International Ocean Colour Science Meeting 2013

Advancing Global Ocean Colour Observations

SUBMITTED ABSTRACTS

Topical Area

In situ data and protocols for cal/val

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In Situ Observation Strategies Supporting Future Ocean Color Science

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Summary

The global ocean ecosystem is displaying unprecedented rates of change, forced by a warming climate, higher levels of carbon dioxide, and altered precipitation and land use patterns, all fueled by increasing human population. Ecological stresses resulting from acidification, water column stratification, coastal pollution, and sedimentation are expected to intensify for the remainder of the century, endangering marine services related to food and recreation. Addressing these problems will require science-based decisions supported by accurate and complete knowledge of the Earth ecosystem. Ocean color science, based on a foundation of accurate, in situ observations employing emerging ocean observatory infrastructures and evolving profiling float technology, is poised to play a key role in building that knowledge base. However, deploying and maintaining in situ optical and biogeochemical sensors within a sustained, autonomous observatory presents quality control and assurance challenges that the international ocean color science community must solve to fully realize the capability of future ocean color satellites.

Introduction

Ocean color remote sensing using well-calibrated sensors aboard satellites has emerged as a key contributor to basic knowledge of oceanic and coastal ecology. Continuous and consistent observations stretching back over three decades have revealed optical signals related to seasonal, annual, and decadal scale variability in phytoplankton and suspended sediments and bio-optical responses to extreme events. The satellite data records define historical conditions on a global scale that serve as benchmarks with which to compare future changes. However, emerging oceanic problems related to climate change, e.g., oceanic uptake of atmospheric CO_2 and resulting impacts of ocean acidification, requires that we develop the capability to monitor ocean biogeochemical processes in greater detail and fidelity. To meet these challenges, future ocean color satellite systems, such as the NASA Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) and Geostationary Coastal and Air Pollution Events (GEO-CAPE) missions, will include sensors capable of imaging the ocean throughout the visible and near-infrared spectrum with greater spatial and spectral resolution and radiometric sensitivity. These enhanced capabilities are expected to result in better understanding of phytoplankton populations and primary production rate, relationships between ocean biological and physical processes, carbon transport between terrestrial, atmospheric, and oceanic environments, and impacts of climate variability and trends on present and future ocean services.

Providing accurate information derived from ocean color imagery requires a well coordinated and executed program of in situ observations designed to aid in the calibration of satellite sensors and validate operational and emerging product algorithms; a process collectively referred to as CAL/VAL. Historically, this has been accomplished through field operations involving research vessels, moorings (e.g. MOBY and BOUSSOLE), and stationary offshore platforms (e.g., the Aqua Alta Oceanographic Tower) and dedicated to CAL/VAL objectives. While these approaches serves well the development and production of heritage standard products and should be continued to support future satellite systems, future in situ operations must also be more integrated with physical and biogeochemical observation activities if we are to maximize the value of future ocean color remote sensing systems and achieve the stated ocean color science goals related to climate change.

Over the last quarter century, autonomous ocean observing systems have emerged to yield continuous data streams of increasingly interdisciplinary scope. These ocean observatories, using both moored and mobile platforms, have resulted in new insights regarding biogeochemical processes, often in response to ocean physical, atmospheric, and terrestrial forcing. Optical (spectral a, b_b, c, E_s, E_d, and PAR) and biogeochemical (DO, pH, CO_2, and nutrient) sensors, of utility in ocean color research, have evolved to form the core of many modern ocean observatories, such as the Australian Integrated Marine Observing System (IMOS) and the United States Integrated Ocean Observing System (IOOS). In the case of IOOS, the Ocean Observatories Initiative (OOI) component currently under construction will come on line in 2015 and will field a variety of optical and biogeochemical sensors within moored arrays and on ocean gliders at two coastal sites (the Pioneer array off the northeast coast of the US and the Endurance Array off the northwest coast) and four high latitude sites (the Irminger Sea in the North Atlantic, Ocean Station PAPA in the North Pacific, the Argentine Basin in the South Atlantic, and the South Pacific off the southwest coast of Chile). Observatories such as these can potentially fill critical ocean color science data needs in the future.

In addition to fixed observatories, the international Argo program offers opportunities to develop profiling floats with optical and biogeochemical sensors and to deploy them in consort with the 3000+ existing Argo floats collecting temperature and conductivity data. The Argo program plans to start deploying floats equipped with dissolved oxygen sensors, in addition to temperature and salinity.

In order to continue the production of heritage products and achieve future ocean color science goals, in situ observations must exceed the accuracy requirements of the remote sensing algorithm. While this can largely be achieved using ship-based operations, biofouling often corrupts moored optical and biogeochemical sensors within a few days to weeks of deployment unless anti-biofouling measures are incorporated into the sensor and/or deployment design and combined with appropriate operations and maintenance plans. While protocols have been established for ship-based operations in support of ocean color science, such protocols have yet to be established for sustained deployments characteristic of modern ocean observatories and profiling drifters. Given the international scope of problems that ocean color science will address and the need for in situ data representing the global ocean, it is proposed that a working group composed of observatory and float operators be established with international support and participation to develop protocols and standards for sustained, in situ optical an biogeochemical observations.

Conclusions

Ocean color science, based on a foundation of accurate, in situ observations employing emerging ocean observatory infrastructures and evolving profiling float technology, is poised to play a key role in understanding climate-related changes in global ocean ecology. However, deploying and maintaining the necessary in situ optical and biogeochemical sensors within a sustained, autonomous observatory presents quality control and assurance challenges that must be met before the data can be used for CAL/VAL activities or employed in ocean biogeochemical process studies.

Assessments of VIIRS Ocean Color data retrieval performance in coastal regions

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Summary

The quality of the VIIRS Ocean Color (OC) products, namely the normalized water-leaving radiances (nLw) and atmospheric products (i.e., aerosol optical thickness and Angstrom exponent), are analyzed for coastal waters conditions encountered at the LISCO and WaveCIS AERONET-OC sites. Through statistical analysis carried out between the VIIRS, MODIS and AERONET-OC data, the impacts of the different processing schemes on the VIIRS's OC data retrievals are assessed in order to aid the scientific community to better interpret the physical or biogeochemical meaning of the VIIRS data in coastal areas.

Introduction

The Suomi National Polar-orbiting Partnership (NPP) spacecraft was successfully launched on October 27, 2011 bearing several Earth observing instruments, including the Visible-Infrared Imager Radiometer Suite (VIIRS). In processing of OC data from VIIRS, the NASA Ocean Biology Processing Group (OBPG) is deriving a continuous temporal calibration based on the on-board calibration measurements for the visible bands, and then reprocessing the full mission to produce a continuously calibrated sensor data record (SDR) product. In addition, an additional vicarious calibration during SDR to OC Level-2 processing is applied [1, 2]. In this latest processing (version 2012.2), the vicarious calibration is derived from the Marine Optical Buoy (MOBY) data [3] whereas previously it was derived from a sea surface reflectance model and a climatology of chlorophyll-a concentration in the initial processing [2]. More recently, in fulfillment of the mission of the U.S. National Oceanic and Atmospheric Administration (NOAA), the Interface Data Processing Segment (IDPS) developed by Raytheon Intelligence and Information Systems, for the processing of the environmental data products from sensor data records, has gained beta status for evaluation. Consequently , assessments of the VIIRS ocean color products are necessary, especially for coastal, waters to evaluate the consistency of these processing and calibration schemes.

Discussion and results

The ocean color component of the Aerosol Robotic Network (AERONET-OC) has been designed to support long-term satellite ocean color investigations through cross-site measurements collected by autonomous multispectral radiometer systems deployed above water. As part of this network, the Long Island Sound Coastal Observatory (LISCO) near New York City and WaveCIS in the Gulf of Mexico expand those observational capabilities with continuous monitoring, and for the LISCO site, with additional assessment of the hyper-spectral properties of these coastal waters [4]. From investigations carried out over a period of almost one year, there is now a VIIRS dataset based on the data from two coastal AERONET-OC sites, where it has been observed that the VIIRS sensor can capture well the seasonal and temporal variations in the *nLw* data, while exhibiting significant correlation with in-situ data (*R* equal to 0.968 and 0.977 for LISCO and WaveCIS respectively). For the WaveCIS site, VIIRS *nLw* data retrieval is improved with version 2012.2 processing schemes, reducing the retrieval biases at every wavelength. However, that is not the case for the LISCO site, which shows more frequent occurrences of negative water-leaving radiances, and where underestimation in VIIRS *nLw* data is further exacerbated. This points out that the impacts of vicarious calibration procedures are not the same for the coastal areas with different water/atmosphere conditions and probably suggests the need to take into account comparisons between AERONET-OC and satellite data for coastal sites before making decisions on changes of sensor gains.

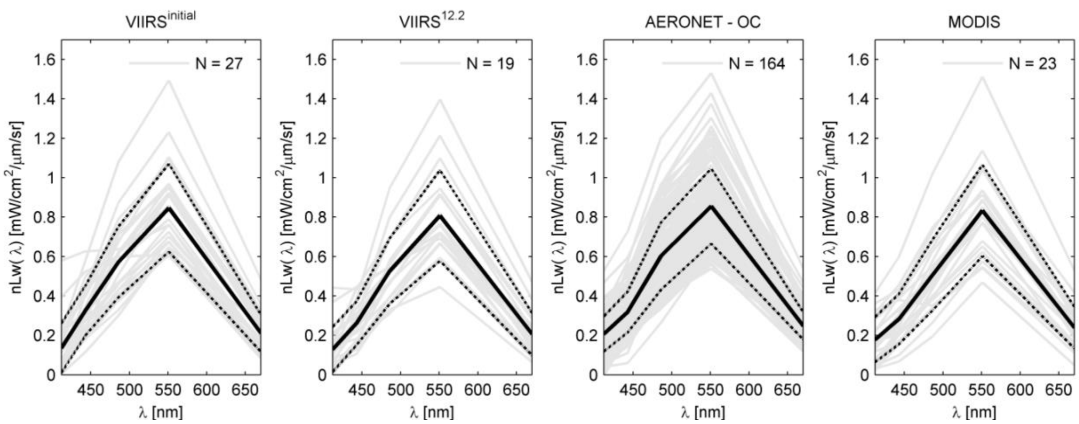

Figure 1. nLw(λ)match-up spectra of VIIRS^{initial}(1stcolumn), VIIRS$^{12.2}$(2nd column), SeaPRISM (3rd column) and MODIS (4th column) for the LISCO site. N is the total number of spectra for each sensor. Grey lines represent the individual spectra. Thick black solid lines indicate average and thick dashed lines indicate ± one standard deviation).

Strong consistency between the time-series *nLw* data retrieved from the VIIRS and MODIS sensors was also observed. Evaluations of the aerosol optical thickness, τ_a, data exhibits significant correlation but with substantial overestimations in the case of VIIRS data. Impacts of the aerosol model selection over the atmospheric correction procedure will be also discussed.

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The MERis MAtchup In-situ Database (MERMAID) and Validation Facility

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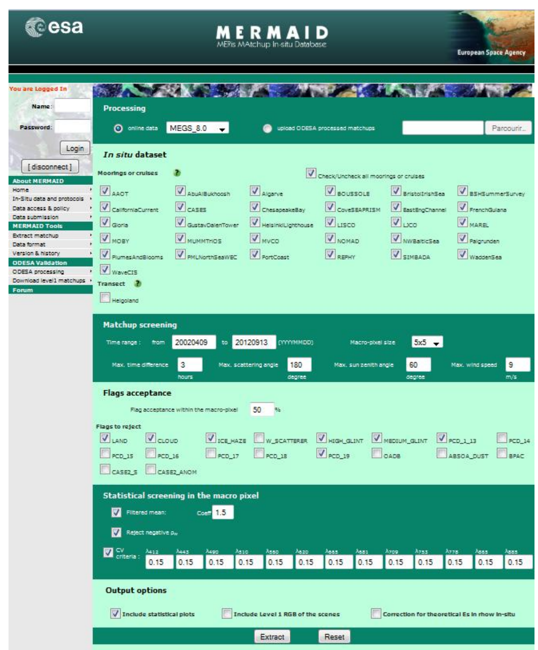
Summary

MERMAID is a freely available facility for validation and development of marine bio-optical algorithms, consisting of a database of bio-optical match-ups, i.e. concurrent in-situ and Earth-Observation data, developed in collaboration with Principal Investigators, including a detailed documentation of the protocols, sanity and quality checks of the datasets and further processings to best match the satellite data. MERMAID complements the Optical Data processor of ESA (ODESA, see dedicated presentation), providing validation against data of known quality in a perfectly controlled configuration.

1. Introduction

An integral requirement for optical satellite sensor cal/val activities is the gathering of reliable match-ups between in-situ data of known quality, and concurrent satellite data extraction. In 2007 the European Space Agency (ESA) initiated together with ACRI-ST and ARGANS the MERMAID facility (http://hermes.acri.fr/mermaid; [1], [2]) to meet this goal for the MERIS sensor, involving closely a community of Principle Investigators (PIs). Since 2011 MERMAID has become a facility open to any ocean colour researcher, aimed at solving two major difficulties: i) bringing together communities of PIs and algorithm developers with traceable protocols, clear data proprietary rights, and easy-to-use data extractions; ii) merging different sources of data, for providing statistically and physically relevant number of match-ups.

MERMAID is an ever-developing database; new scientists are welcome (contact mermaid@esa.int). Use of MERMAID follows adherence to a data policy ensuring PIs' data ownership and MERMAID service acknowledgment.



MERMAID interactive interface

2. Data Catalogue

MERMAID comprises more than 30 in-situ sites worldwide with associated MERIS data extractions (1km resolution). Datasets derive from permanent stations, cruises or transect profiles, and are classified as i) Long-term permanent stations for sensor calibration and validation; ii) Occasional national or international oceanographic cruises; iii) Regular regional measurements by research laboratories; iv) Regular measurements for national water monitoring.

Available in-situ quantities include (not exhaustively):

- **Apparent Optical Properties (AOPs):** e.g. normalised water reflectance (ρ_{wN}) at measurement wavelengths and satellite wavelengths when possible, solar illumination (*Es*);
- **Inherent optical properties (IOPs):** Total absorption coefficient (*a*, including pure seawater absorption a_w), and component absorption coefficients; total scattering (*b*, including pure seawater scattering b_w), and component scattering coefficients; particulate backscattering (b_{bp});
- **Bio-optical constituents concentration:** Total Chl-a and chl_a only derived from HPLC, spectrophotometric chlorophyll-a, fluorometric chlorophyll-a, total suspended matter (TSM);
- **Atmospheric measurements:** aerosol optical thickness (τ) and the angstrom exponent (α) for AERONET-OC sites, both provided at two times bracketing the sensor overpass.

3. Features, facilities and quality control

- **In-situ measurement protocols and QC documentation:** Accompanying all in-situ measurements on the website: i) *AOPs* and *ii) IOPs and in-water constituents.*
- **Interactive matchups building:** MERMAID's interactive interface builds match-ups according to a number of user-selected criteria, with default options following [3]. Criteria include: macro-pixel size, time difference between in-situ and satellite, geometry and flagging to remove unreliable pixels. Statistical screening removes outliers in the macro-pixel.
- **Text data files (merged in-situ and satellite), statistics and graphics:** Statistics of the satellite versus in-situ data; scatter plots and stacked histograms; True colour images of 10°x10°.
- **QC indicators:** to indicate adherence to a clearly defined measurement and processing protocols by the PI, and post-submission quality control performed on the in-situ data;
- **Marine reflectance normalisation:** A bidirectional effects correction on ρ_w; same approach as that used in the MERIS processor and AERONET-OC data.
- **Optical bandshifting:** To minimise potential error caused by mismatched wavebands between in-situ and satellite, the bandshift correction scheme described in [4] is applied in the MERMAID processing of AAOT, Gustav-Dahlen Tower and Helsinki Lighthouse.
- **Correction for in-situ solar irradiance in ρ_w:** To negate potential effects of tilt on buoys in the measured Es values, and to bring consistency in the solar illumination used in the computation of the in-situ reflectance, with the MERIS formulation of Es estimated at ground level.
- **Correction for the skydome on in-situ ρ_w:** AERONET-OC SeaPRISM and MUMMTrios datasets [5].

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Absorption and pigment characteristics of phytoplankton size classes in the Mozambique Channel

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Summary

An in situ study of the absorption and pigment properties of phytoplankton size classes in the Mozambique Channel was undertaken with a view towards application of satellite data to monitor seasonal and interannual change in community structure in the Channel. The relationship between a_{ph} (443) and TChla displayed the usual power function but there was a distinct separation between the size classes in their absorption and TChla characteristics. There were very few data points dominated by microplankton but these were associated with absorption coefficients >0.06 m^{-1} and TChla >0.8 mg m^{-3}. Picoplankton had absorption coefficients of <0.026 m^{-1} and TChla of <0.25 mg m^{-3}. The absorption coefficients for nanoplankton were within the range 0.026-0.06 m^{-1} and the TChla associated with nanoplankton was 0.25-0.8 mg m^{-3}.

Introduction

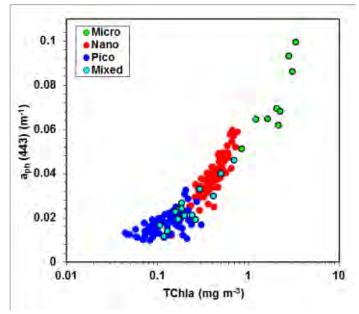
Satellite ocean colour sensors have provided the means to acquire remotely sensed data on phytoplankton for the world ocean [1], and further developments have allowed more detailed observations on the composition of communities from space [2]. Water-leaving radiances that are detected by the satellite sensors are related to the absorption and backscattering of light in the ocean, and size structure of particles influences both absorption and scattering properties [3]. There are established links between phytoplankton classes and biomarker pigments [4] and oceanographic observations have shown links between absorption properties and phytoplankton pigments [5]. This has enabled the development of bio-optical models relating absorption at 443 nm to phytoplankton size classes derived from diagnostic pigments, which can be applied to satellite data to investigate community structure on large scales [6]. In this study, an in situ absorption and pigment data set acquired for the Mozambique Channel was used to examine the absorption characteristics of phytoplankton size classes with a view towards a regional application of satellite data to monitor seasonal and interannual change in community structure in the Channel. The Mozambique Channel is unique in that the physical oceanography is dominated by the flow of anticyclonic and cyclonic eddies through the Channel that has a strong influence on the distribution pattern of phytoplankton.

Discussion

Discrete samples were drawn from the surface and the deep chlorophyll maximum on 3 research cruises in the Channel during 2008-2010 and analysed for spectral absorption by the filter pad technique [7] and pigments using liquid chromatography [8]. Seven diagnostic pigments and weighted coefficients were used to proportion the contribution of the taxonomic groups to the total chlorophyll *a* concentration (TChla) [9]. The taxonomic groups were then allocated to either the micro-, nano- or picoplankton classes. Relationships between absorption at 443 nm (a_{ph} (443)) and TChla associated with each size were examined to determine the absorption characteristics for each class.

Plots of the weighted biomarker pigment/total diagnostic pigment ratio versus TChla confirmed that Fuc and Per could be allocated to the microplankton and Zea to the picoplankton. Similarly, Hex, But and Allo were allocated to the nanoplankton. In the Uitz et al method [9], Chlb plus divinyl Chlb were allocated to the picoplankton but in this study Chlb and divinyl Chlb were partially separated by the HPLC method and Chlb could be quantified as an independent biomarker. The Chlb ratios were very low at TChla levels <0.25 mg m^{-3} and were highest in the 0.25-0.8 mg m^{-3} TChla range. Chlb was therefore allocated to the nanoplankton.

The relationship between a_{ph} (443) and TChla displayed the usual power function but there was a distinct separation between the size classes in their absorption and TChla characteristics. There were very few data points dominated by microplankton but these were associated with absorption coefficients >0.06 m^{-1} and TChla >0.8 mg m^{-3}. Picoplankton had absorption coefficients of <0.026 m^{-1} and TChla of <0.25 mg m^{-3}. The absorption coefficients for nanoplankton were therefore within the range 0.026-0.06 m^{-1} and the TChla for nanoplankton was 0.25-0.8 mg m^{-3}.



a_{ph} (443) versus TChla

Conclusions

In situ observations in the Mozambique Channel indicated that picoplankton generally dominated the surface waters in anticyclonic and cyclonic eddies [10]. But microplankton and nanoplankton could be significant in frontal zones between eddies, and near the Mozambique shelf due to eddy interaction with the continental slope [10]. It is the intention to apply the in situ size class absorption characteristics derived in this study to satellite absorption data to map the surface distribution of micro- nano- and picoplankton in more detail across the Mozambique Channel. A mesoscale investigation of the seasonal and interannual variation in community structure in relation to environmental and climate change can then be undertaken.

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Hidden secrets of absolute radiometric calibration

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Summary

This work aimed to reduce absolute radiometric uncertainties for Ocean Colour (OC) radiometers used for *in-situ* measurements (currently typically >2 % for both irradiance and radiance mode [1]) using NMI (National Measurement Institute) traceable irradiance standards. In order to achieve this objective we characterised the radiometers and the calibration approach using a primary NPL traceable irradiance source and provide a comprehensive uncertainty budget for these measurements. This paper provides recommendations for the OC community on absolute radiometric calibration techniques that could reduce uncertainties, and robust uncertainty budget evaluation.

Introduction

In order to determine the reliability of *in-situ* measurements, an uncertainty budget must be established. The components of the budget will vary depending on the measurement method; i.e. for in-water or above-water systems. Additionally, the specific features of a particular measurement platform or system must be accounted for in the uncertainty budget. Radiometric calibration uncertainties are always present in the uncertainty budgets for OC *in-situ* measurements and they make a significant contribution to the overall uncertainty budget. Currently the uncertainty associated with OC *in-situ* measurements are typically around 5 % for blue and green and rapidly increase over the red part of the spectrum [2], and the absolute radiometric calibration is ~2 % of this.

In this paper we describe an absolute irradiance-mode calibration of OC radiometers, using an FEL lamp as a spectral irradiance reference standard and then we present possible areas of improvement. This paper concentrates on irradiance calibration, as the irradiance of the lamp is both used directly, for irradiance calibration, and as a part with a reflectance tile for radiance calibration.

Discussion

The research was performed on multispectral radiometers manufactured by Satlantic. Each radiometer has seven separate spectral bands each in a physically different position on the instrument head.

The uncertainty associated with the spectral irradiance of a typical primary lamp from an NMI is around 1 % - 0.6 %, k=2 across the visible spectral range. That associated with secondary lamp irradiances is ~1.4 % - 1.2 %, k=2 in the same spectral range. When used to calibrate OC radiometers, additional uncertainties due to alignment, repeatability and current will affect the measurements and must be included in the uncertainty budget. The resultant uncertainty associated with the OC radiometer calibration, including lamp irradiance, alignment, repeatability and current setting will be >2 %.

The uncertainty associated with alignment and repeatability can be easily evaluated from the standard deviation of repeat measurements taken (with and without realignment, respectively). The uncertainty associated with alignment could be reduced through a careful alignment procedure, accurate distance settings, efficient stray light shielding, etc. and this would improve repeatability. The tests at NPL considered aspects of the measurement that are not routinely checked. The general recommendation for a radiance calibration is to increase the lamp tile distance to increase radiance uniformity. However, irradiance responsivity is still measured with a 500 mm lamp-radiometer distance. Figure 1 presents the results of an example FEL lamp irradiance uniformity scan at this distance; the seven blue circles represent the positions of the multispectral radiometer channels. The exact map will vary from lamp to lamp, but generally [1, 3] the maximum irradiance from an FEL is around 2 cm above the optical axis; less frequently a horizontal shift is observed. We found the difference in calibration coefficient between typical calibrations (i.e. with the central channel aligned with the optical axis) and centring each of the channels in turn with the optical axis is up to 1.4 %. This component will influence the results of a standard calibration but is usually not reported.

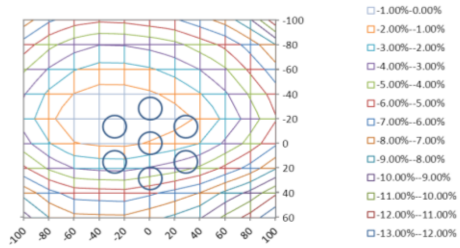

Figure 1 FEL lamp uniformity at 500 mm distance and OCI-200 radiometers channels positions

Another often unreported aspect of calibration is lamp current accuracy. The standard irradiance values from the calibration certificate are only valid for the lamp current setting used in the lamp's calibration and a small offset of 10 mA can lead to a lamp irradiance change of 0.46 % at 515 nm, with increased effect at short wavelengths.

Conclusions

Absolute radiometric calibration is essential for SI-traceable measurements. Uncertainties can be reduced by using a primary irradiance lamp (rather than a secondary standard), through careful alignment procedures and by placing each channel in turn in the centre of the optical axis. Using these approaches we reduced the uncertainty associated with OC-radiometer irradiance responsivity to around 1 % (k = 2). It is important to understand the uniformity of an irradiance source and to provide a correction, either by measuring each channel centrally, or by obtaining a lamp-uniformity scan. The lamp current should be monitored, and ideally controlled, during the calibration and, if any offset noticed, the current offset correction should be applied to the lamp irradiance values.

We expect to achieve further improvements using a monochromatic source, which will allow full spectral responsivity information for each channel. Such sources can also provide higher irradiance, especially in the blue part of the spectrum. NPL has developed a monochromatic source [4] that is portable and suitable for the calibration of both multispectral instruments, such as the ones studied here, and the newer hyperspectral instruments.

This research was performed as a part of the MetEOC Metrology for Earth Observation and Climate Joint Research Project funded by the European Metrology Research Programme EMRP.

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Using in situ fluorescence from animal-borne sensors in the Southern Ocean

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Summary

In the open ocean, phytoplankton are not often masked by dissolved organic matter (CDOM/Gelbstoff), and estimating concentrations of surface Chl-a should be comparatively simple. However, direct measurements are often not possible and limitations of remote sensing tend to be amplified in the high latitudes. Furthermore, satellites can give little resolution of vertical structure of the water column. Fluorescence data returned by animal-borne instruments may provide the means to 'fill in the gaps', provided that information is processed in a way that is useful to the ocean colour community.

Introduction

Phytoplankton respond to light and in summer the euphotic zone often extends as much as 4 times deeper than what satellites can 'see' to. Deep chlorophyll maxima (DCM) are predominantly found over deep ocean basins at depths between 40m - 90m, representing a layer of high biomass that cannot be quantified remotely [1]. In the high latitudes, these phenomena appear to be patchy, yet persistent.

In situ validation is clearly vital. In the Southern Ocean, ship time is especially expensive and limited to a narrow transect in space and time, and autonomous instruments are vulnerable to damage from ice. Fortunately, advances in sampling technologies have made it possible to instrument southern elephant seals (*Mirounga leonina*) with tags capable of measuring and transmitting a range of behavioral and oceanographic data (Sea Mammal Research Unit, University of St. Andrews). Tags are glued to the fur on a seal's head to allow for an Argos-linked aerial to emerge and provide at-sea location during surfacing events [3], and they fall off for retrieval during the annual molt. Salinity, temperature and depth satellite relay data loggers (CTD-SRDL's) are capable of transmitting vertical profiles of salinity (conductivity resolution: 0.003 mS/cm; accuracy: 0.04 mS/cm), temperature (resolution: 0.001°C; accuracy: 0.02°C) and pressure to depths of approximately 2000m [4]. More recently, tags are also capable of measuring fluorescence [5].

Discussion

In order to collect fluorometry data, a Turner Cyclops 7 has been added to the body of a 'conventional' CTD tag. The instrument is programmed to record fluorescence every 2 seconds from 175m to 5m during an ascent, but data is compressed onboard into 10m bins before being relayed to the ARGOS satellite network [4]. Despite this sacrifice in fine-scale resolution, in areas of the Southern Ocean where physical information is difficult to collect using conventional oceanographic methods, animal-borne technologies are invaluable.

For the first time, an adult female southern elephant seal from Marion Island was tagged with a FCTD-SRDL and tracked during the summer of 2012. With insight into deep chlorophyll discovered in other regions of the Southern Ocean, it was hypothesized that a DCM signal would be present over the broad ocean basin to the west of Marion Island. Fluorescence data retrieved through the ARGOS network has shown this to be true, with a strong signal found between 60m – 80m.

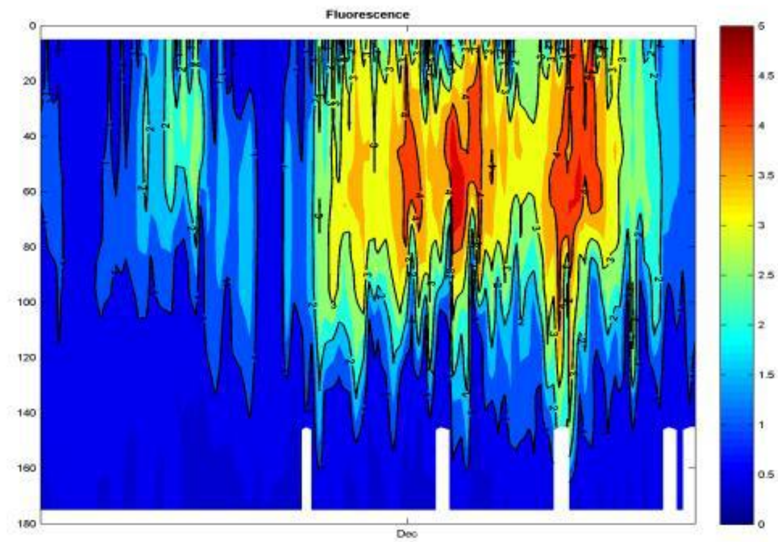

Figure 1. Vertical profiles of fluorescence from the surface to 180m, as collected by an instrumented southern elephant seal from mid-November to late December 2012.

Data were divided into quenched and non-quenched based on the time of day the fluorescence signal was collected, and each dataset was then reviewed separately. Quenched data shows good agreement with MODIS Fluorescence Line Height (L3 8-day composites), whereas non-quenched data shows a relatively good correlation with MODIS Chlorophyll-a (L3 8-day composites).

Conclusion

Currently, animal-borne instruments which measure fluorescence are a useful but possibly underutilized tool for *in situ* validation of ocean colour products. Furthermore, on a vertical scale, this resource may provide the means of elucidating DCM on regional scales.

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Using in-line systems for calibration/validation of Ocean Color; The Tara Oceans example.

E. Boss, J. Werdell, A. Chase, C. Proctor and T. Leeuw.

The 2.5yr long around-the-world Tara Expedition has provided a unique and extensive data set of particulate absorption and attenuation (>300,000 minute averaged spectra). Such data provides the possibility to obtain a significant increase in match-up opportunities as well as to assess sub-pixel variability of IOPs and hence of associated modulation in reflectance. We present preliminary analysis of matching OC products with Tara data (e.g. Chlorophyll, PFTs) and the distribution of sub-pixel variability. We also introduce the upcoming Tara Arctic Circle expedition (5-11/2013) where additional in-line sensors which include the Mote Marine Labs's CDOM Mapper, the WETLabs ALFA and an in-line WETLabs backscattering sensor. This expanded suite of variable could be used validate additional OC products (CDOM, bbp, and additional PFTs).

Autonomous Ship Based Ocean Color Observations on Australian Research Vessels

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Summary

As part of Australia's Integrated Marine Observing System, a "Dynamic above water radiance and irradiance collector" (DALEC) was commissioned in August 2011 on the RV Southern Surveyor to provide an automated stream of hyperspectral information from Australian waters. The DALEC is a radiometrically calibrated spectroradiometer which measures above water-leaving radiance, sky radiance and downwelling irradiance. Designed for autonomous ship deployment, the DALEC incorporates a passive 2 axis gimbal, solar azimuth tracking, embedded GPS, compass and accelerometers for recording sensor geometry. Radiometric data streams from the DALEC are collected in real-time and recorded over the ship's local area network. Preliminary results will be presented from the 9 DALEC deployments carried out in 2011 and 2012 around the Australian Continent.

Introduction

Ships provide an ideal platform to collect spatially diverse ocean color calibration data. As part of Australia's Integrated Marine Observing System, an autonomous ship based system was commissioned in 2011 to provide an above water hyperspectral radiometry data-stream from Australian waters.

The DALEC

The "Dynamic above water radiance and irradiance collector" (DALEC) is a radiometrically calibrated hyperspectral radiometer specifically developed by "In situ Marine Optics" for autonomous ship based deployment [1]. The DALEC contains three Zeiss UV-Vis enhanced spectroradiometers which are designed to measure spectral upwelling radiance (L_u), downwelling radiance (L_{sky}) and downwelling irradiance (E_d) in a near-simultaneous fashion, above water. Each spectroradiometer records 200 channels with spectral resolution of 10 nm, spaced at 3.3 nm intervals. The DALEC sensor head houses the instruments and is designed to be mounted on a boom positioned over the water, typically off the ship's bow. Radiance channel viewing angles (θ_v, θ_s) are fixed to 40◦ off nadir (L_u) and zenith (L_{sky}) when the sensor is held level.

A passive gimbal mount with adjustable damping stabilises the instrument during transit. This allows spectroradiometric measurements to be collected with consistent geometry whilst the ship is in motion. Pitch and roll sensors record data for quality control purposes. An embedded compass, GPS and motor control adjust the sun-relative azimuth angle (ϕ) during data collection. To avoid viewing the ship, the DALEC automatically seeks the 'ideal' sun-relative azimuth within user-defined boom-relative limits. UTC time and GPS coordinates of spectroradiometric measurements are logged allowing quick data comparisons with other transecting measurements and satellite pixels.

A DALEC instrument has been deployed since July 2011 on Australia's Marine National Facility, the RV Southern Surveyor (RV SS). RV SS operates across all of Australia's territorial waters, providing an ideal deployment platform (Fig 1).

The instrument is deployed approximately three meters clear of the RV SS's foredeck protruding one meter forward of the bow to provide an uninterrupted sea viewing angle of ~270° and to reduce the effects of spray from the ship's bow.

The measurement cycle is started at the beginning of each day at sea and stopped at sunset, with data collection at approximately 10 sec intervals. Under normal operating conditions the instrument is left in place on the deployment boom and retrieved only for routine maintenance. Under rough conditions or extended port periods the sensor head is retrieved and the boom is stowed against the forestay.

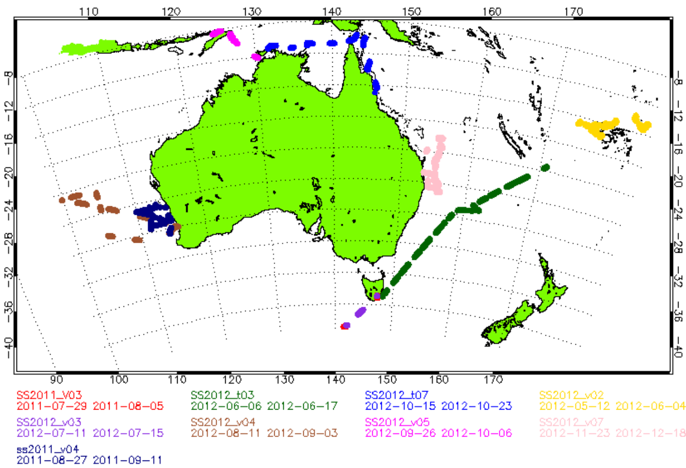

Figure 1. Location of the 119 daily DALEC L1B data files acquired on board RV Southern Surveyor in 2011 and 2012.

Radiometric data stream from the DALEC is collected in real time via a PC installed in the RV SS bridge. The data is tagged with location and orientation metadata recorded over the ship's LAN, allowing for future integration into the onboard data management system.

Results and Discussion

In 2011 and 2012, ~1.4 million spectral triplets (near-simultaneous measurements of L_u, L_{sky} and E_d) were collected during 9 research voyages (Fig 1). Consistent with the IMOS data policy, all DALEC Level 1B data collected to date (119 daily files, ~6.65GB) are freely available to the Australian and international oceanographic community via the IMOS Ocean Portal [http://imos.aodn.org.au/webportal].

For further analysis, the measured DALEC spectra are filtered by applying thresholds on ancillary QC parameters including pitch and roll, sun zenith angle and ship geometry [1]. Data is then processed to L2 reflectances using automated quality control approaches specifically developed for shipborne measurements [e.g. 1, 2]. We will present preliminary results of matchup analysis of L2 DALEC reflectances collected in 2011 and 2012 around the Australian Continent with MODIS data

Conclusions

The commissioning of an automated above water hyperspectral radiometry data-stream from Australian waters significantly augmented Australia's ability to contribute to global and regional Ocean Colour validation and algorithm design activities.

Acknowledgment

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Phytoplankton size classes in the Eastern Atlantic Ocean: using Earth Observation to understand the structure of Marine Ecosystems

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In recent years, the global distribution of Phytoplankton Functional Types (PFT) and Phytoplankton Size Classes (PSC) has been determined by remote sensing. Many of these methods rely on interpretation of phytoplankton size or type from pigment data, but independent validation of the methods has been difficult because of lack of appropriate in situ data on cell size.

This work presents in situ data along a trophic gradient in the Eastern North Atlantic and has the following objective:

- To produce a map cell abundance from remotely-sensed chlorophyll a, using photosynthetic pigments concentration and cell abundances to test a previously developed conceptual model, which calculates the fractional contributions of pico-, nano- and micro-plankton to total phytoplankton chlorophyll biomass (Brewin et al., 2010)

Chlorophyll-a for each size class was estimated from the three component model, and divided by the mean chlorophyll-a per unit cell obtained from combining information from the model, microscope cell counts and flow cytometry.

A previously developed global scale model, which calculates the fractional contributions of pico-, nano- and micro-plankton to total phytoplankton abundances was applied to the database. Intracellular chlorophyll a (Chla) per cell, for each size class, was computed from the cell enumeration results (microscope counts and flow cytometry) and the chlorophyll-a concentration for that size class given by the model. The median intracellular chlorophyll-a values computed were 0.004, 0.224 and 26.78 pg Chla cell^{-1} for pico-, nano-, and microplankton respectively. This is generally consistent with intracellular chlorophyll-a concentrations of different size classes from the literature, thereby providing an indirect validation of the method.

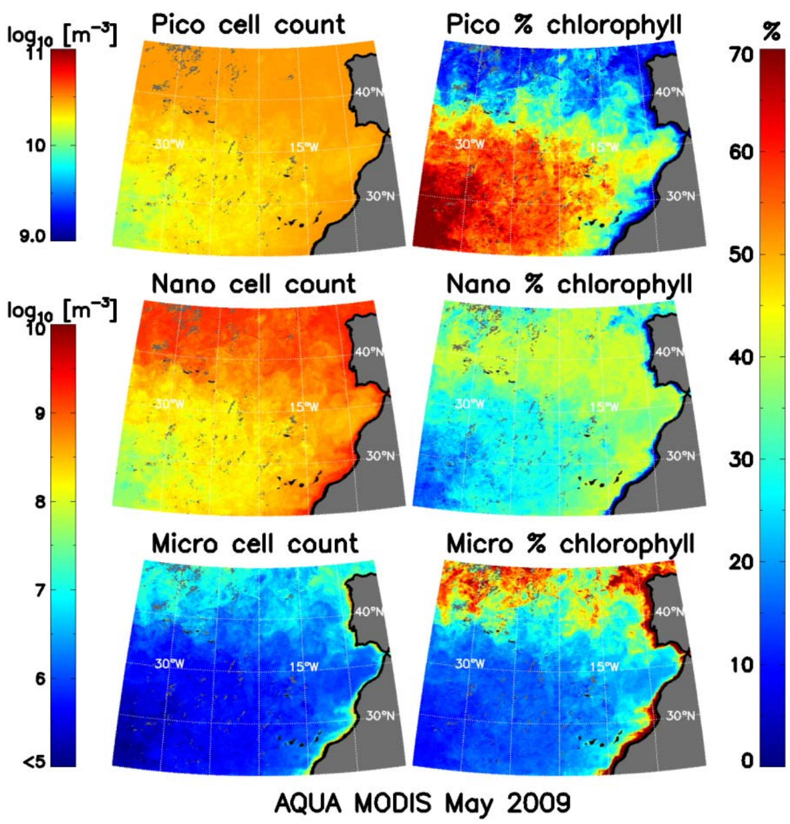

Figure 1 - *Cell abundance estimation and chlorophyll-a relative contribution for the three size classes from remote sensing chlorophyll-a. A Aqua MODIS May 2009 monthly L3 composite was used.*

Using a satellite-derived composite image of chlorophyll-a for the study area, a map of cell abundance was generated based on the computed intracellular chlorophyll-a for each size-class, thus extending the remote-sensing method for mapping size classes of phytoplankton from chlorophyll-a concentration to mapping cell numbers in each class. The map reveals the ubiquitous presence of picoplankton, and shows that all size classes are more abundant in more productive areas.

Our results support the assumption that there is an overall dominance of picoplankton, in terms of cell numbers from oligotrophic to eutrophic regions. More productive areas present higher cell numbers in all cell size classes, but the increase in chlorophyll-a is given by the increment in chlorophyll-a fraction due to larger cells (more details can be seen in Brotas et al, 2013).

The approach presented in this work, whereby the abundance of cell-size classes of phytoplankton can be derived from satellite imagery is a novel and promising contribution to the understanding of the biogeochemical role of phytoplankton in our planet.

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Strategies for autonomous sensors

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Summary

The growing application of autonomous platforms and optical instruments to the study of biogeochemical processes offers a new source for validation of ocean color satellite data and derived biogeochemical products. However, this exciting development also demands new approaches for rigorous calibration of *in-situ* optical measurements and development of optical proxies for biogeochemical variables. Here we present a set of protocols developed during 2008 North Atlantic Experiment that were used to cross-calibrate optical sensors on multiple autonomous platforms, with the final goal of extrapolating biogeochemical parameters to larger spatial and longer temporal scales.

Introduction

The use of optical sensors on autonomous platforms has the potential to expand data sets for validation of ocean color satellite. However, such applications require that *in-situ* sensors are rigorously calibrated. For many optical sensors, pre- and post-deployment laboratory calibration is insufficient, and should be augmented with other approaches, including direct *in-situ* calibration, cross-calibration against well-characterized references, and the use of redundant and/or related sensors. This is particularly critical for arrays of sensors. A mechanistic understanding of the variability in the biogeochemical optical proxies is also necessarily for reducing uncertainty in the derived biogeochemical parameters.

Discussion

The 2008 North Atlantic Bloom (NAB 2008) experiment characterized the patch-scale evolution of the spring phytoplankton bloom using four gliders, a Lagrangian float and intensive ship-based sampling, underpinned by an aggressive sensor calibration effort. Proxy sensors were used for carbon cycle components, with ship-based efforts providing direct calibration and data for constructing proxy relationships. Direct calibrations were propagated to other autonomous sensors through deliberate cross-calibration profiles. NAB 2008 illustrates an effective approach for implementing process-scale calibration of autonomous sensors and provides guidance for the design of larger-scale efforts.

The development of the backscattering-based particulate organic carbon proxy provides a good example of the NAB08 proxy calibration process. All backscattering sensors used during the experiment (n=6) underwent bulk laboratory (factory) pre- and post-calibration [1]. The ship-based backscattering sensor was used as a reference ("gold standard"). Dark counts for the ship-based sensor were measured *in-situ,* and cross checked with manufacturer's dark counts. Factory dark voltage counts (gliders and float) were subtracted from the data, and additional offsets were applied to bring all pre-bloom deep-water values into agreement. Outputs with dark counts subtracted were first converted to volume scattering function, then to particulate backscattering using the factory calibration and current protocols. Near-simultaneous ship-glider and ship-float casts were obtained and used as a base for cross-calibration of autonomous based measurements against the ship-based "gold standard". Ultimately, ship-based particulate organic carbon and backscattering relationship was used to obtain the high-resolution biogeochemical dataset [2], increasing the sample number from n=321 to n=1.5 x 10^6.

Conclusion

The growing number of autonomous, based optical measurements has the potential to become a primary source of validation data in the future, but the community has to be mindful of the challenges associated with this approach. These, and many similar approaches developed during NAB 2008 [3, 4], demonstrated that attention to details, rigorous cross-calibration may remove some of the uncertainties associated with this large pool of optical and biogeochemical measurements, and facilitate its use ocean color validation.

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Australian waters Earth Observation Phytoplankton-type products (AEsOP).

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Summary

The The Australian waters Earth Observation Phytoplankton-type products (AEsOP) project aims to establish an in situ database specifically for the calibration and validation of regional algorithms. The dataset will include multiple coincident parameters such as HPLC pigments (including size fractionated pigments where available), pigment concentration and composition, full spectral absorption (a_{ph}, a_d, a_g), total suspended mater (TSM), Secchi depth and processed data from radiometers, hydroscat, ac-9, ac-s and other instruments from 1997 to the present day. It is envisaged that the first version of this database will available by mid 2013.

Introduction

Since the launch of SeaWiFS, in 1997, satellite-retrieved estimates of chlorophyll-a (chl-a) have been used as a proxy for phytoplankton biomass. The unprecedented spatial and temporal coverage of satellite-generated products, such as chl-a, has enhanced our knowledge of trends in productivity and extended our understanding of biogeochemical processes, on both regional and global scales. Currently standard global algorithms developed for use with the SeaWiFS, MODIS, MERIS or other sensors have been primarily based on atmospheric corrections and *in situ* bio-optical data collected in the northern hemisphere. These conditions are not always applicable to regions within the southern hemisphere. The Australian waters Earth Observation Phytoplankton-type products (AEsOP) project aims to address this situation by establishing an interrogative database of in situ bio-optical measurements which will aid in the development of robust regional algorithms and, when added to the global datasets, enhance the applicability of the standard global algorithms to both hemispheres.

The AEsOP database will build on the bio-optical data archive established by Australia's Integrated Marine Observing System (IMOS) which was established in 2007 and will provide data to the Phytoplankton Functional Types (PFTs) database, currently being established by the International Working Group for PFT Algorithm Development.

Discussion

The NASA bio-optical Marine Algorithm Dataset (NOMAD) is a dataset of *in situ* bio-optical data for use in ocean colour algorithm development and satellite data product validation. NOMAD was compiled using data archived in the SeaWiFS Bio-optical Archive and Storage System (SeaBASS) and comprises data from over 3400 samples, although not all samples have data for all parameters. Comparison of the the values of the chl-a concentration and the absorption coefficients due to phytoplankton, non-algal matter and CDOM between NOMAD and a datset of 1200 values from Australian waters show all the parameters to be significantly lower in Australian waters than they are in waters of the northern hemisphere. Figure 1 illustrates difference, showing an image processed with SeaDAS compared to one processed with a regional algorithm.

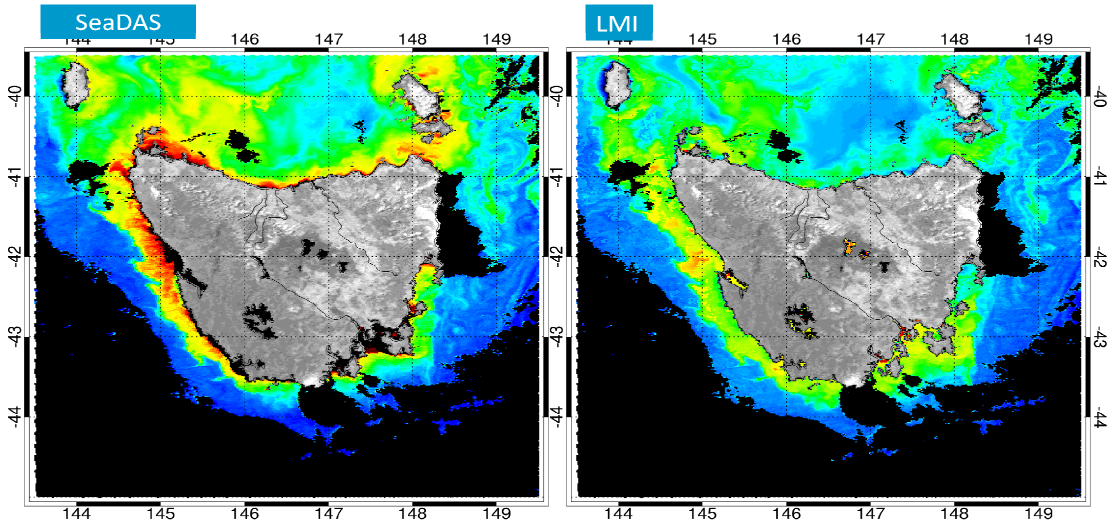

Figure 1 Ocean colour images of the chl-a distribution in Tasmanian coastal waters (13 October 2003) processed by SeaDAS and a regional algorithm

This clearly indicates why the standard global algorithms based on an average bio-optical model for satellite retrieval of parameters such as chl-a, TSM or CDOM often fail in Australian waters.

Conclusions

An interrogative database of bio-optical parameters for Australian waters is being established by the AEsOP project. This database will provide in situ data for the development of robust regional algorithms and, the enhancement standard global algorithms in the future

Acknowledgements

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An improved correction method for field measurements of particulate light backscattering in turbid waters

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Summary

Light backscattering by suspended particles in natural waters is a key parameter in marine optics and for ocean colour remote sensing purposes. The particulate backscattering coefficient is highly correlated to the concentration of suspended solids [1] and its spectral variations are representative of the particle size distribution [2], especially in sediment-dominated coastal and estuarine waters. However field measurements of the particulate backscattering coefficient in turbid waters is problematic mainly due to (i) saturation effects of most sensors developed for the open ocean and (ii) the strong light attenuation along the sensor pathlength which is difficult to accurately account for in highly-reflective waters. Based on results obtained using Monte Carlo simulations, we present an improved correction method for such measurements. The method takes into account the absorption, scattering and particulate volume scattering function of the sampled waters. It is applied to field measurements from the Río de la Plata estuary (Argentina) and a factor 2 difference is observed with the standard correction method. Based on optical closure with the water reflectance signal also measured in the field, we quantify the improvement of the new correction method.

Introduction

Ocean colour remote sensing is a well-established method for retrieving the absorption (a) and backscattering (b_b) coefficients of natural waters. The b_b coefficient is highly correlated to the concentration of suspended solids and is used for mapping of concentrations of suspended particulate matter (SPM) (e.g., [1]) and for retrieving information on the particle size distribution [2]. The development of SPM retrieval algorithms at regional scales therefore requires field measurements of spectral b_b values together with SPM concentration, composition and size distribution. Backscattering sensors initially developed for the open ocean are not adapted to turbid sediment-dominated waters due to saturation problems (e.g., Wetlabs ECO-BB sensors). The Hobilabs Hydroscat sensor is more adapted as it selects the appropriate gain automatically, based on the amount of backscattering detected as well as the amount of background light [3]. This sensor allows the light backscattered at the fixed angle of 140° to be measured at various wavelengths covering the visible, near-infrared and shortwave infrared spectral ranges. However the standard method which corrects for light attenuation from the light source to the detector, due to light absorption and scattering, does not take into account the wide variations of the particulate backscattering ratio encountered in coastal and estuarine waters [4]. This correction simply assumes that that light attenuation is equal to the light absorption coefficient plus 40% of the scattering coefficient, without evidence from radiative transfer calculations or measurements. This certainly leads to great errors in the measured b_b coefficient.

Discussion

Taking into account the exact design of the Hydroscat (HS) sensor, a Monte Carlo code [4] is used to compare the true (imposed) backscattering coefficient to the one obtained applying the standard correction method to the measured signal. Results are used to (i) quantify and explain the errors associated to the standard processing then (ii) propose an improved correction method associated to mininm errors. This new method requires simultaneous measurements of the absorption and scattering coefficients to correct HS data. Several iterations are necessary to determine the true particulate scattering ratio, then quantify the exact light attenuation to be corrected for. The results obtained are valid for a wide spectral range and a wide range of inherent optical waters representative of coastal and estuarine waters.

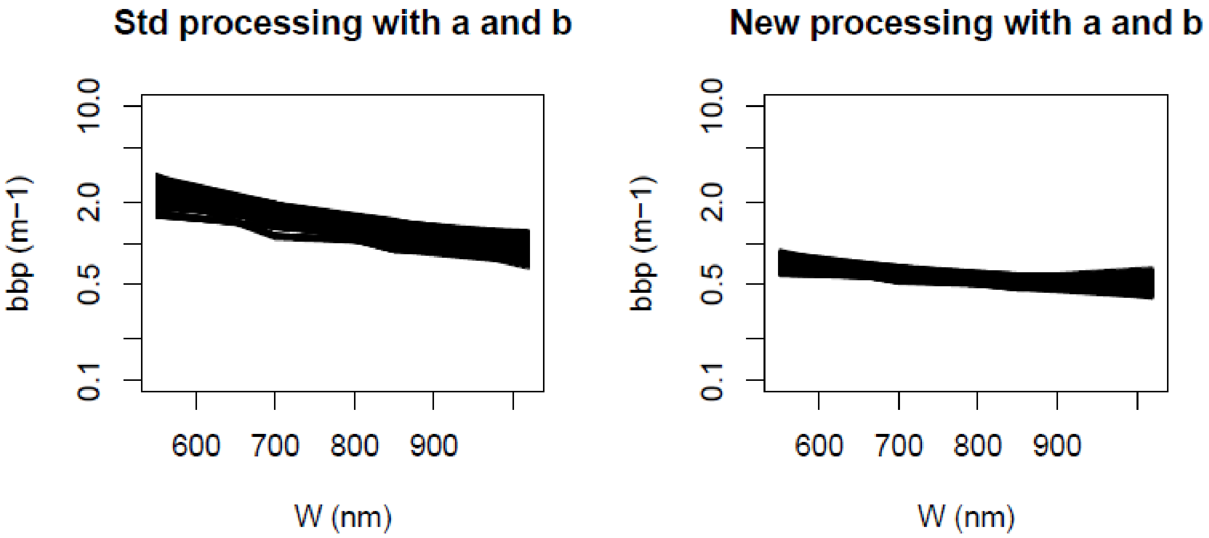

Fig. 1: Particulate backscattering coefficient spectra (b_{bp} in m^{-1}, 550 – 1020 nm) measured in the Río de la Plata estuary using a Hydroscat-4 sensor (HOBI Labs). Comparisons between results (spectral b_{bp} values) obtained using the standard (left) and new processing (right).

The method is applied to a field dataset (light absorption, scattering, backscattering and water reflectance measurements) from the Río de la Plata estuary (for SPM concentrations ranging from 20 to 120 $g.m^{-3}$).

Conclusions

Depending on the correction method applied (standard or Monte Carlo based), a fctor-2 difference is typically observed between the b_b coefficients obtained from HS measurements. The standard correction method actually greatly overestimates light attenuation due to particulate scattering, which results in a large overestimation of the b_b signal. Radiative transfer simulations are finally used to compute the water reflectance signal using as inputs the measured absorption and (back)scattering coefficients. Optical closure with the measured reflectance signal allows assessment of the accuracy of the retrieved b_b signal.

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Summer bio-optical properties in the southeastern Bering Sea

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Spatial patterns of bio-optical properties were studied in the southeastern Bering Sea during cruises in July/August of 2008 and 2009. Phytoplankton and CDOM absorption were highly variable with phytoplankton absorption dominating offshore waters and CDOM absorption dominating in the coastal domain. At most locations elevated sub-surface values of CDOM absorption were associated with chlorophyll-a (chl-a) maxima suggesting the biological source of CDOM in these waters. Water-column spectral optical properties of absorption, scattering and backscattering reflected the vertical variability in phytoplankton and CDOM concentrations. Using an extensive IOP and AOP dataset collected during 2008, good optical closure in spectral remote sensing reflectance was observed between radiometric derived and those modeled using IOPs. CDOM was found to significantly influence both the spectral remote sensing reflectance and diffuse attenuation coefficient. The standard NASA chlorophyll-a algorithm (OC4.v6) was found to overestimate chl-a at low values and underestimate chl-a at high values. We present a regional 3-band MODIS empirical algorithm that addresses this issue in the standard algorithm in the offshore waters of the Bering Sea.

UNCERTAINTY ANALYSIS AND APPLICATION OF IN SITU MEASUREMENTS OF SEA SURFACE TEMPERATURE MEASUREMENT ALONG COASLINE OF LAGOS, NIGERIA: OCEAN COLOUR CONCEPT AND FINDING SOLUTION TO A PERSITENT PROBLEM OF MARINE DEBRIS.

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ABSTRACT

Increased SST may alter coastal ocean currents that have influence on the residence time of water in near shore environments which may have negative consequences on the growth and survival of many aquatic animals and also the ocean colour in that region. We discuss in this paper environmental changes along the coastal line of Nigeria, especially in the region around Lagos, basing on provisional multi-disciplinary analyses of meteorological and maritime observations. The study has revealed that the environmental change in the Nigerian coastal region has been much more apparent than before(i.e. some few years back 1989-2007 and this has an affect on the ocean colour around). Various kinds of ocean debris, transported mainly by coastal wind, are affecting marine and coastal environment severely. Since the current ocean monitoring system is found to be troubled by ocean debris, it is urgent to establish a new system to obtain reliable observational data to monitor and basic knowledge of the definitions of preserving the environment of the coastal region and improving the ocean colour of the environment.

Assessment of MODIS-Aqua Ocean Color and Aerosol Products in the US Northeastern Coastal Region using AERONET-Ocean Color Measurements,

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Abstract

Optical complexity of both waters and atmospheres in coastal environments likely leads to significant issues in the quality of satellite-retrieved ocean color and aerosol products. Routine validation for satellite data product quality is desired and requires high-quality in-situ measurements and matchup analysis. One aspect of a NASA-Ocean Biology and Biogeochemistry program funded project focuses on the coastal satellite ocean color validation near the Martha's Vineyard Coastal Observatory (MVCO) in Massachusetts. The key field component monitors the multi-spectral water-leaving radiances and aerosol optical properties using an above-water automatic sun-photometer, the AERONET-Ocean Color (AERONET-OC, i.e. SeaPRISM) deployed at the MVCO tower since 2004.

Our earlier studies have shown that MODIS-Aqua ocean color products produced by SeaDAS version 6 with a new atmospheric correction scheme (Ahmad et al., 2010; Bailey et al., 2010) improves MODIS-Aqua ocean color products. Recently, a major reprocessing for the MODIS-Aqua ocean color data was released to address issues with instrument degradation, particularly from 2010 to the present.

This study presents an inter-comparison of MODIS-Aqua ocean color and aerosols products by reprocessing 2012 (R2012.0) and by reprocessing (R2010) using AERONET-OC measurements as a reference. It has been found that the MODIS-Aqua water leaving radiance at 412nm in R2012 is significantly lower than that in R2010 starting at the late year 2009 to 2010. At a selected open ocean site (35ºN, 64ºW), a similar feature in nLw 412nm is shown. Between reprocessing R2012 and R2010 there are slight differences in water leaving radiance at 443nm and little differences at longer wavelengths. There are no apparent differences in MODIS-retrieved aerosol properties (i.e. Angstrum exponent (531,869) and AOT at 869nm). Once the latest MODIS-Aqua reprocessing R2013 that is a partial mission reprocessing (2011–2013) becomes available updated validation will be presented in this work.

Applying a new method to measure phytoplankton carbon in the field for validating and constraining satellite-derived estimates of biomass

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Summary

Chlorophyll is routinely used as a proxy for phytoplankton biomass, whether directly measured or estimated from fluorescence. This approach suffers from variability in cellular pigmentation due to physiological acclimation of phytoplankton to environmental conditions (e.g. light and nutrients). Over the last two years, we have developed and tested a method to directly assess phytoplankton carbon (C_{phyto}) using sorting flow-cytometry and elemental analysis. This method is independent of chlorophyll or fluorescence and, thus, provides a measure of phytoplankton biomass that is immune to the confounding effects of photophysiological variability. Two field campaigns to measure phytoplankton carbon were recently completed, one in the Equatorial Pacific and one as part of the Atlantic Meridional Transect. Direct assessments of phytoplankton biomass using this new method will be used to validate and constrain satellite-derived estimates of the standing stocks of microalgae. Preliminary results from the two cruises will be presented.

Introduction

Current methods for estimating phytoplankton carbon in the field rely on proxy measurements, such as chlorophyll (Chl), cell biovolume conversions, or regressions of particulate organic carbon (POC) with Chl. Other means of estimating C_{phyto} include remote-sensing applications that convert optical properties, such as Chl fluorescence or particulate backscattering, into biomass. These values, however, are not well constrained due to the variability of internal pigment concentrations and the lack of field data for validating C_{phyto} retrievals. Physiological variability results in pigment:C_{phyto} ratios that can span more than 1.5 orders of magnitude [1,2]. We developed a more direct method [3] to measure phytoplankton biomass. In contrast to methods that indirectly estimate C_{phyto}, the protocol provided in Graff et al. [3] employs sorting flow cytometry to separate phytoplankton cells from the background particle field; a particulate pool with non-linear relationships over time and space with phytoplankton biomass [4]. The sorted cell sample is then analyzed for its elemental composition through high temperature combustion techniques. This method alleviates effects of phytoplankton photophysiology and avoids filter artifacts which may include the loss of target cells or retention of non-target particulate carbon. The method has been applied in two recent field campaigns in the Equatorial Pacific and on an Atlantic Meridional Transect (AMT) cruise.

Discussion

Lab and field tests of this method showed that the community of cells in sorted samples matched that of the original sample. Most importantly, the C_{phyto} for laboratory cultures using the sort method agreed with published values for the same species using filter based CHN protocols (see Figure). The difference between the laboratory and the field, however, is an unknown background concentration of particles collected on a filter that muddle biomass estimates. Graff et al. [3] also showed that unwanted particles, e.g. bacteria, are efficiently removed from the sorted sample. Thus, the application of this method in the field alleviates the confounding variables of photophysiology and background particulate matter present in other methods.

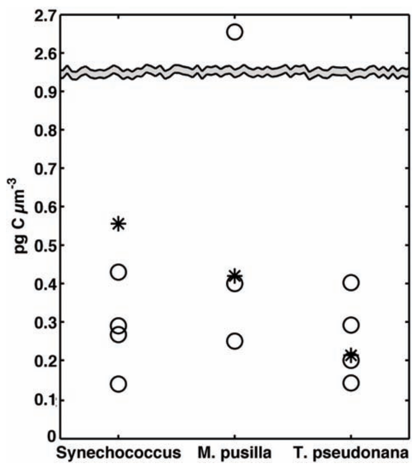

Figure from [3]: Comparison of carbon densities for three species of phytoplankton as determined by the sort method (*) compared to species-specific published values (o).

Efforts during the Equatorial Pacific cruise provided >120 samples and the AMT cruise resulted in >150 samples for direct measurements of C_{phyto}. Continuous in-line optical measurements and discrete sampling for HPLC pigments and POC were also collected. The Equatorial Pacific cruise covered a narrower range of environmental parameters, waters numerically dominated by *Prochlorococcus* and *Synechococcus* (0.05 to 0.38 µg Chl a L^{-1}), while the AMT cruise covered a much larger gradient and included samples dominated by eukaryotic phytoplankton (up to 2.1 µg Chl a L^{-1}).

Conclusions

Results from these two cruises will be the first direct assessments of C_{phyto} that can be used to validate and constrain satellite estimates of phytoplankton biomass. Combined, these data will provide a unique validation of remotely determined C_{phyto} over the range of values that represents the vast majority of the world's oceans. Preliminary data from the two cruises will be presented.

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MODIS/AQUA Ocean Color Validation in the Amundsen Polynya, Southern Ocean

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Summary

Two Years (January of 2011 and 2012) Amundsen Polynya survey for ocean color validation were conducted as part of the Amundsen expedition of KOPRI by Icebreaker ARAON because of the polynya have shown unusually high amount of satellite retrieved chlorophyll-a. On both expedition periods *in-situ* chlorophyll-a and suspended sediments were measured and at the same time absorptions by an organic and inorganic matters and a colored dissolved organic matters were measured for understand of the Inherent optical properties on Amundsen Polynya. In-water profiler (HPRO II/Satlantic Inc.) and above water reflectance acquisition system (HSAS/Satlantic Inc.) were operated for understand of the apparent optical properties as well. The results showed that In-situ chlorophyll-a showed quite different amounts on the both years, even if the MODIS showed similar pattern with amount showed on the both years. The major reason of this difference was due to the suspended sediments amount between the both years. The suspended sediments might be linked with sea ice melting, but the source of suspended sediments are still not know well, because continuous time based survey were not performed much on the Amundsen Polynya. The estimation of primary production on the Amundsen Polynya should be considered after validation of ocean color comparing with in-situ amount. The validation also should be conducted, as possible as, during several years of field survey on the same region.

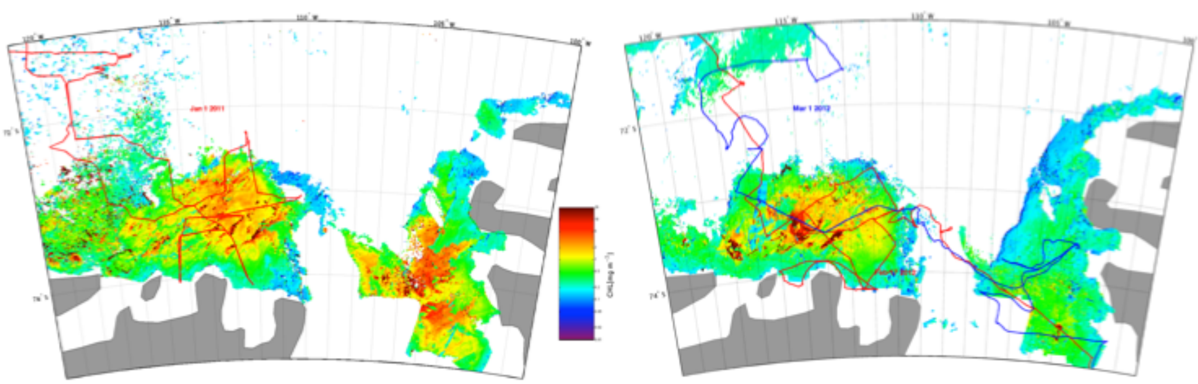

Figure 1. Daily 1km MODIS mosaic on the both expeditions (January of 2011: left, and 2012: right) and the lines on the images indicate the each expedition track by icebreaker ARAON.

A New Paradigm for Interpreting Remotely Sensed Phytoplankton Fluorescence

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Summary

Introduction

Over the past four decades there has been considerable progress in satellite approaches for mapping global distributions of phytoplankton biomass. Now, new algorithms for phytoplankton functional types are bolstering our ability to assess the composition of surface ocean phytoplankton assemblages. Yet ocean color approaches and algorithms for assessing the photosynthetic state of phytoplankton – the third pillar of marine phytoplankton biogeochemistry and ecology – remain notably underdeveloped. Since the early 1970s sun-stimulated fluorescence has been considered an ocean color property with considerable potential for examining phytoplankton's photosynthetic state, but there have been only a few examples where ecologically meaningful results have been derived using fluorescence products from ocean color satellites. *New, innovative efforts are needed in order to advance our ability to use ocean color from space – especially fluorescence – to assess photosynthetic state in phytoplankton.*

Discussion

The attraction of sun-stimulated fluorescence F_{sun} (or passive, solar, or natural fluorescence F_{nat}) as a remotely sensed property is that it is sensitive to a wide range of environmental changes. This makes it ideal for identifying situations in the ocean when photosynthesis is perturbed (e.g., responses to changing nutrient conditions). This sensitivity is also the main drawback of sun-stimulated fluorescence because different environmental perturbations affect phytoplankton F_{sun} differently, in both time scales and magnitude. The daily variability in F_{sun} is highly complex, even in idealized, highly constrained conditions when only one environmental parameter is changed (Fig. 1, top). Phytoplankton physiology has a 'memory' and its current state reflects past events in a strongly nonlinear fashion [1]. As a result, simple linear, correlative, or statistical approaches for interpreting F_{sun} variability may not be appropriate for deciphering these complex dynamics [2, 3].

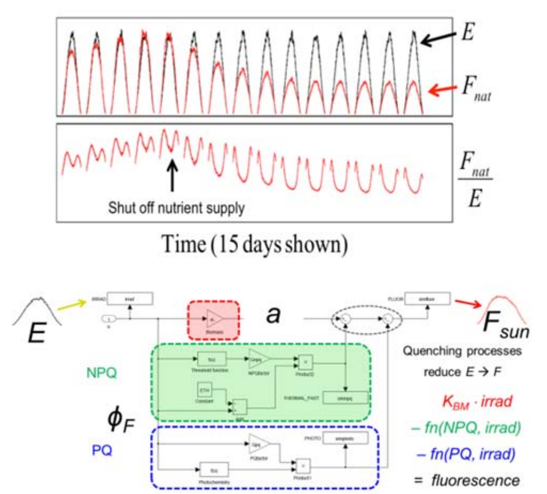

Fig. 1. Top: Laboratory data showing the degree of dynamical complexity in daily F_{nat} *for 15 days before & during nutrient starvation. Daily trends in* F_{nat}/E *can be explained by a dynamical model (bottom) of daily irradiance* E *which predicts daily* F_{sun} *trajectories with only a few parameters.*

Sun-stimulated fluorescence is a remotely sensed ocean color property for which a new, dynamical approach can lead to considerable advances. A dynamical model for F_{sun} (Fig. 2, bottom) shows how observed daily changes in F_{sun} and its apparent yield can be described using only a few basic physiological factors, which works because the model is constructed in a dynamically appropriate fashion. Current quantitative frameworks for interpreting variability in F_{sun} rely on equations that directly relate measured fluorescence to a multiplicative function of factors such as irradiance, chlorophyll, absorption, and so-called 'quantum yield'. Such equations have limits as to the types of dynamical behaviors that they can reproduce. A properly constructed dynamical model can take the complex daily trajectories of F/E (the apparent fluorescence yield) and interpret them to generate day-to-day time series of basic photosynthetic properties, providing insight into photosynthetic saturation (e.g., E_K) and nonphotochemical quenching. Day-to-day changes in these basic aspects of photosynthetic state will reflect acclimations to perturbations in the ocean environment, such as that caused by nutrient availability or insolation. Thus, fed with appropriately resolved within-day measurements of irradiance and F_{sun}, a proper dynamical framework can be used in algorithm development to generate remote sensing products for basic aspects of the photosynthetic state of phytoplankton.

Nonanalytical models for examining the dynamics of complex systems have not yet become part of the mainstream of phytoplankton ecophysiology, but those few that have been developed and examined to date (e.g., [4]) show considerable promise for describing the types of dynamical variability we see in the ocean's sun-stimulated fluorescence. Ocean color measurements of F_{sun} have been historically been used as single-point observations but approaches that consider the within-day variability have been proposed from laboratory studies [2]. The twin MODIS sensors aboard EOS-Terra and -Aqua can provide data for very crude metrics of within-day variability in F_{sun}, but the most significant advances in the use of remotely sensed ocean color to assess photosynthesis in the ocean will likely come from geosynchronous ocean color satellites [5] that collect data for driving such dynamical algorithms.

Conclusions

Oceanic chlorophyll and functional types do not change appreciably over the course of the day but photosynthetic state does, and so appropriate interpretation of sun-stimulated fluorescence from space requires an approach that takes this within-day variability into account. Geosynchronous ocean color observations could provide the data needed for algorithms that generate ecologically useful remote sensing products that track aspects of photosynthetic state from space. Such an approach is equally useful for ocean color sensing by high-altitude AUVs that repeat observations locally within a day.

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ProVal

A new Argo profiler dedicated to the validation of ocean color remote sensing data

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Summary

We present here a new profiling float dedicated to the validation of ocean color remote sensing data. This new autonomous platform, equipped for high quality radiometric acquisition, has a lot of advantages to sample distant areas all year round, but requires also major developments. Specifications of the new ProVal float as well as new opportunities and advantages over other methods to acquire radiometric data will be presented here. The ProVal float development and operations are part of the newly formed Sentinel-3 validation team (S3VT) activities. Intercalibration of ProVal floats with the BOUSSOLE program is planned in this frame.

Introduction

In the late 1990's the physical community designed and implemented the Argo program [1], the aim of which being to develop an array of vertically profiling floats that measure temperature and salinity throughout the world's ocean upper 2000m. After a decade of operation, this program has succeeded in attaining its initial objective of 3000 floats actively profiling (once every 10 days) and providing data with improved accuracy. These data are used by a large array of agencies, researchers and are assimilated into global circulation models. With more than 100,000 Temperature-Salinity profiles during 2008 alone, the Argo array accounts for ~ 95% of the vertical profiles ever measured.

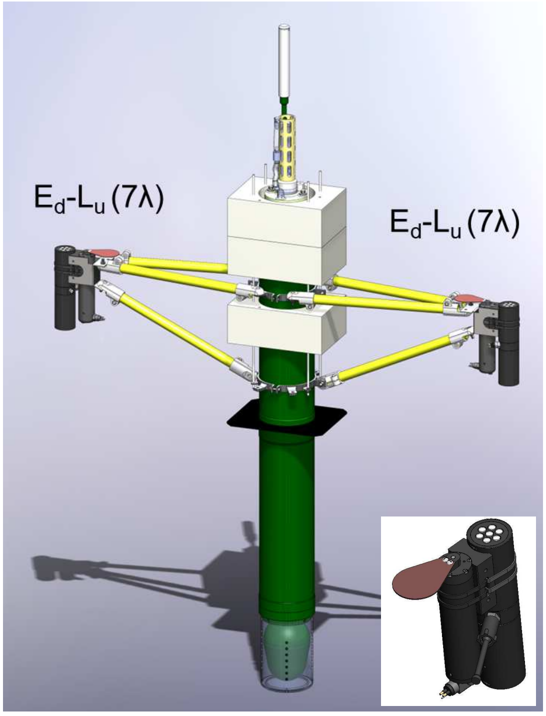
The aim of the ProVal project is to take advantage of the dynamics surrounding Argo floats to develop a profiler dedicated to Ocean Color data validation. This kind of instrument does not have the accuracy of permanent installations (like the Moby or Boussole moorings) but is strongly recommended by the Bio-Argo group of the International Ocean Color Coordinating Group [2]. Advantages of using validation floats are:

- High measurement frequency augmenting the probability of matching-up satellite records: several measurements of surface quantities can be expected every day around solar noon for each float;
- Global distribution of floats allowing year-round the validation of satellite products in a variety of trophic areas of the world ocean: in particular, polar zones or oceanic gyres presently undersampled in database;
- Access through profiling to the vertical dimension of the radiometric quantities, thus facilitating in some environment the extrapolation of the signal to the surface: flexibility is kept for the selection of the extrapolation layer with respect to fixed-depth measurements.
- Consistency of carried radiometric sensors and of calibration and processing methods: this will lead to a reduction of the uncertainty presently found in radiometric data sets gathered from multiple instrumentation/processing measurements carried out during various ship campaigns;

- Near real-time transmission, data processing and distribution: a modification of the sampling strategy in a near real-time mode will allow an extra-sampling of particular areas (for example during a clear sky day in a frequently cloudy region);
- Relatively low cost with respect to ship campaigns.

The ProVal float

The ProVal float is a new profiling float developed by the Laboratoire d'Océanographie de Villefranche (LOV) thanks to a CNES funding. It is based on a new version of the PROVOR float (CTS5, NKE company) equipped with a new acquisition board (developed by Osean company in collaboration with the LOV). This board allows the acquisition of 8 independent sensors and has sufficient CPU capabilities to process recorded data in real time. It is interfaced with a new navigation board (used to drive the float) developed by NKE. This navigation board allows a more complex definition of the float mission and is able to receive navigation commands from the acquisition board. This dialog allows retroactive programming of the float's mission based on scientific measurements, which could be extremely useful for a large number of applications including adapted sampling in function of weather conditions.



The ProVal float with 2 E_d-L_u(7λ) combo

Regarding sensors, the ProVal float is equipped with two identical radiometric combos (E_d-L_u) from Satlantic. Each sensor has the same seven wavelengths (currently 400, 412, 443, 490, 510, 560, 665 nm). Top sensor (Ed) is protected from "marine snow, i.e. particles" by a bioshutter. This configuration with two identical sensors is used to avoid self-shading (one sensor is always on the sunny side of the float) and to allow a monitoring of sensors drift by comparing data from both sensors. The ProVal float is also equipped with a tilt sensor to record the tilt of the profiler during the acquisition. Other sensors, like Chla-fluorescence or backscattering, could be also easily added to the float.

Acknowledgments

The ProVal project is funded by the CNES-TOSCA. This project also takes advantages of other programs oriented on profiling floats: the project remOcean (ERC advanced grant N°246777) and the project NAOS (ANR-10-EQPX-40).

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Characterization of in-situ multi-angle reflectance for turbid productive inland waters: a case study in Meiliang Bay, Taihu Lake, China

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Introduction

The optical field above water surface is anisotropic [1]. It is important to study the directional reflectance properties of the optical field above water, which is useful for investigating the parameters of the model for retriving water quality from remotely sensed data. The bidirectional reflectance distribution function for oceanic waters has been well studied [2]. However, the function for inland waters is still challenged partly due to the lack of in-situ multi-angle remote sensng reflactance. A device equipped with a spectrometer has been designed for measuring multi-angle remote sensing reflectance, which is valueable for sdudying the directional reflectance properties for waters and was used in the cruise over Meiliang Bay, Taihu Lake, China. Using the multi-angle remote sensing reflectance collected during the cruise, the bidirectional reflectance properties have been characterized.

Methods and Results

A cruise was carried out over Meiliang Bay on October 17-18, 2012. It was measured in the cruise the multi-angle remote sensing reflectance and the concentrations of cholorophyll-a, total suspended matter, and colored dissolved organic matter for a total of 9 observation sites. It should be noted that the reflectance data was collected at 17 angles using a specialized device equipped with a spectrometer, as shown in Fig. 1.

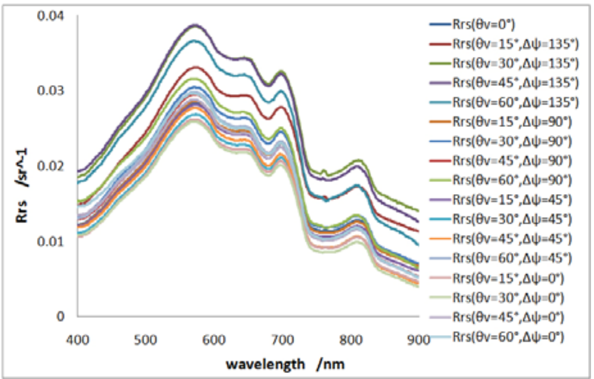
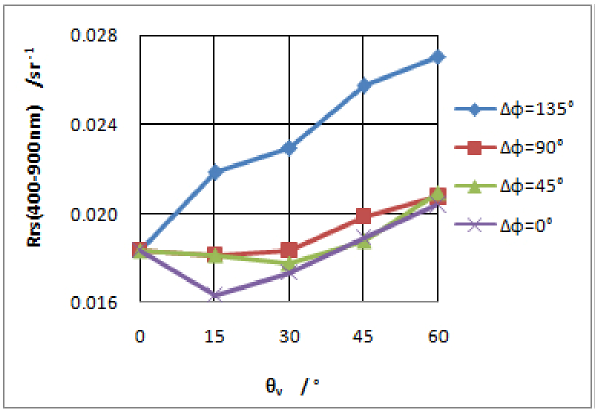


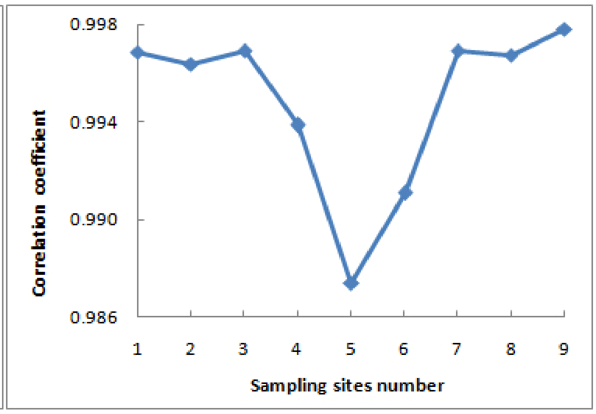
Fig. 1 Multi-angle remote sensing reflectance spectra on a typical sampling site. (Where θ_v is viewing zenith angle; Δψ is relative azimuth angle, which is the difference between viewing azimuch angle and solar azimuch angle, and Δψ is 0° if the sensor and the sun are in the same direction from the target.)

Discussion and Conclusion

Based on the statistics (shown in Fig.2) calculated using the in situ multi-angle remote sensing reflectance, the directional reflectance properties are characterized as follows. (1) The average values of Rrs(400-900nm) in the forward direction of sunlight (Δψ=135°) are much higher than those in opposite and side directions of sunlight (Δψ=0°, 45°, 90°). (2) All the values of the average correlation coefficients for remote sensing reflectance at each two observation angles on each sampling site are higher than 0.986, which means that the spectral shapes of the multi-angle reflectance do not change much with the observation angles. (3) The standard deviations divided by average values of Rrs(400-900nm) range from 7.8% to 41.3%, indicating that the average values of the multi-angle reflectance change much with the observation angles. (4) The standard deviations divided by average values of R_{rs}(645nm/628nm) and R_{rs}(706nm/676nm) range from 0.4% to 2.9%, which means that some band ratios of the multi-angle reflectance do not change much with the observation angles.

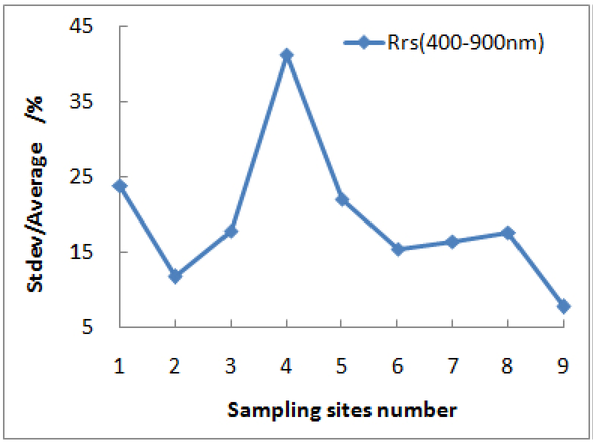
In short, the average values of the multi-angle reflectance change much with the observation angles, but the spectral shapes and some band ratios do not change much. Therefore, spectral shapes and some band ratios can be used in models to reduce the directional effects of optical field above inland waters.

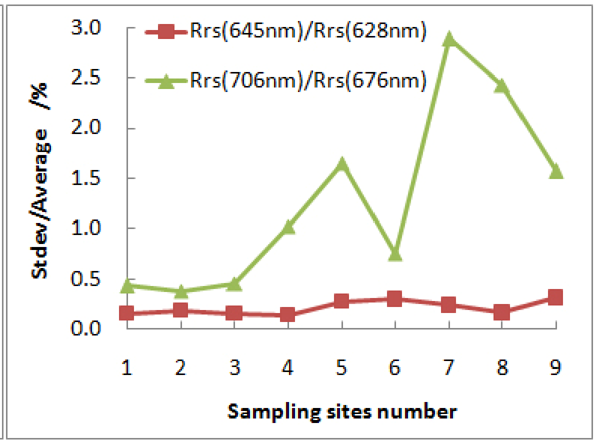




(a) Average values of R_{rs}(400-900nm) in each observation angle

(b) Average values of correlation coefficients between every two observation angles on each sampling site





(c) Standard deviation value of R_{rs}(400-900nm) divided by average value of R_{rs}(400-900nm) on each sampling site

(d) Standard deviation value of two band ratios divided by average value of the two band ratios on each sampling site

Fig. 2 The statistics derived from the in situ multi-angle remote sensing reflectance spectra

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Autonomous observations of arctic phytoplankton activity: The first annual cycle in ice-covered waters

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Arctic bio-floats survive stratification and sea ice! We examine the weekly variability of phytoplankton biomass and primary production as a function of changes in sea ice cover, stratification, and temperature measured in the Greenland Sea over an annual cycle for the first time, using ARGO profiling bio-floats. The Greenland Sea offers an arctic sea with weaker stratification relative to the Beaufort Sea, which allows for a more "standard" ARGO float profiling strategy (i.e., full profiling to 1000 m depth). Delicate buoyancy management is required to overcome the extreme stratification observed in the Arctic Ocean as well as ice avoidance. Each float has a CTD (warming; stratification), a dissolved oxygen sensor (primary production), fluorometer/backscattering sensors (phytoplankton biomass, primary production, particulate organic carbon) and a nitrate sensor (new and net community production), cycling every 5 days under sea ice and in open water.

The float herein was deployed in the north-central Greenland Sea in late summer 2011, where it circulated slowly cyclonically until the end of that year. At that time, it was entrained into the outer limb of the southward-flowing East Greenland Current, keeping very close to the ice edge but generally able to surface and report data. Within a few weeks it arrived at the northern edge of the Jan Mayen Ridge, where it followed the bathymetry and moved quickly eastward and away from the ice edge. Then it stalled, which allowed the eastward-advancing winter ice pack to overtake it. No positions were reported from March-July 2012, evident in Figure 1 as a straight line interpolation of positions at the start and end of this period. Preliminary analysis of drift speeds over the entire deployment to date indicates that the true trajectory over March-July 2012 was probably more circuitous than a straight line: in part, the float likely followed the isobaths westward and then back eastward. Nonetheless, the float remained in a circumscribed region in March-December 2012. In late summer 2012, the sea ice pack began its northward retreat and the distance to the ice edge increased. By the end of January 2013, the float had wandered southward over the central Jan Mayen Ridge, still relatively far away from the ice pack. The course of this float has remained near to or under sea ice providing a unique set of continuous biophysical observations at the ice edge.

A time series of various *observed* (temperature, nitrate, chlorophyll, O_2) and *derived* (NPP, POC) quantities obtained from the float so far will be presented. The float was deployed in the north-central Greenland Sea in late summer 2011, when the surface was warm and fresh (salinity was obtained but is not shown in this figure), oxygen, chlorophyll, and backscatter (POC) values were moderately high, and nitrate concentration was high. Fall and early winter 2011 brings low biological activity and convective deepening and cooling as the float travels southward toward the Jan Mayen Ridge, characteristic of central Greenland Sea conditions. From March-July 2012, on the other hand, the float is overtaken by the ice pack and its associated cold, fresh surface conditions. In July 2012 the ice pack begins to retreat, and the float begins to intermittently surface. This is also when biological activity accelerates and a strong summer bloom follows with elevated biomass, trapped near the surface by high stratification probably associated with ice melt. Fall and early winter 2012 brings a cessation of biological activity and deepening mixed layers.

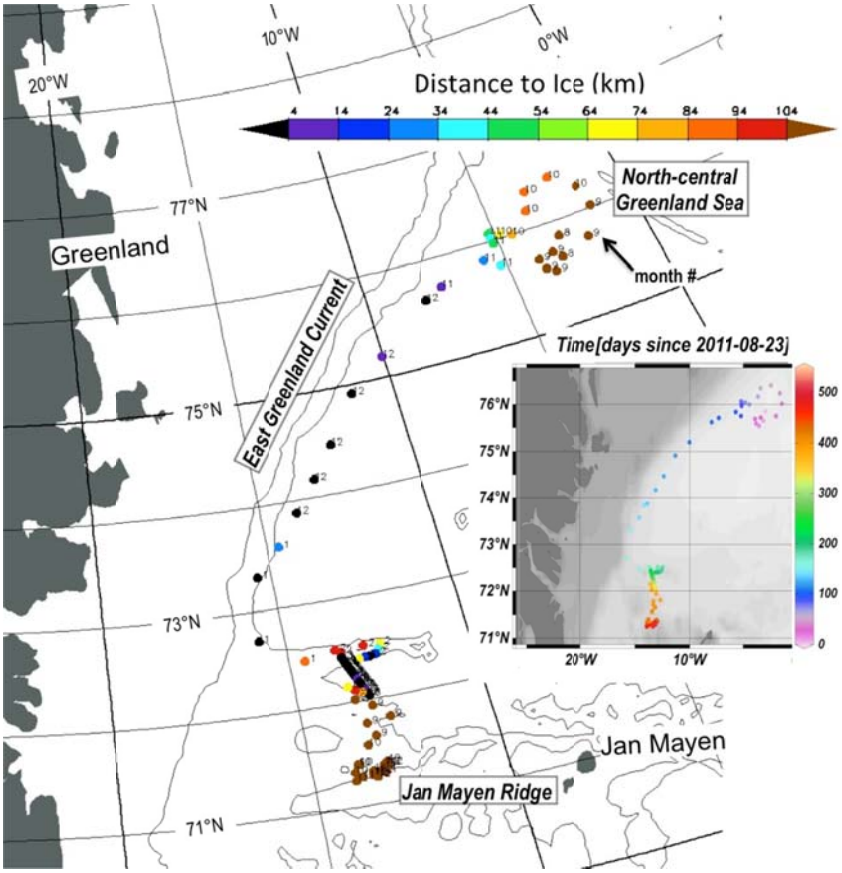

__Figure 1.__ Drift track of APPSS float deployed in the Greenland Sea in summer 2011. "Distance to ice" was determined using the multi-sensor MASIE sea ice data set (http://nsidc.org/data/masie/). The straight section over the northern Jan Mayen Ridge was made by interpolating positions before and after the float was under the ice pack.

Total NPP over the 2012 growth season was also computed, using an arctic-specific chlorophyll – primary productivity relationship and also using fall minus spring nitrate values[1,2]. The results compare favorably with historical values for this region, which are generally averages over large space and time scales. However, a more informative comparison might be obtained with some further "re-analysis" of the historical observations, in order to better determine the ice and water mass regimes that they sampled, relative to those sampled in 2012.

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Towards Improved Scattering Correction for In Situ Absorption and Attenuation Measurements.

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Summary

The performance of several scattering correction schemes for reflecting tube absorption and beam attenuation measurements is evaluated with data collected in European shelf seas. Standard scattering correction procedures for absorption measurements perform poorly due to non-zero absorption in the near infrared and wavelength-dependent scattering phase functions. Two new approaches to correct in situ ac-9 absorption and attenuation are presented. The first is an empirical approach based upon observations of non-zero NIR absorption using a Point Source Integrating Cavity Absorption Meter (PSICAM). The second is a revised iterative correction method based upon Monte Carlo simulations of the optical layout of the ac-9 instrument, and uses coincident backscattering measurements to estimate scattering phase function for correction of scattering losses for both absorption and attenuation measurements. The updated Monte Carlo scattering correction provides excellent agreement with independent absorption and attenuation measurements made with a Point Source Integrating Cavity Absorption Meter (PSICAM) and a LISST (Laser In Situ Scattering and Transmissometry; Sequoia Sci.) respectively. Implications for historic data sets and requirements for application to future data sets are discussed.

Introduction

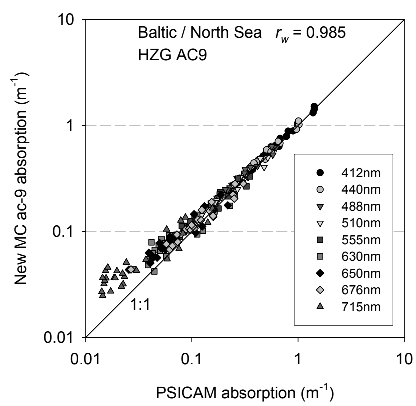
The propagation of light through seawater is regulated by the effect of the optical properties of the water itself and of materials suspended and dissolved within the medium. The spectral absorption, $a(\lambda)$, and attenuation, $c(\lambda)$, coefficients are fundamental optical characteristics of the medium. Measuring the absorption of dissolved substances is normally straightforward and can be easily achieved for normal practical error expectation levels using simple spectrophotometric methods. However, measuring the absorption of turbid media is considerably more complicated due to the effect of scattering on measured signals [1]. Various approaches to resolve this issue have been attempted, with the reflecting tube absorption meter (WET Labs ac-9/-s) becoming a widely adopted instrument within the optical oceanography community for measuring in situ absorption. This method uses total internal reflectance at the flow-tube walls to redirect a portion of the scattered light towards a diffuser in front of a large area receiver with the aim of minimising scattering losses. Even with this setup, it is necessary to perform a scattering correction to account for residual scattering losses [2]. These residual scattering losses can be quite substantial in turbid waters. To date there has not been a thorough validation of the efficacy of the various proposed scattering correction methods for WET Labs ac-9 absorption data using field data. The attenuation of seawater is measured by focusing a transmitted collimated beam of light onto a small aperture and detecting the photons that have not been absorbed or scattered, b(λ), with c(λ)=a(λ)+b(λ). As a result of the aperture having a finite diameter, the optical arrangement has a characteristic collection angle, ψ_c, which is a source of scattering error for the attenuation measurement. Boss et al. [3] recently demonstrated that uncorrected WET Labs ac-9 attenuation values are approximately 50 – 80% of equivalent LISST attenuation data, with the two instruments having in water scattering collection angles of ~0.9 and ~0.027° respectively.

Discussion

The development of a functional PSICAM by Röttgers *et al.* at HZG has provided a new opportunity to validate in situ ac-9 absorption measurements. Two new scattering error approaches are presented here. The first stems from observation of an empirical relationship between the measured ac-9 absorption signal in the NIR and corresponding PSICAM data. This permits calculation of a non-zero NIR offset correction which, together with additional weighting of attenuation values reflecting the observations of Boss et al., provides a new simple empirical scattering correction equation

$$a_{ac9}(\lambda) = a_m(\lambda) - (a_{m715} - a_{715})\left[\frac{(1/e_c)c_m(\lambda) - a_m(\lambda)}{(1/e_c)c_{m715} - a_{715}}\right] \qquad (1)$$

The second ac-9 correction method is based upon a revised Monte Carlo simulation of the absorption flowtube optical layout and uses backscattering measurements in an iterative process to estimate the scattering phase function, enabling correction of both absorption and attenuation data. As well as requiring additional b_b information, this method requires PSICAM validation data to select an appropriate wall reflectance for the absorption flowtube. This parameter is found to vary between ac-9 instruments. ac-9 data corrected using this method matches PSICAM values over a very wide range of IOP conditions.



MC corrected ac-9 data matches PSICAM values

Conclusions

Accurate inherent optical property measurements are essential for interpretation of ocean colour remote sensing signals and for full exploitation of radiative transfer simulation capabilities. We are working towards new correction methods for ac-9 data in the hope that both new and historic data sets can be improved, particularly in turbid coastal waters. Initial results are very encouraging though further work is required to fully establish the extent to which the new methods can be applied across the field.

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High-resolution IOP measurements for ocean color algorithm development support

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Summary

We developed an alongtrack system that measures particle inherent optical properties with high temporal (therefore spatial) sampling frequency, for studies of the links between optical properties and biogeochemical processes on the submesoscale and for applications to ocean color algorithm development for microbial community parameters. We report on several applications of the system for a long transect across the South Pacific and across frontal zones at the edge of mesoscale features in the subtropical Sargasso Sea. Potential applications of the data for developing new algorithms for connecting ocean color to microbial community structure and the limitations of the data will be discussed.

Introduction

In recent years, new capabilities have been developed to assess phytoplankton community structure and organic carbon cycling from satellite ocean color observations. However, validation of these novel remote sensing retrieval approaches and their further development is limited by scarcity of field observations over the variety of biogeochemical provinces of the global ocean. We have developed a flow-through system that measures surface inherent optical properties (IOPs) such as spectral absorption, backscattering and particle size spectra, in whole water and 0.2 micron filtered water. Our field effort is closely coupled to our ongoing collaborative efforts in developing new ocean color products useful for assessing global productivity and carbon cycling. The combination of field and satellite data analyses will enable us to understand the controls on plankton community structure allowing an understanding of the processes by which phytoplankton community structure affects open ocean IOPs and how one can best assess community structure characteristics from IOPs.

The alongtrack IOP system has several main optical instruments (WETLabs BB3 and AC-s, Sequoia LISST) and ancillary sensors including a Sea-Bird CT and flow meters, integrated with the ship's GPS feed for location and time information. The system also includes a Satlantic FIRe fluorescence kinetics system for measuring photosynthetic physiological parameters. The principal feature of the alongtrack system is a 0.2 micron filter cartridge which can be switched in and out of the flow. Under computer control the water is filtered two or three times per hour while the system is running. Under standard conditions the 'filtered' water can be used as a baseline, in which phenomena such as variable CDOM, calibration drift, and uncompensated temperature effects are integrated. When an interpolated 'filtered' record is subtracted from the 'unfiltered' data stream the resultant data are characteristic only of the >0.2 micron particles in the flow.

On the first deployment of the system, a section across the South Pacific at approximately 32 degrees south latitude from Australia to Chile, we observed large-scale changes in particulate backscattering coefficient consistent with the overall ecosystem structure. In the ultra-oligotrophic eastern South Pacific central gyre, the stability of the background allowed observations of daily excursions of b_{bp} and b_{bp} slope parameter, suggesting we were observing diel cycles of cell division.

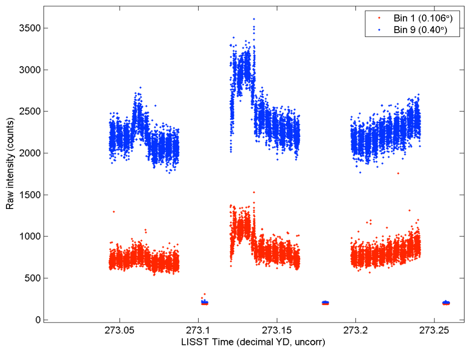

Figure 0: Example raw LISST data collected while crossing Lagrangian coherent structure features in the northern Sargasso Sea, September 2011. The data are raw scattered light intensity at two angle. Individual data are sampled at 1Hz in five minute blocks. Blanks (filtered seawater) can be seen in the gaps. Distance covered is approximately 30 km.

On subsequent deployments of the system in the Sargasso Sea between the Gulf Stream and Puerto Rico, we focused on submesoscale features identified by inferring Lagrangian coherent structures from satellite-altimetery derived circulation. In these studies we ran the system collecting data at 1Hz for 30-40 km crossing features of interest. Data are still in the preliminary stages of analysis, but temperature/salinity fronts were identified in almost all cases. We were also able to observe features in most cases in the inherent optical property data as well, but instrument noise was typically large relative to signal changes (Fig. 1). Changes in the IOPs across the observed temperature fronts could reflect changes in the microbial community structure driven by small-scale patterns of circulation and ephemeral nutrient supply. Instrument calibration drift was significant over the course of all the cruises.

Discussion

Understanding the connections between IOPs, the community structure, biogeochemical processes, and ocean color are goals for our ongoing research. Studies such as these, combined with other physical and relevant biological observations, can allow us to validate future products and determine how much of the variability observed at the submesoscale in satellite imagery is attributable to actual ecosystem variability. At present our ability to do this is limited by the precision of the instruments and the procedures and data processing algorithms required. In the ocean-basin scale studies, the large spatial baselines allowed us to reduce data appropriately and observe ecosystem gradients in helpful ways.

Conclusions

Upcoming ocean color sensors will be able to retrieve IOP and community structure parameters via existing and new algorithms, but these will be difficult to validate. Technological improvement in inherent optical property sensors will be essential for developing and validating the next generation of ocean color algorithms. Instrumental stability needs to be improved and facilities for simple field calibration of sensors should be developed.

Sensor-centric calibration and near-real-time in-situ validation of VIIRS Ocean color bands using Suomi NPP operational data

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Summary

After the launch of Suomi NPP (SNPP) VIIRS, the next generation ocean color sensor would never return to the testing facility. Capturing any existing calibration errors or those created by the space environment can be elusive and validation with in-situ data is sparse. A novel system of tools has been developed with a key acquisition tool installed on the NOAA NSIPS server that enables automated analysis of remote-sensing data from an on-orbit sensor perspective. This allows ocean color products to be tested, calibrated (including polarization residuals) and optimized post launch. It also supports in-situ validation field efforts by allowing scientists to obtain near-real-time data of only the valid retrievals.

Introduction

The automated system was developed to capture daily granules over targeted regions, apply data reduction sorting of good pixels and produce various products that assist ocean color scientists with calibration and validation and granule identification. Results from this automated tool are then ingested by a calibration tool that sorts the data from a sensor-centric approach and subsequently a third tool trends the data by days. Any anomaly, feature or characteristic inherent in the sensor, or algorithm can be identified before analysis of the in-situ match up data.

Discussion

There are two distinct ways to use the automated data. For sensor-centric calibration we used the automated results from the Ocean Overlap Matchup Tool (OMT) and then applied the other two tools, Polarization Verification Tool (PVT) and PVT Analysis and Trending Tool (PATT). The tool design was originally developed to support the verification of the polarization LUT that were tested on the ground and are applied per detector per band per HAM side for all SNPP outputs; however, it proved to be useful in detecting *any* out-of-character feature in the sensor and ocean color algorithm as the results presented here will show. Once these features are investigated and mitigated, the tool will then assess the higher detail characterization including polarization sensitivity residual.

For in-situ validation only the OMT results are necessary to do the matchups though the sensor calibration analysis will provide valuable insight into variations that appear to be in the in-water data that are in actuality introduced by the sensor. These matchups will then be critical in determining the vicarious calibration that is necessary for the optimal ocean color products.

Summary

This presentation shows the results from a recent 100 day study revealing potential sensor artifacts and algorithm features. Features and artifacts are verified through independent analysis from scientists working with in-situ data.

An Underway IOP System for Southern Ocean Observation

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Summary

Gaps in our understanding of the regional characteristics of the sensitivity of biological production in the Southern Ocean are being addressed by high spatial and temporal resolution sampling during the course of a season. A ship-based system for continuous underway measurement of inherent optical properties has been developed to link seasonally-variable bio-optical properties to biogeochemical variables such particle size distribution, phytoplankton pigments, particulate organic and inorganic carbon.

Introduction

The Southern Ocean is arguably the main source of medium-term uncertainty in terms of the effectiveness of global CO_2 mitigation plans. The Southern Ocean Seasonal Cycle Experiment (SOSCEx) is designed to address gaps in our understanding of the regional characteristics of the sensitivity of biological production in the Southern Ocean to changes in spatial and temporal atmospheric forcing. SOSCEx includes numerous underway and autonomous observations that aim to link physical forcing mechanisms with biogeochemical responses over an entire annual cycle.

One component of SOSCEx is a series of underway observations of bio-optical properties of the surface ocean that aim to link water column inherent optical properties (IOPs) to outgoing-satellite visible irradiance as well as in-water biogeochemical properties such as particle size distribution, particulate organic carbon (POC), particulate inorganic carbon (PIC), chlorophyll concentration and phytoplankton accessory pigments. To establish these links, CSIR and Sea Technologies have developed an underway IOP observational system that provides calibration-independent hyperspectral measurements of spectral particulate absorption $a_p(\lambda)$ and attenuation $c_p(\lambda)$ as well as simultaneous measurement of multispectral backscattering $b_{bp}(\lambda)$ using a ship's uncontaminated seawater supply. This system also supports the in-line acidification of seawater, supporting PIC estimates.

Discussion

The CSIR underway IOP system consists of a number of components. To remove optically-troublesome bubbles, the ship's uncontaminated seawater supply is plumbed to a vortex debubbler. Sample water is then distributed to the optical instruments via a series of manual and electronically controlled valves. To provide calibration-independent estimates of $a_p(\lambda)$ and attenuation $c_p(\lambda)$, seawater is periodically diverted through electronically controlled valve to a large surface area 0.2 μm cartridge filter to a WET Labs AC-S hyperspectral absorption and attenuation meter [1, 2]. Best results were found by plumbing the AC-S absorption and attenuation tubes in series as shown in [2]. The plumbing supports continuous higher quality measurements of 0.2 μm-filtered seawater using a TriOS OSCAR integrating sphere absorption meter and also allows simultaneous AC-S and OSCAR measurements unfiltered seawater measurements.

A WET Labs BB-9 measures the volume scattering function at 117° at nine wavelengths and is configured with increased instrument gain for the low biomass waters found in the Southern Ocean. The BB-9 is mounted in a flow-through chamber that provides separate (non-baffled) chambers for each three-wavelength instrument face. Backscattering of the chamber walls has been characterized (see [1]). Glacial acetic acid can be added to the BB-9 flow ahead of a mixing tube and in-line pH probe to lower the pH to 5 and dissolve any suspended calcium carbonate. In post-processing, the stabilized acidified reading is subtracted from the unacidified, raw reading [3, 4]. The difference in readings represent acid-labile scatter which is subsequently calibrated to suspended calcite in the laboratory.

Flow routing is controlled by a microcontroller that switches two three-way ball valves and one on-off ball valve using a single RS-232 interface. Flow meters are mounted at the plumbing outlets leading to the AC-S, OSCAR and three BB-9 flow chambers. A second microcontroller provides continuous calibrated flow rate information via a USB/RS-232 interface, assisting in the quality assurance of the flow-through data. Additional plumbing outlets support continuous measurements of multispectral fluorescence and fast-repetition-rate fluorometry. A single eight-port RS-232 to USB converter is used to aggregate data onto a single logging computer. For the AC-S and BB-9, serial data for each instrument is hard-wired to two serial ports to support simultaneous data logging (via Python scripts) and data visualization (via WET Labs software). Python scripts control valves and record AC-S, BB-9 and flow rate data streams; all logging is time aligned with support for flexible sampling periods. TriOS software also supports flexible sampling and simultaneous GPS coordinate recording.

Conclusion

By taking the difference between temporally adjacent samples of total and filtered seawater, $a_p(\lambda)$ and $c_p(\lambda)$ spectra within the resolution of the AC-S are being obtained. Together with water sample measurements of chlorophyll, POC, PIC and particle size distribution, high temporal and spatial resolution underway estimates of biogeochemical variables in the Southern Ocean are possible.

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Towards Improved Measurements of Absorption by Particulate and Dissolved Matter

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Summary

Improvements of laboratory methods to determine the light absorption coefficient of dissolved and particulate matter are presented. The main improvements are related to an increase of sensitivity and a decrease of susceptibility of methods to light scattering effects. The new methods e.g. allow avoiding correction for scattering. These corrections are necessary in common techniques and rely on assumptions that are not valid in coastal waters, like the assumption that particle absorption at near infrared wavelength is negligible. Recommendations will be given to improve the common practice of absorption determinations.

Introduction

Determinations of light absorption by particulate and dissolved matter in water are essential for developing and validating ocean colour remote sensing algorithms. However, measurements, especially of particulate absorption, are difficult to perform due to often low particle concentrations and the interference of light scattering in common measurement techniques. The absolute error in these methods, e.g. that of the quantitative filter technique (QFT), can be large. Reasons are 1) the common practice to subtract signals in the near infrared to correct for scattering errors, assuming that absorption of natural particles at these wavelengths is negligible and that the scattering influence is wavelength independent, and 2) the variability in the path length amplification of optical measurements with diffuse filters. In measurements of absorption by dissolved matter the main problem is the very low absorption in most oceanic waters.

Discussion

Measurements of dissolved matter in water, known as gelbstoff, are typically done in spectrophotometers with cuvettes of 1 - 10 cm path length. This methods is sufficiently sensitive in inland and coastal waters, but not in clear oceanic waters. Since a few years liquid wave guide capillary systems with path length of up to 2 m are in use and improved the sensitivity of the determination by a factor of 2 to 10, in addition offering the possibility to perform measurements immediately after sampling and filtration at sea. Measurement errors arise from optical changes induced by **differences in salinity between reference and sample water, i. e. proper correction or avoidance of temperature and salinity difference between sample and reference are necessary. Measurements with a point-source integrating cavity absorption meter and such a capillary system are shown to describe the range of methodological errors.**

Particulate absorption is often measured after the particles have been concentrated on filters to increase sensitivity and avoid interference of absorption by water and dissolved matter. This technique (QFT) is used since 50 years and had been improved in different ways (e.g. in the

transmission-reflectance technique [1]). However, problems are unknown scattering losses and amplification of the path length by multiple scattering inside the filter. This amplification has to be corrected by independently determined amplification factors. These determinations of the amplification factor were done with highly concentrated particle suspension (e.g. algal cultures), assuming that the independent method used gives accurate absorption. Scattering errors are often corrected by subtracting the measured signal at infrared wavelengths, assuming that natural particles do not possess significant absorption at these wavelengths, and that the scattering error is wavelength-independent. Both assumption might not be valid, and would then lead to significant systematic errors. Recently methods were developed that are not susceptible to scattering but sensitive enough to be used with natural samples: a point source integrating cavity absorption meter (PSICAM) was shown to accurately determine absorption by particles [2] and dissolved matter [3], a QFT technique measuring a filter inside a large integrating sphere was shown to have as well insignificant scattering errors [4]. Both techniques are combined to obtain accurate absorption coefficients even for very clear oceanic waters. The PSICAM measurements are used to determine amplification factors individually for each filter, reducing the error related to the variability of the amplification factor. These methods were compared to common QFT determinations. The comparison revealed that variability of the amplification factor can lead to errors as high as 30 % in case a general amplification factor is used, and that absorption in the near infrared spectral region is substantial in coastal waters, making a subtraction of near infrared signals inappropriate, as it would induce an underestimations of the particulate absorption at 442 nm of up to 70 %.

Conclusions

Common methods to determine absorption by dissolved and particulate matter suffer from low concentrations in oceanic waters, significant errors induced by light scattering, invalid assumptions in the correction of this scattering errors, and variability in the amplification factor for the QFT. Recent developments in these techniques lead to more accurate determinations and offer the possibility to determine the measurement errors. Similar improvements can be made for in situ measurements of inherent optical properties.

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FIELD VALIDATION OF THE PORTABLE REMOTE IMAGING SPECTROMETER: COASTAL HYPERSPECTRAL REMOTE SENSING IN ELKHORN SLOUGH

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ABSTRACT

Hyperspectral imagery is a useful tool in mapping and monitoring coastal, benthic habitats [1,2]. Factors including high turbidity and fine spatial variability, however, continue to pose challenges in many coastal areas [3]. The turbid, sediment-laden estuarine waters and diverse habitats of Elkhorn Slough terminating in Monterey Bay, California present an excellent study site for testing the limits of hyperspectral imaging spectroscopy. This region was selected for field validation of the Portable Remote Imaging SpectroMeter (PRISM), a new imaging sensor package optimized for coastal ocean processes. PRISM provides spatial resolutions up to 30 cm and spectral resolutions of 3 nm [4]. *In-situ* sampling was conducted concurrent to the PRISM flights to measure inherent optical properties of the water column and sample selected benthic and coastal habitat spectral targets, including eelgrass and salt marsh. Here, we compare spectra obtained from the orthorectified and calibrated imagery using initial atmospheric correction of the imagery from the ATREM model with those collected from sampling locations within Elkhorn Slough. The corrected imagery matched well to *in-situ* remote sensing reflectance (R_{rs}) in magnitude and spectral shape over both the turbid optically deep channel and optically shallow eelgrass dominated targets. These successful results allow us to proceed with processing the imagery for chlorophyll and suspended sediment in the water column, as well as to begin to map the coastal habitats in this diverse area using a variety of radiometrically-based classification approaches. The PRISM sensor data from this validation will be used to address two ecological case studies in the slough, including a shallow water assessment of eelgrass beds and a deep water assessment of the Elkhorn Slough sediment plume. Excellent agreement between the PRISM and in-situ validation spectra provide the foundations for using PRISM to discriminate marine and coastal habitats. With very high spatial resolution the PRISM promises to be a valuable tool in coastal management to map, characterize and monitor coastal ecosystems.

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Current Advances in Uncertainty Estimation of Ocean Color Products

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Summary

In this talk I review recent advances in uncertainty estimation methods for ocean color products and inter-compare their results. Both deterministic and stochastic methods are presented and their results are inter-compared. The stochastic method is more appropriate to estimate actual uncertainty of ocean color derived products than the deterministic methods. Stochastic methods, however, are still limited to few studies and require prior information. The uncertainties in inherent optical properties (IOPs) could be decomposed only if additional information is provided a priori. Using a simple exercise it is shown that atmospheric-induced errors are major contributors to the total error, whereas model-induced errors are intrinsic to the derived IOPs and depend on the used parameterization and number of spectral bands. A self-consistent and operational method is, however, still required to estimate the uncertainties of IOPs.

Introduction

Ocean color radiometric data are related to the physical and biological properties of water constituents through inherent optical properties (IOPs). These IOPs characterize the absorption and scattering of the water column and are used as proxies to water quality variables. The scientific procedure to derive IOPs from ship/space borne remote sensing data can be divided into three steps: i- *forward modeling*, relates the radiometric data to the IOPs of the water column; ii-*parametrization*, defines the minimal set of IOPs whose values completely characterize the observed radiance; iii- *inversion*, derives the values of IOPs, and hence water quality variables, from radiometric data.

Ocean color derived IOPs have an inherent stochastic error component. This is due to the dynamic nature of aquatic biogeophysical quantities, intrinsic sensor fluctuations, model approximations, correction schemes and inversion methods. Due to stochasticity of the measurements, as well as model approximations and inversion ambiguity, the retrieved IOPs are not the only possible set that caused the observed spectrum. Instead, many other IOPs sets may be derived. The probability distribution functions of the estimated IOPs provide, therefore, all the necessary information about the variability and uncertainties. Generally, uncertainty assessment of ocean color data falls under one of two methods, namely deterministic or stochastic methods. Deterministic methods are based on gradient techniques and have been used to assess the uncertainty of IOPs [1, 2]. The main drawback of gradient-based methods is that they depend on the used ocean color model to derive the IOPs and on the radiometric uncertainty. On the other hand, stochastic methods are less dependent on the used ocean color model but need *a priori* information on the errors to do the inference [3]. The problem arises when we attempt to validate these uncertainty models. The uncertainty here is estimated as the difference between ground truth measurement and satellite derived products. Direct matching between ocean color products and field data imbed, however, an inherent scale difference. This scale difference between *in-situ* measurements and a pixel of ocean color satellite is at least three to four orders of magnitude for nadir match-up sites and much larger for off-nadir ones. This huge scale difference adds up an extra uncertainty component when validating ocean color products. Therefore the validation of ocean color derived products should attribute the uncertainty to the scale difference, noise errors, correction errors and retrieval accuracy.

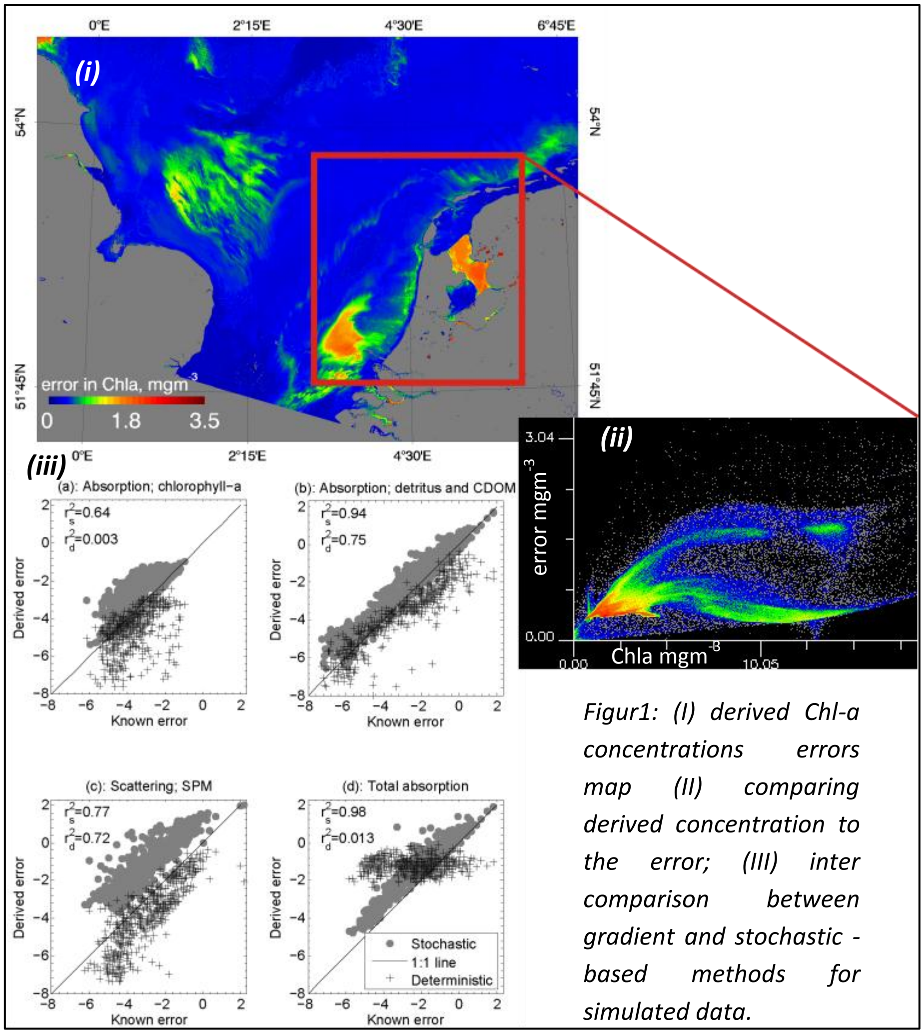
This talk is organized as follow: first I describe the ocean color paradigm, i.e. ocean color models, their parametrizations and inversion. Deterministic methods for error derivation are then described and followed by explanation of stochastic uncertainty methods. The results of both families (deterministic and stochastic) are inter-compared and complimented by an exercise to decompose the different sources of uncertainty. I finalize the talk by discussing the advantages and limitations of error estimation methods and initiate the thoughts for future developments.

Discussions

Figure 1 shows the errors obtained from deterministic model [1]. The model is applied to MERIS image acquired over the North Sea, Fig.1-i

The scatter plot (Fig.1-ii) of the red box shows on the X-axis the derived concentrations of chlorophyll-a (Chl-a) and on the Y-axis the associated errors.

Figure 1-iii shows the estimated uncertainties, expressed as standard deviation, against the known root-mean-square of errors (RMSE) using stochastic and gradient -based methods as applied to simulated IOCCG data set.



Figur1: (I) derived Chl-a concentrations errors map (II) comparing derived concentration to the error; (III) inter comparison between gradient and stochastic -based methods for simulated data.

Conclusions

Stochastic method has a better performance and is more appropriate to estimate actual errors of ocean-color derived products than the gradient based methods. The method, however, has a tendency to overestimate the values of errors and required prior information. A self-consistent and operational method is, therefore, still required to estimate the uncertainties of IOPs.

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Variability of Phytoplankton Absorption in the Tsushima Strait and East China Sea

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Summary

Variations in the phytoplankton specific absorption coefficient, size structure estimated from high performance liquid chromatography (HPLC) pigments, packaging effect as well as pigment composition was different between the Tsushima Strait (TS) waters and the East China Sea (ECS) waters. The TS waters indicated consistent patterns of changes in the size-fractions versus total chlorophyll-a concentration (Tchla), also comparable negative correlations between $a^*_{ph}(440)$ and Tchla with the global ocean. Such characteristic, however, could not be found in the ECS, which might be attributable to the influence of Changjiang freshwater.

Introduction

The ECS receives enormous amounts of freshwater containing very high concentrations of nitrogen from Changjiang River in summer. Waters from the ECS as well as the Kuroshio region form waters in the TS. According to some authors, freshwater discharge could influence the phytoplankton absorption properties [1, 2]. Thus, significant influence of Changjiang freshwater on the ECS should be expected to cause different phytoplankton absorption in the ECS. The objective of this study is to characterize the variability in the phytoplankton absorption in these regions.

Materials and methods

Samplings were conducted in the TS on one cruise in July 2008, and four cruises in the ECS in summer from 2009 to 2011, respectively. Samples collected at surface and subsurface chlorophyll-a maximum (SCM) depth were used. Absorption coefficients and pigment concentrations of phytoplankton were determined by the quantitative filter technique and HPLC, respectively. Diagnostic pigment analysis was applied to estimate size-fractions of pico-, nano-, and micro-plankton from HPLC pigments. Packaging effect index $Q_a^*(440)$ were computed according to Bricaud et al. (2004) [3]. Absorption coefficients of all pigments normalized by Tchla ($a^*_{pigm}(440)$) were calculated to assess pigment composition effects.

Results and Discussion

The total chlorophyll-a (Tchla) specific absorption coefficient at 440 nm ($a^*_{ph}(440)$) was highly variable among and within waters from the Tsushima Strait surface (TS_S), Tsushima Strait SCM (TS_SCM), East China Sea surface (ECS_S) and East China Sea SCM (ECS_SCM) (Fig. 1 (a)). Average $a^*_{ph}(440)$ of TS_S waters was the highest, followed by the ECS_S, ECS_SCM and TS_SCM. Combining the surface and SCM samples, the $a^*_{ph}(440)$ of TS waters varied inversely with Tchla ($P < 0.01$, $R^2 = 0.708$). Meanwhile, the fitted power law function was comparable with that obtained by Bricaud et al. (1995) [4]. However, in the ECS, although significant nonlinear correlation ($P < 0.01$, $R^2 = 0.094$) was found, the fitted power law function was dramatically different from that of Bricaud et al. (1995) [4]. The packaging effect index $Q_a^*(440)$ showed quite similar variations as the $a^*_{ph}(440)$ (Fig. 1 (b)).

The phytoplankton size structure was also widely variable but generally consistent with the variations of $Q_a^*(440)$. The TS_S waters were characterized by a high fraction of pico-plankton, the TS_SCM waters was dominated by micro- and nano-plankton, waters from ECS_S revealed mixed populations, and those from ECS_SCM was mainly dominated by nano-plankton. The variations of size-class fractions suggested that TS waters possessed the typical characteristics of global ocean that pico-plankton was dominant at low Tchla, nano-plankton at medium Tchla, and micro-plankton at high Tchla. However, such characteristics could not be observed in the ECS. The different phytoplankton size structure was possibly related to local nutrient level, especially, large amounts of nitrogen from Changjiang River might be a factor causing the mixed population in the ECS_S.

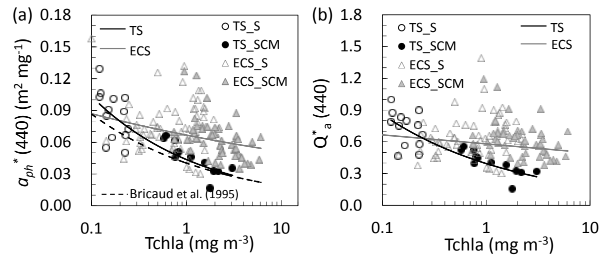

Fig. 1 Variations of $a^*_{ph}(440)$ (a) and $Q_a^*(440)$ (b) as a function of Tchla concentration

Tchla normalized absorption coefficients of all pigments $a^*_{pigm}(440)$ also indicated relative small but significant changes. The difference of $a^*_{ph}(440)$ between ECS_S waters and ECS_SCM waters was clearly observed. The $Q_a^*(440)$ showed no significant difference (Kolmogorov-Smirnov test, $P = 0.20$); however, significant difference of $a^*_{pigm}(440)$ were found between these two areas (Kolmogorov-Smirnov test, $P < 0.01$), which suggested that the difference in $a^*_{ph}(440)$ between ECS_S waters and ECS_SCM waters might mostly result from the pigment composition. In contrast to the ECS waters, the TS_S waters and TS_SCM waters showed no significant difference in $a^*_{pigm}(440)$ (Kolmogorov-Smirnov test, $P = 0.31$) but significant difference in $Q_a^*(440)$, which implied the packaging effect was probably the main factor causing the difference in $a^*_{ph}(440)$ between the TS_S waters and TS_SCM waters.

Conclusion

Probably due to the influence of Changjiang freshwater, variations in phytoplankton size structure and pigment composition were different between the Tsushima Strait waters and East China Sea waters, in turn, these differences might cause significantly different phytoplankton absorption properties.

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