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Monthly variability of chlorophyll and associated physical parameters in the southwest Bay of Bengal water using remote sensing data

* [1]R.K.Sarangi, Shailesh Nayak[2] & R.C.Panigrahy[3]

[1]Marine and Earth Sciences Group, Remote Sensing Applications Area,
Space Applications Center (ISRO), Ahmedabad - 380 015, India

[2]Indian National Center for Ocean Information Services (INCOIS), Hyderabad - 500 055, India

[3]Department of Marine Science, Berhampur University, Bhanja Bihar, Berhampur - 760 007, Orissa, India

*[E-mail : sarangi@sac.isro.gov.in]

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In the present paper, we have carried out analysis of surface chlorophyll-a concentration in the seas around India obtained using the Indian Remote Sensing satellite IRS-P4 Ocean Colour Monitor (OCM) data. The focus was given to southwest Bay of Bengal where such studies are scanty. The study portraits the chlorophyll-a pattern during July 1999-June 2000. The monthly sea surface temperature (SST) trend and wind patterns using NOAA-NCEP and Quickscat Scatterometer data, respectively, were studied, to elucidate their impact on chlorophyll distribution. This helped to decipher how the reversing monsoon wind induces algal blooming in the surface waters of the study area. Several features like eddies, algal blooms and coastal plumes were observed. Highest mean chlorophyll was observed in January (northeast monsoon) and lowest in May (summer inter monsoon). Adjacent Arabian Sea water found predominantly productive than the Bay of Bengal water. Higher wind speed around 10 m/s in southwest and northeast monsoon shows about two fold increase in chlorophyll concentration to 1.0-2.0 mg/m^3 and the SST has shown gradient and decrease of about 1-2ºC in the BoB and off southern India, respectively.

[**Key words:** IRS-P4 OCM, chlorophyll, physical parameters, SST, wind speed/vector, Bay of Bengal, remote sensing]

Introduction

Ocean colour data have profoundly enhanced our understanding of the global distribution of phytoplankton by providing a synoptic and temporally cohesive picture of phytoplankton biomass variability, which has only partially been resolved by previous shipboard sampling[1-3]. Satellite ocean colour imagery has been used to estimate chlorophyll-a concentrations as an indicator of phytoplankton abundance[4]. The influence of phytoplankton on the colour of the sea has been studied for several decades. It is well understood that the chlorophyll-a, the primary photosynthetic pigment in the phytoplankton, absorbs relatively more blue and red light than green, and the spectrum of backscattered sunlight or colour of the ocean water progressively shifts from deep blue to green as the concentration of phytoplankton increases[5]. Satellite ocean colour data provide the practical means for monitoring the spatial and seasonal variations of near-surface phytoplankton, and sediment dynamics. This information is essential for the study of ocean primary production, global carbon and other biogeochemical cycles, as well as fisheries research.

Optical properties of oceans are of fundamental interest for all oceanographic disciplines. Their variability is largely determined by variations in the ecology of the system and biological response to the physical and chemical environment. The horizontal and vertical distribution of attenuating particles, such as phytoplankton and biogenic detritus material affect the way in which heat is stored in the upper ocean, providing a fundamental link between optical properties of the ocean and physical oceanography[6,7]. Basin-to-global scale composite images are used as input to calculate primary production and to describe and quantify seasonal cycles on a global scale. Such images are also one of the important data sources for understanding how physical processes affect biological distributions on ocean basins and global scales.

*Ph: 079-26914360/26914336
Fax: 079-26915825

Bay of Bengal has several distinguishing features, which make it a particularly unique and dynamic area of study. Like the extensively studied Arabian Sea to its west is semi-enclosed basin in the north Indian Ocean is forced by seasonally reversing monsoons[8]. Its major distinctive feature however, is the tremendous fresh water flux that it receives from rivers. The fresh water influx together with the monsoon winds exerts a strong influence on the surface water circulation and stratification. Bay of Bengal is usually considered less productive compared to the Arabian Sea. Although many major river systems bring in large quantities of nutrients, narrow shelf and persistent cloud cover and low light penetration are responsible for low productivity[9]. Very few measurements are available on the phytoplankton and its seasonal variability to support these studies. Some of them are, data collected during the south-west monsoon[10] and the study aimed at understanding the seasonality varying processes controlling phytoplankton productivity in the upper layers of Bay of Bengal[9] using ocean colour imagery from Ocean Color Temperature Scanner (OCTS) and Sea Viewing Wide Field of View (SeaWiFS) data. A unique feature of the Bay is a western boundary coastal upwelling (when most of the classical coastal upwelling regions of the World's ocean occur along eastern boundary of the ocean basins). Coastal upwelling along the east coast of India has received considerable attention over the past three decades both in theoretical and observational studies[11-14]. A theoretical study[13] indicates upwelling from January to July and sinking from August to December.

Like the Somali current in the Arabian Sea, the East India Coastal Current (EICC) reverses direction twice a year, flowing north-eastward from February until September with a strong peak in March-April and south-eastward from October to January with strongest flow in November[15-18]. The circulation in the Bay of Bengal is characterized by anti-cyclonic flow during most months and strong cyclonic flow during November[19]. It is also known for the cyclones it breeds[20]. The seas in the vicinity of the tip of India experiences winter monsoon, gap wind events[21]. Gap winds are caused by gaps in elevated topography at the coast or even in mountains and pressure gradient. These events are characterized by high wind stress, high turbulent heat loss in the Gulf of Mannar. It is well known that, north of 10^0 N, the Indian Ocean undergoes drastic atmospheric and hydrospheric changes under the influence of the semi-annual reversal of monsoon winds[20]. The information about the ocean water and its nutrients and circulation dynamics along the coast has paramount importance in understanding the numerous ocean processes[21]. The role of ocean dynamics on productivity needs to be studied on seasonal and different time scale basis.

In the present paper, we have carried out analysis of IRS-P4 OCM data to study the monthly variability of chlorophyll and influence of various parameters; NOAA-NCEP derived sea surface temperature (SST) and NASA-Quickscat Scatterometer retrieved wind speed. The resent results show the distribution of chlorophyll and reversing monsoon wind induced algal blooming in surface waters in the study area.

IRS-P4 OCM Sensor

The ocean colour monitor (OCM) of the Indian Remote Sensing satellite IRS-P4 is optimally designed for the estimation of chlorophyll in coastal and oceanic waters, detection and monitoring of phytoplankton blooms, studying the suspended sediment dynamics and the characterization of the atmospheric aerosols. IRS-P4 satellite OCM launched successfully by the Polar Satellite Launch Vehicle (PSLV) on May 26, 1999 from Sriharikota, India. The technical specifications of the OCM sensor[22] are mentioned in Table 1.

OCM Data Processing

The retrieval of ocean colour parameters such as phytoplankton pigment (chlorophyll-a) in oceanic waters, involves two major steps like atmospheric correction of visible channels to obtain normalized water leaving radiances in shorter wavelengths and second application of the bio-optical algorithm for retrieval of phytoplankton pigment concentration.

Atmospheric correction of the IRS-P4 OCM imagery

In the ocean remote sensing, the signal received at the satellite altitude is dominated by radiances

Table 1 – Monthly surface chlorophyll range in the southwest Bay of Bengal water

Months	Chlorophyll Grade	Chlorophyll range (mg/m^3)
July-September	High	1.0-2.0
October	High	1.0-2.0
January-March	Low	0.4
April-May	Glint affected	-
June	Moderate	1.0

contribution through atmospheric scattering processes and only 8-10% signal corresponds to oceanic reflectance[22]. Therefore it has been mandatory to correct the atmospheric effect to retrieve any quantitative parameter from space. The OCM scenes were corrected for atmospheric effects of Rayleigh and aerosol scattering using an approach called long wavelength atmospheric correction method. The approach used[23,24] the two near infrared channels at 765 and 865 nm to correct for the contribution of molecular and aerosol scattering in visible wavelengths at 412, 443, 490, 510, and 555 nm. The water leaving radiances derived from atmospheric correction procedure was used to compute chlorophyll-a pigment concentration.

Chlorophyll algorithm

A number of bio-optical algorithms for retrieval of chlorophyll have been developed to relate measurements of ocean radiance to the *in situ* concentrations of phytoplankton pigments. An empirical algorithm[25] (known as Ocean Chlorophyll 2 or OC2) was proposed and operated on SeaWiFS ocean colour data. This algorithm captures the inherent sigmoid relationship between $R_{rs}490/ R_{rs}555$ band ratio and chlorophyll concentration C, where R_{rs} is the remote sensing reflectance. The algorithm operates with five coefficients and has following mathematical form.

$$C = 10^{[0.319 - 2.336 * X + 0.879 * X2 - 0.135 * X3]} - 0.071$$

where, C is chlorophyll concentration in mg/m^3 and $X = \log_{10} [R_{rs}490/ R_{rs}555]$, where R_{rs} is remote sensing reflectance. This algorithm has been used for generating the chlorophyll maps, using IRS-P4 OCM derived water leaving radiances. The chlorophyll retrieval accuracy[26] obtained is within $\pm$ 30%.

Dataset

IRS-P4 ocean colour monitor (OCM) sensor data archived from NRSA Data Center, Hyderabad, have been analyzed to generate chlorophyll images during July 1999-June 2000. About 70 satellite overpasses having minimum cloud coverage data covering the south-west Bay of Bengal and ocean region were selected for the analysis. The chlorophyll images were geometrically corrected and gridded with 2^0 latitude and longitude interval. The path 10 and row 14 scenes of IRS-P4 OCM data were processed and chlorophyll images were generated for each day. Monthly averaged chlorophyll images were generated from the above data. NOAA-NCEP derived monthly averaged Sea Surface Temperature (SST) and Quickscat Scatterometer wind speed/vector composite data for our study area were procured from PO.DAAC, JPL/NASA archive and were processed for our study area during July 1999-June 2000. The Quickscat Scatterometer Level-3 data set consists of 25 km^2 gridded values of scalar wind speed and corresponding meridional and zonal components of velocity. The calculated wind speed and direction data were represented in the Quickscat Level-3 data (http://www.ssmi.com/quickscat/wind). The SST data products were retrieved for our study area during July 1999-June 2000 (http://Podaac.jpl.nasa.gov/).

Results and Discussion

Chlorophyll observation from OCM images

The monthly averaged chlorophyll composite images indicated the chlorophyll variability in the southern peninsular water off the Indian coast for a year (July 1999-June 2000) (Fig. 1, Table 1). During the southwest monsoon period July-September, high concentration chlorophyll (1.0-2.0 mg/m^3) patches were observed (Fig. 1). During October (post monsoon

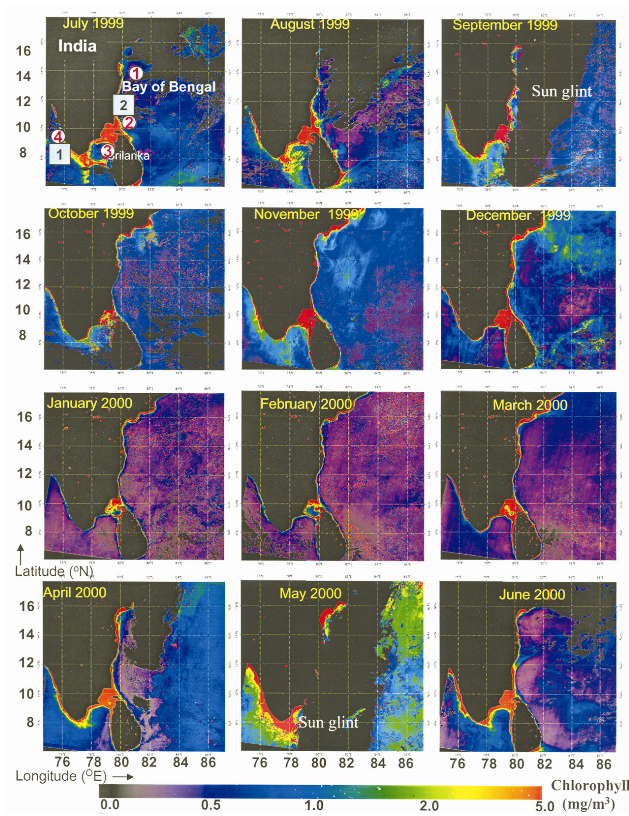

Fig. 1—IRS-P4 OCM derived monthly averaged chlorophyll images during July 1999-June 2000 locating points (1-4) and pockets (1,2) in July 1999 image

period), there was indication of monsoon impact with the high wind speed enhancing the turbulence in the water column and also high chlorophyll concentration in the coastal region due to land runoff and river fluxes. With the initiation of the northeast monsoon during November-December, the high concentration patches were dominant in the Bay of Bengal (here onwards BoB) and the tip around southern peninsula of India (Fig. 1). Unusual high concentration features were observed in the BoB water in December off the Andhra coast in the post super-cyclone period[27]. The monthly averaged image of December 2000 (Fig. 2) has been compared with the December 1999 image. During the late winter period in January-March, there was no variation in chlorophyll distribution and it persisted around 0.4 mg/m^3. During April-May and September 2000, portions of images along the Indian east coast were effected by sun glint as observed from the simulation study of IRS-P4 OCM data[28] in Indian waters. Similar sun glint effects have been observed in our study (Fig. 1). In June, there were several oceanic features in the coastal and offshore region and concentration was peaking to 1.0 mg/m^3, due to initiation of south-west monsoon (Table 1).

Analysis has been carried out to study the monthly chlorophyll variability in four different locations, viz. 1. off the Krishna-Godavari delta, 2. off the Palk Bay, 3. off the Gulf of Mannar and 4. off Cochin (adjacent Arabian Sea water) (Fig. 3). The chlorophyll range was observed to be within 0.25-0.8 mg/m^3 in the offshore water for the four locations during July 1999-June 2000. Stations 1, 3, 4 showed the peaks of chlorophyll concentration (here onwards CC) (~0.6 mg/m^3) during southwest monsoon and station 2 showed the peak with effect of northeast monsoon. During March-May period, the CC was reduced to 0.3 mg/m^3, which may be due to the surface heating during summer. During March and April, the plots for all the 4 stations indicate the low CC around 0.35 and 0.25 mg/m^3, respectively, when the wind are weak (Fig. 3). The wind speed and its magnitude were low (~5 m/s) during this period, which introduced strong stratification in the water column. This would hamper supply of nutrients to the surface and would result in low CC.

The CC is found to be higher than 2.0 mg/m^3 in the Gulf of Mannar[21]. In the BoB, though the CC are found higher during the months of November-January, the seasonal variations are found to be very less. Above the Gulf of Mannar, high values of around 5.0 mg/m^3 of CC have been found around Palk Strait in the month of April may be due to local effects[22]. Explanation given earlier that the high values of CC in the Palk strait compared to the other parts of the Bay of Bengal is attributed to the very low depth (10-15 meter) in the region[22]. Our study for selected points indicates comparatively less CC than the previous studies carried out in the south-west Bay of Bengal.

The mean and standard deviation of chlorophyll range for study area were 0.12-0.37, 0.27-0.71 mg/m^3, respectively. Highest chlorophyll was in January (north-east monsoon) and lowest in May (summer inter

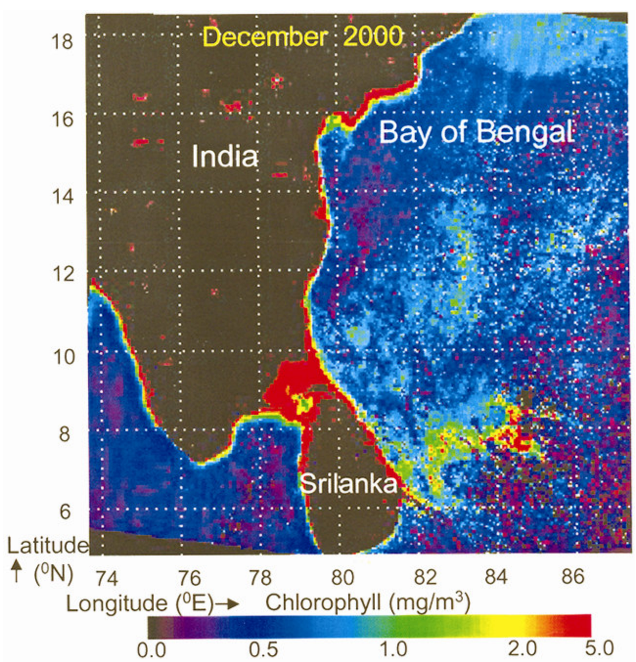

Fig. 2—IRS-P4 OCM derived monthly averaged chlorophyll for December 2000 covering the Bay of Bengal and southern peninsular Indian water

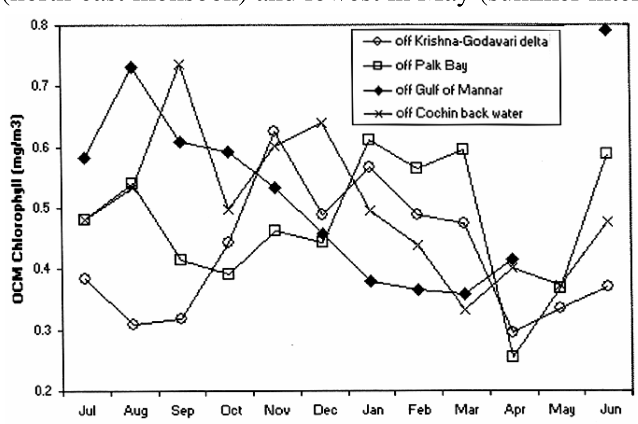

Fig. 3—IRS-P4 OCM derived monthly averaged chlorophyll for four different locations (1-4 in Fig.1) in the southern Indian water during July 1999-June 2000

monsoon) (Fig. 4). The selected pockets, Pocket.1 in the adjacent Arabian Sea; 74^0 54'-76^0 6' E Latitude and 7^0 54'-9^0 6'N Longitude and Pocket.2 in the Bay of Bengal; 78^0 48'-81^0 E Latitude and 11^0-12^0 12'N Longitude were studied in terms of mean and standard deviation histogram (Fig. 4a,b). Each pocket comprised about 350/350 pixels and scan lines in the OCM image (Fig. 1). The mean and SD for pocket 1 ranged between 0.139-0.571 and 0.046-0.22 and for pocket 2 ranged between 0.284-0.788 and 0.054-1.080, respectively. Adjacent Arabian Sea water found predominantly productive than the Bay of Bengal waters. In the adjacent Arabian Sea highest chlorophyll observed in July (South-west monsoon) and in the Bay of Bengal, highest chlorophyll observed in February (North-east monsoon) periods. The surface chl-a during the south-west monsoon along the coastal, offshore and open ocean stations ranged between 0.16 and 0.38, 0.18-0.23 and 0.14-0.46 mg/m^3, respectively. During the post cyclone period the surface as well as column integrated chlorophyll-a showed high values at all stations, the maximum surface chl-a concentration was 0.97 mg/m^3 was recorded off 13^0N, Chennai, where the dilution due to fresh water influx was more during November. The surface chl-a during this period varied from 0.29-0.97, 0.3-0.49 and 0.22 to 0.29 respectively[29]. Similar high CC features have been observed in earlier study using OCM data[27].

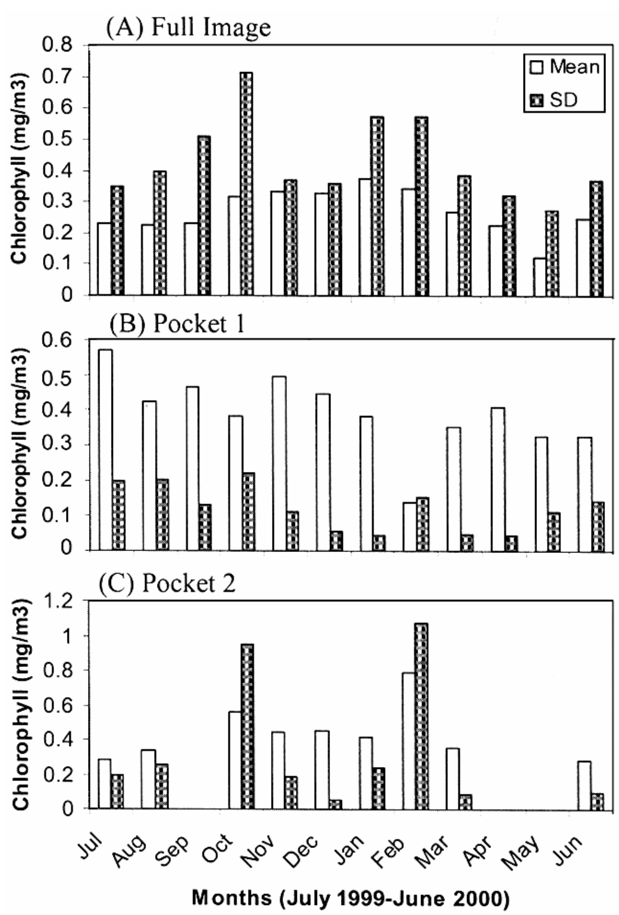

Fig. 4—Mean and standard deviation histogram plot for the monthly averaged chlorophyll images (a) and for two selected pockets (1,2) from Bay of Bengal and adjacent Arabian Sea (b,c)

Interrelationship of chlorophyll with SST and wind speed

The OCM derived chlorophyll has been linked with ocean surface physical parameters like the NOAA-NCEP derived monthly averaged SST and Quickscat scatterometer derived wind speed/vector maps have been retrieved and interpreted. The SST range was 25-30ºC during a year period (Fig. 5). The high chlorophyll in the BoB off the Andhra coast (12-16^0N) is associated with the low temperature (~26ºC) in December and high wind speed (~10 m/sec). The temperature was higher (~30ºC) during April-May-June months in the BoB (Fig. 5).

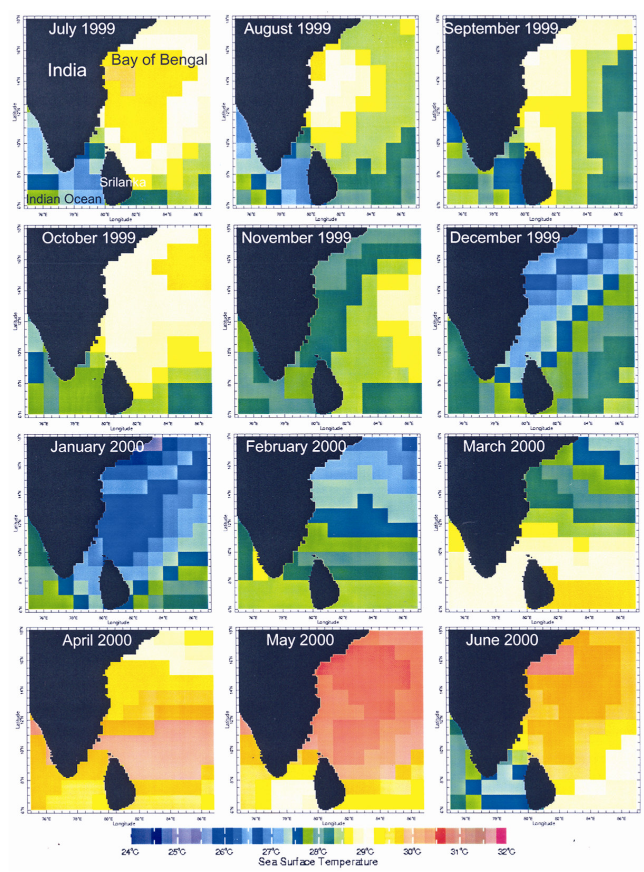

Fig. 5—NOAA-NCEP derived monthly averaged Sea Surface Temperature Map during July 1999-June 2000

The wind speed variation ranged between 2-10 m/s. The wind speed was high (~10 m/s) during June-July-August and the low (~5 m/s) during February-March-April months (Fig. 6). Thus, the high wind speed and low temperature seems like linked to increase in chlorophyll and several oceanic features and low wind speed and rise in temperature has shown low ranges of chlorophyll during this study.

Southwest monsoon (June-September)

During June-September, the southwest monsoon period, the high wind speed 10 m/s has been observed and decrease in SST around 1ºC has been observed around the southeast coast of India. Hence the increase in chlorophyll (1.0-2.0 mg/m^3) has been remarkably observed with algal bloom like features between July-October 1999 and similar feature has been seen during June 2000. Usually in July the wind blows from a southwesterly direction, favourable to upwelling along the east coast of India[29]. In general, the ship drift climatology[30] shows a northerly current

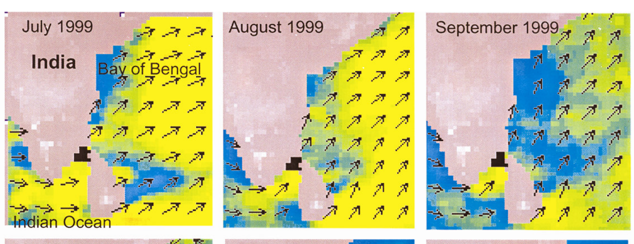

Fig. 6—NASA Quickscat Scatterometer derived wind speed/vector maps during July 1999-June 2000

along the western boundary during July even though the wind direction and current pattern along 13^{0}N and 15^{0}N were favourable to the upwelling. Coastal upwelling driven by monsoon winds is identified as the physical mechanism causing nutrient enrichment in the surface layer. Eddy pumping as a possible mechanism of vertical transfer of nutrients across the halocline to the oligotrophic eutrophic zone in the Bay of Bengal during summer monsoon when open ocean is higly stratified[31]. The southwest monsoon current (SMC), which flows eastward south of Srilanka and then into the BoB advects the upwelled water eastward along its path[19, 32]. Wind driven coastal upwelling and increased river run-off during the following season, the southwest monsoon (July-August) increased the phytoplankton biomass dramatically (92 mg m^{-2})[9]. During summer monsoon (June-September), the West India Coastal Current (WICC) has been observed to be activated along Indian coast, it has been moved towards southeast direction in the west coast of India and moved below Indian tip and Srilanka, finally moved towards the east coast of India[33]. Using chlorophyll images derived from the Sea-viewing Wide Field of view (SeaWiFS) for the Indo-Pacific region from October 1997 to September 1998, elevated chlorophyll has been found[34] south of Srilanka during August 1998.

Along east coast of India upwelling has been reported at a few positions during the southwest monsoon[12,14,29]. During southwest monsoon SST showed an increase from offshore 28º to 29.2ºC towards inshore[29]. During post-cyclone period, the SST distribution in general showed a reverse trend with warmer waters offshore (28.6ºC) and colder waters inshore (27ºC). A comparison with climatology (Levitus Climatology Atlas) showed that the observed values are at least 2-5ºC lower. Thermal structure along 11^{0}N (off Karaikal, Tamilnadu coast) shows up sloping of isotherm towards the coast, indicating the signatures of subsurface upwelling during the southwest monsoon[29]. Ocean current maps plotted using the data from NODC/NIO web portal, has been displayed (Fig. 7). The ocean currents direction has been observed to be varying month-wise. During the southwest monsoon (June-September) and early fall inter-monsoon (October), the ocean current direction has been observed to be in southeasterly direction, moving from the Arabian Sea towards the southern tip of India and approached towards the Bay of Bengal water.

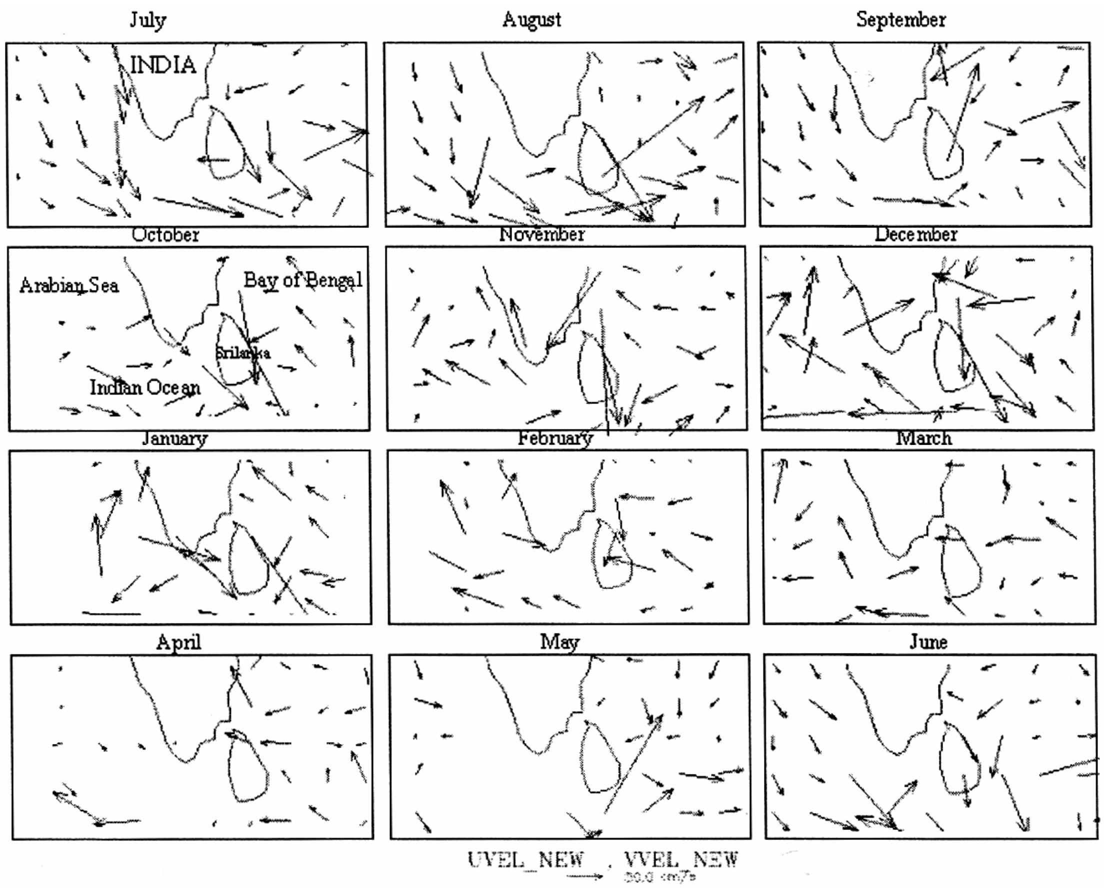

Fig. 7—Seasonal ocean currents along southern Indian water for different months prepared from the dataset available in the NIO web page

The chlorophyll rich waters from the Indian coast also advects along with the southwest monsoon current (SMC) towards Srilanka[35]. East of Srilanka the open ocean upwelling associated with the Srilankan dome is also found to be an important process that upwell nutrients[19] and enhances CC in surface[36]. The open ocean Ekman pumping drives a cyclonic gyre known as Srilankan dome (SLD) east of Srilanka[37]. SeaWiFS images of the summer monsoon of 1998 indicate a seasonal bloom south Srilanka[34]. Similar high CC (~1.0-2.0 mg/m^3) features/BLF are seen from OCM image analysis during July-September (Fig. 2). The general eastward flow in the north Indian Ocean during summer, which is called the Southwest monsoon current (SMC), flows eastward south of India, turns around Srilanka and enters the Bay of Bengal. The intrusion of SMC into the Bay of Bengal is studied using expandable bathythermograph (XBT) observations along the shipping route between Srilanka and Malacca Straight, TOPEX/POSEIDON sea surface height (SSH) anomalies and OGCM[38]. The chlorophyll (here onwards chl) distribution around Srilanka is closely connected to the path of the SMC. The most striking example for this is the advection of high chl east of Srilanka along the path of SMC and the bifurcation thereafter, as seen in the OCM images. The southwestward flow of chl rich water from the Indian tip towards Srilanka is caused by Ekman drift. Offshore meandering of the chl band is also seen in OCM images along the northeast coast of Srilanka under the influence of the prevailing currents in this region (Fig. 1).

Fall Inter-monsoon (October-November)

The BoB features several cyclones during October-December. These cyclones can form eddies and consequential roles in the formation of high CC patches in the BoB water. Other clear evidence for the intensification of the bloom by cyclones is along 12^{0}N off the Indian coast and east coast of Srilanka during 2000. Thus, the cyclones intensify the bloom/high CC in the region of influence and evidenced by our study using OCM data[27] and using *in situ* data[29]. During October-November 1999 the high wind speed ~8 m/s shows increase in chlorophyll to about 1.0 mg/m^3. The increased biological production along the southwest coast, especially off Chennai was primarily due to the combined effect of nutrient enriched land runoff and equator-ward western boundary current (WBC) along with a complimentary effect of the super cyclone which hit the Orissa coast on 29 October, 1999 which was supported by the results from our previous work[27] carried using IRS-P4 OCM derived chl images along the Orissa coast during the post cyclone period further up the coast. Surface chl at six offshore locations in the southwestern BoB during November 1999[29] ranged from 0.22-0.49 mg/m^3, similar to the values from our analysis using OCM images. Bifurcation of EICC has been observed east of Srilanka during October-December period, results obtained using the high resolution OGCM, satellite altimeter, Argo float profiles and ocean colour data[39]. As a result of this bifurcation, there is offshore transport of chl rich low salinity water from the coast of Srilanka. Similar bifurcation and movement of chlorophyll feature has been observed around the east coast of Srilanka during December 1999 (Fig. 1).

Northeast monsoon (December-March)

The mechanism carrying the high CC and bloom features are due to the phytoplankton population in this region during the northeast monsoon is limited by nutrients but not light[9,40]. Entrainment of nutrient rich water by wind mixing is not efficient in the BoB[41]. The northeasterly winds during November-December do not favour coastal upwelling along the east coast of India. The low salinity water advected by the equator ward EICC from the northern BoB forms a narrow band close to the coast. Chl carried by the EICC does not get advected offshore in the southwestern BoB because of the Ekman transport[19] is towards the coast and a southward flow pushes the water towards the coast between 13-15^{0}N. During November, the change in the direction of current has been seen to be in north-westerly direction. Similar trend was observed up to February with scattered current vectors around the coastal water around India and Srilankan coast. During February-May, there is a well developed anti-cyclonic gyre in the BoB and a pole ward east India coastal current (EICC)[17]. During the winter monsoon (December-March), the movement of EICC has been activated and it moved southwest in the east coast of India and turned towards west via the Indian bottom and bottom of Srilanka and moved northwards along Indian west coast[33] (Fig. 7). The seasonal northeast and southwest direction of surface ocean currents has been observed and the chlorophyll pattern along the coastline has been observed in respective flow or direction (Fig. 1).

During December 1999-March 2000, the northeast monsoon period high wind speed around 10 m/s has been observed in December and January and cooling (27ºC) in Bay of Bengal and gradient of SST about 1-2ºC shows increase in chlorophyll concentration (~1.0 mg/m^3) and chlorophyll patches have been observed (Fig. 1). During northeast monsoon in December, surface temperatures were lower in the north and along the coast and all over the bay temperature inversions suggested cooling of surface waters by the northeasterly winds[42] and other study[43,44]. February-March does not show impact of wind and hence less variation chlorophyll and SST gradient. The high CC patches disappear entirely by the middle of February[37] as seen in our study (Fig. 1). During winter, intrusion of Bay of Bengal waters into the Arabian Sea, when southward flowing East India Coastal Current (EICC) carrying low salinity waters from the northen Bay feeds into the West India Coastal Current (WICC) flowing north along the shelf in the Arabian Sea. Advection of nutrients by this intrusion triggers enhanced levels of chlorophyll near the southern part of the western shelf of India and may play a role in altering the biogeochemistry of this intense hypoxic region[31].

Formation of a patch of anti-cyclonic curl near the south India tip is an important characteristics of the winter monsoon (NE monsoon), Dec-March[20,45]. A major contribution to the high CC or bloom feature comes from Ekman pumping (EP). The circulation in the northwestern BoB during northeast monsoon consists of a cyclonic gyre[37,46]. This cyclonic gyre forced primarily by upward EP caused by positive (anticlockwise) wind stress curl and upwelling within this gyre cools the sea surface. So the monthly temperature map shows the results of cooling in our study during these months (NOAA-NCEP derived SST maps, Fig. 5). Winter cooling of surface waters has been reported[44] at the head of the bay in January when SSTs were the lowest and measured 25ºC, the gradient has been seen in our study in SST images but OCM does not show significant gradient in chlorophyll biomass. The SST shows the gradient of around 1ºC in the Bay of Bengal and off southern India.

Spring inter-monsoon (April-May)

During inter-monsoon period, April-May 2000 there has been increase in SST and decrease in wind speed. In March-April (pre-southwest monsoon), the pole ward flowing East India Coastal Current brought to the surface, nutrient laden cooler waters that enriched the coastal region. High CC patches are seen in our study in the coastal waters of AP, 14-16^0 N. During pre southwest monsoon (inter monsoon period, April-May), Bay of Bengal could be summarized as a region of low productivity with the WBC enhancing productivity in the coastal region to some extent and localized regions of very high production resulting from eddies or re-circulation zones as seen in earlier study using OCM data[9]. The pole-ward flowing of EICC of the pre-southwest monsoon disappeared by May[47] and upwelling was observed along the western boundary of the basin. The trend of current in northwesterly direction has been observed during April and May months (Spring Inter-monsoon, SIM). The coastal water does not indicate any current pattern during SIM[33]. Legeckis[48] demonstrated the appearance of western boundary current in the BoB using SST data obtained from Advanced Very High Resolution Radiometer (AVHRR) onboard NOAA-9 satellite. Some local studies used *in situ* measurements along the eastern coast of India in order to describe this western boundary current of the seasonal subtropical gyre in the BoB[17,42,47].

The study confirms the chlorophyll pattern in the form of surface features and indicators of the ocean currents in the southwest Bay of Bengal like the EICC, WBC and SMC. There has been observation of algal blooms in the southern tip of India and around Srilanka during the southwest monsoon with effect of monsoon wind and currents. The present study is in agreement with the previous work confirming with the chlorophyll patterns and associated features, but the concentration observed in our study is comparatively lower than the previous works reported based on *in situ* data.

Conclusion

Present study portraits about the monthly scale and seasonal variability of phytoplankton pigment chlorophyll in the southern peninsular India imparting the BoB, Arabian Sea and Indian Ocean region. Several features like eddies, algal bloom and coastal plumes were observed. Highest mean chlorophyll was in January (northeast monsoon) and lowest in May (summer inter monsoon). Adjacent Arabian Sea water found predominantly productive than the Bay of Bengal water. The chlorophyll variability during southwest and northeast monsoon and inter-monsoon phases has been understood. The corollary information obtained from SST and wind speed/vector data was interesting. As the relevance is in high chlorophyll concentration with decrease in SST during winter months and low chlorophyll with increase in SST during summer months was observed. Similarly, the northeasterly and southwesterly movement of wind and ocean currents, like EICC/WBC, SMC etc. have been correlated and reflected in ocean chlorophyll features obtained from IRS-P4 OCM data. Higher wind speed around 10 m/s in southwest and northeast monsoon shows about two fold increase in chlorophyll concentration to 1.0-2.0 mg/m^3 and the SST has also shown gradient and decrease of about 1-2ºC in the BoB and off southern India, respectively. So, the role of cyclone, upward movement of nutrient rich water by Ekman pumping and upwelling are the causes for the high CC/algal bloom in the BoB water in the SW, NE and inter-monsoon period. The role of upwelling in the southwest BoB may be the cause for the low SST and high elevated chlorophyll. Further investigations are needed for detailed inter-seasonal and inter-annual variability with respect to causing phenomena and the parameters in the less studied BoB water using the satellite and *in situ* data.

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