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## EXTENDING THE OPERATIONAL LAND IMAGER FOR FRESHWATER RESEARCH: RETRIEVAL OF AN ORANGE CONTRA-BAND FROM PAN AND MS BANDS

The Operational Land Imager (OLI) onboard Landsat 8 has found successful application in fresh and coastal water remote sensing. Its radiometric specification and high spatial resolution can resolve optical variability in small water bodies. However, the limited multispectral (MS) band set restricts the number of parameters that can be retrieved. One relevant information that cannot be directly retrieved is the presence of cyanobacteria. This identification capability has been demonstrated for sensors with a band centered near 620 nm, the absorption peak of the diagnostic pigment phycocyanin (PC). While OLI lacks such a MS band in the orange region, this information is contained in its panchromatic band. This study explores the extraction of that information by a scaled difference with the MS bands. A set of 369 in situ spectra acquired in diverse lakes in Belgium and The Nederlands was used to develop and test a retrieval algorithm based on multilinear regression. The algorithm achieved a mean absolute percentage error of 3.19% and a bias of -0.76%. The robust retrieval of the orange reflectance contra-band in optically diverse environments was tested against the freshwater Optical Water Types, showing that a correction is necessary only for very clear waters (Chla < 1 mg/m$^3$). Finally, the retrieved band is shown to convey independent information from the adjacent MS bands when PC to Chla ratio increases above unity. An example application to OLI imagery is presented over a cyanobacteria bloom in lake Erie. The present method is distributed in the ACOLITE atmospheric correction code.

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## MONITORING FLOATING ALGAE WITH ULTRAHIGH TEMPORAL RESOLUTION HIMAWARI-8 DATA

Himawari-8 (H8) is a geostationary meteorology satellite launched and operated by Japan Meteorological Agency (JMA) and takes measurements at a temporal resolution of ~10 minutes. Although designed as a meteorological satellite, H8 has 3 bands in the visible domain, 1 band in the near infrared and 2 bands in the mid-infrared to observe the Earth system, all with reasonable signal-to-noise ratios, thus has strong potentials to provide observations of ocean color properties in a high-temporal-resolution fashion. In this study, the Floating Algae Index (FAI) developed for ocean color satellites is adapted to process H8 for monitoring the dynamic variations of floating algae. The distribution of FAI of Taihu Lake, China, derived from H8 was compared with that derived from concurrent MODIS images (a total of 52), and we found the correlation coefficient is 0.87, with the area of intense FAI calculated from both images differ by just 2.5%. These results support the use of H8 measurements to obtain reliable observation of floating algae at ultrahigh temporal resolutions (10 minutes), thus significantly improve our capabilities to monitor and study this material in aquatic environments. It is also found that FAI is more stable and more applicable compared to the traditional NDVI and EVI indexes used for algae monitoring. Applications of FAI from H8 over Taihu Lake, the Yellow Sea and Gulf of Tonkin are further presented as examples.

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## SATELLITE OCEAN COLOUR BASED HARMFUL ALGAL BLOOM IDENTIFICATION FOR IMPROVED RISK ASSESSMENT AND MITIGATION

The aquaculture industry faces environmental threats from harmful algal blooms (HABs), which have the potential to cause devastating economic losses. Satellite earth observation offers a cost effective method for operational monitoring of HABs over vast areas. Whilst the Chl-a product, often used as a proxy for phytoplankton biomass, can be used to indicate high biomass blooms, there is a clear need for value-added products that not only alert on bloom presence, but also on the bloom type and persistence. The high biomass nature of the regional waters provide strong assemblage related spectral variability, which can be exploited with the spectral bands of OLCI and MERIS. This study demonstrates the identification of three different phytoplankton types relevant to the aquaculture industry of South Africa. Thresholds of known spectral reflectance features, including the Fluorescence Line Height (FLH), the Maximum Chlorophyll Index (MCI) and the reflectance trough depth at 510 nm, are used to identify blooms that pose a high hypoxia and/or toxicity risk. These techniques are applicable to both OLCI and MERIS reflectance data and are routinely used by the aquaculture industry in South Africa for timely risk assessment and mitigation. Using both MERIS and OLCI data we produce risk climatology maps which provide critical information on the site selection of industries sensitive to the presence of HABs, such as aquaculture farms and desalination plants.

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## HIGH-RESOLUTION SATELLITE REMOTE SENSING OF COASTAL RED TIDES USING LABORATORY MEASUREMENTS OF MESODINIUM RUBRUM OPTICAL PROPERTIES

Mesodinium rubrum is a globally-distributed photosynthetic marine ciliate known to form ephemeral and massive red tides in coastal areas, such as estuaries, fjords, and upwelling zones. Though M. rubrum does not produce toxins, it has been identified as prey for Dinophysis spp., a dinoflagellate responsible for the diarrheic shellfish poisoning toxin. M. rubrum blooms are generally classified as Harmful Algal Blooms (HABs) due to their impact on water quality (i.e., oxygen depletion, modification of food-web dynamics). Detection, sampling, and quantification of such HABs is notoriously challenging due to the speed at which this ciliate can grow, swim, aggregate, disaggregate, and/or be consumed. Here, we present a novel detection and quantification method based on ocean colour satellite remote sensing. The inherent optical properties (absorption and backscattering coefficients) of M. rubrum were first characterized using laboratory measurements. Second, a simplified radiative transfer model was used to simulate the specific signature of M. rubrum, in terms of remote sensing reflectance (Rrs). Third, a detection and quantification algorithm was developed based on the specific shape of the simulated Rrs spectra: a 705 nm peak associated with high Chlorophyll-a biomass and a green trough associated with Phycoerythrin absorption. Fourth, the algorithm was applied to the 2016-2018 archive of Sentinel-2 satellite data. Several red tides were successfully detected, allowing us to study the spatio-temporal dynamics of M. rubrum blooms at high resolution (20 m, 5 days revisit) over a wide coastal area. Massive blooms of other species (e.g., Lepidodinium chlorophorum) were also observed and successfully discriminated.

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## BIO-OPTICAL ANOMALIES IN THE MEDITERRANEAN SEA: AN UPDATE

The Mediterranean Sea has been considered for a long time to be "bio-optically anomalous", so that standard ocean color algorithms fail to provide correct estimates of chlorophyll a concentrations over this oceanic area. Such anomalies imply that bio-optical relationships linking the inherent optical properties (absorption and scattering) of the various substances to chlorophyll a concentrations deviate from the average relationships observed in the world ocean. Since the mid-90's, several studies based on in situ (or satellite) measurements were performed to address this question, and different possible causes were invoked (presence of coccolithophores, influence of desert dust, excess of colored dissolved organic matter,... or a combination of these factors). There has been, however, no clear consensus on the origins of these bio-optical anomalies. In addition, the impact of possible specificities in algal community composition (pigments or size structure), has not been well documented. Recently, large in situ datasets have become available with the deployment of Biogeochemical-Argo profiling floats, and with recent cruises such as the PEACETIME cruise. These recent datasets, as well as the compilation of absorption data gathered during numerous cruises since the 90's, provide new insights into bio-optical anomalies in the Med Sea.

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Oral Session 7
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## EXPLORING GEOSTATIONARY HIMAWARI-8 OBSERVATIONS FOR COASTAL OCEAN COLOUR APPLICATIONS ON THE GREAT BARRIER REEF

Remote sensing of ocean colour has been fundamental to the synoptic-scale monitoring of marine water quality over the Great Barrier Reef (GBR). However, observations from current polar orbiting satellites, such as MODIS-Aqua and Sentinel-3 have been insufficient to quantify the diurnal variability of ocean colour in highly dynamic coastal environments such as the GBR. To overcome these limitations this work presents the development, validation and application of a physics-based coastal ocean colour algorithm for the geostationary Advanced Himawari Imager (AHI) on-board Himawari-8. Despite being designed for meteorological applications, AHI offers the opportunity to estimate ocean colour features every 10 minutes, in four broad visible and near-infrared spectral bands and at 1 $km^2$ spatial resolution. Observing ocean features from daily to less than hourly basis is a vast improvement, suggesting the potential to capture changes in dynamic coastal phenomena not previously possible, such as the migration of flood plumes. A coupled ocean-atmosphere radiative transfer model was used to simulate the AHI bands for a realistic range of in-water and atmospheric optical properties of the GBR and for a wide range of sun and observing geometries. The simulations were used to develop an inverse model based on Artificial Neural Network techniques to estimate the concentrations of chlorophyll-a, total suspended sediments and absorption of yellow substances directly from the AHI top-of atmosphere spectral radiance. The algorithm was validated with concurrent in situ data across the coastal GBR and an application of the Himawari-8 observations is presented during post-cyclone flood conditions in 2017.

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Wednesday, October 10

Oral Session 7

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## CHARACTERIZING DIFFUSE ATTENUATION OF REEF AND ADJACENT WATERS IN HAWAII AND BERMUDA

Knowledge of water clarity is important to both reef ecology and remote sensing of shallow waters. However, there are currently few published records of water optical properties for coral reefs. The purpose of this study is to characterize the range and variability of the spectral diffuse attenuation coefficient (Kd) in coral reef and adjacent waters. Using a Biospherical PRR-800, approximately 200 vertical profiles of downwelling spectral irradiance were collected across the reefs and nearby optically deep waters of Hawaii and Bermuda. A single spectral Kd was calculated for each profile. Results reveal water types ranging from clear oceanic to strongly turbid coastal. The primary driver of the magnitude of Kd is suspended sediments, while the shape of Kd is heavily dependent on colored dissolved organic matter (CDOM). Chlorophyll does not appear to be an important driver of Kd. These results are consistent with well-known reef characteristics: (a) Suspended sediments are ubiquitous on coral reefs and chiefly comprised of calcium carbonate, which is effectively spectrally flat; (b) Reefs generate large amounts of DOM; and (c) Suspended chlorophyll is typically very low in the water column above reefs. This presentation discusses these patterns and their implications to reef ecology and remote sensing.

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## SPECTRAL PROPERTIES OF SARGASSUM REFLECTANCE SPECTRA: RELATIONSHIPS WITH SARGASSUM FRACTIONAL COVERAGE AND DEPTH

Since 2011, holopelagic Sargassum spp. algae, commonly found in the Sargasso Sea, repeatedly stranded on Caribbean and African coasts causing large ecological, societal and economical damages. Their sources and the causes of their arrival in the North tropical Atlantic are still unknown. With their high spatial and temporal resolutions, ocean color satellite sensors are powerful tools to study Sargassum distribution. Sargassum detection is made using specific spectral indexes (e.g. MCI for MERIS/OLCI and FAI/AFAI for MODIS/VIIRS), but the relationships between these index values and the corresponding Sargassum coverage and biomass is still poorly constrained. In 2017, a large dataset of above-water reflectance spectra of Sargassum rafts were acquired during two campaigns in the North Tropical Atlantic using TriOS RAMSES hyperspectral radiometer (350 to 950 nm). A camera was coupled to TriOS radiometers to take simultaneous pictures of the sampling area. For each spectra, the corresponding Sargassum fractional coverage as well as an indicator of the Sargassum depth (surface/sub-surface), were then extracted from these pictures. Here we present the relationships obtained between these two parameters and several algae indexes, such as AFAI and MCI. First results indicate a good linear correlation between these indexes and the Sargassum fractional coverage. Classification and functional PCA methods on spectral data were also used to better understand the variability in magnitude and shape of reflectance spectra with the Sargassum fractional coverage and depth. Results of this study allow to develop new algae indexes and algorithms to identify and estimate Sargassum coverage from remote sensing reflectance.

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## REMOTE SENSING OF SARGASSUM HORNERI BLOOMS IN THE EAST CHINA SEA

A floating algae bloom in the East China Sea was observed in Moderate Resolution Imaging Spectroradiometer (MODIS) imagery in May 2017. Using satellite imagery from MODIS, Visible Infrared Imaging Radiometer Suite (VIIRS), Geostationary Ocean Color Imager (GOCI), and Ocean Land Imager (OLI), and combined with numerical particle tracing experiments and laboratory experiments, we examined the history of this bloom as well as similar blooms in previous years and attempted to trace the bloom source and identify the algae type. Results suggest that one bloom origin is offshore Zhejiang coast where algae slicks have appeared in satellite imagery almost every February–March since 2012. Following the Kuroshio Current and Taiwan Warm Current, these "initial" algae slicks are first transported to the northeast to reach South Korea (Jeju Island) and Japan coastal waters (up to 135°E) by early April 2017, and then transported to the northwest to enter the Yellow Sea by the end of April. The transport pathway covers an area known to be rich in Sargassum horneri, and spectral analysis suggests that most of the algae slicks may contain large amount of S. horneri. The bloom covers a water area of ~160,000 km$^2$ with pure algae coverage of ~530 km$^2$, which exceeds the size of most Ulva blooms that occur every May–July in the Yellow Sea. The record-high 2017 S. horneri bloom is hypothesized to be a result of high water temperature, increased light availability, and continuous expansion of Porphyra aquaculture along the East China Sea coast.

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## MODELING REMOTE SENSING REFLECTANCE OF HIGHLY TURBID WATERS

Several models relating remote sensing reflectance to water inherent optical properties (IOPs) have been developed. In particular, the reflectance is expressed as a function of a parameter u which is defined as a ratio of backscattering to extinction coefficients. We note that the quadratic model reported by Gordon et al (1988) has been widely accepted and validated. A more recent model by Lee et al (2004) separated the contributions by water and particle scattering. Most models however, only consider oceanic waters where scattering is low. This is not the case in coastal or inland waters with high suspended sediment load. Using Hydrolight simulations in waters with high scattering coefficient values, we found that the quadratic relation is not sufficient to describe the corresponding remote sensing reflectance. A polynomial of at least fourth degree is required to fit the simulation results at high u. Monte Carlo simulations were conducted to investigate the relation between the remote sensing reflectance and the u parameter at similar IOP values. Results of Monte Carlo simulations confirm the quartic relation derived from Hydrolight. Application of this relation in the retrievals of IOPs from remote sensing reflectance of highly turbid waters would prevent the overestimation of scattering constituents in such waters.

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## THE EFFECT OF OPTICAL PROPERTIES ON SECCHI DEPTH AND IMPLICATIONS FOR EUTROPHICATION MANAGEMENT

Successful coastal management requires reliable monitoring methods and indicators. Besides Chlorophyll-a concentration (Chl-a), Secchi Depth (ZSD) is widely used for water-quality assessment and as eutrophication indicator. In Case2 waters dissolved organic matter (CDOM) and inorganic suspended particulate matter (SPIM) also influence the under-water light field, and ZSD. In situ data from Swedish coastal gradients in three optically different regions were collected in 2010-2014. Regional empirical linear multiple regressions based on optical variables explained the ZSD well ($R^2_{adj}$ = 0.53 to 0.84). The effects of the predicting variables to the variance in $R^2_{adj}$ for ZSD models were analyzed by commonality analysis and showed large differences between regions. CDOM explained most of the variance in the Bothnian Sea (46%), together with SPIM (42%) and 70% alone in the Skagerrak; a combination of all three parameters contributed most in the Baltic proper (53%); Chl-a generally contributed only modest to variations in ZSD. The link between Chl-a and ZSD was weaker in areas with high CDOM and SPIM. These results impact the goals for achieving good water quality status of ZSD, based on reductions of Chl-a. Analysing the threshold for good Chl-a status, showed that ZSD is neither a sufficient indicator for eutrophication, nor for changes in Chl-a. Terrestrial run-off, physical and hydrological conditions indirectly effect the optical components determining ZSD. Natural coastal gradients in ZSD influence the reference conditions for other eutrophication indicators, e.g. underwater vegetation. Hence, setting targets for ZSD based on reducing Chl-a might in some cases be inappropriate and misleading.

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## NOVEL APPROACHES TO DERIVE THE PARTICULATE ORGANIC CARBON FROM SPACE IN COASTAL WATERS”: APPLICATION TO THE MERIS DATA SET OVER GLOBAL COASTAL WATERS

Last decades, different algorithms were developed for case 1 water to derive the surface concentration of particulate organic carbon (POC), and the integrated POC content over the mixed layer depth or the euphotic depth. Most of these algorithms are not suitable for coastal waters, mainly because of the presence of mineral particles as well as high CDOM concentrations, which greatly impact the radiometric signal. More recently, some algorithms were developed for the assessment of POC from OCR over coastal and estuary regions. However, they were developed from geographical restricted areas and were not tested on a large independent dataset. In this study, we compared the performance of 4 coastal algorithms on a database composed of 833 samples from various contrasted bio-optical coastal environments (Vietnam Sea, English Channel, French Guyana, North Sea and Mediterranean Sea). The dataset includes coincident measurements of biogeochemical parameters (POC [45.36– 5743.51 mg/m$^3$], SPM [0.207-1945.34 g/m$^3$], and Chla [0.02–48.32 mg/m$^3$]), hyperspectral Rrs, and IOPs (absorption and backscattering). Because none of these algorithms provide satisfactory results over the whole POC range, novel approaches have been developed: IOPs-based, band-ratio empirical and classification approaches. Besides the evaluation of these algorithms on an independent dataset, we also analyze the origin of the variability within these empirical and semi-analytical algorithms. The best approach has then been applied to the full MERIS dataset (GlobCoast) to characterize the spatio-temporal patterns of POC over the global coastal waters.

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## GLOBAL DECADAL SHIFTS IN COCCOLITHOPHORE BLOOM DISTRIBUTION

Analyses of coccolithophorid bloom distribution during the CZCS (1978-1986) and SeaWIFS (1997-2010) era show large distributional changes in bloom occurence; particularly in the mid- to high-latitude oceans. To bridge the observational gap between these two sensors, alternative bloom detection algorithms have been developed to exploit the available data from the visible channel of AVHRR. Despite being notably less sensitive than its ocean colour counterparts (3% vs SeaWIFS Channel 5), AVHRR-based approaches have been successfully used to identify and monitor coccolithophorid blooms in many high-latitude ocean cases. However, the lack of a consistent calibration across AVHRR platforms, and challenges in comparing multiple orbits, has prevented this approach from being applied to the global ocean until now. Here, we describe the production of a new, 40-year, global, remote sensing reflectance (Rrs) data set, derived from the consistently calibrated and geolocated AVHRR top-of-atmosphere reflectances, provided by the NOAA v5.3 PATMOS-X 0.1 degree resolution climate data record. Coccolithophorid blooms, identified in this product, are validated where possible against contemporaneous ocean colour imagery. Time series analysis of coccolithophore occurence, suggests marked shifts in bloom distribution, including a pronounced reduction in the mid-latitude North Atlantic, over a time period where climatic shifts have been shown to be demonstrable. Conversely, while bloom patterns in the high-latitude Southern Ocean (known as the Great Calcite Belt) are more episodic, they appear to be more robust, remaining undiminished into the 21st Century.

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## COUPLED EARTH OBSERVATION-ECOPHYSIOLOGICAL MODELING APPROACH TO SITE SELECTION FOR EXPANDING SHELLFISH AQUACULTURE

The potential for and productivity of shellfish aquaculture is strongly influenced by sea surface temperature (SST), and the concentration and nature of suspended particulate matter (SPM), which can both be monitored from space to determine shellfish growth conditions. Phytoplankton is a main food source for suspension-feeding bivalves. In too high concentrations, SPM has been documented to have a negative impact on shellfish physiological response. Growth has been quantitatively linked to these parameters and to SST through ecophysiological Dynamic Energy Budget (DEB) modelling for a number of species, including Crassostrea gigas. Here, the spatiotemporal variability of SST, SPM, and Chl (as a proxy for phytoplankton concentration) is considered by using Earth Observation data to drive DEB modeling for C. gigas in Bourgneuf Bay, France, thereby obtaining spatial distribution maps of the growth potential from near-shore to off-shore locations. An algorithm blending framework based on the dynamic identification of optical water type (OWT) has been applied to the entire MERIS full-resolution archive to take the optical diversity of the coastal ocean into account, so that the Chl and SPM algorithms selected for each OWT can be seamlessly merged for generic inshore-to-offshore application. Resulting growth potential maps are then used in site selection, and to investigate the potential for expanding aquaculture offshore from intertidal areas, where oyster farming already occupies much of the available space. Validation of satellite-retrieved SST, SPM, and Chl, used as model inputs, and model-output growth potential (oyster dry flesh mass; shell length) is demonstrated using corresponding in situ data.

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## A MODEL FOR DERIVING BENTHIC IRRADIANCE IN THE GREAT BARRIER REEF LAGOON USING MODIS SATELLITE IMAGERY

We developed a new ocean color model to derive benthic photosynthetically active radiation (bPAR) for waters of the Great Barrier Reef Marine Park (GBRMP), Australia. For coral reefs and other marine environments, the underwater light field is critical to ecosystem health. However, for the GBRMP, which spans 344,400 $km^2$, bPAR is still poorly understood as data currently do not exist at relevant spatial and temporal scales. We addressed this challenge by using satellite-derived bPAR from MODIS-Aqua imagery. The bPAR model uses: (i) surface values of the downwelling solar irradiance, Es(λ), (ii) high-resolution bathymetry data, and (iii) the spectral diffuse attenuation coefficient, Kd(λ), calculated from derived spectral inherent optical properties. Using Beer-Lambert law, Es(λ) is propagated to the seafloor and spectrally integrated to derive instantaneous bPAR. Matchups between concurrent satellite-derived bPAR and in situ values recorded at several depths indicate that the model performs very well in the GBRMP with an average relative measurement error of 22%, a multiplicative bias range of 0.90 – 1.05 (e.g., the model on average is 10% lower or 5% greater than the observed values), and regression metrics of $r^2$ = 0.60 – 0.78, slope = 0.98 – 1.22 and intercept = -0.28 – 0.06. We demonstrate the model in central GBRMP, revealing patterns of strong inter- and intra-annual variability. Our model will be highly valuable to assess changes in bPAR in response to drivers, and its effects on benthic primary productivity. Concurrent work is also underway evaluating bPAR as a potential GBRMP water quality metric.

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