CHAPTER 09

SPATIAL AND TEMPORAL VARIABILITY OF CHLOROPHYLL-A CONCENTRATION IN THE SOUTH EASTERN ARABIAN SEA (SEAS)

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1. Introduction

Satellite remote sensing is being effectively used in monitoring the ocean surface. Among the ocean observing satellite sensors, ocean colour sensors make use of visible band of electromagnetic spectrum (shorter wavelength). The use of shorter wavelength ensures fine spatial resolution of these parameters to depict oceanographic characteristics of any region having significant spatio-temporal variability. The Southeastern Arabian Sea (SEAS; encompassing between 70.5-77.5°E longitude and 8-15°N latitude) is such an area showing very significant spatio-temporal oceanographic and atmospheric variability due to the seasonally reversing surface winds and currents (Shankar *et al.*, 2002; Shetye *et al.*, 1990) (Figure 1). Consequently, the region is enriched with features like upwelling, sinking, eddies, fronts, *etc*. Among them, upwelling brings nutrient-rich waters from subsurface layers to surface layers. During this process primary production enhances, which is measured in ocean colour sensors as high values of chlorophyll a (Chl a) (Banse, 1959, Johannessen *et al.*, 1987, Shetye *et al.*, 1990), satellite observations (Jayaram, 2011) and model studies (Shankar *et al.*, 2002, Haugen *et al.*, 2002; Shaji and Gangopadhyay, 2007). The present work analyses the spatial and temporal variability in Chl a provided by satellite ocean colour sensors to understand oceanographic variability in the SEAS.

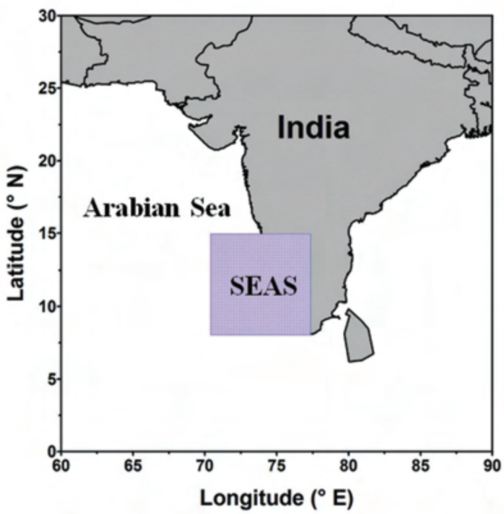

Fig. 1. Study area (SEAS) is demarcated using the violet shaded box in the Arabian Sea

2. Data

a. Chl a

Global Area Coverage on monthly Chl a at 9x9 km^2 of SeaWiFS sensor during the period September 1997- December 2010 were extracted from the NASA website (http://oceandata.sci.gsfc.nasa.gov/).

b. Wind

Daily averaged wind data on zonal and meridional scale were extracted from QuikSCAT for the period 19 July 1999 – 19 November 2009 (ftp://www.ssmi.com). Monthly wind was generated from the above dataset using ferret software. The alongshore component was calculated for each area using the monthly averaged dataset.

c. SST

SST from MODIS / AQUA sensor at 9 km spatial resolutions were downloaded from ocean colour website (http://oceandata.sci.gsfc.nasa.gov) on monthly scale.

d. Sea Surface Height Anomaly (SSHA)

Monthly SSHA data during January 1992 - February 2010 were downloaded from AVISO (www.aviso.soest.hawaii.edu). The SSHA data obtained from AVISO is the merged product of TOPEX, ERS and Jason-1 altimetry. The data has a spatial resolution of 0.33°.

e. Rain data

Weekly rainfall data from TMI sensor (December 1997 – February 2011) at 0.25° x 0.25° spatial resolution was downloaded to generate monthly rainfall rate.

3. Results

3.1. Spatial variability - Climatology of Chl a in the study area

Distribution of Chl a is examined to understand the climatology of these parameters in the study area. In this regard, the monthly averages generated from the data provided by the sensors SeaWiFS is used. The spatial distribution of Chl a brought out seasonal as well as regional scale variability along the SEAS with maximum ranges of the variability during the southwest monsoon period (Figure 2).

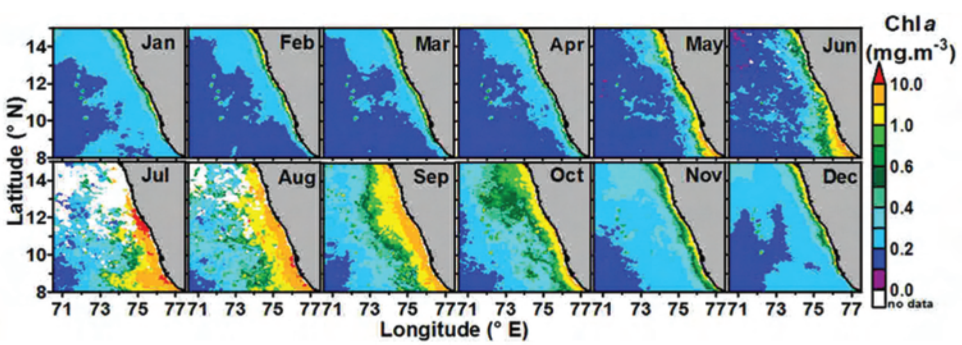

Fig. 2. Monthly climatology of Chl a in the SEAS. The upper panels represent the distribution pattern during January to June and the lower panel during July to December.

In general, the values of Chl a are high near the coast during all the months, which decreased towards offshore. During May, a marginal increase in Chl a sets in and this trend continues up to August. In addition, a significant cross-shore gradient is established in the southern area by June, which moves northward to encompass the entire study area by August and undergoes gradual decay during subsequent months. Similar to its intensification, the decay also starts from the south and moves northward. The gradient starts weakening from September and disappears from the southern area by October. By November, it fades off the northern area too. Thereafter, low Chl a values continue up to April all through the area.

3.2. Temporal variability

Most of the oceanographic and atmospheric parameters exhibit temporal variability. The time series observations on Chl a as obtained from SeaWiFS images during September 1997 – December 2010 is analysed to understand the temporal variability on Chl a. Spatial distribution has established the existence of large spatio-temporal variability in the study area especially during the southwest monsoon. Monthly Chl a were averaged for the selected area to explain their temporal variability. The influence of local environmental conditions (wind, ocean current, SSH and SST) on these parameters were also examined.

In general, Chl a in SEAS showed high values (> 1.20 mg m^{-3}) during June – September and very low values (~0.25 mg m^{-3}) during December – April. May and October / November can be considered as transition periods (Figure 3). The above three phases complete an annual cycle that recurs, while peak values occur during one of the months and found to vary each years between July and September (Table 1). In the following section, the corresponding supporting parameters representing oceanographic and atmospheric conditions were examined, to understand their influence on Chl a distribution.

The supporting parameters showed that in general, low SST/ SSHA and high equatorward components of currents and winds existed during the southwest monsoon. SST was found to follow a bi-annual oscillation, with lowest value in one of the months during the southwest monsoon, whereas, SSHA showed an annual cycle again with minima in one of the months during the southwest monsoon. The surface alongshore currents change its direction poleward during the northeast monsoon, but the alongshore winds has equatorward components irrespective of the season (0 to -5 ms^{-1}). The equatorward winds intensified during the southwest monsoon, except during 2006 and 2007. Thus, in general, the supporting parameters showed maximum equatorward current / wind and low SST / SSHA during the southwest monsoon, with their peak in one of the months similar to Chl a. In this context, it is to be noted that this low SST / SSHA and strong equatorward current / wind

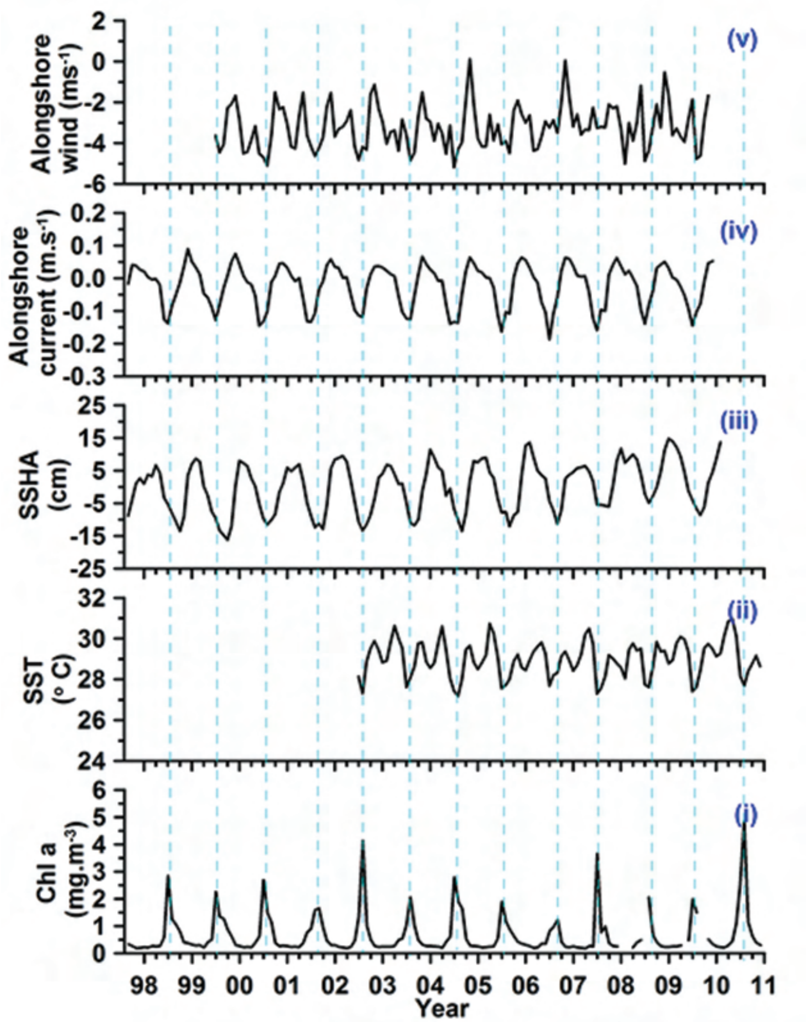

Fig. 3. Temporal variability in (i) Chl a, (ii) SST, (iii) SSH, (iv) alongshore surface current and (v) alongshore surface wind averaged for SEAS. The dotted vertical lines denote peak values of Chl a. The gap indicates non-availability of data. (Figure is redrawn from Shalin and Sanilkumar, 2014).

are associated features of upwelling (Bruce *et al.*, 1998; Shankar and Shetye, 1997; Shankar *et al.*, 2002). Therefore, the co-occurrence of high Chl a along with the above maxima/ minima of the supporting parameters during the southwest monsoon period suggests close linkage to them with upwelling. Further, the low SST and highest Chl a values co-occurred with the highest southward current/ wind in the same month or within the differences of one month during most of the years. This observation showed the increase in Chl a would have induced by upwelling as these factors are favorable for upwelling.

Table 1. Months during which maxima/ minima occurred in Chl a, SST, SSHA, current and winds in SEAS

Year	Maximum Chl *a*	Minimum SST	Lowest SSHA	Maximum southerly current	Maximum southward wind
1998	Jul	-	Oct	Jul	-
1999	Jul	-	Oct	Jul	Aug
2000	Jul	-	Aug	Jun	Aug
2001	Sep	-	Oct	Jul	Aug
2002	Aug	Aug	Aug	Aug	Jul
2003	Aug	Jul	Sep	Aug	Aug
2004	Jul	Aug	Sep	Jun	Jul
2005	Jul	Jul	Sep	Jul	Sep
2006	Sep	Jul	Sep	Jul	Mar
2007	Jul	Jul	Oct	Jul	Mar
2008	Aug	Aug	Aug	Jul	Feb
2009	Jul	Jul	Sep	Jul	Aug
2010	Aug	Aug	-	-	-

Conclusion

In general, Chl a in the SEAS (70.5-77.5°E, 8.0-15.0°N) follows an annual cycle with their maxima during the southwest monsoon period. Moreover, significant cross-shore gradient is observed on Chl a during the period, with high values (>1.0 $mg.m^{-3}$) near the coast. This gradient develops in the south by June and propagated north such that it encompasses the entire study area by August. Similarly, the decay of the gradient starts during September from south and moves north and completes the process by November. The spatial distribution on the three parameters showed large regional variability.

The supporting parameters showed low values of SST and faster southward current/ wind during the southwest monsoon period. These are the indicative features of intense upwelling. In most of the cases, the month of lowest SSTs and faster southward currents coincided with the month of peak Chl a. Therefore, the increase in Chl a were attributed to enhanced upwelling as evident from the supporting parameters. The present work brings out the utility of ocean colour data to study the oceanographic features in the SEAS, especially the upwelling phenomenon and its spatio-temporal variability.

Influence of upwelling in controlling surface chlorophyll was corroborated by time series analysis of monthly data on chla, SST, SSHA, winds, and currents. Peak values of chl-a were always concomitant with the highest equator-wards surface currents and lowest SST/SSHA.

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