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Hyperspectral Variability of Phytoplankton Blooms in Coastal Waters off Kochi, South-eastern Arabian Sea

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Abstract

Ocean colour radiometry offers cost-effective, frequently acquired synoptic data pertaining to phytoplankton biomass in surface waters and is of considerable value in monitoring and better understanding of algal blooms. Algal blooms have occur frequently in coastal waters resulting in severe negative impacts to local marine ecosystems and communities. Remote sensing reflectance [$R_{rs}(\lambda)$] and absorption coefficients of phytoplankton blooms were measured in coastal waters off Kochi, South-eastern Arabian Sea, to investigate differences in the absorption and reflectance of different types of blooms. Peaks of the $R_{rs}(\lambda)$ spectra of *Trichodesmium* spp. bloom were at 490 nm, while those of non-bloom areas were 482, 560 and 570 nm. The absorption maximam of phytoplankton were at 435, 437, 438 and 439 nm in the blue region and 632, 674, 675 and 635 nm in the red region respectively for *Trichodesmium* spp., *Chaetoceros* spp., *Dinophysis* spp. and *Prorocentrum* spp. blooms. The study showed that the variation of $a_{ph}(\lambda)$ with Chl a dominates the behavior of the $R_{rs}(\lambda)$ peak in these blooms.

Keywords: Phytoplankton absorption, remote sensing reflectance, bloom, bio-optics, Arabian Sea

Introduction

Marine phytoplankton influences the thermodynamic processes by air-sea exchange of gases like carbon dioxide and inorganic sulfur compounds affecting the global climate system. There is an increase in the frequency of occurrence of harmful algal blooms (HABs) worldwide (León et al., 2006). Blooms are caused by changes in tide patterns, wind direction and speed, precipitation and river runoff (Cloern, 1996). The reversal of monsoon winds and increase in anthropogenic enrichment and eutrophication has led to increased number of harmful algal blooms (Dwivedi et al., 2006; Padmakumar et al., 2010). Diatom or dinoflagellate blooms in coastal waters are usually caused by upwelling (Padmakumar et al., 2010). The necessity for close monitoring of hydrology of the west coast of India was pointed out, but *in-situ* data of apparent and inherent optical properties of blooms in the Arabian Sea is limited (Usha et al., 2013). Hydrology along with the inherent and apparent optical properties of phytoplankton blooms can be used as an effective tool in detecting HABs from space. This is a preliminary study which measured the apparent and inherent optical properties of four phytoplankton blooms observed off Kochi, south-west coast of India with an objective to determine the variation in absorption properties of different bloom causing phytoplankton.

Materials and Methods

Data was measured for three different blooms along latitudes 10°00′02"N, 10°02′58"N and 9°56′256"N and longitudes 76°06′05"E, 76°09′15"E and 75°52′216"E respectively during May 2009, August 2010, December 2010 and March 2011 (Fig. 1). During August 2010 and December 2010, blooms occurred in the same location. Surface sea water samples from the bloom sites were collected onboard using Niskin plastic water sampler Hydro-Bios™ of 2.5L capacity. Samples were stored in clean polyethylene bottles in ice and transported to laboratory for further analysis. The samples were

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stored in the cold storage at -20°C till further analysis.

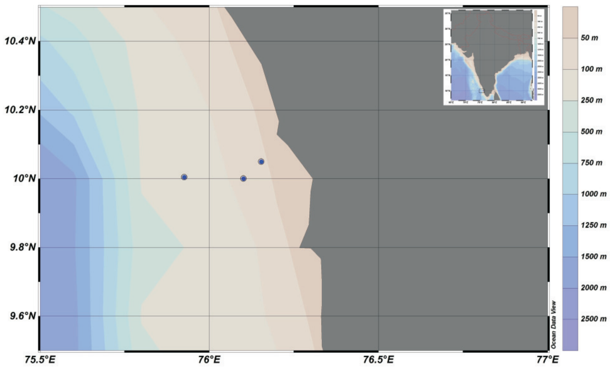

Fig. 1. Map showing the locations from where bloom samples were collected

Water samples were collected separately and preserved in formaldehyde (4% v/v) solution for phytoplankton species identification. The numerical density of phytoplankton was determined using Sedgewick-Rafter plankton counting chamber using Leica™ generic DMIL inverted microscope (Tomas et al., 1997; Cupp et al., 1949; Subrahmanyam et al., 1953).

The hydrographic parameters were measured according to standard protocols (Grasshoff, 1983, Kishino et al., 1985). For Chlorophyll a determination aliquots filtered under low vaccum (<10 cm Mercury) through glass micro fibre filters were used and the concentration measured in Turner™ design 10AU Fluorometer as per EPA method 445.0 using Welshmeyer Kit (Kishino et al., 1985). Samples were analyzed in the laboratory within 8 h of collection. Absorption by phytoplankton (a*ph (λ)) was measured according to quantitative filter pad method using Shimadzu™ UV-2450 attached with integrating sphere [Mitchell et al., 1990; Strickland & Parsons, 1972, Stuart et al., 2000]. Scanning was done from 400-750 nm at 1nm interval before and after rinsing the filter paper with methanol to determine detrital absorption (Kishino et al., 1985; Cleveland & Weidemann, 1993; Kyewalyanga et al., 1998; Bricaud et al., 2004). Chlorophyll specific phytoplankton absorption, [a*ph (λ)], was determined by the ratio difference of the total particulate material absorption, ap (λ) and non-pigmented detritus material absorption, a_d (λ) to that of chlorophyll concentration.

$$a_{ph}(\lambda) = a_p(\lambda) - a_d(\lambda)$$

The spectral remote-sensing reflectance (Rrs) and photosynthetically active radiation (PAR) was measured with a Satlantic Hyperspectral Radiometer. The Satlantic hyperspectral ocean color radiometer (Hyper OCR) measures radiations of 255 channels of optical data with wave lengths ranging from 300–1200 nm. The profiler design include hyperspectral sensors of OCR – 3000 series, temperature, pressure, tilt, chlorophyll a, CDOM and salinity sensors. The instrument was deployed in the sea from the aft of the ship in free falling mode. Data was collected when the tilt and descending speed was less than 3^o and 0.5 ms^{-1} respectively. Continuous data was collected in the deck unit which was connected with instrument via power telemetry cable. Data was recorded using SatView software and multi-level processing was carried out using the Prosoft software.

Results and Discussion

The most dominant phytoplankton during the bloom in May 2009 was the diatom *Chaetoceros* spp., (4 89 578 cells L^{-1}) with other species like *Skeletonema costatum*, *Nitzschia* spp., *Asterionella japonica* and *Oscillatoria* spp. contributing considerably to the composition. In August 2010, *Dinophysis* spp. (3 08 460 cells L^{-1}) was the dominant phytoplankton followed by *Gyrodinium* spp. and *Protoperidinium* spp. *Prorocentrum* spp. (1 50 000 cells L^{-1}) was identified as the most dominant phytoplankton during December 2010. In March 2011 *Trichodesmium erythraeum* (15 25 714 cells L^{-1}) was identified as the dominant phytoplankton. The water colour was off white for *Chaetoceros* spp. bloom while brick red for *Dinophysis* spp., and *Trichodesmium* spp. blooms. For *Prorocentrum* spp., pale reddish colour was observed for the waters in the bloom area.

Average chlorophyll concentration in the water collected during *Chaetoceros*, *Dinophysis*, *Prorocentrum* and *Trichodesmium* spp. blooms were 7.5, 37.16, 1.737 and 24.43 mg m^{-3} respectively.

Absorption by particulate matter was high in *Prorocentrum* bloomwhereas the a*ph (440) values were highest for *Chaetoceros* bloom (0.909 m^2 mg^{-1}). a*ph spectra (Fig. 2) showed a sharp and narrow peak for *Chaetoceros* spp. bloom but for *Trichodesmium* spp. bloom it was sharp and with short valley. Flat peaks were observed in the green region of the spectra for *Dinophysis* spp. and *Prorocentrum* spp.

blooms. Peaks of the $R_{rs}(\lambda)$ spectra of *Trichodesmium* spp. blooms were at 490 nm, while those of non-bloom areas were at 482, 560 and 570 nm (Fig. 5). The absorption maximum of phytoplankton were 435, 437, 438 and 439 nm in the blue region and 632, 674, 675 and 635 nm in the red region respectively for *Trichodesmium* spp., *Chaetoceros* spp., *Dinophysis* spp. and *Prorocentrum* spp. blooms.

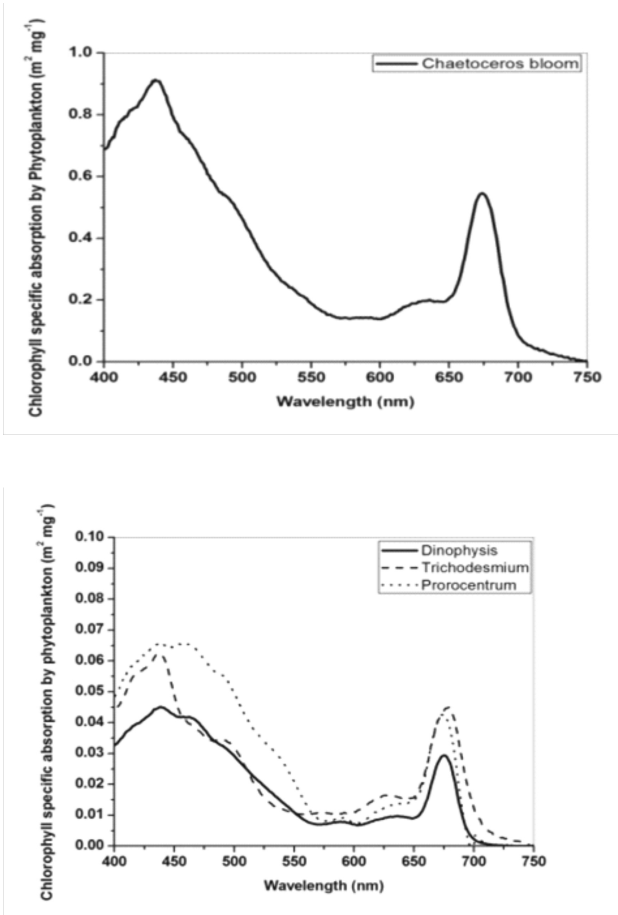

Fig. 2. Chlorophyll specific absorption by phytoplankton spectra for (a) *Chaetoceros* spp. (b) *Dinophysis* spp., *Trichodesmium* spp. and *Prorocentrum* spp.

The CDOM absorption (aCDOM(440)) for *Chaetoceros, Dinophysis* and *Prorocentrum* spp. blooms were 0.068 m-1, 0.093 m^{-1} and 0.122 m^{-1} respectively (Fig. 3). *Trichodesmium* spp. bloom showed highest aCDOM at all wavelengths. aCDOM(440) for *Trichodesmium* spp. bloom were 2.009 m^{-1}. The salinity values during *Trichodesmium* spp. bloom was 34.38 psu and for *Chaetoceros, Dinophysis* and *Prorocentrum* spp. blooms it were 30.9, 27.1 and 32.96 psu respectively.

Detritus absorption also showed marked difference for the different blooms. Minimum $a_d(440)$ was observed for the *Prorocentrum* spp. bloom (0.036 m^{-1}) and highest for *Trichodesmiums* pp. bloom (1.74 m^{-1}).

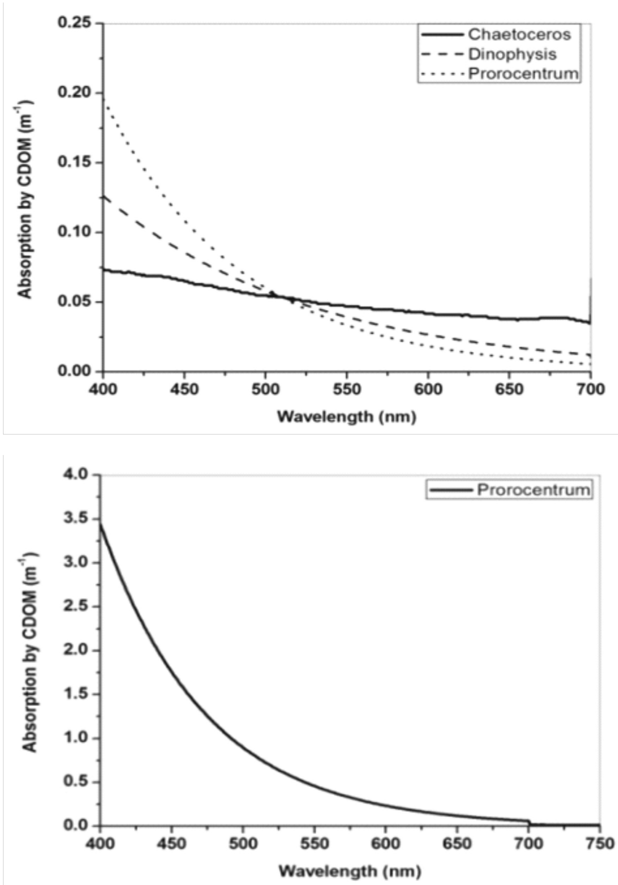

Fig. 3. Spectra showing absorption by CDOM for the phytoplankton blooms observed during the study.

For *Dinophysis* spp. bloom the detritus absorption at 440 nm was 0.388 m^{-1}.

The values for PAR are shown in Fig. 4. It varied from 56% (surface) to 15% (15 m depth) for *Prorocentrum* spp. bloom and from 21% (surface) to 13% (15 m depth) for *Trichodesmium* spp. bloom.

The remote sensing reflectance spectra are shown in Fig. 5. Peaks of $R_{rs}(\lambda)$ were at 490 nm for *Trichodesmium* spp. bloom and 479 nm for *Prorocentrum* spp. bloom. The peak values for nonbloom waters varied between 0.005-0.007 Sr^{-1} in the study area. For *Trichodesmium* spp. bloom, a high reflectance was observed towards the red regions.

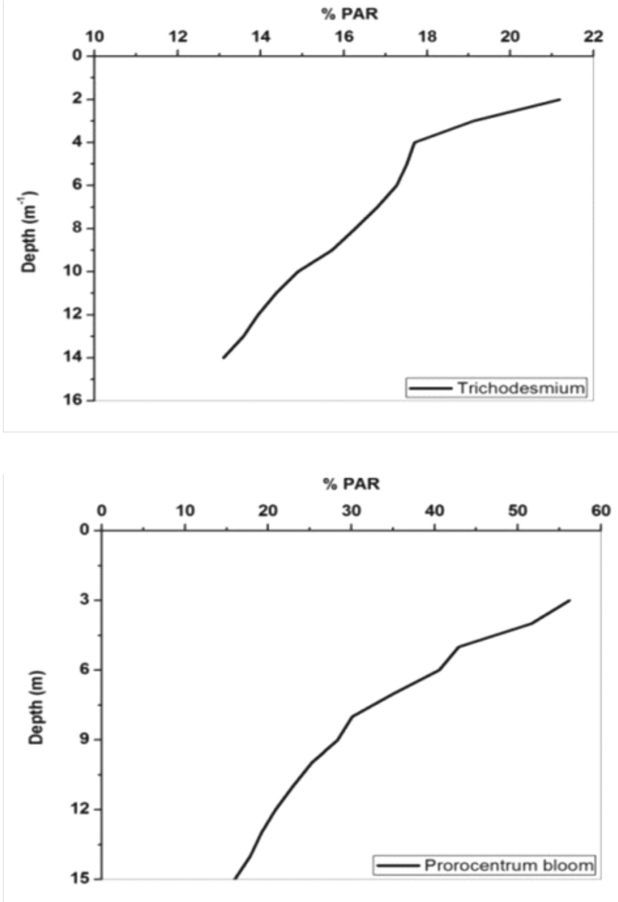

Fig. 4. Graphs showing photosynthetically available radiation (PAR) for *Trichodesmium* spp. and *Prorocentrum* spp. dominant blooms.

The aim of the present study was to obtain an insight into the apparent and inherent optical properties of different phytoplankton blooms that occurred off Kochi, south-west coast of India. The a*ph (λ) was high for *Chaetoceros* spp. dominated bloom when compared with *Dinophysis* spp., *Prorocentrum* spp. and *Trichodesmium* spp. absorption spectra. Stuart et al. (2000) has reported that the absorption in the green part of the spectrum by diatom population is enhanced due to absorption by fucoxanthin. They also reported that fucoxanthin/ chlorophyll a ratios were higher for the diatom population than for the prymnesiophyte (Cyanobacteria-*Trichodesmium* spp.) population.

The *Trichodesmium* spp. bloom showed higher absorption by CDOM. Major source of CDOM is terrestrial runoff. Salinity measured during the

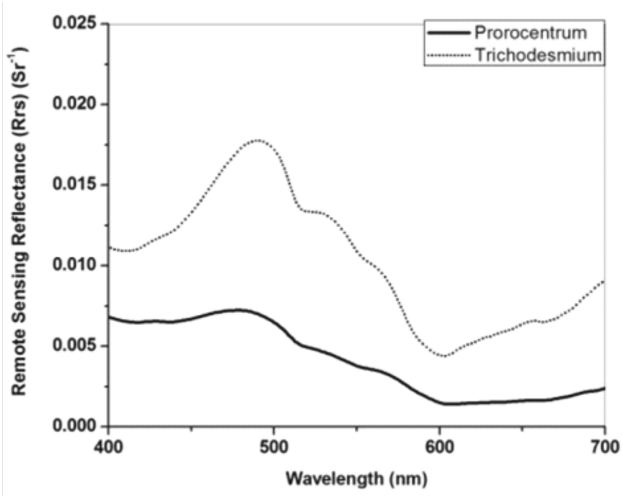

Fig. 5. Remote sensing reflectance spectra for *Prorocentrum* and *Trichodesmium* spp. dominated bloom.

bloom was 34.38 psu. Fu and Bell (2003) reported that maximum growth of *Trichodesmium* spp. species occurs in the salinity range 33-37psu. High CDOM absorption is due to in situ degradation of phytoplankton (Zhang et al. 2009). PAR measured was high for *Prorocentrum* spp. bloom. But the remote sensing reflectance was high for *Trichodesmium* spp. bloom which contains pigment phycoerythrin. The water-leaving radiance at 555 nm will be higher for *Trichodesmium* spp. than other phytoplankton due to the influence of phycoerythrin fluorescence. The surface blooms of *Trichodesmium* spp. would have high reflectance in the near infrared (Kutser et al., 2004; Subramaniam et al., 1999). In our results too high reflectance towards the NIR region was observed.

Bio-optical data analyzed in this study leads to the optical properties of four different phytoplankton blooms that occurred off Kochi. Data from the study showed considerable variations in the absorption and reflectance spectra of four different phytoplankton blooms. The study highlights that *Trichodesmium* spp. bloom can be identified by reflectance peak at 490 nm and *Prorocentrum* spp. bloom by 479 nm and absorption peaks at 632 and 635 nm in the red region of the visible spectrum. *Chaetoceros* and *Dinophysis* spp. had absorption peaks around 675 nm. This is mainly due to the difference in the pigment composition of dominant phytoplankton. Knowledge on the reflectance and absorption spectra of blooms obtained from South-eastern Arabian Sea can be used in remote sensing applications of the area for monitoring harmful algal blooms. Further studies are needed to understand the optical properties of these blooms along coastal waters.

Acknowledgements

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