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Comparison of chlorophyll distributions in the northeastern Arabian Sea and southern Bay of Bengal using IRS-P4 Ocean Color Monitor data

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Abstract

Water masses of different temperature and salinity partially govern the distributions of chlorophyll concentration. In the present paper, chlorophyll concentration has been deduced over the northeastern Arabian Sea and the southern Bay of Bengal using Ocean Color Monitor (OCM) data onboard Indian Remote Sensing Series Polar satellite (IRS-P4). The chlorophyll concentration is found to be higher in the northeastern Arabian Sea compared to those in the southern Bay of Bengal. The higher chlorophyll concentration is found during the northeast monsoon compared to those during the pre- and post-monsoon period and also in the coastal water compared to the open ocean. Higher spatial and seasonal chlorophyll distributions in the northeastern Arabian Sea compared to the southern Bay of Bengal is attributed to the shallow depth of the shelf in the Arabian Sea.

Keywords: Chlorophyll; IRS-P4; OCM; Arabian Sea; Bay of Bengal

1. Introduction

Oceans occupy almost 70% of the Earth's surface, which play an important role in the climatic conditions of the adjacent land regions. India has approximately 6000 km long coastline. The information about the ocean water and its nutrients and circulation dynamics along the coast has paramount importance in understanding the numerous ocean processes. In the ocean, the physical, chemical, and biological processes are linked in an intimate manner (Tang, Kawamura, & Luis, 2002). Oceanic features such as chlorophyll concentration, current boundaries, sea surface temperature, ocean fronts and eddies, suspended particulate matter, and dissolved organic matter influence the ocean dynamics and its interaction with the atmosphere. Long-term ocean color satellite monitoring provides an important tool for better understanding of the marine processes, ecology, and the coastal environmental changes (GEOHAB, 1998; Kawamura & the OCTS team, 1998; Yoder, McClain, Feldman, & Esaias, 1993; Tang & Kawamura, 2001; Tang et al., 2002; Tang, Ni, Kester, & Muller-Karger, 1999; Tang, Ni, Muller-Karger, & Liu, 1998). Ocean color is determined by the interactions of incident light with the constituents present in the water. Accurate measurements of light radiance at visible wavelengths produce ocean color data, which are related to the constituents present in the water. Such measurements are used to monitor the level of biological activity and presence of materials in the ocean water. Ocean color information on a global scale is also important in studying the bio-geochemical cycles of carbon–nitrogen and sulfur (Chauhan et al., 2002). Efforts have been made to study the chlorophyll distributions in the Arabian Sea (Nakamoto, Prasanna Kumar, Oberhuber, Muneyama & Frouin, 2000; Madhupratap et al., 1996; Tang et al., 2002) and its influence on the sea surface temperature (Sathyendranath, Gouveia, Shetye & Platt, 1991), whereas limited efforts on the detailed study with high-resolution data have been made in the coastal regions of the northeastern Arabian Sea and southern Bay of Bengal. The northeastern part of the Arabian Sea is one of the high productive zones and the southern part of the Bay of Bengal is not much productive compared to the Ganges–Brahmaputra delta in the northern Bay of Bengal (Chauhan, Nagur, Mohan, Nayak, & Navalgund, 2001). The continental shelf in this part of the Arabian Sea is much shallower compared to the shelf in the southern Bay of Bengal. The objective of the present paper is to study the variability of the

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chlorophyll concentrations in the two oceans having contrast continental shelf. In the present paper, we discuss the distribution and comparison of the chlorophyll concentrations in these regions as well as the deeper part of the oceans and the effects of the seasonal changes on the chlorophyll concentrations.

2. Data and atmospheric correction

The launch of the Ocean Color Monitor (OCM) sensor onboard IRS-P4 satellite has been a boon to the scientific community involved in the analysis and characterization of the chlorophyll concentration in the oceans. Recent ocean color sensors like OCTS (Tang & Kawamura, 2001; Tang et al., 2002) and SeaWiFS (Ruddick, Gons, Rijkeboer, & Tilstone, 2001) have been proved to be useful in studying the chlorophyll concentrations, but they have poor spatial resolution (700 m for OCTS and 1.1 km for SeaWiFS) compared to IRS-P4 OCM data. The IRS-P4 OCM sensor has eight spectral channels in visible and near-infrared wavelengths (412–865 nm) with spatial resolution of 360 m and revisit cycle of 2 days (Kundu, Sahoo, Mohapatra, & Singh, 2001). The OCM sensor with high resolution has provided tremendous scope for quantitative assessment of the ocean color more accurately. We have considered IRS-P4 OCM data,

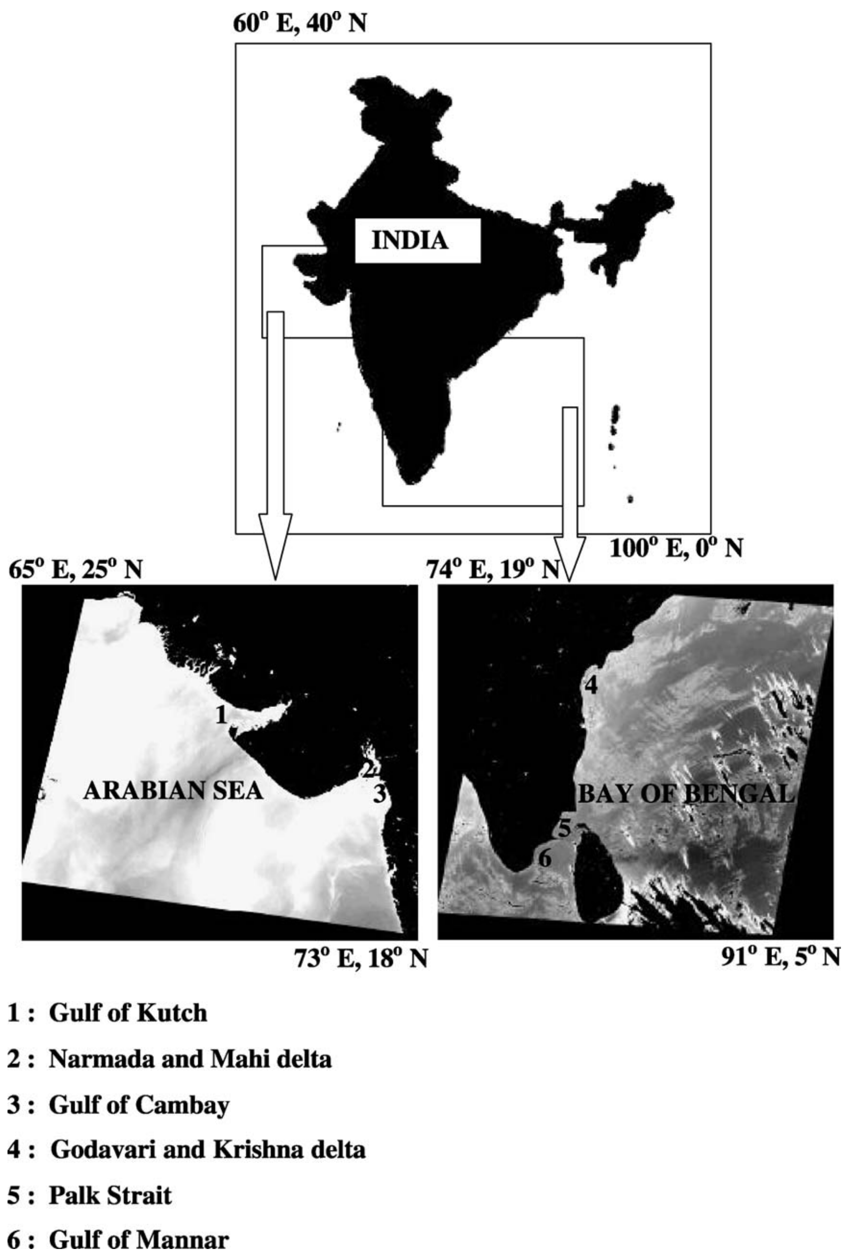

Fig. 1. Study area.

which is available in unsigned 16-bit format. For the present study, we have taken the OCM data covering the southern Bay of Bengal bounded by 74°E to 91°E longitude and 5°N to 19°N latitude, one of the cloud-free day in the months of November 1999–May 2000 and the northeastern Arabian Sea bounded by 65°E to 73°E longitude and 18°N to 25°N latitude for the months of January–April 2000 (Fig. 1). The IRS-P4 OCM data are available on cost; therefore, our study is based on the limited data. The OCM data in eight bands have been imported using ERDAS Imagine 8.3.1, and images have been displayed in eight bands. These images are georeferenced by taking suitable ground control points with the help of toposheets of the area. The details of IRS P4 OCM sensor have been given by Kundu et al. (2001).

Chlorophyll concentration in the ocean can be estimated from the radiance detected in a set of suitably selected wavelengths through a retrieval procedure. In the case of spaceborne ocean color remote sensing, the sensor-detected radiance is a mixture of the radiation emerging from the water (water-leaving radiance) and the solar radiation back-scattered by the air molecules (Rayleigh scattering) and the aerosols (mainly Mie scattering) in the atmosphere. The last two parts of the radiation, called the atmospheric path radiance, is quite strong and constitutes more than 85% of the radiance at the top of the atmosphere (TOA). The TOA radiance is measured by the OCM sensor at all eight wavelengths. The radiance due to Rayleigh scattering has been computed. Considering the spectral nature of the water in the near-infrared wavelength, bands 7 (765 nm) and 8 (865 nm) of OCM have been chosen to retrieve the aerosol radiance (Gordon, 1997). The TOA radiance consists of the Rayleigh and aerosol radiance, since the water-leaving radiance at the near-infrared region is zero. The aerosol radiance at other wavelengths has been computed using the extrapolation method (Gordon, 1997). Thus, the water-leaving radiance in the other wavelengths of the OCM sensor has been deduced for the estimation of the oceanic parameters correctly by subtracting the atmospheric contribution (due to Rayleigh and Mie scattering) from the TOA radiance using the approach discussed by Chauhan et al. (2002).

3. Retrieval of chlorophyll concentration

Numerous bio-optical algorithms for chlorophyll (C) retrieval have been developed to relate measurements of ocean radiance to the in situ concentrations of phytoplankton pigments. In the present study, the algorithm developed by Chauhan et al. (2001) has been used for the retrieval of the chlorophyll concentration. This algorithm captures the inherent sigmoid relationship between $R_{rs}(490)/R_{rs}(555)$ band ratio and Chlorophyll concentration C, where R_{rs} is remote sensing reflectance. The water-leaving radiance at different wavelengths have been transformed to the reflectance values at those wavelengths and are used in the algorithm. This algorithm operates with five coefficients and has following mathematical form

$$C = 10\hat{}(0.319 - 2.336 \times R + 0.879 \times R^2 - 0.135 \times R^3) - 0.07 \quad (0.01\ \mathrm{mg/m^3} \le C \le 50\ \mathrm{mg/m^3}),$$

where C is chlorophyll concentration in mg/m^3 and $R = \log_{10}[R_{rs}(490)/R_{rs}(555)]$, R_{rs} is remote sensing reflectance in corresponding band.

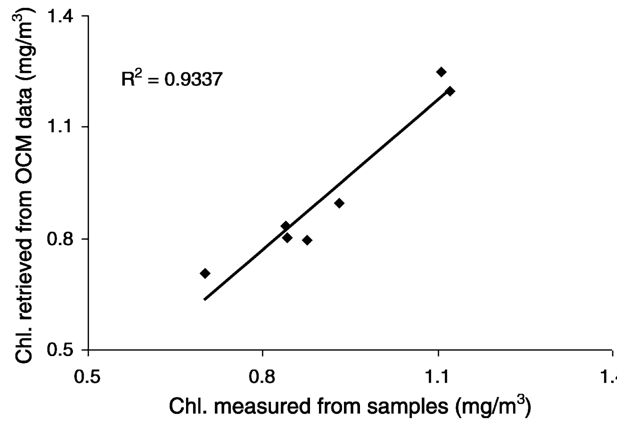

Fig. 2. Correlation between chlorophyll concentrations retrieved from OCM with in situ measurements.

Selvavinayagam, Surendran, and Ramachandran (2002) have measured the chlorophyll concentration of samples collected from the Tuticorin coasts in the Gulf of Mannar (Fig. 1) in the Bay of Bengal on May 28, 2002 during ORV Sagar Kanya SK-149c ship cruise. The in situ measurements of chlorophyll concentrations by Selvavaniyagam et al. have been compared with the values retrieved form OCM data covering the region on May 28, 2000. The chlorophyll concentrations retrieved from OCM data show good correlation (with correlation coefficient .93) with the in situ measurements of chlorophyll concentrations (Fig. 2), which validates the retrieval of chlorophyll concentrations in case 2 coastal water. The above algorithm has also been found to be working good for case 1 water of the Arabian Sea and the Bay of Bengal (Chauhan et al., 2002). In the present study, this algorithm has been used to retrieve the chlorophyll concentrations.

4. Results and discussion

The spatial and temporal distribution of the chlorophyll concentration in the parts of the Bay of Bengal and the Arabian Sea have been found to be different. Unlike the northeastern Arabian Sea, the chlorophyll concentration in the southern Bay of Bengal is low (< 1 mg/m^3) in general. In the deeper part of the Bay of Bengal and the Arabian Sea, the chlorophyll concentration shows very little variations, both spatially and temporally (0.1–0.5 mg/m^3). The chlorophyll concentration shows higher values in the northern

Arabian Sea (2–5 mg/m^3) and in the Gulf of Kutch (5–8 mg/m^3) and the Gulf of Cambay (7–10 mg/m^3) (Fig. 3). Tang et al. (2001) have also found similar chlorophyll concentrations in the northern Arabian Sea using OCTS images. In the Narmada–Mahi delta region near western coast of India (Fig. 1), the chlorophyll concentration is high (4.5–6 mg/m^3). In the southern part of the Bay of Bengal, the chlorophyll concentration is found to be less than 3 mg/m^3. Fig. 3 shows the variations of the chlorophyll concentration in some coastal regions of the northeastern Arabian Sea and the southern Bay of Bengal. The chlorophyll concentrations in the Gulf of Cambay, Gulf of Cambay, and Narmada–Mahi delta in the northeastern Arabian Sea have been found to decrease from the months of January–April. Compared to the Narmada and Mahi delta, the chlorophyll concentration in the Krishna and Godavari delta in the Bay of Bengal is found to be low (3.5–4 mg/m^3) for all the months except January (Fig. 3). In the Palk Strait between India and Sri Lanka (around 10°N), the chlorophyll concentration is found to be higher than 2 mg/m^3 during all the months, but the values are low (<1.5 mg/m^3) in the Gulf of Mannar (Fig. 3). In the northeastern Arabian Sea and the southern Bay of Bengal, the chlorophyll concentrations show highest values in the month of January. In the Bay of Bengal, the chlorophyll concentration abruptly decreases from 1 to 3 mg/m^3 in the coastal areas to <0.5 mg/m^3 after 11–12 km from the coast. In the Arabian Sea, the change is not abrupt; rather, the chlorophyll concentration shows scattered distribution with high patches in the Gulf areas in the Arabian Sea, and these patches are found to diminish in offshore. In the deeper part of the Arabian Sea ($\sim$ 30 km away from the coast), the chlorophyll concentration is found to be <0.5 mg/m^3.

Higher chlorophyll concentration in the northern Arabian Sea is attributed with the winter cooling phenomena during the months of January to March. In the Bay of Bengal, though higher chlorophyll concentrations are found during the months of November–January, the seasonal variations are found to be very less. Another high value ($\sim$ 5 mg/m^3) in the chlorophyll concentration in the Palk Strait (Fig. 3) in the month of April may be due to local effects. In contrast, the seasonal variations are very prominent in the Arabian Sea. The northern Arabian Sea is characterized by offshore and onshore chlorophyll blooms during the northeast monsoon period (Tang & Kawamura, 2001), where the southern Bay of Bengal is found to produce no such bloom. Yoder (2000) has found anomalous pattern of chlorophyll concentration caused by monsoon wind-induced upwelling in the North Indian Ocean compared to the other oceans. The chlorophyll concentration found by Yoder (2000) is about 0.35 mg/m^3 during the month of January, which decreases further up to the month of May (0.15 mg/m^3). In the Arabian Sea, similar trend has been found in the coastal regions and the deeper part of the ocean, whereas in the northeastern coastal regions higher (>5 mg/m^3) chlorophyll concentration is found. The chlorophyll concentration in the southern Bay of Bengal is found to be higher during the month of January, which is comparable with the chlorophyll concentrations found in the Arabian Sea and the northern Indian Ocean.

The open ocean water in the Bay of Bengal has lower nutrient concentrations compared to those in the Arabian Sea. The low nutrient content in the ocean water of the Bay of Bengal is the prime cause of the low chlorophyll concentration in the Bay of Bengal. The high values of chlorophyll concentration in the Palk Strait compared to the other parts of the Bay of Bengal is attributed to the very low depth (10–15 m) of the region. This leads to the vertical mixing of the saline water with the fresh water carried by the rivers in this region and upwelling of the nutrients. In other regions of the Bay of Bengal, the vertical mixing and the upwelling of the nutrients are not strong enough to support high primary production compared to those in the Arabian Sea. In contrast, the northern Arabian Sea is characterized by cooling and densification during Janu-

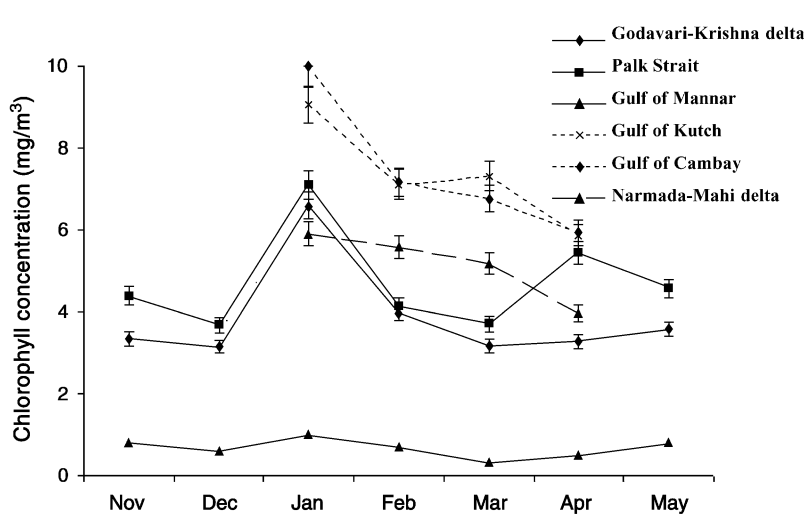

Fig. 3. Chlorophyll concentrations in coastal part of the Arabian Sea and the Bay of Bengal.

ary–March (Prasanna Kumar & Prasad, 1996). This leads to the high salinity of the Arabian Sea water, which initiates convective mixing and injection of nutrients into the sea surface from the thermocline regions. The nutrient injection is responsible for the higher chlorophyll concentrations in the northern Arabian Sea during this period. In the Arabian Sea, most of the primary production occurred below the surface during the northeast monsoon and just after the monsoon, the vertical mixing bring them at the surface. The Bay of Bengal, though experiences the onset and retreat of monsoon compared to those of the Arabian Sea, the low nutrient concentration of the water, and the lack of upwelling of nutrients due to its typical ocean dynamics, cause little chlorophyll production in the water compared to those in the Arabian Sea.

5. Conclusion

The lower chlorophyll concentrations have been found in the southern Bay of Bengal compared to those in the northeastern Arabian Sea. The Gulf areas in the northeastern Arabian Sea are characterized by higher chlorophyll concentrations. The seasonal variations of the chlorophyll concentration in the southern Bay of Bengal are found to be insignificant compared to those in the northeastern Arabian Sea. The higher chlorophyll concentration in the northeastern Arabian Sea is attributed to the vertical mixing of its water and upwelling of water, rich in nutrients, whereas the Bay of Bengal water has low nutrient concentrations; as a result, low chlorophyll concentration is found.

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