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REMOTE SENSING OF PHYTOPLANKTON FLUORESCENCE IN NORTHERN ARABIAN SEA

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Abstract

This paper is about remotely sensed phytoplankton fluorescence, its monitoring and spatio-temporal mapping. We examined several remote sensing variables provided by the National Aeronautics and Space Administration (NASA) by the GES DISC Giovanni system. These variables are Normalized Fluorescence Line Height (nFLH), Photosynthetically Active Radiation (PAR), chlorophyll a (chl-*a*), Diffuse Attenuation Coefficient at 490 nm, and Remote sensing reflectance 678 µm monthly data during April, 2011 to March, 2012 from the Moderate Resolution Imaging Spectro-radiometer (MODIS) satellite sensor data. Results highlight the use of selected variables which are useful for mapping ocean productivity and its spatial patterns.

Key words: Remotely sensed fluorescence, Phytoplankton, Chlorophyll-a Fluorescence, Photosynthetically Available Radiation (PAR), Normalized Fluorescence line height (nFLH).

Introduction

Global ocean biology and fluctuations in climatic conditions may be linked with phytoplankton photosynthesis in the physical environment. Alterations in phytoplankton physiology have interactions with the oceanic environment and can express it at large, but phytoplankton function has proven extremely challenging to characterize globally (Li *et al.*, 2013). The use of remote sensing for estimating ocean productivity is not a new concept. It has been effectively integrated as a very powerful tool for the past few decades, since the commencement of global ocean color observations (Lee *et al.*, 2015; Krug *et al.*, 2017). As we know that downwelling solar radiation is absorbed in ocean surface layers, which enhances the algal production and estimated as chl-*a*. The variation in ocean color in seawater is primarily determined by the concentration of phytoplankton in the open sea (Behrenfeld *et al.*, 2006; Khan *et al.,* 2015).

Remote sensing makes it easier to understand phytoplankton fluorescence by providing physiological information that was previously possible only in laboratory and field studies. Satellite interpretations from visible and near-infrared bands provide ocean information. The algorithm-based fluorescence has great advantages for the assessment of phytoplankton chl-*a* (Abbott *et al.*, 1999; Huot *et al.*, 2005; Behrenfeld *et al.*, 2009).

The primary use of remote sensing of fluorescence has been for the estimation of chlorophyll concentration and primary production (Morrison & Goodwin, 2010). The emission of solar radiation from the plants in longer wavelengths is called fluorescence, and it can indicate the rate of photosynthesis (Falkowski, 1992; Freedman *et al.*, 2002). The intensity of fluorescence depends on how much light is absorbed, how efficiently it can be delivered to the reaction centers, and how fast the absorbed (excitation) energy can be passed through the photosynthetic system. Therefore, factors such as PAR, chl-*a*, and water clarity are extremely important (Huot *et al.,* 2005; McClain, 2009).

Fluorescence may be helpful for spatial monitoring of phytoplankton physiological state and its interaction with climate. During photosynthesis, fluorescence can be detected by multi-spectral sensors mounted on satellites (Behrenfeld and Falkowski, 1997; Grace *et al.*, 2007). As discussed by previous researchers (Ruimy *et al.*, 1999; Hilker *et al.*, 2008, Papageorgiou, 2007), during the process of photosynthesis all healthy vegetation re-emits some portion of light energy absorbed from sunlight by fluorescence.

In this study phytoplankton dynamics are represented in the form of maps for which data was obtained by closely observing data from the bands in the red part of electromagnetic spectrum recorded by Moderate Resolution Imaging Spectro-radiometer (MODIS) data. The Northern Arabian Sea is selected because this area has extreme climatic parameters due to seasonal variations in environmental conditions, especially the air and water (Burkill *et al.*, 1993; Thompson *et al.*, 2007). This area has a unique biodiversity, including several common and rare species of algal blooms such as seasonal brown, green, and red algal flora representing important components of the region (Raghukumar & Anil, 2003; Madhav & Kondalarao, 2004; Lee *et al.*, 2000).The objective of this paper is to provide information about freely available (validated) NASA data to botanists, oceanographers, geographers, and allied scientists about evaluation of phytoplankton photosynthesis from space. Limited data is used in this study; larger quantities of data may be much better for long-term assessment of plant production and its dynamics. This study, however, shows the relationship of the variables related to chlorophyll fluorescence.

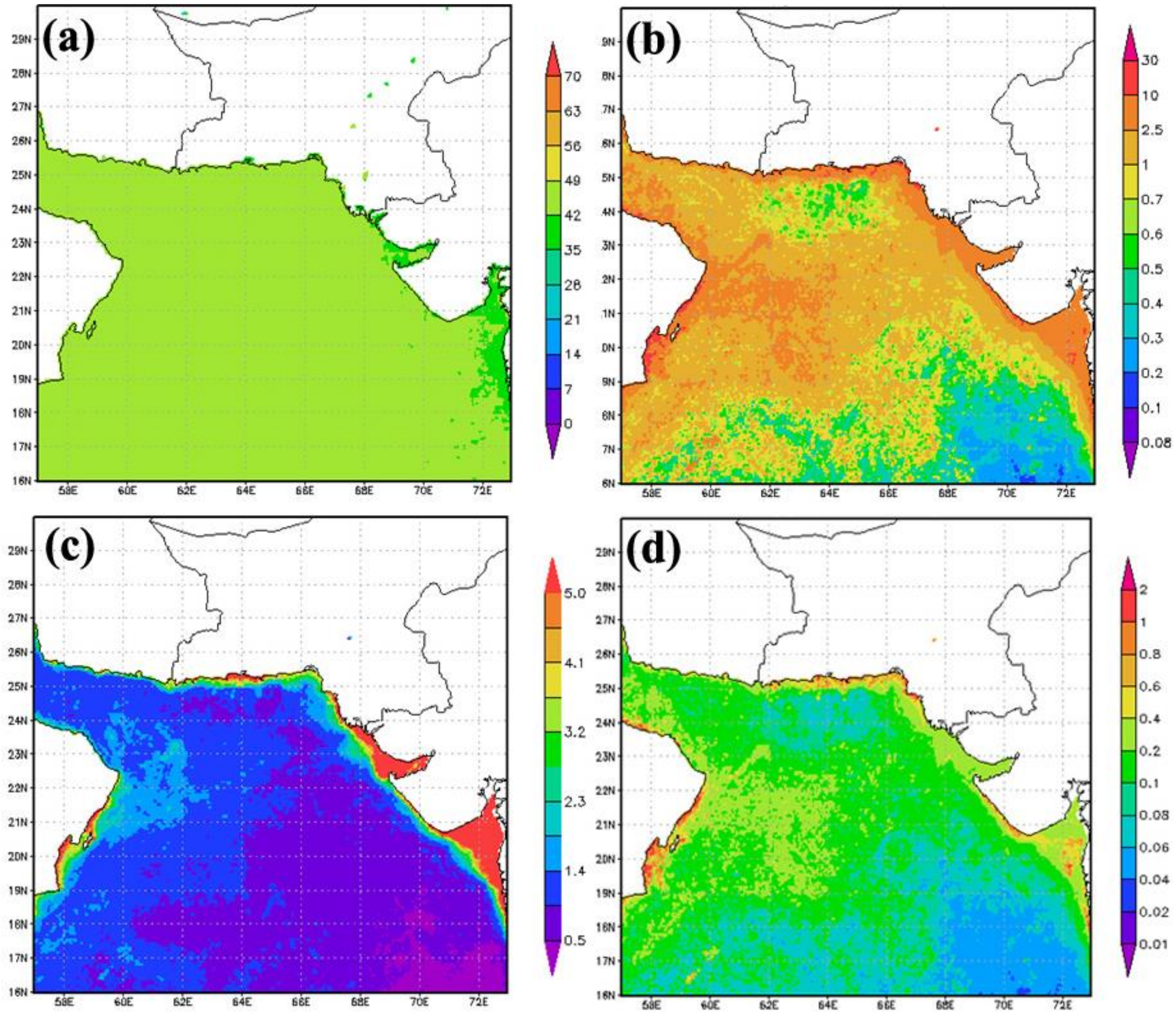

Fig. 1. MODIS data from April 2011 to March 2012- (a) Photosynthetically Available Radiation 4 km (Einstein/m sq/Day) (b) Chlorophyll-*a* Concentration 4 km (mg/m3) (c) Normalized Fluorescence Line Height (nFLH) 4 km [(10^-2) mW cm-2 µm-1 sr-1] (d) Diffuse Attenuation Coefficient at 490 nm 4 km [1/m].

Materials and Methods

Study area: The study area is the northern Arabian Sea, bounded between 57 to 73 degree East longitude and 16 to 30 degree North latitude. This region is rich in meso-scale features where strong seasonal variations in the concentration of phytoplankton are observed, for which the strongest forcing factor is the Indian Ocean monsoon (Krey *et al.*, 1973; Kleijne *et al.*, 1989; Veldhuis *et al.*, 1997; Li & Ramanathan, 2002). Upwelling effects result in highly productive pelagic waters and high plankton productivity along the coasts of adjacent countries like Pakistan, India, Iran, and Oman, which supports the massive diversity of small herbivorous and other marine species (Piontkovski *et al*., 2011; Al-Hashmi *et al*., 2010).

Remote sensing data: We scrutinize nFLH, PAR, chl-*a*, Diffuse Attenuation Coefficient at 490 nm, and remote sensing reflectance at 678 µm data sets from April, 2011 to March, 2012 to provide an intra-annual assessment, obtained from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) online data analysis system Giovanni, https://giovanni.gsfc.nasa.gov/giovanni/.

Results and Discussion

Figure 1a shows the distribution of PAR in the study area ranges from almost 40 to 50 Einstein/m sq/day. Figure 1b shows chl-*a* distribution the entire region, and is noticeably higher at shallower depth near the coastline of most countries. The nFLH distribution can be seen in figure 1c. Most of the fluorescence takes place near shore and within estuarine waters, due to higher chl-*a* concentrations. The K490 data is frequently used for water clarity. The distribution of K490 values is shown in figure 1d, which reveals the distribution of fluorescence in phytoplankton has some relationship with chl-*a* distribution and nFLH. It demonstrates that these three variables have similar distribution pattern, so clearly these variables have positively correlated distributions, as shown in figure 2 (a to d).

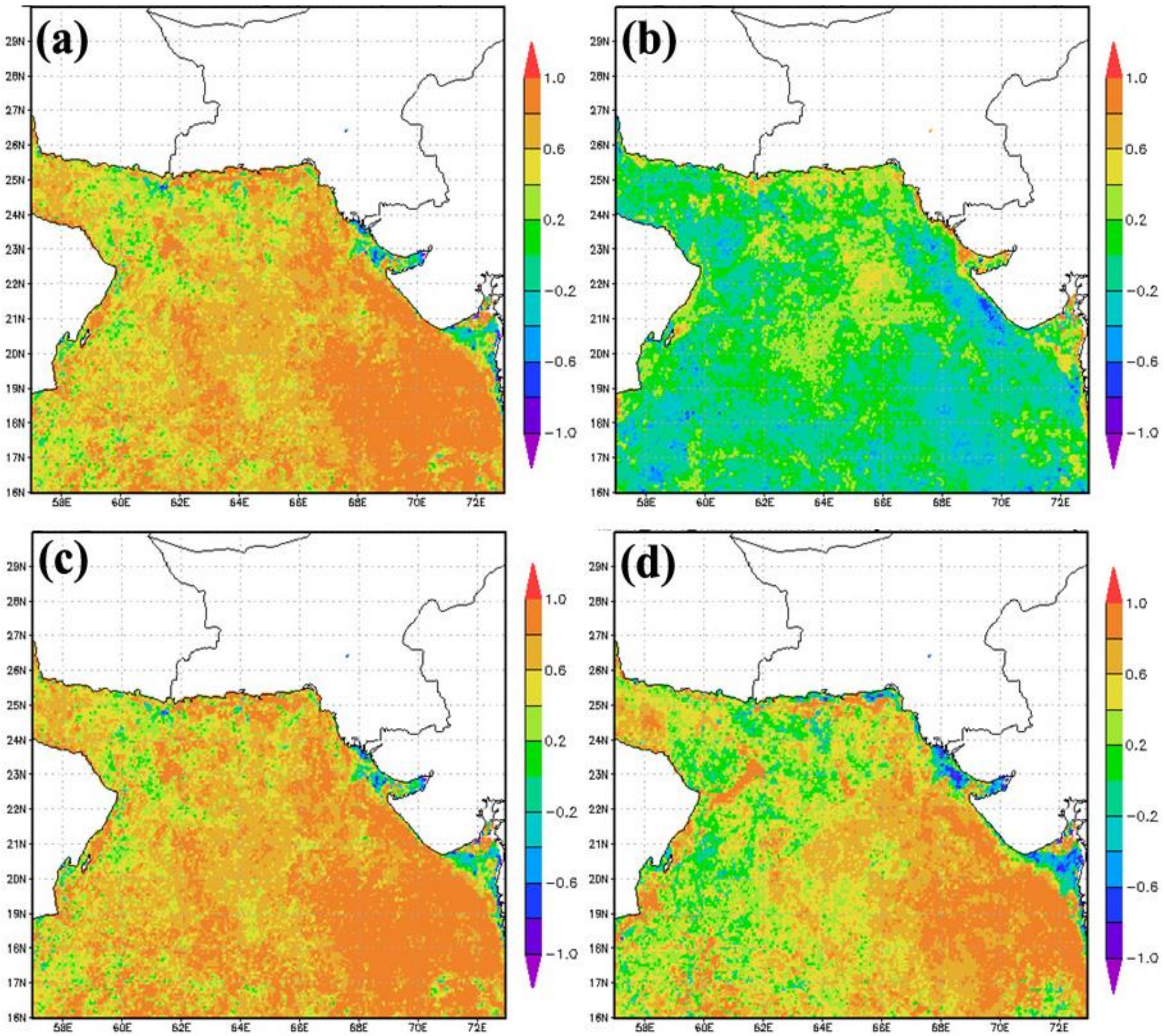

Fig. 2. Correlation among variables (a) chl-*a* 4 km (mg/ m3) and Normalized Fluorescence Line Height (nFLH) 4 km [(10^-2) mW cm-2 µm-1 sr-1] (b) Photosynthetically Available Radiation 4 Km (Einstein/m sq/Day) and chl-*a* 4 km (mg/ m3) (c) Normalized Fluorescence Line Height (nFLH) 4 km [(10^-2)-mW cm-2 µm-1 sr-1] and Diffuse Attenuation Coefficient at 490 nm 4 km [1/m] (d) Chl-*a* concentration 4km (mg/ m3) and Remote sensing reflectance 678 µm (sr-1).

Field-based monitoring of phytoplankton populations over vast areas of the ocean through ship surveys is not ideal and is in fact, ineffective and usually requires significant investment of time, human effort, and funding. Monitoring phytoplankton biomass, due to its influence on water quality and ocean productivity is very vital. Environmental changes influence phytoplankton biomass as they are recognized and verified as environmentally sensitive plants, which can be impacted with shifts in the seasonality of blooms, or phenology, resulting from changing temperature and nutrient conditions. In order to evaluate the satellite-derived chlorophyll some studies are already discuss phytoplankton dynamics. Satellite-derived chlorophyll are closely correlated to phytoplankton. The chlorophyll concentration values and the overall distribution pattern was found to match reasonably well with many studies (Chaturvedi & Narain, 2003; Khan *et al.*, 2015). The highest concentrations were observed at almost all locations during the January-February period. The extending of mixed layer and subsequent changes in visual and physicochemical properties of euphotic zone can influence phytoplankton community dynamics in the northeastern Arabian Sea during winter monsoon (Bemal *et al*., 2018).

Remote sensing observations, therefore, have been integrated by researchers for the estimation of the amount of chlorophyll in order to monitor spatio-temporal variations of ocean productivity at various scales (Rascher & Pieruschka, 2008; Blondeau-Patissier *et al.*, 2014). Now, chlorophyll fluorescence in phytoplankton biomass can improve global knowledge on physiology and photosynthetic efficiency, in both the marine and terrestrial realms. Moreover, for better interpretation, seasonal variation in the presence of phytoplankton may be well integrated by climate models (Antoine and Morel, 1996, Pettorelli *et al.*, 2005, Gower *et al.*, 2004; Behrenfeld *et al.*, 2006).

Conclusion

The present work discusses phytoplankton growth and its associated factors. Marine ocean primary productivity can be estimated by using remotely sensed fluorescence. In phytoplankton during photosynthesis, physiological performance responds to changing physical condition like PAR, resulting in variation in the value of nFLH. Remotely sensed data also helps to define associations among several variables that are associated with ocean primary productivity.

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