Comparison of chlorophyll concentration in the Bay of Bengal and the Arabian Sea using IRS-P4 Ocean Color Monitor, and MODIS Aqua

Prashant Chaturvedi, Anup K. Prasad, and Ramesh P. Singh[@]
Department of Civil Engineering, Indian Institute of Technology, Kanpur - 208016, India

[@]Email: ramesh@iitk.ac.in

ABSTRACT: Ocean Color Monitor (OCM) onboard the Indian Remote Sensing Satellite IRS-P4 has been used to retrieve chlorophyll concentration in the Bay of Bengal and the Arabian Sea using a bio-optical algorithm. Cloud masking and atmospheric corrections have been performed before applying mapping function to derive chlorophyll concentration from IRS-P4 OCM data. We have retrieved chlorophyll concentration from OCM, and MODIS during the summer and winter season along the eastern and western coast of India at every 1 degree latitude at increasing distance (25, 50, 100, 150 and 200km) away from the coast as well as near river mouths for the period 2000-2003. We have also studied spatial and temporal dynamics of monthly MODIS Aqua (for period July 2002-April 2004). The seasonal dynamics of chlorophyll concentration over the Bay of Bengal and the Arabian Sea have been discussed using OCM and MODIS for both the coastal region and the open sea.

KEYWORDS: IRS P4 OCM, Chlorophyll, Arabian Sea, Bay of Bengal

1. INTRODUCTION

Remote sensing from space is one of the most efficient and modern tool for understanding the dynamics of our planet. Two third parts of the Earth's surface is covered by water of which oceans form a major proportion. Oceans affect the climate on a global scale. Economically also it has a great influence on society. Since India is surrounded by water from three sides (in the west the Arabian Sea, in the south the Indian Ocean and in the east the Bay of Bengal), long-term time series of satellite ocean color measurement are important for understanding of the atmospheric and ocean parameters (Tang and Kawamura, 2001). These parameters are important in understanding the coupling between land-ocean-atmosphere which play an important role in influencing the climate and weather conditions of the Indian sub-continent. Chlorophyll concentration dynamics over the Arabian Sea and the Bay of Bengal have been studied using various satellite data such as OCM and CZCS data (Banse and English 2000; Dey and Singh, 2003). Kumar *et al.* (2002) have discussed reasons for low productivity of the Bay of Bengal during the summer monsoon season. A quantitative assessment of the oceanic parameters is the prime objective of the present paper. In addition, with the limited dataset, efforts have been made to validate the chlorophyll concentration derived from IRS P4 OCM with MODIS Aqua.

2. REMOTE SENSING OF THE CHLOROPHYLL CONCENTRATION

Bio-optical algorithms are derived from the statistical regression of water leaving radiance versus chlorophyll concentration in many cases. An empirical algorithm has been proposed for SeaWiFS ocean color data (O'Reilly *et al.*, 1998). According to this algorithm, there is an inherent sigmoid relationship between $R_{rs}490/R_{rs}555$ band ratio and chlorophyll concentration (C), (R_{rs} - remote sensing reflectance). This algorithm retrieves low as well as high chlorophyll concentration, signifying a better retrieval even in the case of 'case 2 water'. Below is the mathematical form (with 5 coefficients) of the algorithm:

For, mg/m^3 0.01 mg/m^3<= C <= 50 mg/m^3,
$C = 10^{\wedge} (0.319–2.336 * R + 0.879 * R^2 – 0.135 * R^3) – 0.071$ ..... (1)
where C is the chlorophyll concentration in mg/m^3
$R = \log_{10} [R_{rs} (490) / R_{rs} (555)]$

This algorithm is found to be good even for case 1 water of the Arabian Sea (Chauhan *et al.*, 2000). We have used equation (1) for the retrieval of chlorophyll concentrations in the Arabian Sea as well as the Bay of Bengal.

3. IRS P4 OCM AND MODIS DATA

3.1. IRS P4 OCM

IRS P4 Satellite was launched by the Indian Space Research Organization (ISRO) on May 26, 1999 with two different payloads namely Ocean Color Monitor (OCM) and Multi-frequency Scanning Microwave Radiometer (MSMR). OCM serves in optical frequencies while MSMR serves in microwave frequencies. OCM operates in eight spectral bands in the visible and NIR region of the EM radiation. The OCM takes advantage of push broom scanning system for getting better radiometric performance and higher spatial resolution. The large swath of OCM provides high revisit time (2 days). It operates in 8 bands of visible and near infrared wavelengths. OCM is advantageous in terms of data handling system with high quantization resolution. OCM optics is based on one lens per band concept. Details of the OCM payload characteristics are described in IRS P4 Handbook, 1999.

3.2 MODIS Sensor and Data Product

MODIS is a key instrument onboard the Terra and Aqua satellites. The MODIS instrument operating on both the Terra and Aqua spacecraft has a viewing swath width of 2,330 km and views the entire surface of the earth every one to two days. Its detectors measure 36 spectral bands between 0.405-14.385 μm, and it acquires data at three spatial resolutions 250m, 500m, and 1,000m. Terra and Aqua satellites provide high radiometric sensitivity (12 bit) in 36 spectral bands. The MODIS onboard of the Aqua satellite has been providing data since June 24, 2002. It passes south to north over the equator in the afternoon. Daily overpass Level -2 data have been used for the comparison with OCM chlorophyll concentration. Monthly average Level-3 MODIS Aqua Chl-a concentration product have been used for time series analysis.

4. RESULTS AND DISCUSSION

The chlorophyll concentrations have been retrieved over the regions of the Arabian Sea and the Bay of Bengal to study the temporal variations of IRS P4 OCM data set for the period 2000 – 2003. The chlorophyll concentrations have been estimated at distance of 25, 50, 100, 150, and 200km from both the Indian coasts at 1° latitudinal separation. The location of samples, along the coast, for 25-50km distance (25km width of sample block) is shown in Figure 1.

Over the Arabian Sea, the chlorophyll concentrations have been found to be higher compared to the Bay of Bengal. The two gulf areas, the Gulf of Cambay and Kutch show maximum values (Figures 2, 4). Significant variations of chlorophyll concentrations are found in remote Ocean, chlorophyll concentrations at 25 km distance from the coast are found to be higher than that of 50 km and 100 km distances. In general, the chlorophyll concentrations decrease from coast to deep sea.

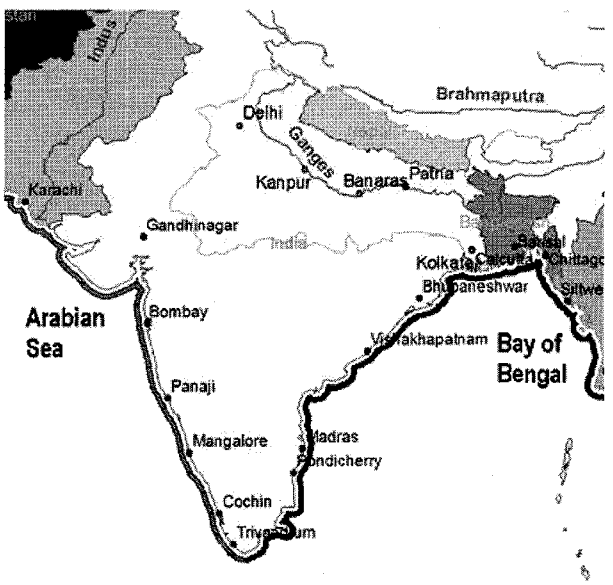

Figure 1. Location of chlorophyll sampling region (25-50km) along the western and eastern coast of India.

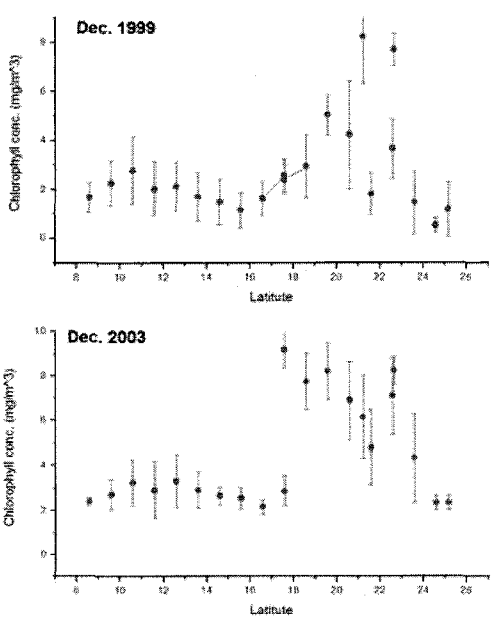

Figure 2. Chlorophyll concentration in the western coast (25-50km) during the winter season.

The chlorophyll concentration in the Bay of Bengal is low during the summer season while show higher values during the winter season. Highest Chl-values are found in the northern Bengal (near river mouths such as Ganga (or Ganges) river) during the monsoon season when heavy river discharge also brings large amount of suspended sediments along with the organic matter (Figures 3, 5).

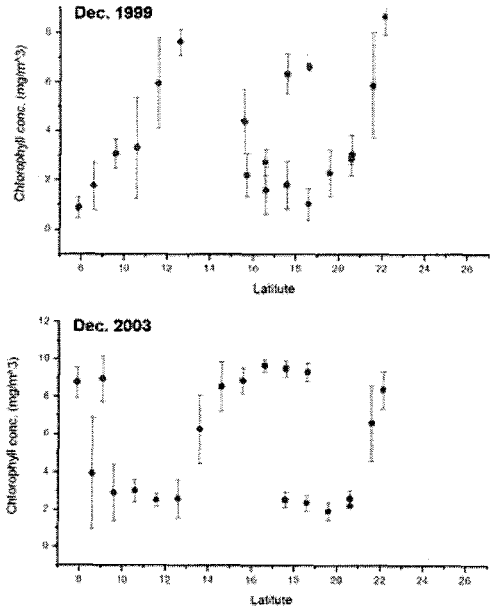

Figure 3. Chlorophyll concentration in the eastern coast (25-50km) during the winter season.

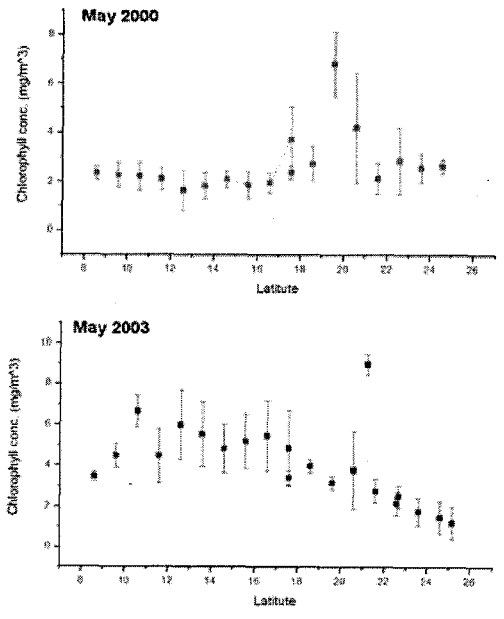

Figure 4. Chlorophyll concentration in the western coast (25-50km) during the summer season.

At the eastern coast of India around the deltaic regions of Ganga, Mahanadi, Krishna, Godavari and Kaveri rivers, high Chl-a values have been observed (Figure 3). Similar observations are found at the river mouth of Narmada along the west coast in the Arabian Sea (Figure 2). The chlorophyll concentrations show that in general, the Bay of Bengal region is less productive compared to the Arabian Sea.

The phytoplankton bloom during winter in the Bay of Bengal region is mainly attributed to the ocean upwelling driven by Ekman pumping (EP).

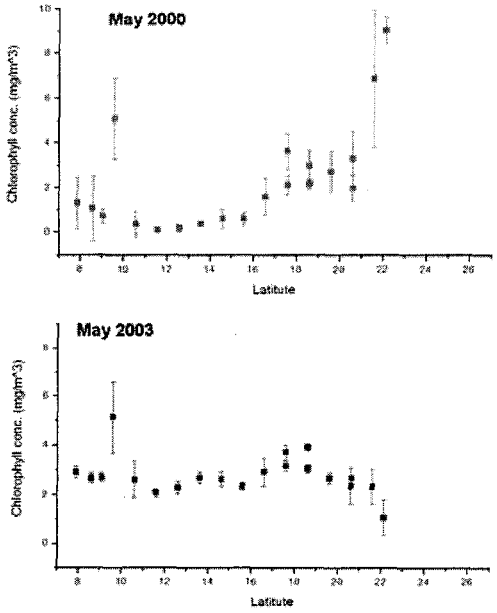

Figure 5. Chlorophyll concentration in the eastern coast (25-50km) during the summer season.

The cyclones in the Bay of Bengal are also responsible for the local chlorophyll blooms (Kundu *et al.*, 2001).

The main reason for Bay of Bengal being less productive is that the high rainfall and river discharge freshen the upper layer of water in the Bay of Bengal region and also the SST is found to be warmer compared to the Arabian Sea, as a result a strongly stratified surface layer in the Bay of Bengal region is observed. The weaker winds over the Bay of Bengal fail to erode this stratified layer, so wind driven vertical mixing in the water does not take place to a greater depth. This restricts supply of nutrients into the upper layers. On the other hand, in case of the Arabian Sea the advection of nutrient rich water into the euphotic zone makes this region highly productive.

Higher Chl-a concentrations are observed during December and January, some part of the northern Arabian Sea is likely associated with the winter cooling phenomenon.

In the present study, Chl-a retrieved from IRS P4 OCM data have been compared with the MODIS satellite data for different months of the years 2000, 2001, 2002 and 2003. The Chl-a

retrieved from IRS P4 OCM data is compared with the MODIS Aqua data. The comparison study has some limitation due to the availability of MODIS data for the same scene, and also in terms of time and day. The MODIS AQUA data are available free of cost for every day, whereas the IRS P4 OCM data although the resolution is higher, have to be purchased. Due to its higher cost, the comparison of data is limited to the data available on a day in the month.

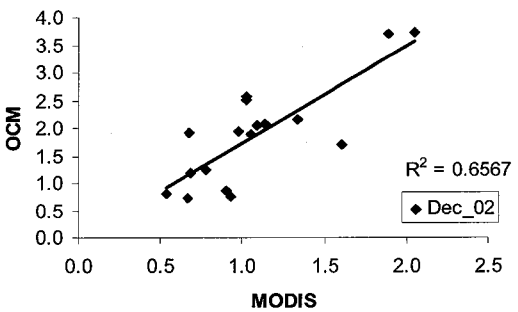

Figure 5. Correlation between IRS P4 OCM and MODIS Aqua derived chlorophyll concentration.

5. CONCLUSION

The present study using IRS P4 OCM and MODIS data show high chlorophyll concentration in the Arabian Sea compared to that in the Bay of Bengal. The two gulf areas, Gulf of Cambay and Kutch show maximum values. In general, the chlorophyll concentrations decrease from coast to deep sea. Higher Chl-a value are observed during December and January, in some part of the northern Arabian Sea, which is likely associated with the winter cooling phenomenon. Over the Bay of Bengal region during winter months, variations in Chl-a represent the patches of phytoplankton blooms which is found to be common during December to January, these patches disappear in later months. The phytoplankton bloom during winter in the Bay of Bengal region is mainly attributed to the ocean upwelling driven by Ekman pumping. At the eastern coast of India, around the deltaic regions of Ganga, Mahanadi, Krishna, Godavari and Kaveri rivers, high Chl-a value have been observed. Similar observations are found at the river mouth of Narmada along the west coast in the Arabian Sea. Correlation between IRS P4 OCM Chl-a and MODIS Aqua are found to be moderate.

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