Distribution of Satellite derived surface Chlorophyll-a and associated physical parameters in the Northern Bay of Bengal

Article · December 2019

Muhammad Shahinur Rahman
Bangladesh Oceanographic Research Institute

Md. Kawser Ahmed
University of Dhaka

Md Jobaer Alam
University of Dhaka

Seema Rani
Bangladesh Oceanographic Research Institute

Distribution of Satellite derived surface Chlorophyll-a and associated physical parameters in the Northern Bay of Bengal

Muhammad Shahinur Rahman[1], Md. Kawser Ahmed[2,3], Md. Jobaer Alam[2], Seema Rani[3,a], Sultan Al Nahian[1], K. M. Azam Chowdhury[2,b]

[1]Physical and Space Oceanography Division, Bangladesh Oceanographic Research Institute (BORI), Ministry of Science and Technology, Cox's Bazar-4730, Bangladesh

[2]Department of Oceanography, University of Dhaka, Dhaka-1000, Bangladesh

[a]Coastal and Ocean Management Institute (COMI), Xiamen University, China

[b]Ocean University of China, Qingdao, China

[3]International Centre for Ocean Governance (ICOG), Faculty of Earth & Environmental Sciences, University of Dhaka, Dhaka-1000

Abstract

In this study, we analyze climatological monthly pattern of surface chlorophyll a (Chl-a) concentration and associated physical parameters (sea surface temperature, Photosynthytically Active Radiation, diffuse attenuation coefficient, wind and wind stress curl) during the period 2003–2014 in the Northern Bay of Bengal (NBOB) using remote sensing derived data. The highest mean Chl-a is found in August (0.60 mg/m3) and the lowest value in June (0.32 mg/m3). Sea surface temperature (SST) and Photosynthetically Active Radiation (PAR) shows bimodal distribution. The area with high and low value of diffuse attenuation coefficient (kd490) has associated with continental fresh water flux. Wind distribution map shows well organized reversal direction in summer and winter. There is huge spatial variability is seen for every parameters in the NBOB. High Chl-a is always associated with coastal portion and gradually decreased with the distance from coast. Partial correlation analysis shows that Chl-a highly correlated with river discharge. This study also suggest that northern part and western part is influenced by river derived nutrients and eastern part is influenced by wind in the NBOB.

1. Introduction

In the ocean, phytoplankton is the main primary producer and approximately half the net primary production of the global biosphere depends on it (Field et al, 1998). Chl-a is the proxy product for phytoplankton abundance and has been used as a biomarker which distribution reveals the magnitude of biomass or primary productivity in the oceans (Beebe, 2008; Suwannathatsa and Prungchan, 2013; Picado A. *et al*, 2014). Ocean colour measured from space provides information on the concentration of chlorophylla (Chl-a). Furthermore, Sea surface temperature (SST), Photosynthytically active radiation (PAR), diffuse attenuation coefficient (Kd490), wind estimation (speed and direction) which are important physical parameters for understanding chl-a (phytoplankton) variability are also estimated through remote sensing technology (Navarro, G., *et al*, 2012). The capability of monitoring spatially and temporally distribution of various bio-physical variables have been greatly improved compared to in situ techniques with modern remote sensing techniques. Previous study concluded that Bay of Bengal is a region of low productivity compared with the Arabian sea due to strong stratification and absence of deep wind-mixing (Gomes *et al*., 2000; Prasanna Kumar et al., 2002), lack of prominent upwelling areas (La Fond, 1957, Shetye et al., 1991), lack of winter-driven convective mixing (Jyothibabu *et al*., 2004; Prasanna Kumar *et al*., 2010), cloud coverage and sediment load (Qasim, 1977; Radhakrishna, 1978). In this paper we analyze the monthly spatial distribution pattern of these bio-physical parameters and find out the relationship between them.

2. Materials and Methods

2.1 Study Area

The study area is in the northern part of the Bay of Bengal bounded on west by the east coasts of India, on north by the deltaic region of the Ganges-Brahmaputra-Meghna river system, and on east by the Myanmar peninsula. It covered from the head of the Bay of Bengal to 16o N The study area which was considered for this research was started from 10m isobaths as baseline to avoid the local effect. The occupied area was about 584585 square kilometers. The southern boundary of the study area is cut by Open Ocean. Bangladesh is situated at the head of the Northern Bay of Bengal. Mighty GBM river system with numerous rivers drain huge amount of fresh water in the northern part as well as head bay. Mohanadi, Godaveri , Kaveri etc river has bring fresh water in Western part and the influence of fresh water is comparatively low in ECB where fresh water signature seen due to Irrawaddy river discharge (Sengupta, D. et al., 2016). South part of the study area is controlled by Oceanic process.

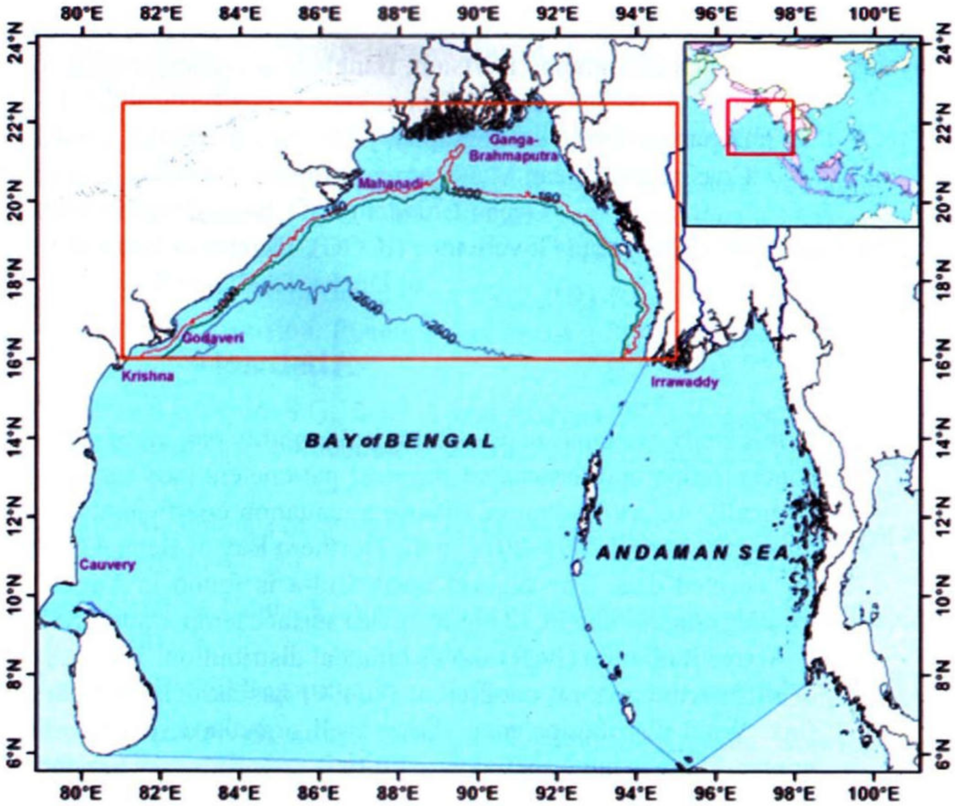

Figure 1: Map of Study Area with contour shows the isobaths of red (180m), green (1000m) and yellow (2500m)

2.2 Data and Methods

Satellite derived Chl-a, sea surface temperature (SST), Photosynthytically active radiation (PAR) and diffuse attenuation coefficient (Kd490) which obtained by MODIS Aqua were downloaded from Giovanni through the website: [http://disc.sci.gsfc.nasa.gov/Giovanni]. The monthly global data are chosen and downloaded for study area from the website [http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month].

Daily zonal (u) and Meridional (v) wind speed and direction, Wind curl (τ) has downloaded through ERDDAP (Easier access to scientific data) of NOAA website: (http:/coastwatch.pfeg.noaa.gov/erddap). The wind data and wind curl data were ASCAT derived daily data and spatial resolution is 0.250x0.250 degree from Nov, 2009 to Oct, 2014.

2.3 Data pre-processing and reconstruction

The study area (NBOB) has large amount of cloud coverage especially in summer monsoon period. MODIS derived parameters (especially Chl-a) does not provide data in cloudy day which results gappy data. The standard Chl-a estimation algorithm has developed for open ocean water (case 2) where color of ocean surface depends on it (O'Reilly et al., 2000). For Chl-a, any pixel which have value more than 5 mg/m3 has excluded to overcome the detritus or colored dissolved organic matter derived overestimation.

To analyze the bio-physical parameters for NBOB, we calculated the monthly mean and SD value for each pixel of study area during 2003 to 2014. We produce monthly mean and SD map of parameters for better understanding the intra-annual spatial pattern of these parameters in NBOB. We also calculate the Pearson partial correlation among the parameters for understanding the relationship between them.

3. Result and Discussion

3.1 Monthly average of Chl-a and associated physical parameters

Figure 2 represent the Monthly distribution of mean and SD of Chl-a concentration from 2003 to 2014. The results showed that the relatively higher values (>0.75 mg/m3) were observed along coasts and relatively low (~0.25 mg/m3) in the open parts of the Northern Bay of Bengal.

The relative higher values of Chl-a (>0.75 mg/m3) is always seen in northern portion as well as head bay. From July to October this relative high value extended to the western parts of the NBOB, while in eastern part, relative high value seen from December to March. From the SD map, monthly Chl-a variability is high in coastal region and prominent in head bay when river discharge is highest. In the open ocean, no significant variability has seen.

Figure 3 represent the monthly mean and SD value for SST in NBOB. High SST value observed from April to October and low value observed during November to March. High amplitude of SST value is seen in northern portion of NBOB. It is seen that eastern part of NBOB experienced high SST than western portion except March, June, July, August and September.

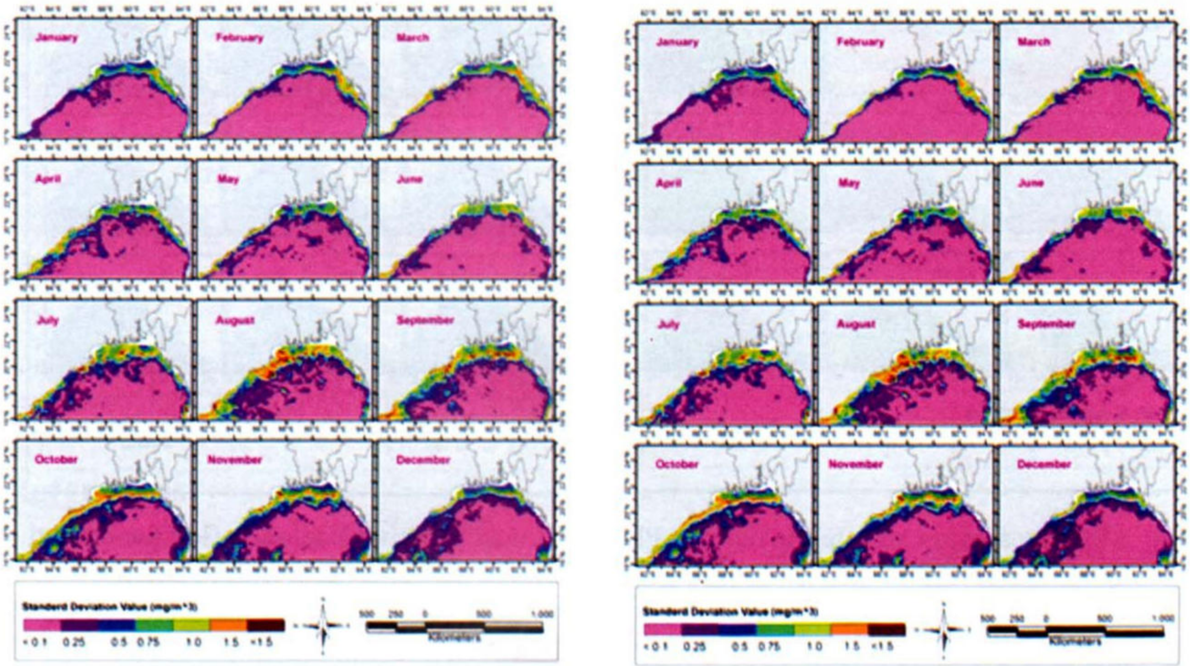

Figure 2: Monthly average of satellite derived Chl-a concentration (left panel) and Standard deviation map of Chl-a (Right panel) during 2003–2014

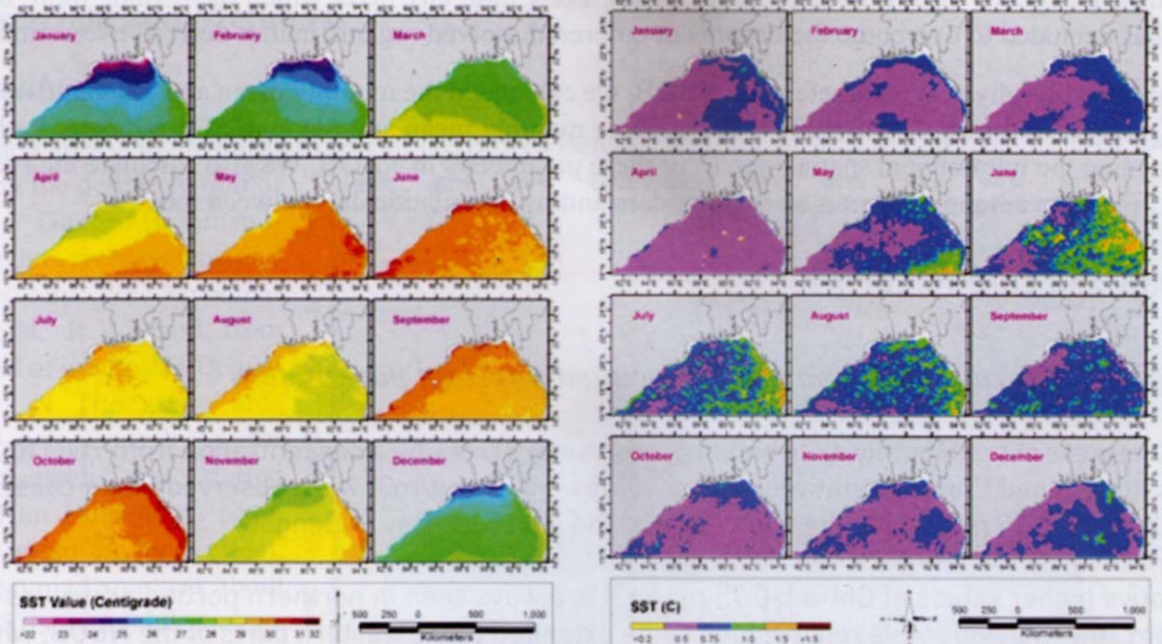

Figure 3: Monthly average of SST (left panel) and Standard deviation map of SST (Right panel) during 2003–2014

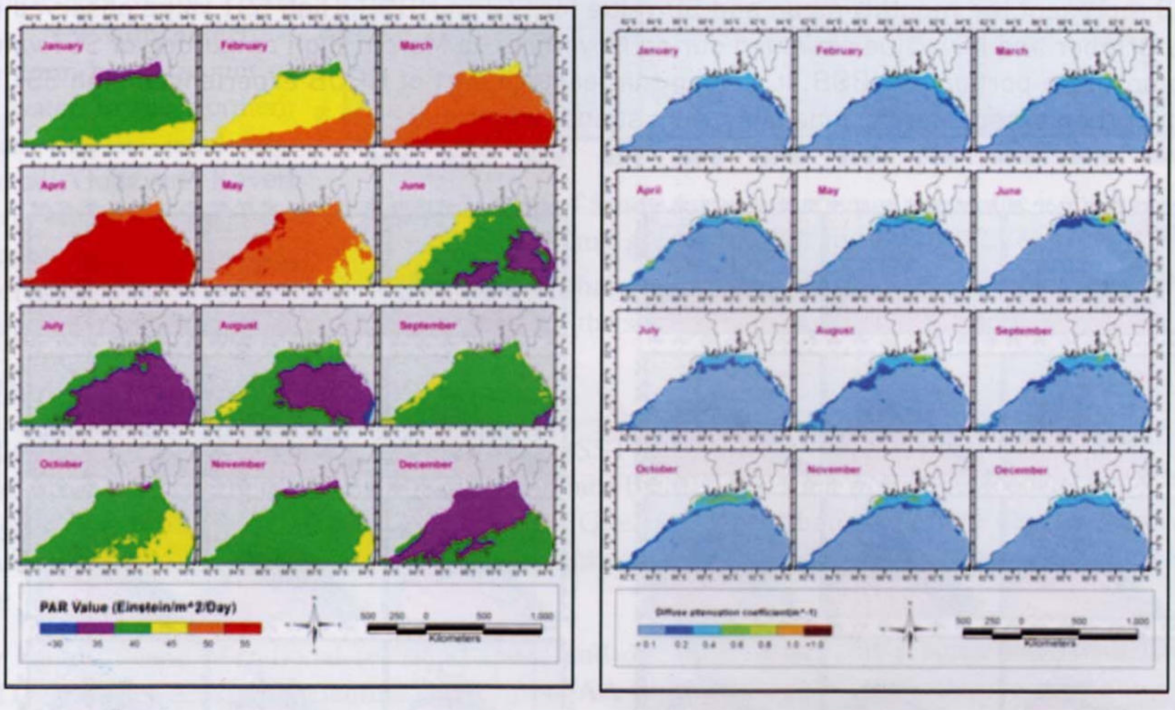

Figure 4: Monthly average of satellite derived Photosynthically Active Radiation (left panel) and diffusive attenuation coefficient (Kd490) in Northern Bay of Bengal (right panel).

PAR is the down welling flux of photons just below the sea surface integrated over the wavelength range of 400–700 nm which is strongly affected by the presence of water vapor/cloud. From the annual cycle of PAR distribution map (Figure 4 left panel), there are two types PAR distribution pattern is seen and this pattern is may be due to two factors. One pattern is north-south direction which explained by the sun's movement and another is east-west direction and possible reason is cloud coverage.

In order to explore the possible influence of the river flux in curtailing the downward penetration of solar radiation, diffuse attenuation coefficient (Kd490), which represents the rate at which light at 490 nm is attenuated with depth. From the figure, most area of the bay is transparent except the coastal region. From figure 4 (right panel), Coastal region specially northern coastal part of the bay contain high Kd490 value which indicate the higher turbidity and sediment load as well as river influx as a result of GBM carrying sediment. This state also supports the study of Das S.C in 1978. In western part also some are with high Kd490 value in river mouth. Kd490 is also a parameter which indicates the optical characteristics of water

Monthly wind speed and direction is shown in figure 5 (left) and it is seen that NBOB experienced with reversal wind pattern in summer and winter monsoon. Wind speed is higher in summer time with south west direction than winter time north east wind. There is not well developed wind pattern has seen in both pre and post monsoon period. Figure 5 (right) has represent the wind stress curl pattern where positive wind stress curl indicate the region of upward Ekman pumping and vice versa. From the figure, Positive wind stress curl seen in summer time because of strong wind speed which is favorable for upwelling but it is not occurred due to of the equatorward advection of a river plume (Shetye *et al*., 1991; Vinayachandran and Kurian, 2007) and the propagation of a downwelling coastal Kelvin wave (McCreary *et al*., 1996b; Vinayachandran *et al*., 1996). Along the eastern part of the coastal bay, winds are favorable for coastal upwelling during December–March (McCreary et al., 1996b).

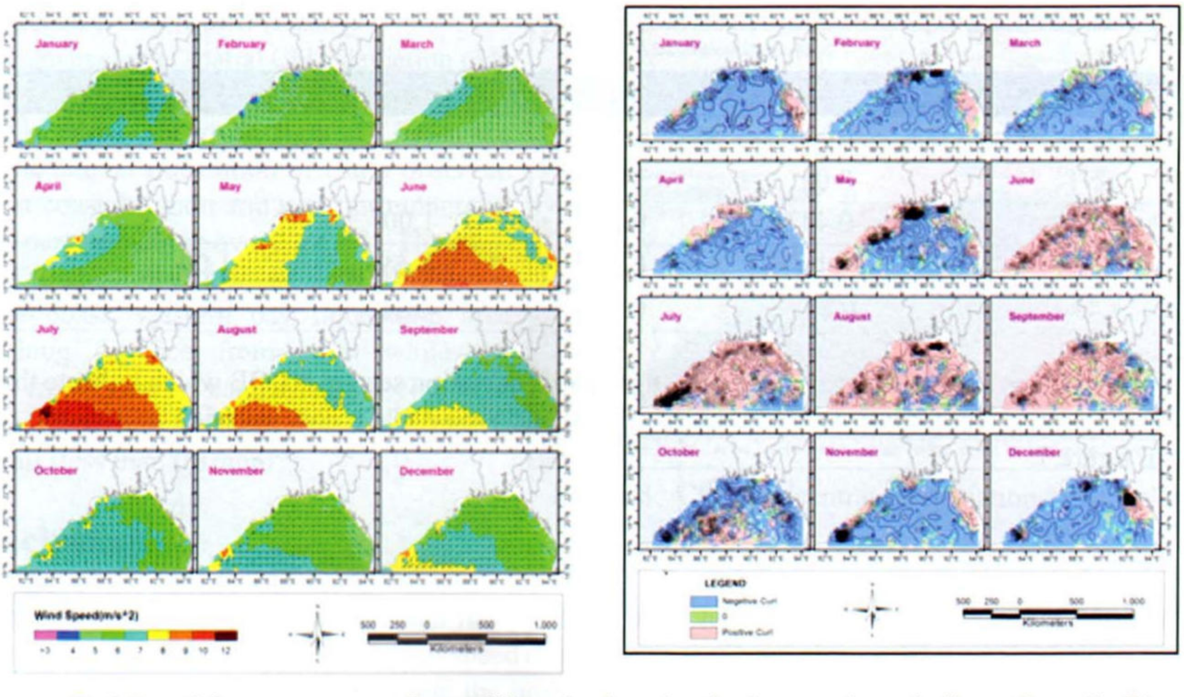

Figure 5: Monthly average of satellite derived wind speed and direction (left) and wind stress curl (right)

3.2 Relationship among Chl-a and associated physical parameters

In Figure 6, the monthly mean and SD value (Spatial) of Chl-a and other physical parameters is represented. Highest mean Chl a observed in august (0.60mgm-3) and low in June (0.32mg m-3). SST shows a bi modal distribution and the highest mean SST observed in October (29.64oC) and low in January (25.84oC). Two high peaks are observed in fall and spring Inter-monsoon where the value is almost same and two low peaks in summer and winter monsoon where the winter monsoon is prominent. Physical processes like upwelling, remote forcing, circulation, river discharge etc. may produce regional differences in the SST field (McCreary *et al.*, 1993). The seasonal boundary currents and upwelling could be responsible for variability along the east coast of India and large annual low SST appears in the head of the Bay resulting from the river discharge of cold waters during winter (Legeckis, 1987). The highest mean PAR is observed in April (52 E/m2/day) and low in July (33 E/m2/day). PAR shows a bi modal distribution like SST.

The highest monthly mean wind speed is observed in July (8.2 ms-1) and low in March (5.2 ms-1). The wind speed shows a plateau during summer monsoon which drops drastically towards either side. The highest mean Kd490 is seen in August (0.79m-1) and lowest in January (0.59m-1). River input is very much dependent on south western monsoon which bring huge rainfall in continent brings the sediment loaded water with huge nutrients to the bay (Vinayachandran, 2009).

In correlation matrix among the parameters, Kd 490 which indicate the river influenced water have highly positive correlation with Chl-a due high nutrient carried by river water (table 1). SST has positive correlation with wind and inverse relationship is seen between PAR and wind. There is not significant correlation among other parameters which explained by high spatial SD value for bio physical parameters.

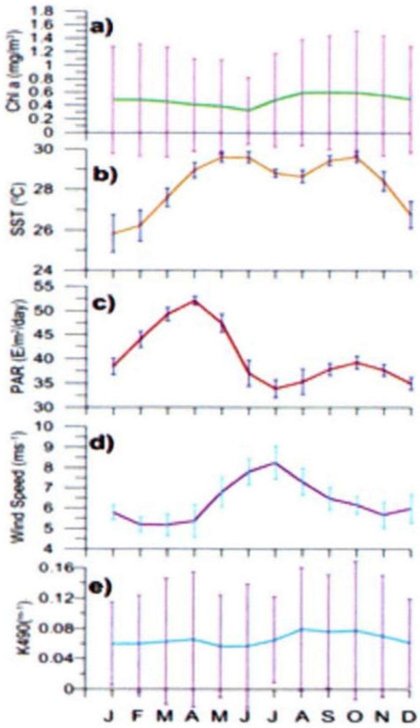

Figure 6: Monthly averaged value for a) Chl-a, b) SST, c) PAR, d) wind speed e) kd490 in

	Chl	SST	PAR	Wind	K490
Chl	1.00				
SST	-0.04	1.00			
PAR	-0.44	0.02	1.00		
Wind	-0.11	**0.53**	**-0.59**	1.00	
K490	**0.87**	0.36	-0.32	0.07	1.00

Every parameter has a high SD (spatial) value. Huge spatial deviation seen in NBOB which indicate the process is varies with space. In order to see the monthly highest and lowest Chl a concentration as a spatial context is shown in figure 7.

3.3 Spatial variability of Chl-a in annual cycle

From the figure 7, seasonal cycle is quite easier to detect the spatial variation. Highest Chl a concentration in yearly cycle observed during winter and spring monsoon in eastern bay and fall inter monsoon in western bay. Only some area is highest Chl a during summer monsoon in central bay as well as open sea.

During summer monsoon lowest Chl a concentration in yearly cycle observed mainly in Open Ocean and during winter monsoon, lowest Chl a concentration area observed in western bay. During fall and spring monsoon, comparatively small area experienced with yearly lowest Chl a concentration. Interesting observation is some part of Open Ocean experienced with both highest and lowest Chl a concentration during summer monsoon but different months.

Figure 7: Monthly Chl a concentration in study area, upper figure show highest value and lower figure represent lowest value in annual cycle. This two figure also represent the seasonal high and low value (blue shade for spring inter monsoon, Green shade for summer monsoon, yellow shade for fall inter monsoon and red shade for winter monsoon).

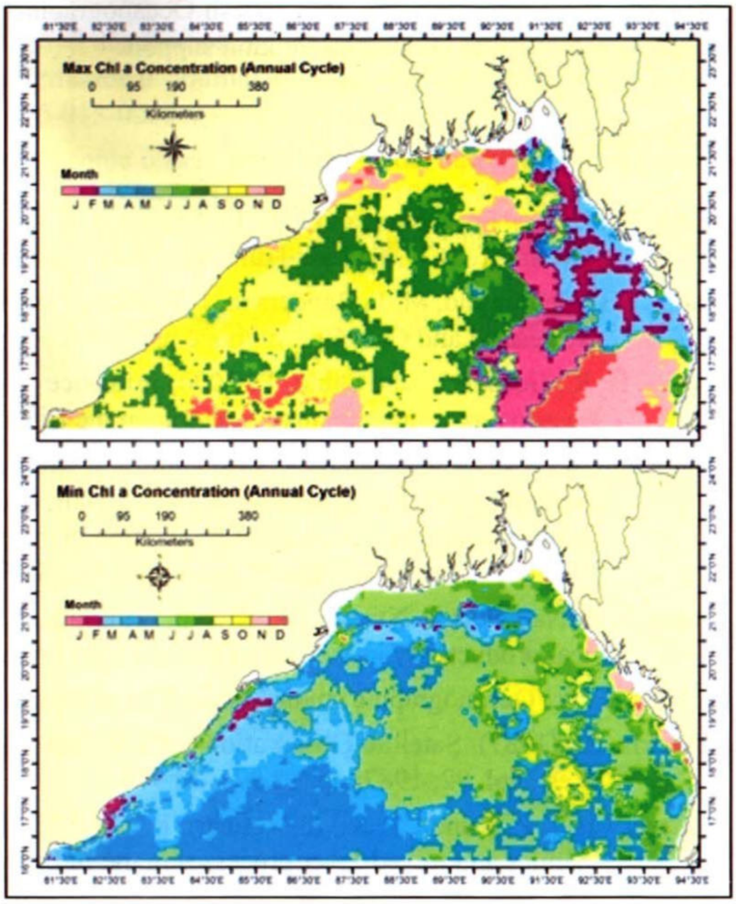

Figure 7

In an annual cycle the spatial Chl a deviation map is prepared to investigate the intensity of Chl a magnitude which shown in figure 8. From the figure, the annual fluctuation of Chl a observed mostly in coastal region and more prominent in northern part (sometime over 3 mgm^{-3}). The magnitude of fluctuation is decrease with the distance from the coast. Western bay fluctuation area covers long distance from coast while the distance from coast in eastern bay is comparatively small. Observed Open sea fluctuation is very small (less than 0.1mgm^{-3}).

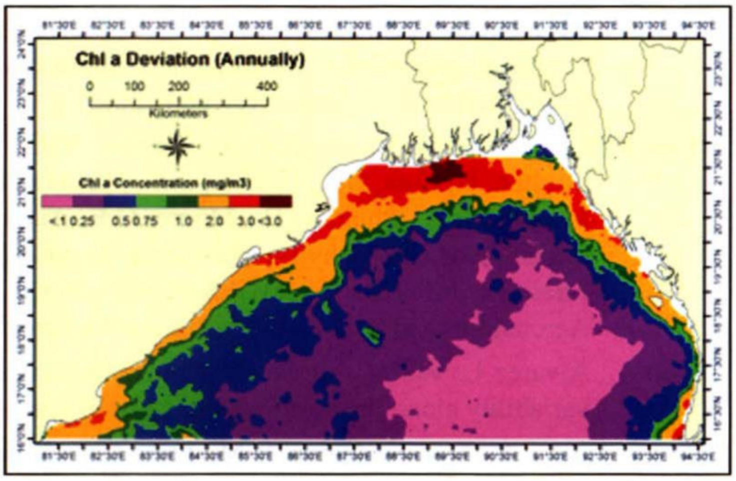

Figure 8: Chl a concentration deviation in annual cycle.

4. Conclusion

In this paper, Climatological monthly map has produced for Chl-a, SST, PAR, Kd490 from 2003-2014 and 2009-2014 for wind speed/direction & wind speed curl. These map shows the spatial pattern of these parameters distribution. High spatial SD value indicate the high variability of these parameters in spatial context. Chl-a annual cycle (Max and min) indicate the yearly high and low value of any specific location. Further study should be focused on more specific spatial context.

Acknowledgements

The authors are grateful to the Bangladesh Oceanographic Research Institute (BORI) and the Department of Oceanography, Dhaka University for kind support.

References

Beebe, W., (2008). Production and Life. In: Sverdrup, K. A. and E. V. Armbrust., An Introduction to the World's Oceans. (eds.), McGraw-Hill., New York publishers. 2008; pp. 371-388.

Field, C. B., Behrenfeld, M. J., Randerson, J. T., Falkowski, P. Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components. Science. 281, 237-240, 1998.

Gomes, H. R., Goes, J. I., and Saino, T.(2000) Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal, Cont. Shelf Res.,20, 313–330.

Jyothibabu, R., P. A. Maheswaran, N. V. Madhu, T. T. Mohammed Ashraf, Vijay John Gerson, P. C. Haridas, P. Venugopal, C. Revichandran, K. K. C. Nair, and T. C. Gopalakrishnan. "Differential Response of Winter Cooling on Biological Production in the Northeastern Arabian Sea and Northwestern Bay of Bengal." Current Science 87, no. 6 (2004): 783-91.

Kumar, S. P., Narvekar, J., Nuncio, M., Kumar, A., Ramaiah, N., Sardesai, S., ... & Paul, J. (2010). Is the biological productivity in the Bay of Bengal light limited?. Current science, 1331-1339.

La Fond, E. C.: Oceanographic studies in the Bay of Bengal, P. Indian Acad. Sci., 46B, 1–43,1957.

Legeckis, R., (1987). Satellite Observations of a Western Boundary Current in the Bay of Bengal. Geophys. Res., vol. 92; 1987; pp. 12,974–12,978.

McCreary Jr, J. P., Kundu, P. K., & Molinari, R. L. (1993). A numerical investigation of dynamics, thermodynamics and mixed-layer processes in the Indian Ocean. Progress in Oceanography, 31(3), 181-244.

McCreary, J.P., Han, W., Shankar, D., and Shetye, S.R., (1996b). Dynamics of the East India Coastal Current: 2. Numerical Solutions. Geophys. Res., vol. 101; 1996; pp. 13,993–14,010.

Navarro, G., Caballero, I., Prieto, L., Vázquez, A., Flecha, S., Huertas, I.E. and Ruiz, J., 2012. Seasonal-to-interannual variability of chlorophyll-a bloom timing associated with physical forcing in the Gulf of Cádiz. Advances in Space Research, 50(8), pp.1164-1172.

O'Reilly, J.E., Maritorena, S., Siegel, D.A., O'Brien, M.C., Toole, D., Mitchell, B.G., Kahru, M., Chavez, F.P., Strutton, P., Cota, G.F., Hooker, S.B., McClain, C.R., Carder, K.L., Muller-Karger, F., Harding, L., Magnuson, A., Phinney, D., Moore, G.F., Aiken, J., Arrigo, K.R., Letelier, R., Culver, M., 2000. Ocean color chlorophyll a algorithms for SeaWiFS, OC2, and OC4: version 4. In: Hooker, S.B., Firestone, E.R (eds.), SeaWiFS Postlaunch Calibration and Validation Analyses, Part 3. National Aeronautics and Space Administration Technical Memorandum 2000-206892, vol. 11, pp. 9–23.

Picado A., Alvarez I., Vaz N., Varela R., Gomez-Gesteira M., Dias J.M. (2014) Assessment of chlorophyll variability along the northwestern coast of Iberian Peninsula, Journal of Sea Research, 93 ,2–11

Prasanna Kumar, S., Muraleedharan, P. M., Prasad, T. G., Gauns, M., Ramaiah, N., De Souza, S. N., & Madhupratap, M. (2002). Why is the Bay of Bengal less productive during summer monsoon compared to the Arabian Sea? Geophysical Research Letters, 29(24), 88-1.

Qasim, S. Z.(1977) Biological productivity of the Indian Ocean, Indian J. Mar. Sci., 6,122–137.

Radhakrishna, K. (1978) Primary productivity of the Bay of Bengal during March–April 1975, Indian J.Mar. Sci., 7, 58–60.

Sengupta, D., G. N. Bharath Raj, M. Ravichandran, J. Sree Lekha, and F. Papa (2016), Near-surface salinity and stratification in the north Bay of Bengal from moored observations, Geophys. Res. Lett.,43, 4448–4456, doi:10.1002/2016GL068339

Shetye, S. R., Shenoi, S. S. C., Gouveia, A. D., Michael, G. S., Sundar, D., and Nampoothiri, G.(1991) Wind-driven coastal upwelling along the western boundary of the BOB during the southwest monsoon, Cont. Shelf Res., 11, 1397–1408.

Suwannathatsa S. and Wongwises P. (2013) Chlorophyll distribution by oceanic model and satellite data in the Bay of Bengal and Andaman Sea, International Journal of Oceanography and Hydrobiology, Volume 42, Issue 2, DOI: 10.2478/s13545-013-0066-y

Vinayachandran, P. N., and J. Kurian (2007), Hydrographic observations and model simulation of the Bay of Bengal freshwater plume, Deep Sea Res., Part I, 54, 471–486, doi: 10.1016/j.dsr.2007.01.007.

Vinayachandran, P.N., Shetye, S.R., Sengupta, D. and Gadgil, S., 1996. Forcing mechanisms of the Bay of Bengal. Curr. Sci, 70(10), pp.753-763.

Vinaychandran, P.N., (2009). Impact of Physical Processes on Chlorophyll Distribution in the Bay of Bengal; Geophysical Monograph Series. 185, 71–86.