Tuesday, October 9
Oral Session 3
08:30–10:30

08:30–08:50

RETHINKING APPROACHES FOR INFORMATION RETRIEVAL FROM OCEAN COLOUR

For several decades, metrics of ecological and biogeochemical process have been derived from ocean colour using empirical or semi-analytical methods. These methods provide reasonably accurate estimates of chlorophyll-a concentration (Chl-a) and various inherent optical properties (IOPs) across a wide variety of water types. However, accurate retrieval of these parameters in optically complex waters where atmospheric correction is challenging remains elusive. We argue that it is time to modernise our approach to information retrieval from ocean colour in these challenging scenarios, and use signals that include the atmosphere instead of trying to subtract it by estimation. Here, we present results from research performed as part of the first NASA PACE (Phytoplankton, Aerosol, Cloud and Ocean Ecosystem) Science Team activities, which demonstrate the feasibility of deriving Chl-a and IOPs from ocean colour using non-traditional modeling techniques. Specifically, we investigated the performance of an empirical orthogonal function-based algorithm, and various machine learning approaches. The models were trained and tested using a modified version of the NASA NOMAD in situ-to-satellite SeaWiFS matchup data set and a synthetic dataset derived from a coupled ocean-atmosphere radiative transfer model. In comparisons with the 'true' data, all models were found to retrieve Chl-a and spectral IOPs accurately (Chl-a: R^2 = 0.76-0.84, mean percent difference (MPD) = 29-36%, slopes ~ 1; IOPs: R^2 = 0.72-0.90, MPD ~ 0-25%), demonstrating the potential of these approaches to retrieve ecological and biogeochemical in otherwise intractable scenarios.

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MULTI-BAND ATMOSPHERIC CORRECTION (MBAC) ALGORITHM WITH ERROR PROPAGATION FOR OCEAN COLOR RETRIEVALS

NASA's current Atmospheric Correction (AC) algorithm for ocean color utilizes two bands and their ratio in the NIR to estimate the aerosols optical thickness and type. The algorithm then extrapolates the spectral dependence of aerosols to the visible wavelength for the correction, based on model assumptions. Future advanced ocean color sensors, such as the Ocean Color Instrument (OCI) onboard the Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE) satellite, will be capable of measuring the hyperspectral radiance from 350 to 900 nm and at 7 discrete SWIR channels: 940, 1038, 1250, 1378, 1615, 2130, and 2260 nm, with high radiometric accuracy. To optimally employ this unprecedented instrument capability, we propose an improved AC algorithm that utilizes all window channels in the NIR to SWIR spectral coverage to reduce the uncertainty in the AC process, namely Multi-Band AC (MBAC). A theoretical uncertainty analysis indicates that the MBAC algorithm can largely reduce the uncertainty in the remote sensing reflectance (Rrs) retrievals of the ocean caused by sensor random noise. In optically complex waters where the NIR signal is contaminated by the turbid waters, the MBAC algorithm in the SWIR improves the AC since it is less sensitive to the water turbidity. We will show results of ocean color retrievals after applying the MBAC algorithm to MODIS, VIIRS, and simulated OCI data. The MBAC algorithm and an error propagation technique of the AC process has been implemented in NASA's SeaDAS program and we will show the per-pixel uncertainty in the Rrs.

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IMPROVING THE ATMOSPHERIC CORRECTION OF OLCI OVER TURBID WATERS BY USING THE SWIR BAND AND A NEW BASELINE RESIDUAL TECHNIQUE

Since April 2016, the OLCI era has begun, providing a new opportunity for atmospheric correction of turbid waters due to its novel spectral band in the SWIR: the new band at 1016 nm, much less expensive for the mission than longer SWIR bands, such as MODIS' 1240, 1640 and 2130 nm bands but, with suitable algorithm development, may give similar and even better performances than far-SWIR and NIR bands for turbid water atmospheric correction. Although water absorption at this band is 6.9 and 11.8 times higher than 865 and 779 nm NIR bands, it is still not enough to fully absorb the backscattered signal produced by suspended sediments in optically-complex waters such as Río de la Plata (Argentina). This means that an alternative to the "black-pixel" approach is needed for this sensor in this region. In this work, we present a turbid water atmospheric correction algorithm developed for OLCI, based on Baseline Residuals (BLRs), i.e. spectral quantities computed from spectrally close triplets of (Rayleigh-corrected) reflectances in the Red/NIR/SWIR bands in the same way as the Fluorescence Line Height algorithm. The BLR algorithm is then evaluated and compared to results obtained with standard atmospheric correction approaches. The BLR approach showed better spatial decorrelation between atmospheric and water signal, and better estimates of Total Suspended Matter (match-up analysis using in situ data from Buenos Aires Province). Different BLR-water reflectance relations were evaluated based on reflectance models and OLCI data. Future efforts will be put in validating water reflectance using field measurements.

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Tuesday, October 9
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EFFECTS OF EARTH CURVATURE ON ATMOSPHERIC CORRECTION FOR OCEAN COLOR REMOTE SENSING

In this study, a vector radiative transfer model for the coupled ocean-atmosphere system with consideration of the effects of Earth curvature (named PCOART-SA) was developed using the pseudo-spherical approximation. Both downward and reflected solar beam radiation were corrected accounting for Earth curvature effects. Validation showed that the PCOART-SA results agreed well with literature benchmarks and the CDISORT and AccuRT model results. Based on PCOART-SA, Earth curvature effects on Rayleigh-scattering radiance including polarization were investigated. The results showed that the influence of Earth curvature increased rapidly with solar zenith angle, with influences up to 1%, 3%, and 12% for solar zenith angles at 75°, 80°, and 85°, respectively, which should be considered for high accuracy atmospheric correction. We also found that the Rayleigh-scattering look-up table in SeaDAS after version 7.2 showed significant bias at high solar zenith angles, which needs further investigation. Finally, using the PCOART-SA model, we generated Rayleigh-scattering lookup tables for Aqua/MODIS with consideration of Earth curvature effects, which can be directly used in SeaDAS.

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Tuesday, October 9
Oral Session 3
08:30–10:30

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ADJACENCY EFFECTS IN COASTAL WATERS

Coastal regions definitely represent a challenge in ocean color (OC) remote sensing due to simultaneous potential radiance contributions from non-covarying in-water optically active components, sea bottom and nearby land. The latter contributions, neglected in default atmospheric correction procedures, constitute a source of perturbations in satellite data and derived products. This work presents results from an extensive theoretical analysis of adjacency effects (AE) in typical multi-sensors observations of coastal seawaters. As an example, results indicate AE still above OLCI-RR noise level at ~36 km offshore for typical land covers (green and dry vegetation, white sand, bare soil, concrete, snow), except in the case of green vegetation at the red wavelengths. OLCI-FR data, characterized by significantly higher noise, are considerably less sensitive to AE. Results further indicate a noteworthy AE seasonality. While radiometric perturbations in the signal at the sensor are proportional to the land albedo, this does not hold for biases on derived radiometric products (e.g., Rrs) due to compensations between AE affecting the bands from which the atmospheric properties are determined and the bands at which the primary products are retrieved. With specific reference to in situ measurements performed in coastal regions to support ocean color validation activities (e.g., AERONET-OC), the analysis indicates the need to account for adjacency contributions to increase the accuracy of matchup analysis. Specific investigations on AE from the Lampedusa Island further indicates no land perturbations for distances larger than ~15 km offshore, where a potential System Vicarious Calibration site could be positioned.

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Tuesday, October 9
Oral Session 3
08:30–10:30

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AN ANALYTICAL FRAMEWORK FOR CALCULATING UNCERTAINTY IN NASA OCEAN COLOR OBSERVATIONS

Quantifying uncertainty in derived ocean color data products serves several purposes including, but not limited to, allowing end-users to: assess if datasets are fit-for-purpose, assess if observed temporal change is greater than uncertainty, assimilate errors into climate models, and assess consistency among sensors. Recently, first-order error analysis methods have been proposed that directly propagate radiometric uncertainty through an ocean color algorithm to derive data product uncertainty. First-order error propagation methods benefit from being computationally efficient, making them suitable for implementation in NASA's ocean color processing software. Here, we present an analytical framework, based on first-order error propagation theory, to directly calculate uncertainties in NASA ocean color products given uncertainties in spectral remote-sensing reflectances. We show by using first-order uncertainty propagation it is possible to identify the magnitude of individual uncertainty sources within an algorithm. Additionally, we evaluate how data product uncertainties affect down-stream estimates of productivity and other ecologically-relevant variables. Collectively, the analytical framework presented here is anticipated to be valuable to scientists designing next-generation bio-optical algorithms. In this work, we utilized a high quality in situ hyperspectral radiometric dataset that can be spectrally subsampled to match the spectral characteristics of most existing ocean color sensors. This includes NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission that is currently under development and will carry the first dedicated hyperspectral ocean color sensor.

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Tuesday, October 9
Plenary Session 2
14:00–14:40

14:00–14:40

EXPLORING A NEW ANALYTICAL RELATIONSHIP FOR OCEAN COLOR

Radiative transfer (RT) approximations relating remote sensing reflectance to bb/(a + bb) have been tremendously useful to the ocean color community for decades. Current algorithms to account for bidirectional reflectance distribution function (BRDF) effects in the proportionality (e.g., Morel et al. 2002; Lee et al. 2011) have relied on assumptions about angular scattering by particle fields because measurements of oceanic particle volume scattering functions (VSFs) have been historically lacking. Such assumptions are impactful, as the BRDF is effectively controlled by the VSF. We now have an increasing database of VSF measurements over the last 10 years with which we can assess other algorithm approaches where the VSF is explicitly represented. Related work has culminated in a fully analytical algorithm based on the RT approximation of Zaneveld (1995) with performance effectively equivalent to full RT simulations with Hydrolight when a constant VSF shape derived from our extensive measurements is assumed in the backward direction. The unknown inputs are absorption and backscattering, as with the conventional bb/(a + bb) relationship, so similar approaches to inversion can be directly applied. The algorithm shows improved performance relative to current state-of-the-art look-up table (LUT) based BRDF algorithms, i.e. Morel et al. (2002) and Lee et al. (2011). As a result, the algorithm shows good potential for future ocean color inversion with low bias, well-constrained uncertainties (including the VSF), and explicit terms that can be readily tuned.

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Tuesday, October 9
Oral Session 4
14:40–15:40

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PERSISTENT UV REFLECTANCE PEAKS IN THE GULF OF MAINE OBSERVED USING ABOVE-WATER, HYPERSPECTRAL RADIOMETRY: NEW OBSERVATIONS FROM THE GULF OF MAINE NORTH ATLANTIC TIME SERIES (GNATS)

The Gulf of Maine North Atlantic Time Series (GNATS)—a ferry-based, ship-of-opportunity program operating aboard a high-speed catamaran ferry—has regularly sampled across the widest part of the Gulf of Maine between Portland, Maine, USA and Yarmouth, Nova Scotia, Canada, for the last 20 years. The GNATS transect crosses four major coastal water masses, each with a different influence of phytoplankton, colored dissolved organic matter and suspended sediments. We also deploy a glider equipped with spectral Lu and Ed sensors (including a UV channel) along the same transect. In 2017, we transitioned our above-water radiometry from spectral-reflectance measurements (7 bands between 412 and 685nm) to hyperspectral- reflectance measurements (137 bands between 350 and 803nm with ~3.3nm resolution). We will present an analysis of these hyperspectral UV reflectance observations from the Case II coastal waters. In particular, we will focus our presentation on 1) the presence of persistent peaks in UV reflectance associated with specific water masses, and 2) relating the UV reflectance peaks to independently-measured hydrographic, optical, biological and chemical variables. One of the more prominent trends that we have observed is a persistent reflectance peak at 380-400 nm that varies as a function of changes in cloud/fog cover. Based on the rapidity of the change and the spectral quality, we hypothesize that we are seeing a reflectance change due to mycosporine-like amino acids (MAAs), UV-absorbing, photoprotective compounds known to be synthesized by various microalgal taxa including dinoflagellates, cyanobacteria, prymnesiophytes and diatoms.

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Tuesday, October 9
Oral Session 4
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AUTONOMOUS SHIPBORNE IN SITU REFLECTANCE DATA IN OPTICALLY COMPLEX COASTAL WATERS FOR VALIDATION OF SENTINEL-3 IMAGERY: A CASE STUDY OF THE SALISH SEA, CANADA

Present limitations on the use of satellite imagery to derive accurate chlorophyll concentrations arise from the lack of sufficient in situ measurements for validation of satellite reflectance. We installed a set of hyperspectral radiometers on a commercial ferry to measure radiances and irradiance with solar tracking capability that permits autonomous operation (SAS Solar Tracker, ST). We present ST in situ water leaving reflectance data (RrsST) and accompany ferry box and CODAR data, and Sentinel-3 imagery acquired in the spring and summer of 2016 in Salish Sea, for a total of 560 in situ matchup measurements. Measured ST data were processed to RrsST with an optimization to account for the regional bio-optical properties defined as SCDOM=0.0155, aCDOM = 0.007-3.0, and bb* = 0.0013. Level 1 Sentinel-3 images were processed with Polymer 4.7, C2RCC 0.15, and the standard ESA Level 2 water leaving reflectance products. Rrs from POLYMER and C2RCC compared to RrsST shows R^2 above 0.9 and mean relative percentage difference (MRD) for the visible wavelengths of 17% and 14% for ocean and 15% and -7% for plume waters, respectively. A novelty dataset, composed of ferrybox biogeochemical (chla, CDOM, and turbidity) and CODAR data, allowed for a robust spatiotemporal traceability of the uncertainties associated with the quality of matchups in the interface of the Fraser River plume and ocean waters. This analysis revealed that the uncertainties are proportional to the local current speed and direction and heterogeneity of water masses, adding to errors >50% between RrsST and Rrs from Sentinel-3.

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Tuesday, October 9
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LAGRANGIAN BIO-OPTICAL CHARACTERISTICS OF A MESOSCALE DIPOLE IN THE NORTH PACIFIC SUBTROPICAL GYRE

Mesoscale dynamics are the most energetic motions in the ocean and an important source of horizontal variability in open ocean ecosystems. Here we investigated the mesoscale physical and biogeochemical variability by measuring the differences between adjacent mesoscale eddies of opposite polarity. We deployed one Lagrangian optical profiler (Wirewalker, Del Mar oceanographic) in each eddy center resulting in the collection of ~1200 vertical profiles of hydrography, photosynthetically available radiation, oxygen, and optical proxies for pigment (fluorescence) and particle (scattering and beam attenuation) concentrations. The cyclonic and anticyclonic eddies of this study showed marked differences in their bio-optical characteristics whereby the cyclone contained more pigments and particles in the deep euphotic layer, near the depth of the chlorophyll maximum. Furthermore, the primary production of the deep euphotic community was also higher in the cyclone, as suggested when considering the amplitude of the diel oscillation of beam attenuation as a proxy for gross photosynthesis. The water column of the anticyclone contained distinct layers of particle accumulation including below the base of the surface mixed layer, around 75 meters, and at and below the chlorophyll maximum. The backscattering to beam attenuation ratio shows that different particles accumulated in different layers thus providing a proxy to identify different communities in the water column. Besides observing clear differences between the eddies, we measured temporal changes on relatively short time scales (~13 days) documenting that the North Pacific Subtropical Gyre, once thought to be a near steady state ecosystem, exhibits high frequency temporal variability.

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Tuesday, October 9

Oral Session 5

16:20–17:40

16:20–16:40

SEASONAL EVOLUTION OF LIGHT TRANSMISSION THROUGH ARCTIC SUMMER SEA ICE

Light transmission through sea ice has been identified as a critical process for energy partitioning at the polar atmosphere-ice-ocean boundary. Transmission of sunlight influences direct sea ice melting by absorption, heat deposition in the upper ocean, and in particular primary productivity. While earlier observations relied on a limited number of point observations, the recent years have seen an increase in spatially distributed light measurements underneath sea ice using remotely operated vehicles (ROV). These measurements allow us to reconstruct the seasonal evolution of the spatial variability in light transmission. Here we present measurements of sea ice light transmittance from 6 years of polar ROV operations. The dataset covers the entire melt cycle of Central Arctic sea ice. Data is combined into a pseudo timeseries describing the seasonal evolution of the changing spatial variability of sea ice optical properties. Snow melt in spring increases light transmission continuously, until a secondary mode originating from translucent melt-ponds appears in the histograms of light transmittance. This secondary mode persists long into autumn, before snow fall reduces overall light levels again. Comparison to several autonomous time series measurements from single locations confirms the detected general patterns of the seasonal evolution of light transmittance variability. These results allow for the evaluation of two different light transmittance parameterizations, implying that light transmission is overestimated in current ice-ocean models.

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Tuesday, October 9
Oral Session 5
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16:40–17:00

RECONSTRUCTING OPTICAL PROPERTIES IN THE MEDITERRANEAN SEA : THE COMBINED USE OF BGC-ARGO AND SATELLITE DATA WITH NUMERICAL MODELS

We hereby present the potential of using in-situ data and remote sensing products, both as model inputs and output validation tools, within the Mediterranean Sea biogeochemical modelling framework. One example of merging different techniques was investigated by adopting a 1-D version of the 3-D biogeochemical model based on the OGSTM-BFM system, where we used a BCG-Argo data set comprised of 31 floats for the period between 2012 and 2016. The photosynthetically active radiation profiles served as the external optical forcing, whereas fluorescence-derived chlorophyll profiles were compared with the model output regarding deep chlorophyll maximum and chlorophyll concentration magnitudes. Furthermore, satellite data from the Copernicus Marine Data Stream were acquired in order to update the algorithm that has been used so far in the 3-D biogeochemical model within the E.U. Copernicus Marine Services. The objective was to quantify the sensitivity of model results using climatological vs. improved Kd data (based on ESA CCI merged files for Kd490) in terms of chlorophyll and primary productivity. Chlorophyll concentrations were validated also through the use of a quality-controlled HPLC dataset, which was compared to corresponding model outputs at given locations. Such an integrated approach is useful as a first step towards the improvement of the optical component of the 3-D biogeochemical Mediterranean Sea model, striving towards the implementation of a hyperspectral radiative transfer model, which would present a fundamental upgrade to obtain a more accurate description of the underwater light field, impacting both hydromechanics and biogeochemistry. Results will be discussed at the conference.

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17:00–17:20

OPTICAL INVERSIONS USING GLIDERS: METHOD DEVELOPMENT, VALIDATION AND APPLICATION WITHIN THE GULF OF MAINE

Autonomous underwater gliders have enabled the full water column to be studied at high spatial detail, but only a few studies currently exploit the potential of bio-optical gliders, equipped with both radiometric and backscattering sensors, as a unique platform for developing and evaluating inversion methods. We have used Slocum gliders since 2008 to compliment the ongoing Gulf of Maine North Atlantic Time Series (GNATS), which has been sampling biological, chemical and optical properties in surface waters of the Gulf of Maine since 1998. The gliders are equipped with instruments for measuring spectral upwelling radiance, spectral downwelling irradiance, chlorophyll-a fluorescence, CDOM fluorescence and particulate backscattering. In this study, we present a novel method for the quality control and classification of glider-acquired radiometric profiles, and demonstrate how they can be used to estimate inherent optical properties (IOPs). For 3418 profiles measured within 3 hours of local apparent noon, we found the backscattering coefficient could be estimated with a median absolute error of 1.15 (i.e. 15% variability between the measured and estimated value) and a bias of 2%. Glider-measured apparent optical properties (AOPs) allow us to estimate IOPs which in turn can be used to estimate biogeochemical properties. Ultimately, this allows highly reliable studies of both the temporal and spatial distribution of phytoplankton populations and other optically significant materials (OSMs), and the impact of OSMs on light availability for phytoplankton growth throughout the euphotic zone across the Gulf of Maine.

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Tuesday, October 9
Oral Session 5
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17:20–17:40

MAPPING IN SITU CHLOROPHYLL VARIABLE FLUORESCENCE USING AUTONOMOUS UNDERWATER GLIDERS

Accurate ecosystem models and assessment of the marine carbon budget require an understanding of the physiological responses of phytoplankton to physical forcing, such as nutrient and light availability. However, phytoplankton physiology and photosynthesis are poorly sampled using traditional shipboard techniques over the relevant spatial/temporal scales. Here, we report the integration of a Fluorescence Induction and Relaxation (FIRe) sensor in a Slocum glider (FIRe glider), allowing autonomous high-resolution and vertically-resolved measurements of physiological variables together with physical oceanographic data, and assess the potential insights this technology can bring to the phytoplankton physiology scientific community. A key advantage of this integration is the ability to make in situ variable fluorescence measurements under ambient light, providing a better understanding of the physical controls of primary production. Several targeted missions were conducted in the West Antarctic Peninsula using the FIRe glider that documented physiological responses (e.g. photosynthetic efficiency, Fv/Fm) to light stress using fluorescence kinetics. Diel cycles collected showed a clear daily cycle dependent on the magnitude of incident radiation. Different photoacclimation regimes were observed and evaluated under varying mixed layer depths conditions by modeling the light saturation parameter, Ek, using the light – photosynthetic efficiency relationship. Incorporating the FIRe system on a glider platform provides a novel approach for addressing topics of persistent/outstanding uncertainty due to the variable temporal and spatial scales at which they operate, such as the role of vertical mixing in phytoplankton dynamics and physiology.

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