# Intra-annual variability of Chlorophyll-a and Sea Surface Temperature (SST) in the Northern Bay of Bengal



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# Intra-annual variability of Chlorophyll-a and Sea Surface Temperature (SST) in the Northern Bay of Bengal

**Muhammad Shahinur Rahman[1], Md. Kawser Ahmed[2],[4], Md. Jobaer Alam[2], Ishrat Jahan Mili[3], Seema Rani[4,a] and K. M. Azam Chowdhury[2,b]**

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

[2]Department of Oceanography, University of Dhaka, Bangladesh.

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

[b]Ocean University of China, Qingdao, China

[3]Bangabandhu Sheikh Mujibur Rahman Maritime University, Dhaka-1216, Bangladesh

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

## Abstract

The aim of this paper is to find out the intra-annual variability of satellite derived chlorophyll-a (Chl-a) and sea surface temperature (SST) in the Northern Bay of Bengal from 2003 to 2014. Cloud coverage of summer monsoon time restricts the satellite data which overcome with the Data Interpolating Empirical Orthogonal Function (DINEOF) method. The highest Chl-a value is found in august (0.69 mg/m3) and lowest in May (0.39 mg/m3). Monthly SST distribution showed bimodal distribution where the highest SST value was found in October (29.700C) and May (29.660C) and Lowest SST was found in January. The highest spatial coverage of relatively high Chl-a (>0.5 mg/m3) is found in August (29.6%) and the lowest in May (14.3%). The Chl-a variability is mainly controlled by river discharge which brings huge nutrients in Northern and Western portion. However, Eastern portion is controlled by North-eastern wind which induces local upwelling. An inverse correlation (r=-0.5) is seen between Chl-a and SST in winter primarily in eastern portion of the Northern Bay of Bengal.

## 1 Introduction

Chlorophyll-a (Chl-a) is the main pigment which phytoplankton uses in photosynthesis to convert nutrients and carbon dioxide, which are dissolved in sea water into plant materials. Commonly, Chl-a, b, c and Phaeophytin are the most occurring pigment in seawater. Their concentrations showed wide variation. For water quality monitoring and ecological studies, Chl-a 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). In the ocean, phytoplankton is the main primary producer. Photosynthesis (food production for growth and reproduction) is completed by using sunlight and nutrients along with chl-a. Most other living organisms in the sea depend on this process either directly or indirectly for their own growth and reproduction. In the food chain, and there is a very large lag of time and distance between primary production and the appearance of large predators, sometimes many miles and many months in the food chain.

Sea surface temperature (SST) is an important geophysical parameter which used for quantitative studies of the Earth atmosphere and ocean. SST plays important role on earth climate. Light and nutrient loads are very important for phytoplankton growth and it is closely related with water column stratification. Water column stratification is indicted by SST anomalies (He *et al.*, 2010).

The Bay of Bengal is region of low biological productivity compared with the Arabian Sea from many literatures which proved by nearly all shipboard observations (Vinayachandran *et al*, 2009). several factors associated with this low productivity such as lack of prominent upwelling areas (La Fond, 1957, Shetye *et al.*, 1991), absence of deep wind-mixing and strong stratification (Gomes *et al.*, 2000; Prasanna Kuamar *et al.*,2002), cloud coverage, sediment load (Qasim, 1977; Radhakrishna, 1978), and lack of winter-driven convective mixing (Jyothibabu *et al.*, 2004; Prasanna Kumar *et al.*, 2010).

The standard Chl-a estimation algorithm has developed for open ocean water (case 2) where color of ocean surface depends on chlorophyll concentration (O'Reilly *et al.*, 2000). In this study, we only used the standard Chl-a algorithm due to lack of regional algorithm. Satellite derived parameters variability is used as indicators of hydro-biological processes and dynamics of Chl-a biomass.

# 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.

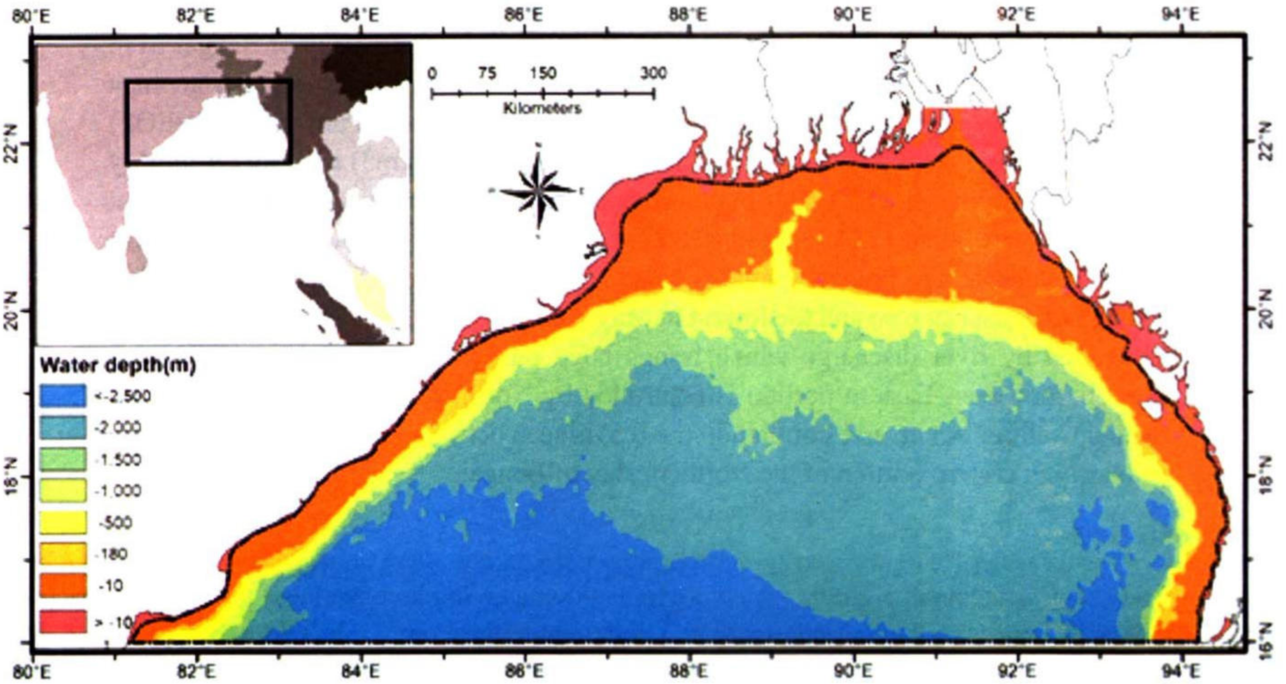


Figure 1: Map of Study Area with bathymetry. Legend shows the water depth of Northern Bay of Bengal

## *2.2 Data and Methods*

Satellite derived Chl-a, sea surface temperature (SST) are 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] for 2003 to 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 wh0ich results gappy data.

Fig. 2 shows the spatial distribution of monthly valuable pixel for the period of 2003 to 2014. Data unavailability is most problematic in summer monsoon (JJA). Most area of the Northern Bay of Bengal has data less than

50% in this period. Pre monsoon (April-May) and post monsoon (September) month also experienced with cloud and provide 75% data.

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 compute a complete time series data without missing value and to overcome the data gaps problem, the Data Interpolating Empirical Orthogonal Function (DINEOF) method was performed for reconstructing the monthly SST and Chl-a data. The Beckers and Rixen (2003) had presented DINEOF reconstruction method and this method used by Beckers et al. (2006). In this method, dominant spatial and temporal patterns are identified and the missing data are filled. It is a self-consistent, parameter-free technique to reconstruct gaps in data that does not require this type of a-priori information. Recently, DINEOF has been widely used to reconstruct incomplete oceanographic data sets in the South Atlantic Bight (Miles et al., 2009), the North Sea (Sirjacobs et al., 2011), the Mediterranean Sea (Volpe et al., 2012), the Gulf of Maine (Li and He, 2014). This technique has some advantages than classical approaches such as optimal interpolation (Zhao and He, 2012). Additionally, it provides an accurate datasets allowing to study SST and Chl-a (Li and He, 2014).For more detailed method descriptions and applications of DINEOF, Interested readers can refer to Alvera-Azcárate et al. (2007); Beckers and Rixen (2003) and Miles, et al. (2009).

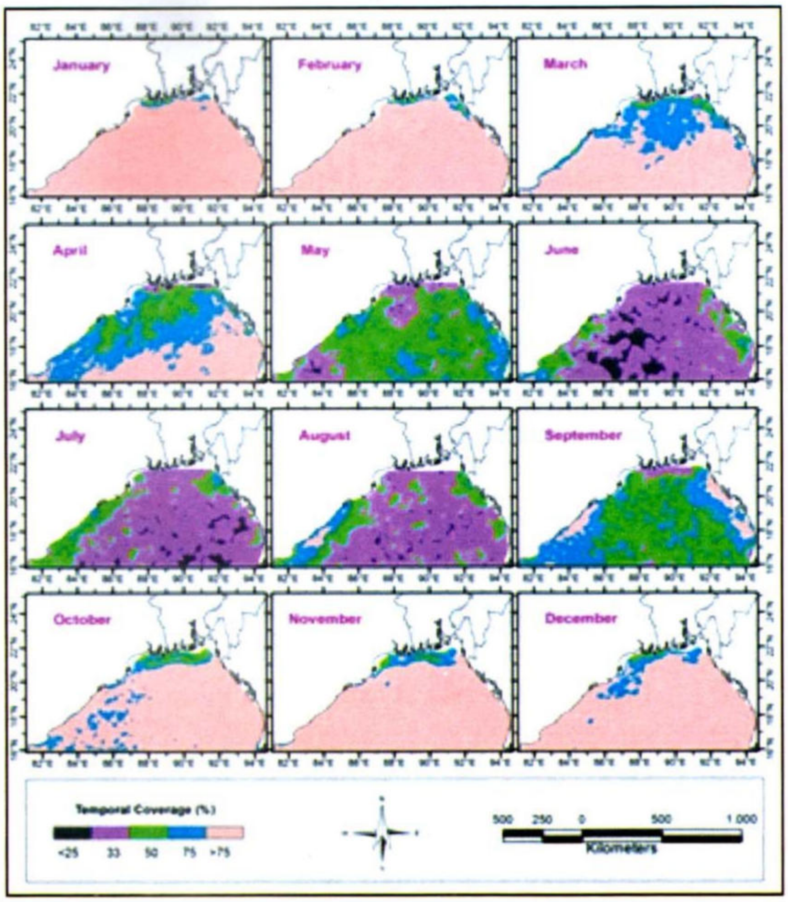

Figure 2: Monthly spatial distribution of valuable pixels (%) for satellite derived chl-a

To analyze the spatial variability of the oceanic parameters, monthly climatologial map has produced by DINEOF derived reconstructed monthly mean value of each grid point where missing value problem has overcome. For analyzing the correlation between Chl-a and SST we calculate the correlation value for each grid during 2003-2014.

## 3. Result and Discussion

### *3.1 Monthly average of SST and Chl-a*

Monthly distribution of averaged Chl-a concentration from 2003 to 2014 are shown in Fig. 3. The results showed that the Chl-a concentration is relatively low (~0.25 mg/m3) in the open parts of the Northern Bay of Bengal, and higher values (>0.75 mg/m3) were observed along coasts.

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 September this relative high value extended to the western parts of the NBOB, while in eastern part, relative high value seen from December to March.

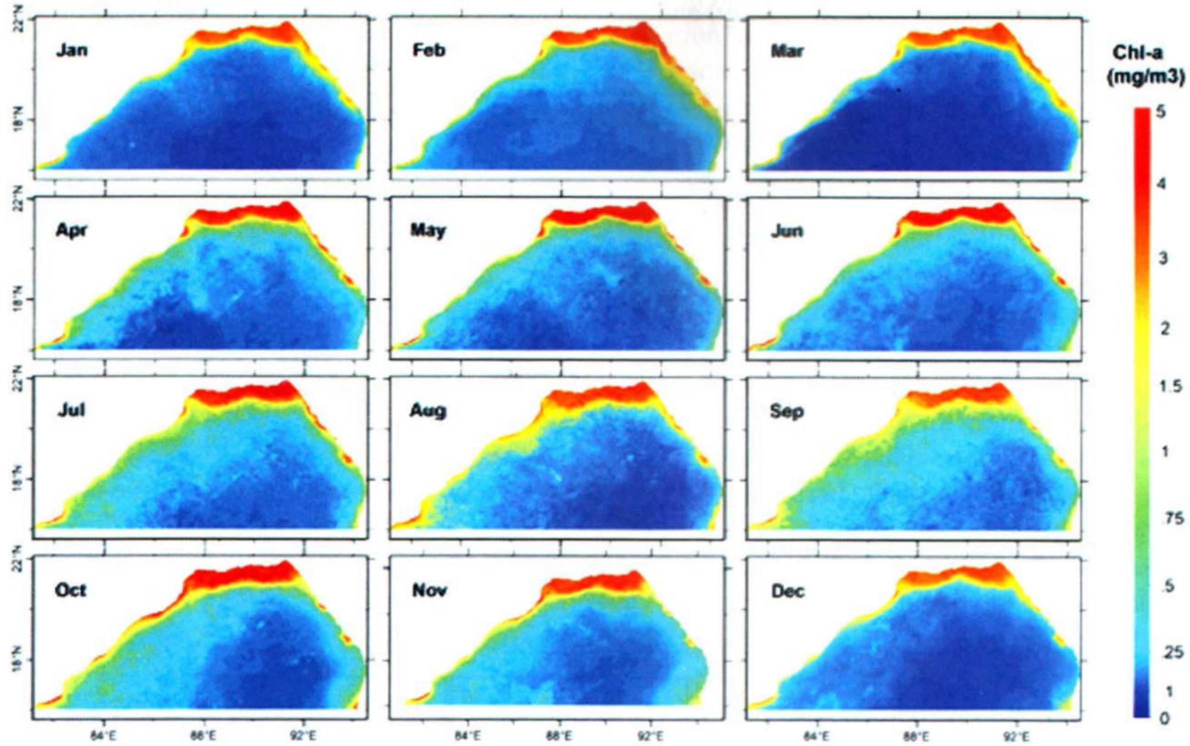


Figure 3: Monthly average of satellite derived Chl-a concentration during 2003–2014

Figure 4 represents the monthly distribution of SST concentration from 2003 to 2014. Here the 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. Most of the time, eastern coast experienced high SST than western coast except March, June, July, August and September.

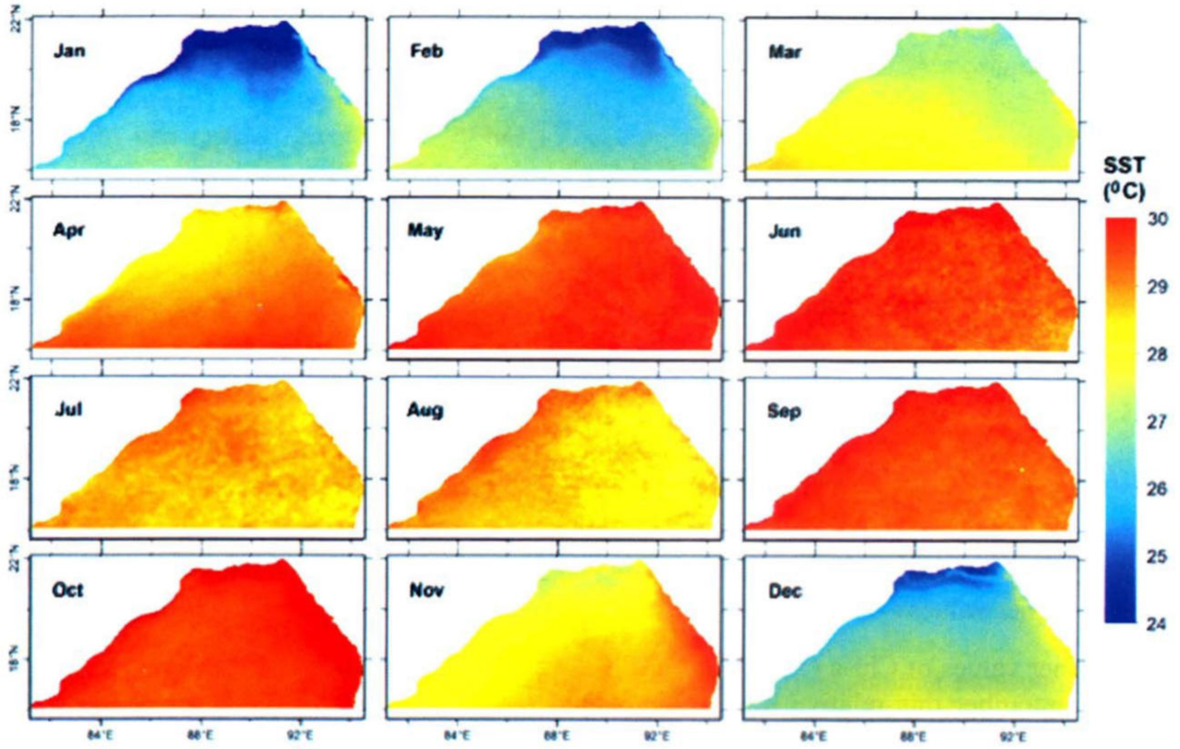


Figure 4: Monthly distribution of sea surface temperature (SST) during 2003–2014

Figure 5 shows the monthly area-averaged variation of the SST and Chl-a concentrations of the NBOB over time. The peak Chl-a concentration was observed in August (0.68 mg/m3) and lowest in May (0.39 mg/m3). Mighty GBM supplies huge amount of nutrient which is the possible reason for chl-a dynamics. SST of the study area has shown bi-modal distribution. One high peak observed in pre monsoon season in May (29.66 0 C) and another peak seen in post monsoon period in October (29.70 0C).One low peak found in January (25.70 0C) and other is in August (28.69 0C) and this SST decreases in summer monsoon period due to heavy cloud coverage.

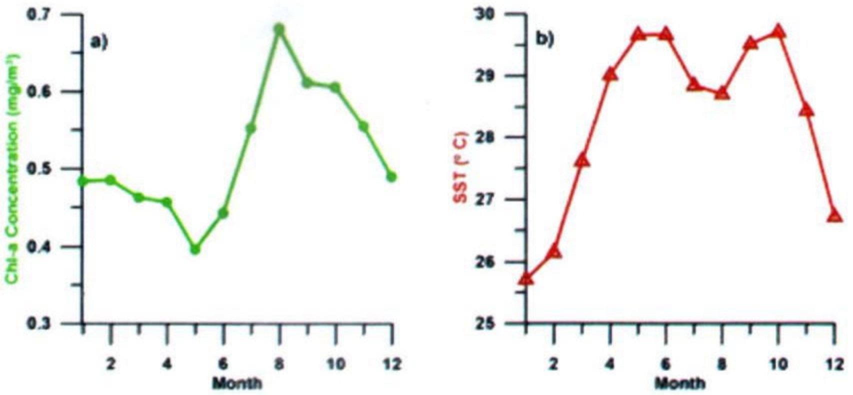

Figure 5: Monthly variations of Chl-a (a), and SST (b) in NBOB

Fig.6 shows the percentage of the area average monthly Chl-a concentrations and SST by area for each class values. The maximum coverage area of Chl-a values is less than 0.25 mgm-3 which highest coverage found in may and lowest in august. Highest coverage of relatively high chl-a concentration (>0.50 mgm-3) observed in August (29.6%) and lowest coverage seen in may (14.3%).SST value between 28o C to 30o C covers more than 95% area of NBOB from April to November. More than 30o C has seen in October (1.18%) and very negligible in June and July (less than 0.2%).

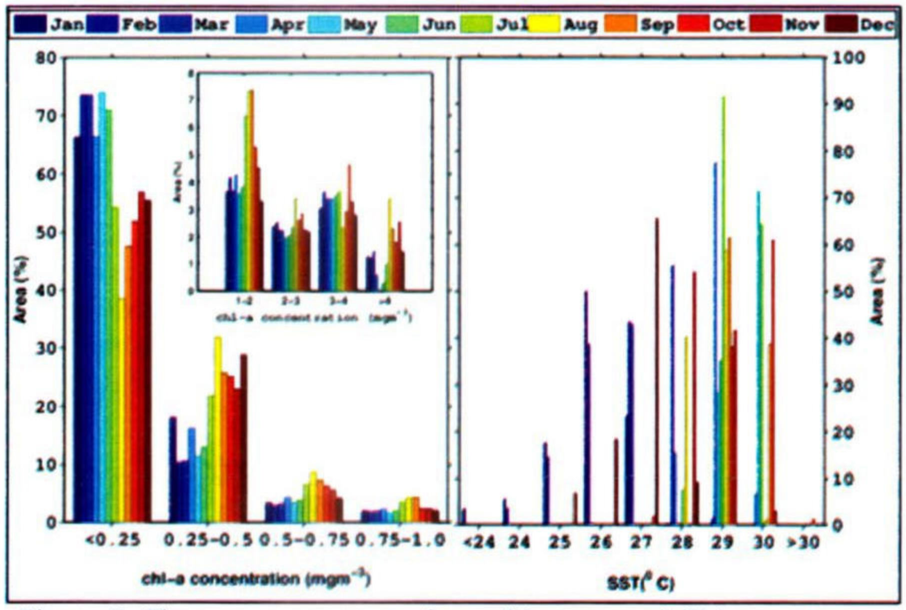

Figure 6: The area percentage of monthly averaged Chl-a concentration (left) and SST (right) during 2002–2014.

## *3.2 Seasonal average of SST and Chl-a*

Seasonal distribution of averaged SST and Chl-a concentration from 2003 to 2014 are shown in Fig. 7. The results showed that the Chl-a concentration is relatively low (~0.25 mg/m3) in the open parts of the NBOB, and higher values (>0.75 mg/m3) were observed along coasts. The seasonal variation of chl-a is negligible in head bay. Eastern portion and Western portion show seasonal variation of chl-a. In summer, the cha-a concentration increases in western portion which still activate in autumn also. This increase is explained by the river influx which carries huge nutrient (Baliarsingh *et al.*, 2015). River flows continues in autumn also and the high chl-a seen in autumn. After that the flow decreases and relative high chl-a value (>0.50 mg/m3) is decreased and shrink to coastal portion only in winter. Low Chl-a value (<0.25 mg/m3) dominate in spring. A slight increase of chl-a concentration is seen in april. Baliarsingh *et al.* (2013) reported that the increased value of chl-a concentrations during March–April was associated with nuitrient distribution with localized upwelling in the shelf region. Rapid growth of phytoplankton to reach bloom status due to this local upwelling (Gouda and Panigrahy 1996).

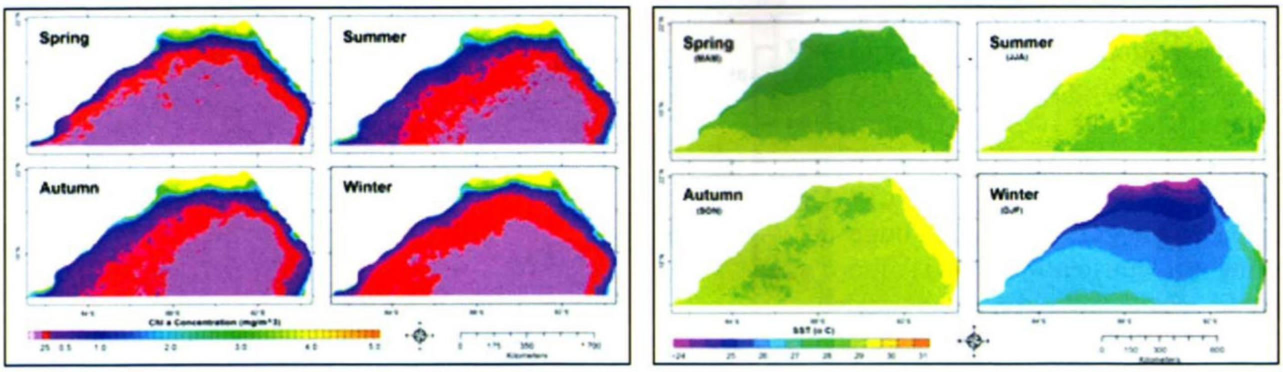


Figure 7: Seasonal average of satellite derived Chl-a concentration (left panel) and SST (right panel) during 2003–2014

In eastern portion, chl a concentration is observed highest in winter monsoon lowest in spring monsson. In winter monsoon, wind comes from NE direction and upwelling seen due to positive wind curl which enhances the chl-a concentration in this part (Vinayachandran, 2009). In spring, wind direction is not well organized and upwelling is disappeared which is the reason for lowest chl-a concentration.

Seasonal variation of SST shows two general features. In spring and winter, the SST gradient has seen north south direction. Northern part is cool SST and increasing towards south which explained with the sun movment. In summer and autumn, SST gradient shows west east gradient but opposite direction in two seasons. Fig.8 shows the percentage of the area average seasonal Chl-a concentrations and SST by area for each class values. The maximum coverage area of Chl-a values is less than 0.25 mgm-3 which highest coverage found in spring and lowest in winter. Highest coverage of relatively high chl-a concentration (>0.75 mgm-3) observed in Autumn (16.8%) and lowest coverage seen in spring (12.0%).SST value more than 28o C covers 100% area of NBOB all around the year except winter season. More than 30o C has seen in October (1.18%) and very negligible in June and July (less than 0.2%). In winter, more than 27o C covers 48.4% area.

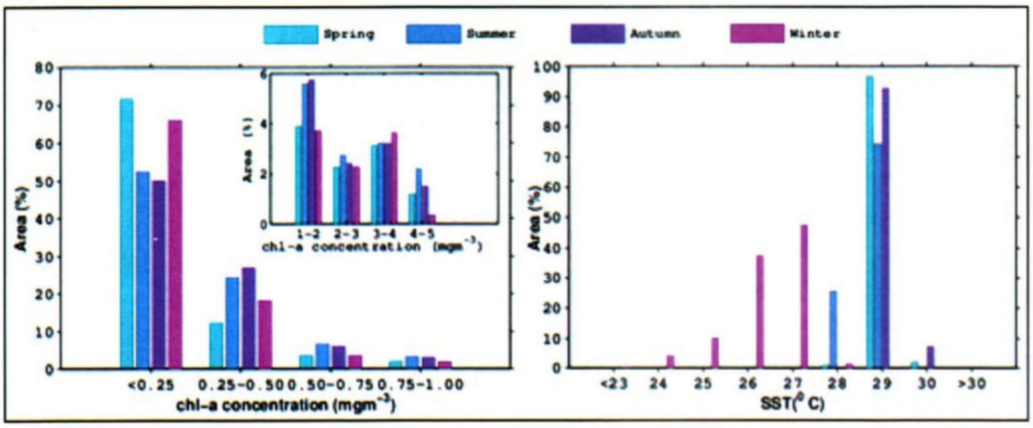


Figure 8: The area percentage of seasonal averaged Chl-a concentration (left) and SST (right) during 2002–2013.

## *Correlation between Chl-a vs SST*

The correlation between Chl-a and SST using monthly time series from 2003 to 2014 data for each grid point is mapped in Figure 9. The correlation map shows a negative correlation between Chl-a and SST in pre-monsoon and winter monsoon month in the western portion of NBOB. This signature is seen due to north easterly monsoon wind which is favorable for upwelling and nutrient rich water comes to surface and create bloom type incident (Nagabhatla et., al 2016). In eastern portion there is also negative correlation is seen in a narrow width during winter time and possible reason is river induced cold water which bring nutrient for phytoplankton growth in December and January time. There is no significant correlation is found in other region or time.

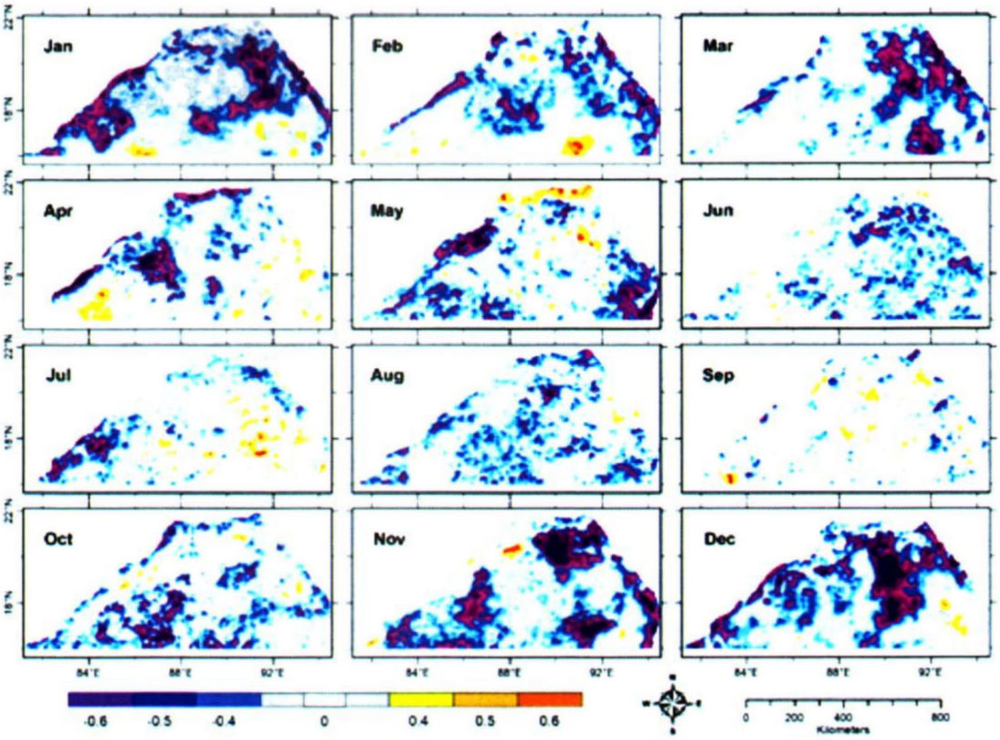


Figure 9: Monthly correlation map between Chl-a concentration and SST

## 4. Conclusion

The paper represent the intra-annual and seasonal distribution of the satellite derived chl-a and SST for the Northern Bay of Bengal, a least studied ocean bodies. In this paper, we reconstruct the missing data by using DINEOF method which is well accepted method in scientific community. Then the monthly distribution map of SST and Chl-a has produced which revealed the spatial pattern of these two parameters. Finally, monthly correlation maps are produced to find out the correlation between SST and chl-a in the Northern Bay of Bengal and discuss the possible mechanism for variability. Further study is required for better understanding the processes by using in situ data.

## Acknowledgements

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