distribution. The GAA$_{SPM}$ could therefore be a preferred algorithm for retrieving C_{SPM} over regions with a wide-range of C_{SPM}, such as river plume areas.

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No. 126

A soft-classification-based chlorophyll-a estimation method using MERIS data in the highly turbid and eutrophic Taihu Lake

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Abstract: Soft-classification-based methods for estimating chlorophyll-a concentration (Cchla) by satellite remote sensing have shown great potential in turbid coastal and inland waters. However, one of the most important water color sensors, the MEdium Resolution Imaging Spectrometer (MERIS), has not been applied to the study of turbid or eutrophic lakes. In this study, we developed a new soft-classification-based Cchla estimation method using MERIS data for the highly turbid and eutrophic Taihu Lake. We first developed a decision tree to classify Taihu Lake into three optical water types (OWTs) using MERIS reflectance data, which were quasi-synchronous (± 3 h) with in situ measured Cchla data from 91 sample stations. Secondly, we used MERIS reflectance and in situ measured Cchla data in each OWT to calibrate the optimal Cchla estimation model for each OWT. We then developed a soft-classification-based Cchla estimation method, which blends the Cchla estimation results in each OWT by a weighted average, where the weight for each MERIS spectra in each OWT is the reciprocal value of the spectral angle distance between the MERIS spectra and the centroid spectra of the OWT. Finally, the soft-classification based Cchla estimation algorithm was validated and compared with no-classification and hard-classification-based methods by the leave-one-out cross-validation (LOOCV) method. The soft-classification-based method exhibited the best performance, with a correlation coefficient (R2), average relative error (ARE), and root-mean-square error (RMSE) of 0.81, 33.8%, and 7.0 μg/L, respectively. Furthermore, the soft-classification-based method displayed smooth values at the edges of OWT boundaries, which resolved the main problem with the hard-classification-based method. The seasonal and annual variations of Cchla were computed in Taihu Lake from 2003 to 2011, and agreed with the results of previous studies, further indicating the stability of the algorithm. We therefore propose that the soft-classification-based method can be effectively used in Taihu Lake, and that it has the potential for use in other optically-similar turbid and eutrophic lakes, and using spectrally-similar satellite sensors.

Keywords: chlorophyll-a estimation; optical water types (OWTs); soft-classification-based method; MEdium Resolution Imaging Spectrometer (MERIS)

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No. 127

Light scattering by pure seawater: Recent advancement

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Light scattering by pure water and seawater is a fundamental physical property of water. It also plays a critical role in studying ocean through the optical means, such as the Ocean Color, because the molecular scattering by water and dissolved sea salts serves as the background that is unavoidably measured by the optical sensors. Here, we report the latest advancement in this field. The scattering by water exhibits an anomalous pattern with temperature, having a minimum scattering at temperature that varies from 24.6 °C for pure water to 27.5 °C for seawater of salinity 40 PSU. We investigated, for the first time, the effect of pressure on the scattering by seawater. Increase in pressure causes a decrease in the scattering because the increased pressure suppresses the random thermal motion of molecules and therefore reduces the microscopic fluctuations in density and in concentration (for seawater only), which in turn lower the fluctuation in the refractive index. The scattering decreases approximately by 12-13% from the surface to a depth of 10000 m. For ocean color application, pressure effect can be safely ignored, but it has to be accounted for the scattering measurements are taken directly at deeper depths, such as by BGC-Argo floats. Otherwise, the particulate backscattering would be underestimated. Also, for the first time, we examined the variation of the depolarization ratio of water with salinity. Our measurements showed that the value of the depolarization ratio increases slightly with salinity by about 10-20% for S = 40 PSU.

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No. 128

Linkages between surface algae and bottom oxygen in the Chesapeake Bay

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Hypoxia has been an ever increasing issue threatening aquatic ecosystems globally. In coastal waters, the primary cause of rising hypoxia is generally attributed to the enhancement of algal growth by eutrophication and subsequent benthic decay of algae-derived organic matter. Although mechanistically robust, this opinion has rarely been supported with direct evidence. Here we show linkages between surface phytoplankton and bottom oxygen in the Chesapeake Bay using high-resolution time series of satellite-derived chlorophyll data. We found that when oxygen supply and consumption are balanced, dissolved oxygen in bottom waters of the Bay is significantly correlated with surface algal biomass during the preceding weeks. The degree of their correlation exhibits a bimodal temporal variation. The two maxima occur during March-April and July-September, which can be deemed as seasonal hotspots of organic sinking flux likely associated with diatom/ zooplankton fecal pellets, and marine snow, respectively. We also observed feedback effects on phytoplankton from bottom hypoxia. From May to September when bottom hypoxia is most severe and hypoxia-induced nutrient release is at its peak, bottom dissolved oxygen is most significantly correlated with surface algal biomass during the following ~8 weeks. These results have significant ramifications for improving hypoxia forecast in coastal systems, and corroborate the opinion that hypoxia is a self-sustaining phenomenon and is difficult to reverse once occurs.

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No. 129

Phytoplankton species identification in Yangtze estuary adjacent waters: A similarity matching algorithm based on characteristic bands selection.

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Abstract: Based on simulation remote sensing reflectance spectra (R_{rs}) dataset of 11 single phytoplankton species with various water optical conditions, we conduct a similarity matching method, combined with phytoplankton characteristic bands selection (we called "BS-SI"), to identify dominant phytoplankton species from field measurements of water surface reflectance spectra in Yangtze estuary and its adjacent waters. Microscopic examination results of phytoplankton species show that this combination performs well in identifying dominant phytoplankton species, the identification accuracy of 119 stations (three cruises in July 2015, May 2016, and May 2017) is 91%, higher than the similarity index (SI) method (71%), after algorithm contrast on different optical components contribution of absorption, we find that BS-SI method presents better identification results than SI method in low phytoplankton absorption contribution condition, and the sensitivity analysis results indicate that the BS-SI is more insensitive to changes in SPM (suspended particulate matter) and CDOM (colored dissolved organic matter) than SI, more sensitive to changes in chlorophyll concentration, which indicates that BS-SI presents better identification effects in more extensive water conditions than SI method, by specific phytoplankton species identification ability analysis, we find that *Thalassiosira weissflogii* is most difficult to distinguish among all species, while *Karenia mikimotoi* and *Prorocentrum donghaiense* are the most distinguishable species, and the spectral resolution effects are also elaborated and we draw the conclusion that under 4nm resolution conditions, the phytoplankton species can't be identified well (matching accuracy is less than 50%), however, the BS-SI method presents better identification effects than SI method with the decreasing of spectral resolution.

Keywords: phytoplankton species identification; similarity index; characteristic bands selection.

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