

# MONTHLY AND SEASONAL VARIABILITY OF CHLOROPHYLL AND SST ALONG ODISHA AND BENGAL COAST IN THE NORTHWEST BAY OF BENGAL USING MODIS-AQUA DATA

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## Abstract

Time series analysis of the chlorophyll and sea surface temperature (SST) on monthly and seasonal scale images have been retrieved for the Odisha, Bengal coast and adjoining coastal water along the northwest Bay of Bengal region, from MODIS-Aqua satellite datasets archive. The two year datasets during 2014 and 2015 have been processed using Erdas Imagine and Envi softwares to generate the monthly scale images for analysis. The Odisha and Bengal coast water during most of the months showed very high chlorophyll concentration ranging 0.01-5.0 mg/m<sup>3</sup> in the monthly composite images during 2014 and 2015. During April-June high chlorophyll plumes of concentration >2.0 mg/m<sup>3</sup> have been observed. Near the coast, high chlorophyll concentration patches and stripes are seen almost 10kilometers from the coastline and seen parallel to coastline in southward direction. There has been plumes of high chlorophyll seen from Dhamara and Mahanadi estuarine fluxes carrying water with high enriched nutrients and lower salinity and moves to the coastal water, hence the high chlorophyll concentration (1.5-3.0 mg/m<sup>3</sup>) observed. The impact of southwest monsoon (June-September) and northeast monsoon (November-December) has been observed in enriching the coastal water productivity along both the Odisha and Bengal coast. The SST has been ranged 24-32<sup>0</sup>C throughout the years. The cooling trend (24-27<sup>0</sup>C) has been seen during November-May period along the coastal water along Odisha and Bengal coast and other months showed higher SST. The year 2015 shown little warmer SST as compared to the year 2014 and hence the chlorophyll has been observed with reciprocal trend and there is observation of bimodal trend within years. This study will be helpful in assessing the regional scale productivity in terms of chlorophyll and temperature variability on monthly and seasonal scale for the two years. The in situ data sets will also be interpreted to observe the dynamic trend of ocean productivity and water quality parameters.

## **1.Introduction**

Bay of Bengal, the largest bay of the world is been considered as the most dynamic bay (Abdulkader et al. 2013) with several distinguishing features which makes it a unique area. It receives large fresh water influx from perennial rivers and also faces monsoon winds, which affects the surface water circulation and stratification. In this marine ecosystem variable influx rate of fresh water remarkably alter the environmental condition. The northeast Bay of Bengal including Odisha and Bengal coast are ecologically sensitive area for fishery and other marine product harvesting (Choudhury

& Pal, 2010). This coast is vulnerable to cyclonic storms and faces tropical dry and wet climate. The coast line of West Bengal and Odisha extends up to 157km and 480km respectively. Both these coast receives large fresh water flow from major rivers like Hugli, Subarnarekha, Budhabalanga, Brahmani & Baitarani, Mahanadi, Devi, Rushikulya etc. Particularly for this region large scale satellite generated SST and chlorophyll report is nil. As this coast covers a large area and has a remarkable influence on perennial land mass hence the monthly and seasonal variability in water quality is needed.

In a marine ecosystem chlorophyll-a is the major photosynthetic pigment. The chlorophyll concentration represents phytoplankton biomass and also the productivity of the water body. Chlorophyll concentration of open-ocean plays an important role in the control of SST by trapping the solar radiation in surface layer (Satyendranath et al. 1991). The sea surface experiences several spatiotemporal variability compared to the bottom layer and also directly interacts with the varying atmospheric condition, hence the sea surface water quality variability study is an important aspect. The SST of Bay of Bengal is greatly influenced by the presence of land mass on its three sides (Shamsad et al. 2012). The solar energy received at the water surfaces of the oceans help in the process of photosynthesis by phytoplankton. In the aquatic ecosystem SST and chlorophyll are interrelated with each other and together regulates the productivity. The present study is based on observation of monthly and seasonal variability of SST and chlorophyll in surface layer of Odisha and Bengal coastal water in the northeast Bay of Bengal using Modis-Aqua satellite images. Satellite image generated data are useful for understanding the large scale variability in SST and chlorophyll. For the largest bay of the World i.e. the Bay of Bengal it is difficult to observe large scale variability in SST and chlorophyll through in situ observation, where the satellite derived results can provide wide range data in a regular basis. This also helps to understand the effect of physical processes on biological system of ocean water. Ocean colour measurement and the fate of light in the ocean are useful for describing biological dynamics in surface layer (Lorenzen, 1972).

Few in situ based works have been carried out on variability of SST and chlorophyll in northeast Bay of Bengal (Rakhesh et al. 2006; Paul et al. 2007; Fernandes & Ramaiah, 2009; Sabu et al. 2015). Limited work has been reported in Bengal and Odisha coast pertaining to SST and chlorophyll variability, some of the notable works of Bengal coast include (Choudhury & Pal, 2010; Moharana & Patra, 2014) report on Odisha coast was carried out by (Srichandan et al, 2014; Narveker & Kumar, 2014). Remote sensing based SST and chlorophyll observation for northeast Bay of Bengal is scanty (Sarangi, 2011; Narvekar & Kumar, 2014). Hence the present study will help to provide baseline information on satellite derived seasonal variability of SST and chlorophyll in Odisha and Bengal coast in addition to this it also help to understand the effect of climate change on Odisha and Bengal coastal water dynamics.

## 2. Objectives of the study

- (i) Analysis of the MODIS-Aqua data during the period January-December 2014-2015 along the Odisha and Bengal coastal water to observe the monthly and seasonal scale variability of chlorophyll and SST.
- (ii) To inter-relate the impact of temperature on chlorophyll and its variability from monthly to seasonal and inter-annual scale for the study area.
- (iii) To understand the satellite derived chlorophyll and SST variability with the in situ measured water quality parameters at coastal stations.

## 3. Data and Methodology

MODIS (Moderate Resolution Imaging Spectroradiometer) Aqua sensor data for SST and chlorophyll were retrieved from <http://www.nasa.gov/> archive for the period of one year (2014-2015). The datasets were then processed through ERDAS *Imagine* and Envi software for generation of SST and chlorophyll colour images. MODIS-Aqua datasets were processed in order to analyze the monthly/seasonal and annual changes in chlorophyll concentration and SST around the Odisha & Bengal coast in the northwest Bay of Bengal water. Level-3 MODIS Aqua dataset (Source: <http://modis.gsfc.nasa.gov/oceancolor>) of 4kilometer resolution has been processed. The chlorophyll and SST images were retrieved using ENVI- 4.4 software. The OC-3 empirical algorithm (also known as Ocean Chlorophyll 3, Morel and Maritorena, 2001), which has been operated on MODIS-Aqua ocean colour data. The algorithm is incorporating the remote sensing reflectance ( $R_{rs}$ ) basing on 3 bands 443, 488 and 551 nm for computing chlorophyll concentration C. The algorithm has been used to retrieve low as well as high chlorophyll concentration which means a better retrieval even in case 2 waters. The algorithm operates with five coefficients and has following mathematical form:

$$C = 10^{(0.283 - 2.753 * R + 1.457 * R^2 - 0.659 * R^3 - 1.403 * R^4)},$$

Where  $R = \log_{10} [(R_{rs443} > R_{rs488}) / R_{rs551}]$  and  $R_{rs}$  is remote sensing reflectance. In OC-3 algorithm, there should be no negative  $R_{rs}$  value, so the greater value is to be considered from the channels  $R_{rs443}$ nm and  $R_{rs488}$ nm as numerator and to be divided by  $R_{rs555}$ nm as denominator. The algorithm is expected to be estimating within  $\pm 35\%$  error accuracy (Morel and Maritorena, 2001), as per the radiometric validation with in situ datasets.

The MODIS-Aqua SST data of 4 km resolution has been processed and provided SST with accuracy of 0.2°C. Monthly scale SST datasets were imported in ENVI software to generate the SST image. The images were gridded and color coded using the same software. The SST and chlorophyll concentration along Odisha coast was ranged from 24 - 32°C and 0.01 - 3.0 mgm<sup>-3</sup>. The MODIS-Aqua derived chlorophyll and SST images have been generated for the study area covering the coordinate ranges [Latitude 19-22°N; Longitude 85-88°E].

### **In-situ Data**

Two years SST, Chlorophyll, Salinity, nutrients and other water quality data have been collected for the coastal water stations namely Digha, Chandipur, Dhamra, Paradip and Astarang covering the Bengal and Odisha coast, east coast of India (Fig. 1). The data points were collected from surface, 3m and 6m depths for different stations and transect points. These above data points were categorically classified into 3 seasons i.e., summer, monsoon and winter respectively. The datasets were collected during the following months for all five stations covering the seasons between 2014-2016.

<b>Months and Year</b>	<b>Data collected in Stations</b>
November 2014	Digha Chandipur, Dhamra
January 2015	Chandipur, Dhamra, Paradip, Astarang
March 2015	Chandipur, Dhamra, Paradip, Astarang
July 2015	Dhamra
September 2015	Dhamra, Paradip
November 2015	Digha, Chandipur, Dhamra, Paradip, Astarang

Data were collected from near shore to 10Km coastal water transect in 1Km interval, which covers surface, 3m and 6m depth for the sub-transect points. The datasets have been planned for interlinking with satellite images.

### **4.0 Results and discussion**

The MODIS aqua satellite data derived chlorophyll and SST monthly images have been generated during 2014 and 2015 for the Odisha and Bengal coastal water regions (Fig. 1). The chlorophyll monthly trend for two years have been plotted and it shows Odisha coast data resulted high concentration and ranged 0.01 to 5.0 mg/m<sup>3</sup> (Fig. 2). Similarly, SST has been interpreted during 2014-2015 for Odisha and Bengal coastal water on monthly scale and ranged between 24-32°C (Fig. 3).

This is a preliminary work to study the variability of phytoplankton pigment, chlorophyll concentration on monthly scale along the Odisha and Bengal coastal region using Modis-Aqua data.

The chlorophyll concentration range scale 0.01-5.0 mg/m<sup>3</sup> during the study period 2014-2015. The study area is linked to seasonal rivers like Mahanadi, Brahmani, Baitarani, Ganges/Hugli rivers, Devi, Rushikulya estuaries, etc. Hence, the river flux is predominant covering the northeast and southwest monsoon seasons. The post monsoon impacts have been observed in chlorophyll images. The algal bloom features with high chlorophyll concentration patches (1.0-2.5 mg/m<sup>3</sup>) seen off Odisha coast during April-May 2014 predominantly. Similar plumes of rivers are seen during 2015 April-May-June with intense algal bloom patches, due to the river plumes off Mahanadi, Brahmani & Baitarani etc. and which seems along the Bengal coast too. The Sundarban coastal water mostly seen very high chlorophyll concentration due to highly turbid water and enriched nutrient (Fig.2), where the ocean colour algorithm may not be working well due to more sediment concentration and lesser depth.

The SST images are interpreted during 2014-2015 (Fig. 3). The SST observed to be lower (24-27/28°C) on monthly scale images During November-May covering 7-months and rest 5-months, June-October indicates intense warming features (28-31°C) along the Odisha and Bengal coast, which is very peculiar, in terms of the southwest monsoon flux and rainy season concerned. The coastal water chlorophyll also showed the increasing trend during this period. Which is interesting and also difficult to understand, deviates from the classical trend. Hence it reflects that there is not upwelling during June-October. There is river fluxes and nutrient enrichment, which might be enhancing the chlorophyll over the study area during June-October. As in situ data showed the presence of high nitrate (>10µM) and silicate (>6µM) concentration over the study area covering 5-stations measurement. So, this may be the reason to enhance coastal water productivity, even if the temperature was higher (28-31°C) during June-October period. Winter cooling of SST (25-27°C) has been observed during November-February period (Fig.3).

The Fig. 4 Indicates the variation in the monthly and inter-annual scale chlorophyll and SST mean during 2014-2015. January-June 2015 phase has shown high chlorophyll concentration (CC) for than the year 2014. Rest of the months July/August to December 2014 the CC observed higher than the year 2015 phase (Fig. 4). Similarly, the SST monthly scale trend does not deviate much. Still, there is gradient observed in 2-phases. Likely, the 1. January-June shows one typical trend during 2015; lower SST and higher chlorophyll (Fig. 4a and 4b). During other time frame, 2. August-December, higher SST during 2015 and lower chlorophyll during 2015 (Fig. 4a and 4b). The reciprocal nature of SST and chlorophyll has been seen in 2-phases of the year. The year 2014 also follows the similar trend. It shows a bimodal/bi-annual kind of distribution as observed in both the years. The correlation/scatter plot (Fig. 5a-5c) does not show the classical trend/pattern between chl and SST, may be due to the biannual/bimodal distribution as discussed above (Fig. 4a and 4b). Only in the lower range of SST, the classical inverse trend with chlorophyll has been observed (Fig. 5b). Between the SST range 25-28°C,

the scatter is less and for the range 28-31°C, the scatter is more. It also followed the bimodal relationship. Detailed analysis with in situ comparison would be interesting.

The seasonal variation and assessment of hydrology of northwest Bay of Bengal has been carried out. The water sample were collected from five different stations namely Digha, Chandipur, Dhamra, Paradip and Astarang and studied during November 2014 to March 2016. For each station 11 sub transect points were selected, starting from coast up to 10km in to the sea at an interval of 1km. The northern and central Bay of Bengal is influenced by three major seasons i.e. summer (March-June), monsoon (July-September) and winter (October-February). SST is an important parameter in a marine ecosystem. Variation in SST can be directly related to seasonal changes (Vadivukkarasi et al. 2014). In our study site the SST ranged between 23.81°C±3.19 to 30.79°C±0.35. The minimum value has been reported in winter season at Chandipur water, whereas maximum was at Paradip during monsoon. The lowest SST in winter season was due to lower atmospheric temperature. In summer higher insolation caused increase in SST in BOB water. Generally, the surface water temperature is influenced by the intensity of solar radiation, evaporation, fresh water influx and cooling and mix up with ebb and flow from adjoining neritic waters (Achary et al. 2014). The seasonal variation of BOB water shows two peaks of SST, one in summer and another one in monsoon season. In Dhamra and Paradip coastal water, maximum SST was reported in monsoon followed by summer and winter. In Digha, Chandipur and Astarang SST was maximum in summer followed by winter season.

Generally, chlorophyll concentration of northern and central BOB was found to be ranged between (2.45mg/m<sup>3</sup>±0.10 – 5.23mg/m<sup>3</sup>±0.25), which was higher than southern BOB. High nitrate concentration has been attributed to increase in phytoplankton population. As BOB experiences many cyclonic storms and heavy rainfall, which causes maximum nutrient influx through riverine water. During the present study maximum chlorophyll was reported in Dhamra region during summer and minimum in Paradip during winter. Moderate temperature and less turbid water in summer attribute to higher chlorophyll concentration. The in situ data range of high chlorophyll (2.35-5.4) is matching with the satellite derived trend around the coastal water. Similarly, the in situ SST range is interpreted. The in situ SST minima observed to be lesser (by 3-4°C) than the satellite image minima data and in situ SST maxima matches well with satellite maxima and observed around 31°C. The comparison is on gross and the satellite images are on monthly scale and with 4kilometer resolution pixels, but in situ data collected on individual day and samples measured at few centimetre scale. Still the comparison has been established and the synoptic scale maps have been interpreted over the study area and produced new results like the monthly/seasonal and inter-annual scale distribution pattern of chlorophyll and SST and their interrelationship. More details analysis with multiple parameters and validation activities will provide better insight into this kind of work on regional scale hydrobiology and water quality based ocean productivity study, etc.

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## References

- Choudhury, A.K. and Pal, R. (2010) Phytoplankton and nutrient dynamics of shallow coastal stations at Bay of Bengal, Eastern Indian Coast. *Aquatic Ecol*, Vol. 44; pp 55-71.
- Lorenzen, C.J. (1972) Extinction of light in the ocean by phytoplankton. *J.Cons.Int.Explor.Mer.*, Vol. 34; pp 262-267.
- Moharana, P. and Patra, A.K. (2014) Lunar rhythm in the planktonic biomass of Bay of Bengal at Digha-on-sea (W.B.). *Indian Journal of Life Sciences*, Vol. 3(2); pp 81-86.
- Morel, A. and Maritorena, S., 2001, Bio-optical properties of oceanic waters: A reappraisal, *Journal of Geophysical Research*, 106, pp 7163–7180.
- Narvekar, J. and Prasanna Kumar, S. (2014) Mixed layer variability and chlorophyll a biomass in the Bay of Bengal. *Biogeosciences*, Vol. 11; pp 3819-3843.
- Paul, J.T., Ramaiah, N., Gauns, M. and Fernandes, V. (2007) Preponderance of a few diatom species among the highly diverse microphytoplankton assemblages in the Bay of Bengal. *Mar Biol*, Vol. 152; pp 63-75.
- Rakshesh, M., Raman, A.V. and Sudarsan, D. (2006) Discriminating zooplankton assemblages in neritic and oceanic waters: A case for the northeast coast of India, Bay of Bengal. *Marine Environmental Research*, Vol. 61; pp93-109.
- Sabu, P., Asha Devi, C.R., Lathika, C.T., Sanjeevan, V.N., and Gupta, G.V.M. (2015) Characteristics of a cyclonic eddy and its influence on mesozooplankton community in the northern Bay of Bengal during early winter monsoon. *Environ Monit Assess*, Vol. 187(330); pp1-19.
- Sarangi, R.K. (2014) Impact of cyclones on the Bay of Bengal chlorophyll variability using remote sensing satellites. *Indian Journal of Geo-Marine Sciences*, Vol. 40(6); pp 794-801.
- Shamsad, Farukh, M.A., Chowdhury, M.J.R. and Basak, S.C. (2012) Sea surface temperature anomaly in the Bay of Bengal in 2010. *Environmental Science & Natural Resources*, Vol. 5(2); pp77-80.

Srichandan, S., Panda, C.R. and Rout, N.C. (2014) Summer distribution of zooplankton in coastal waters of Odisha, East coast of India. *International Journal of Oceanography and Marine Ecological System*, Vol. 3(1); pp 9-25.

### Figure Captions

Fig. 1 Study area and the in situ data sampling stations.

Fig. 2 The distribution pattern of monthly scale chlorophyll along the Odisha and Bengal coast as retrieved from Modis-Aqua datasets.

Fig. 3 The distribution pattern of monthly scale SST along the Odisha and Bengal coast as retrieved from Modis-Aqua datasets.

Fig. 4 The monthly and inter-annual variation of (a) chlorophyll and (b) SST during 2014-2015 along the Odisha and Bengal coastal water, as derived for MODIS-Aqua satellite data.

Fig. 5 Modis-Aqua derived monthly mean SST and chlorophyll scatter plot indicating the correlation trend: (a) January-December, (b) January-June and (c) July-December data points over the study area during the period 2014-2015.

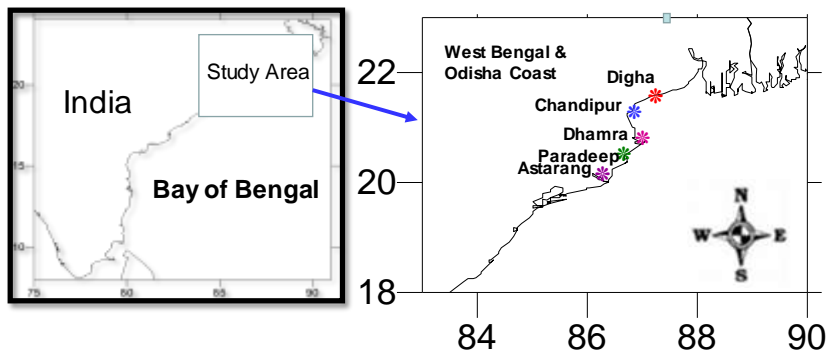
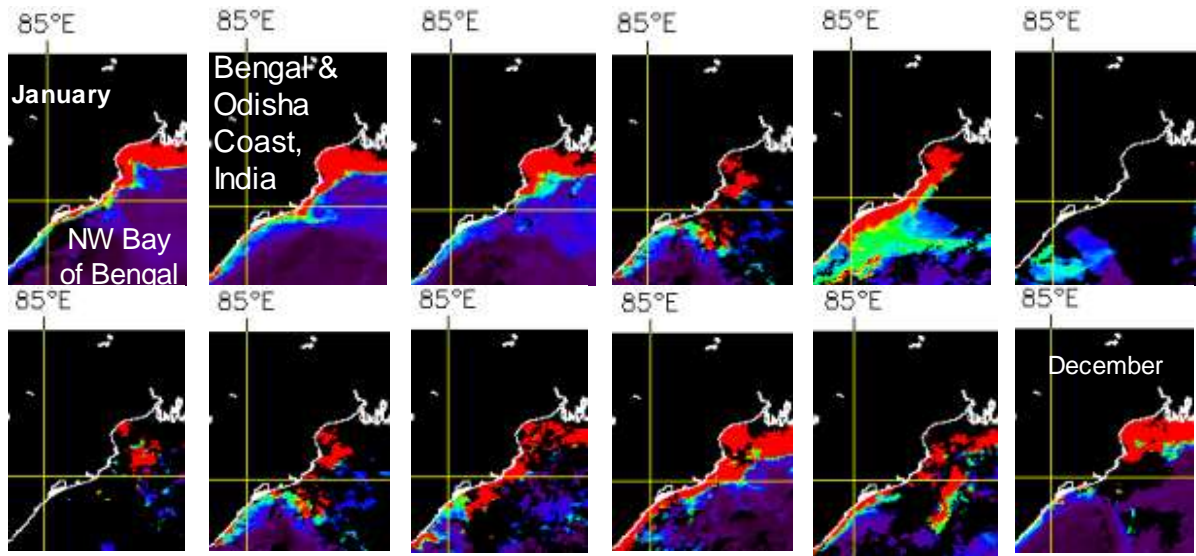


Fig.1



**January-December 2014**



**January-December 2015**

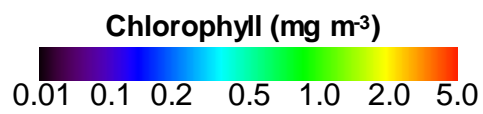
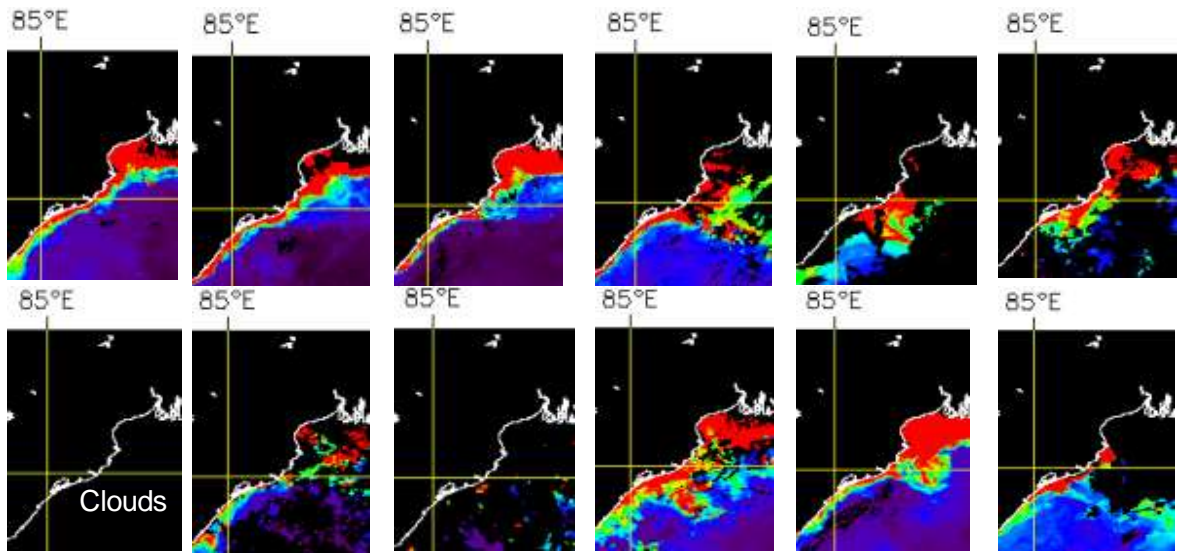
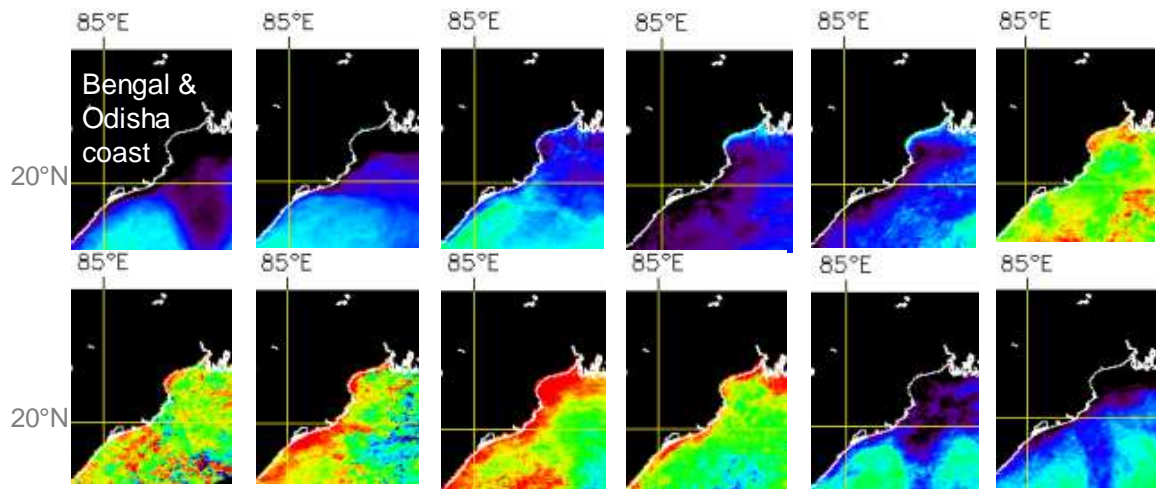


Fig.2

**January-December 2014**



**January-December 2015**

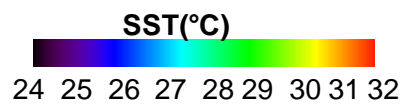
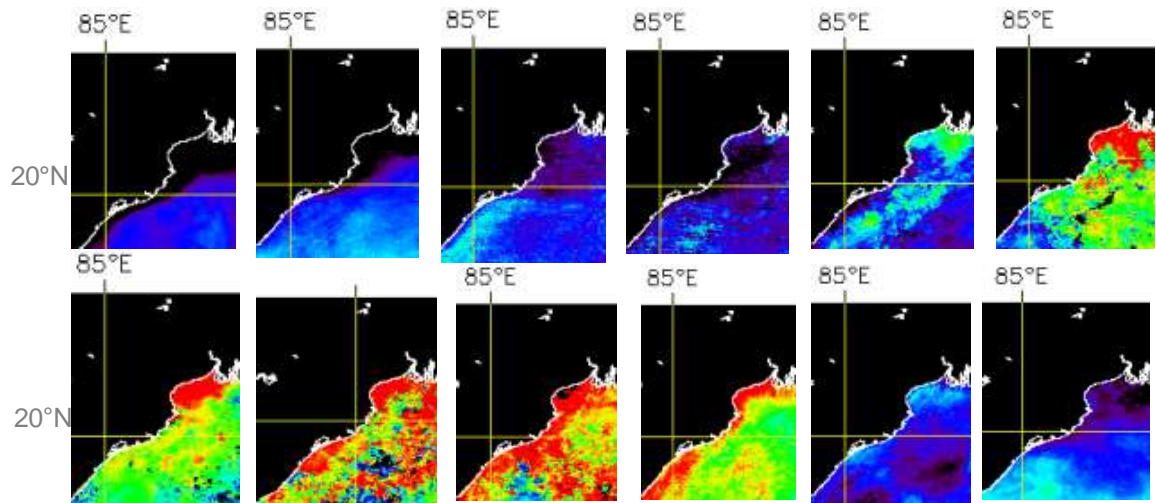


Fig.3

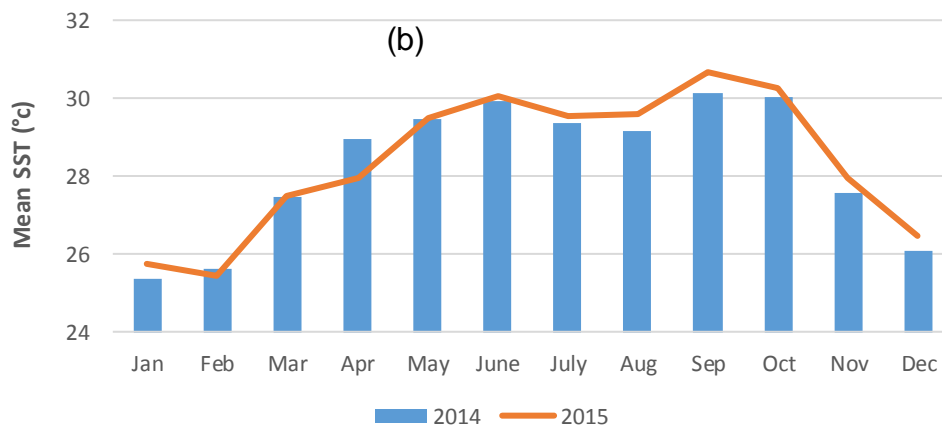
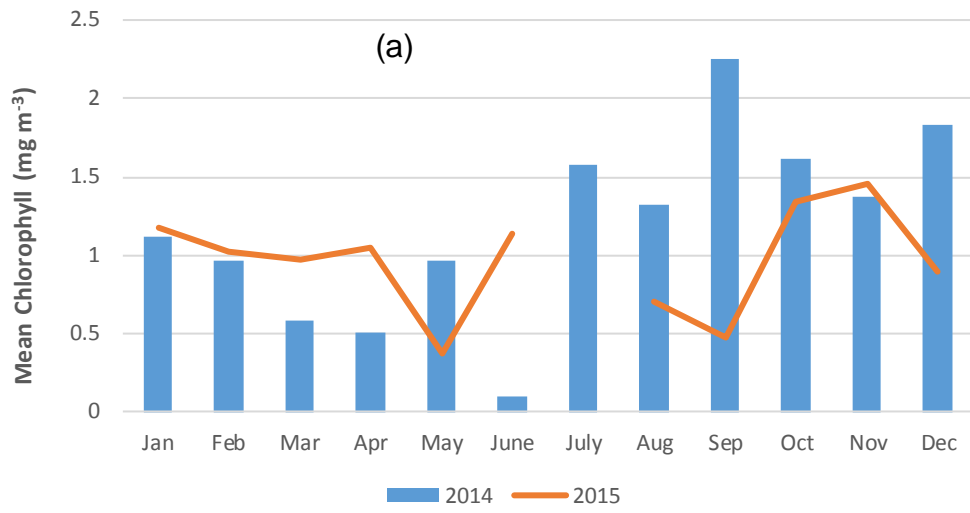


Fig.4

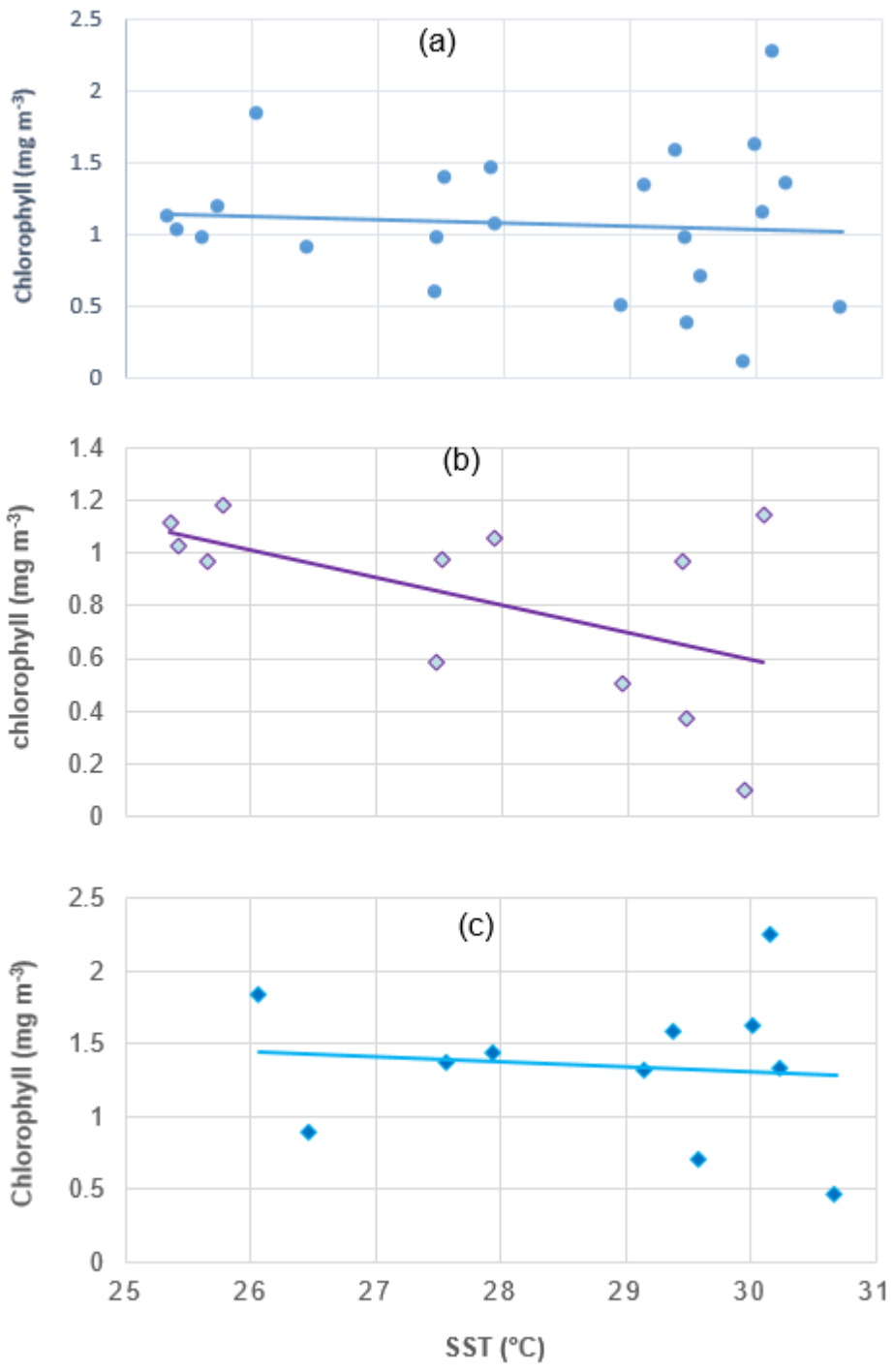


Fig.5