Comparison of chlorophyll concentration in the Bay of Bengal and the Arabian Sea using IRS-P4 OCM and MODIS Aqua

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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. Chlorophyll concentrations have been retrieved from IRS P4 OCM, and used MODIS chlorophyll product during the summer and winter seasons at every 1 degree latitude along the eastern and western coast of India for the period 2000-2003. Present study consists the spatial and temporal monthly variations of chlorophyll concentrations from MODIS data for period July 2002-April 2004. Seasonal dynamics of chlorophyll concentrations along the coastal region and in the open sea of the Bay of Bengal and the Arabian Sea is discussed using IRS P4 OCM and MODIS.

[Keywords: IRS P4 OCM, Chlorophyll, Arabian Sea, Bay of Bengal]

Introduction

Remote sensing from space is one of the most efficient and modern tool for understanding the dynamics of our planet. Long-term time series of satellite ocean color measurement are important for understanding the atmospheric and ocean parameters. Chlorophyll concentrations dynamics over the Arabian Sea and the Bay of Bengal have been studied using various satellite data such as OCM and CZCS data. Kumar et al. (2002) have discussed reasons for low productivity of the Bay of Bengal during the summer monsoon season, however, Vinayachandran and Mathew (2003) have found enhancement of chlorophyll concentrations during north-east monsoon period and during cyclones in the Bay of Bengal. Present study consists Chl-a concentrations from IRS P4 OCM data using algorithm developed by Indian scientists for Indian ocean waters. Further, we have compared Chl-a deduced from IRS P4 OCM data from MODIS Chl-a product which is not a tested product. A limited quantitative evaluation of Chl-a deduced from IRS P4 OCM data shows a reasonable correlation with MODIS Chl-a product.

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. According to this algorithm, there is an inherent sigmoid relationship between \( R_{rs,500/555} \) 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:

\[
C = 10^\left(0.319 - 2.336 \times R + 0.879 \times R^2 - 0.135 \times R^3 - 0.071\right) \quad \ldots (1)
\]

where \( C \) is the chlorophyll concentration in mg/m³

\[
R = \log_{10} \left[\frac{R_{rs}(490)}{R_{rs}(555)}\right]
\]

This algorithm is found to be good even for case 1 water of the Arabian Sea (Chauhan, 2000). We have used equation (1) for the retrieval of chlorophyll concentrations in the Arabian Sea as well as the Bay of Bengal. The algorithm developed by Chauhan (2000) is based on field and laboratory studies. Similar algorithm is also developed for suspended
solids using IRS P4 OCM data utilizing different OCM bands. Use of these two algorithms provide information about the Chl-a and suspended solids separately. The present paper deals with the spatial variations of Chl-a in the Arabian Sea and the Bay of Bengal.

3. IRS P4 OCM and MODIS Data

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 EM radiation. OCM takes advantage of push broom scanning system for getting better radiometric performance and higher spatial resolution. 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. OCM data is very expensive and not freely available. In the present study, we have used limited data due to its cost and tried to compare with MODIS data which is freely available.

MODIS Sensor and Data Product

MODIS is a key instrument onboard the Terra and Aqua satellites. 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. 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 concentrations. Monthly average Level-3 MODIS Aqua Chl-a concentrations product have been used for time series analysis.

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. Chlorophyll concentrations have been estimated for both the Indian coasts at 1° latitudinal separation. Location of samples lie along the coast, for 25-50km distance, a thick 25km width of sample block all along the coast is shown in Figure 1. Average of five pixels at each location for chlorophyll concentrations using IRS P4 OCM data had considered in the present study.

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.

The chlorophyll concentrations in the Bay of Bengal is found to be low during summer season while show higher values during winter season. Highest Chl-values are found in the northern Bengal (near river mouths, e.g. 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). During monsoon period due to surface runoff, nutrients in the river water is higher compared to other seasons.

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). In general, the chlorophyll concentrations in the Bay of Bengal are found to be lower than 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).

The cyclones in the Bay of Bengal are also responsible for the local chlorophyll blooms. The main reason for the Bay of Bengal being less productive is that the high rainfall and river discharge freshen the upper layer of water in the Bay
Fig. 1—Location of chlorophyll sampling region (25-50km) along the western and eastern coast of India.

Fig. 2—Chlorophyll concentrations in the western coast (25-50km) during the winter season.
Fig. 3—Chlorophyll concentrations in the eastern coast (25-50km) during the winter season.

Fig. 4—Chlorophyll concentration in the western coast (25-50km) during the summer season.
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 east and west coasts of India is covered with 4 scenes of IRS P4 OCM. An attempt have been made to compare IRS P4 OCM derived chlorophyll concentrations and MODIS Aqua chlorophyll product for the month of December 2002 since the maximum cloud free locations were found during December 2000 – 2003. Figure 6 shows the comparison of Chl-a retrieved from IRS P4 OCM data with MODIS Chl-a product at various locations along the east and west coast for the month of December 2002 (Figure 6) covering the coast either on December 15 or December 16, 2002. In the comparison, locations at the extreme north eastern part of the Bay of Bengal were not considered since the scene alternate day IRS P4 OCM data was not available due to technical problem. Due to this limitations, we have found 16 data points for comparison of Chl-a deduced from IRS p4 OCM and MODIS Chl product. The correlation between IRS P4 OCM and MODIS Aqua data is found to be $R^2 = 0.65$. Chl-a from IRS P4 OCM data show a higher estimation of chlorophyll concentrations compared to MODIS Chl-a product in the month of December. The comparison study is limited 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 is not freely available. The IRS P4 OCM product has to be purchased, as a result the IRS P4 OCM data is not used by many scientists and also studies are very limited.

**Conclusion**

The present study using IRS P4 OCM and MODIS data show high chlorophyll concentrations in the Arabian Sea compared to that in the Bay of Bengal. The limited study also show that the estimation of chlorophyll concentrations from IRS P4 OCM data is higher compared to the MODIS data in the month of December. The two gulf areas, Gulf of Cambay and Kutch show maximum chlorophyll values. In general, the chlorophyll concentrations decrease from coast to deep sea. Higher Chl-a value are observed during December and January, in some parts 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 blooms 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. Detailed analysis of IRS P4 OCM data is required to compare with the MODIS chlorophyll product. Such study will be of great importance to the Indian and international community for the quantitative use of IRS P4 OCM and MODIS data product but the main limitation is the high cost of IRS P4 OCM data.

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