

Formulation of an Empirical Relation between Chlorophyll and Sea Surface Temperature in the Southeastern Arabian Sea

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ABSTRACT

Present study formulates an empirical relation between sea surface temperature (SST) and chlorophyll (Chl) in the Southeastern Arabian Sea using data collected during 2017. SST was found to decrease due to upwelling of cold nutrient rich waters, thus causing enhancement of Chl in the coastal and nearshore waters. Based on this, an empirical relationship exists which is inversely correlated during peak upwelling and intense biological production. The linear regression generated a significant correlation coefficient ($0.52 \leq R^2 \leq 0.64$) in the month of July, August and October. Although other factors influence Chl, SST can be considered as a significant indicator of biological production with respect to seasonal upwelling. Among the empirical relations, a definite single equation requires the assessment of subsurface Chl to reveal the underlying relationship.

Keywords: Upwelling; Sea surface temperature; Chlorophyll; Arabian Sea

1. INTRODUCTION

Arabian Sea experiences strong seasonality in biological production in which the summer monsoon induces intense upwelling, vertical mixing and phytoplankton blooms along the southwest coast of India^{1,2,3}. On the other hand, pre-monsoon causes stratification in the water column thereby limiting the availability of subsurface nutrients for phytoplankton proliferation. Moreover, the surface layer of the Arabian Sea waters seems to be warmer ($> 30\text{ }^\circ\text{C}$)⁴ during the pre-monsoon season (April-May). The anthropogenic pressures along the coast is high, due to agriculture, industrial growth, excessive fishing, mariculture, terrestrial runoff and fresh water influx thus, increasing the nutrient budget of the coastal waters^{5,6}. All these factors significantly alter the physical oceanography of the region which might influence positively or negatively the biogeochemical processes occurring in the ocean. As phytoplankton constitutes the primary trophic level, it has been directly affected by environmental changes due to different climatic scenarios. Understanding these biophysical relationships in ocean environment is a milestone in explaining marine ecosystem response to different environmental forcings^{7,8}. Phytoplankton plays a major role in oceanic carbon cycle since it accounts for 50 per cent of global biological production⁹. Primary productivity fluctuates seasonally as well as regionally in the marine environment affected by the variation in numerous physical and chemical factors. Specifically, the physical drivers such as temperature, wind speed, sea surface height, light availability, etc. profoundly alter the biological production intensity in coastal and marine systems¹⁰. In this regard, several studies have been carried out in the Atlantic

and Pacific region to reveal the relationship between biophysical variables particularly, sea surface temperature and Chlorophyll¹¹⁻¹⁴. Interestingly, these studies suggest that a significant linear relation exists between the physical variables and phytoplankton abundance. In this context, the present study aims to verify the relation between seasonal physical forcing namely, SST and seasonal Chl in the Southeastern Arabian Sea using linear regression analysis. Furthermore, the objective includes the formulation of an empirical relation between the variables studied.

2. MATERIALS AND METHODS

Surface water sampling were carried out onboard five cruises of *INS Sagardhwani* (Cruise No. 194, 202, 203, 204 and 207) in 12 transects running perpendicular to the coast of Southwest India in the Arabian Sea. The study area lies between $7\text{ }^\circ\text{N}$ to $15\text{ }^\circ\text{N}$ latitude and $72\text{ }^\circ\text{E}$ to $79\text{ }^\circ\text{E}$ longitude, and sampled during February to October 2017. The map showing sampling locations is as given in Fig. 1.

Chl in the water samples were analysed fluorimetrically using turner designed 10AU Fluorometer. Water samples were filtered through 25 mm $0.45\text{ }\mu\text{m}$ GF/F filter and followed by extraction with 90 per cent acetone. Then, the samples were vortexed and kept in darkness at $-4\text{ }^\circ\text{C}$ for 24 h. After centrifugation, fluorescence was measured in the extracted samples and Chl is calculated. The SST was obtained from conductivity-temperature-depth (CTD) profiler deployed at respective stations.

3. RESULTS AND DISCUSSION

The monthly variation of SST in the Southeastern Arabian Sea is as given in Fig. 2. SST ranged between $24.4\text{ }^\circ\text{C}$ and $30.9\text{ }^\circ\text{C}$

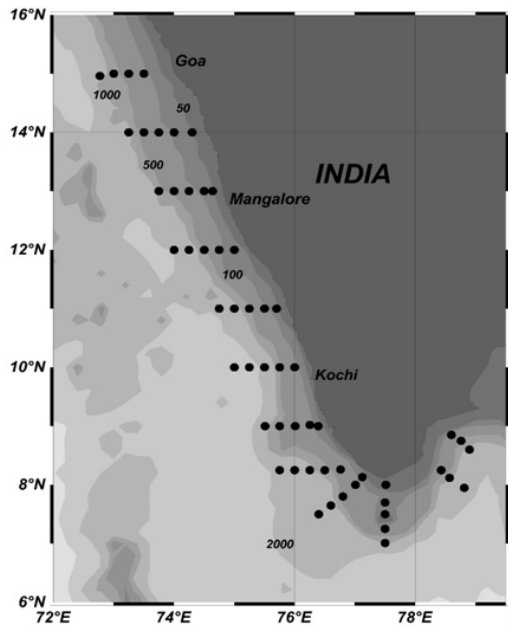


Figure 1. Map showing study area, bathymetry and sampling locations.

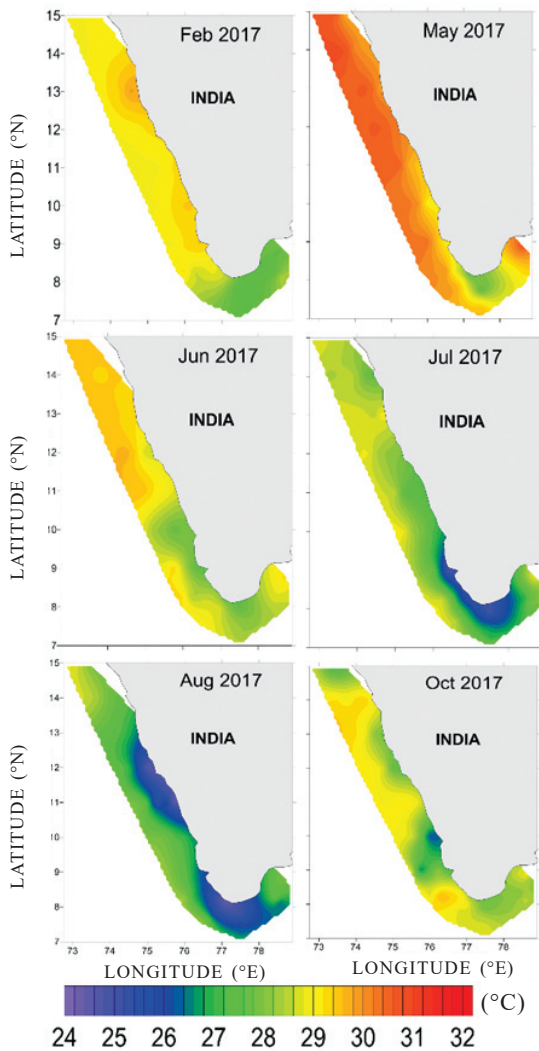


Figure 2. Monthly SST in the Southeastern Arabian Sea during Feb-Oct 2017.

in the entire study region. It shows a maximum in May and a gradual decrease from June to August followed by an increase in October 2017. High SST during April-May is driven by the net heat gain during pre-monsoon and minimum wind mixing. During southwest monsoon, upwelling along the western boundary drove low SST from June-August. As the monsoon withdraws consequently, decay of upwelling process causes SST rise in the succeeding months. This change in physical oceanography obviously have an influence in the biological production in terms of Chl which can be observed in its distribution pattern as given in Fig. 3. The concentration of Chl varied from 0.05 mg m^{-3} to 5.95 mg m^{-3} during Feb-Oct 2017. The minimum Chl in the pre-monsoon results from nutrient limitation in the surface layers. This is because the warming stratifies the ocean and suppress the mixing of nutrients from the subsurface reducing Chl¹⁵. To assess the biophysical relationship between SST and Chl, linear regression was

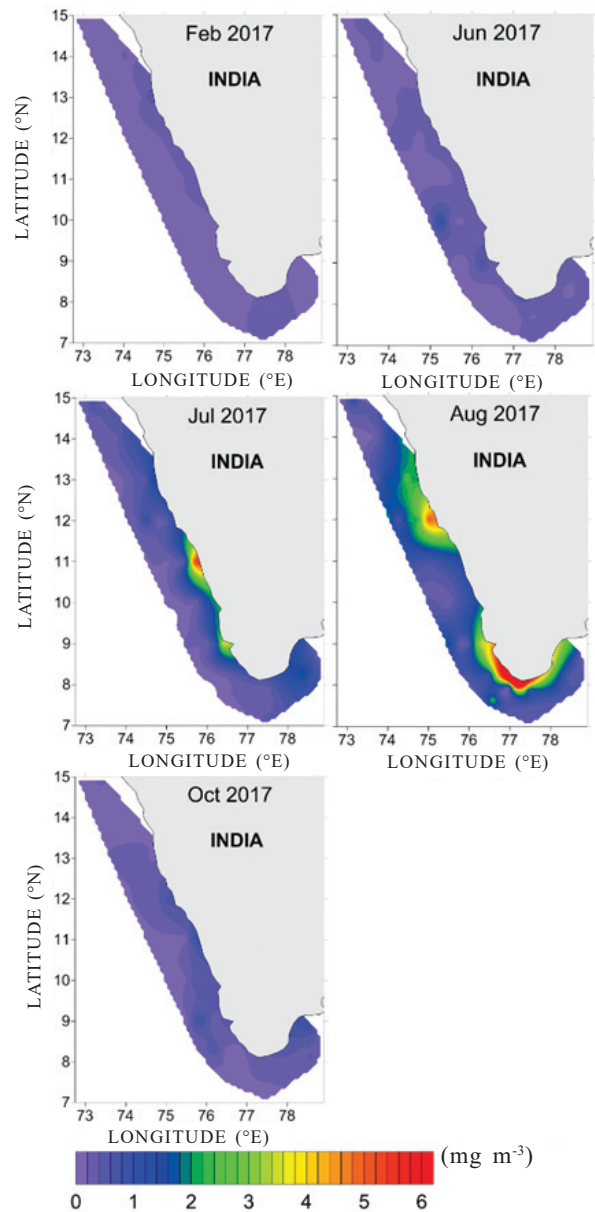


Figure 3. Monthly Chl during the study period.

adopted and the scatter plot generated significant results as shown in Fig. 4. Here, the pre-monsoon plot (Feb) shows moderate correlation indicating that stratification is partially correlated to reduction in Chl. Chl averages 0.16 mg m^{-3} (Feb) to 1.43 mg m^{-3} (Aug) which implies a gradual increase from pre-monsoon to monsoon season. The maximum Chl concentration was observed during the monsoon due to intense upwelling which brings cold nutrient rich subsurface water to upper layer thus, promoting biological production.

The upward movement of cold waters to the surface concurrently with increase in Chl level substantiates an inverse relation between these variables. As can be seen from the correlation plot, there exists a significant correlation between SST and Chl even though, numerous factors influence primary productivity. The correlation coefficient (R^2) amounts to 0.62, 0.64 and 0.52 in the month of July, August and October, respectively. This indicates that the progression of upwelling generates favourable conditions for phytoplankton growth as well as a significant decrease in SST. In addition, phytoplankton blooms can be observed along the coast suggesting the interaction of coastal waters with rocky shorelines inducing horizontal and vertical gyres as a source of nutrient inputs to surface layers. Chl was found to be enhanced between $7^\circ\text{N} - 9^\circ\text{N}$

$^\circ\text{N}$ latitude and $75.5^\circ\text{E} - 79^\circ\text{E}$ longitude due to high nutrient inputs preferably through upwelling as previously reported by Thomas¹⁶, *et al.*.

In contrast to this, a similar peak of Chl was observed between $10^\circ\text{N} - 13^\circ\text{N}$ latitude and $73.75^\circ\text{E} - 76^\circ\text{E}$ longitude which can be attributed to nutrient loaded fresh water influx through riverine/estuarine discharges. Although high levels of Chl persists in the month of August, it decreased to $0.07 \text{ mg m}^{-3} - 0.91 \text{ mg m}^{-3}$ averaging 0.26 mg m^{-3} in October due to the decay of upwelling and the Chl concentration may be associated with nutrient regeneration from biodetritus. In general, Chl recorded high concentration along the near shore and coastal waters compared to offshore regions.

The linear regression suggests numerous empirical relations of significant correlation coefficient (Table 1) above 0.5 between surface Chl and SST. The R^2 values for respective months indicate that the inverse correlation becomes more significant when the system changes from high SST/low Chl to low SST/high Chl domain. This baseline study supports the hypothesis that a variation in SST with respect to upwelling would affect the distribution of Chl in the Southeastern Arabian Sea and an inverse relationship exists. For a comprehensive evaluation of Chl and SST relationship in the study region, future work should include the assessment of subsurface Chl concentration.

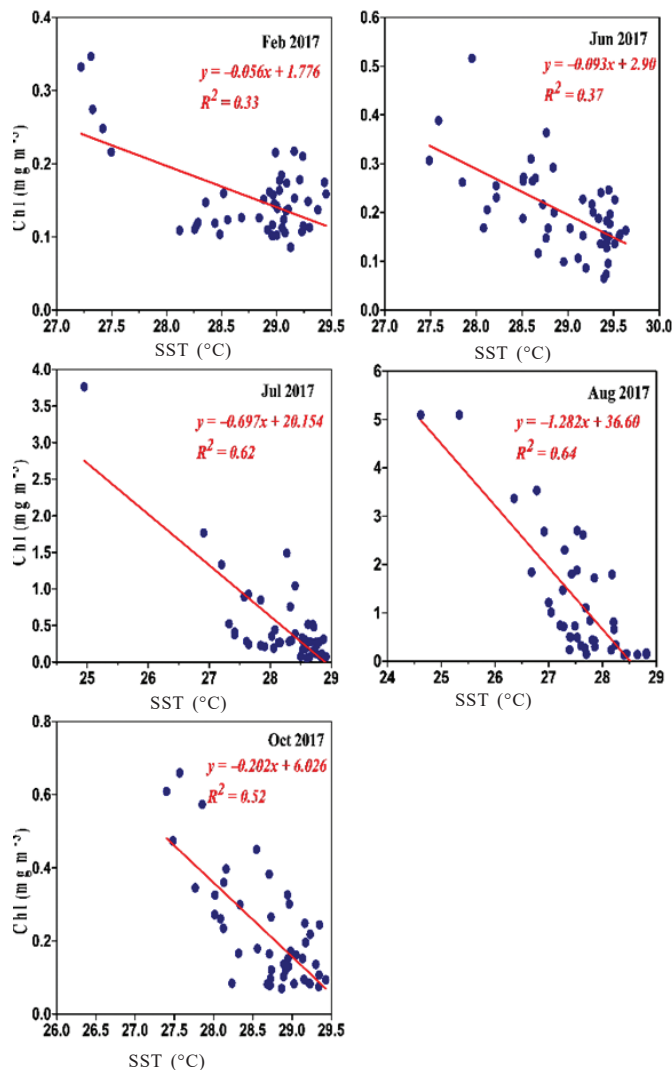


Figure 4. Scatter plot of SST vs Chl.

Table 1. Result of linear regression analysis

Region	Month	Linear Regression	R^2	
All region	Feb	$\text{Chl} = -0.056 * \text{SST} + 1.776$	0.33	
	Jun	$\text{Chl} = -0.123 * \text{SST} + 3.77$	0.38	
	Jul	$\text{Chl} = -0.697 * \text{SST} + 20.154$	0.62	
	Aug	$\text{Chl} = -1.282 * \text{SST} + 36.60$	0.64	
	Oct	$\text{Chl} = -0.202 * \text{SST} + 6.026$	0.52	
$7-9^\circ\text{N}$	Feb	$\text{Chl} = -0.064 * \text{SST} + 1.960$	0.53	
	$75.5-79^\circ\text{E}$	Jun	$\text{Chl} = -0.112 * \text{SST} + 3.386$	0.41
		Jul	$\text{Chl} = -0.301 * \text{SST} + 8.785$	0.21
	Aug	$\text{Chl} = -2.256 * \text{SST} + 62.893$	0.44	
	Oct	$\text{Chl} = -0.244 * \text{SST} + 7.183$	0.81	
	$10-13^\circ\text{N}$	Feb	$\text{Chl} = 0.073 * \text{SST} - 1.992$	0.24
$73.75-76^\circ\text{E}$		Jun	$\text{Chl} = -0.022 * \text{SST} + 0.840$	0.01
	Jul	$\text{Chl} = -0.331 * \text{SST} + 9.757$	0.27	
	Aug	$\text{Chl} = -1.474 * \text{SST} + 41.472$	0.79	
	Oct	$\text{Chl} = -0.286 * \text{SST} + 8.497$	0.66	

4. CONCLUSIONS

High SST gradient indicates effective upwelling process and prevalence of cold nutrient rich waters in the surface layer. Hence, mixing of nutrients into the surface layer causing enhanced Chl concentrations. The study observed that minimum SST range ($24.4^\circ\text{C} - 28.8^\circ\text{C}$) was coincident with mean Chl concentrations (1.43 mg m^{-3}) peak. Chl revealed a well-defined coast-offshore gradient showing a decrease in concentration from the coast to offshore waters. Significant

inverse relation ($R^2 = 0.52-0.64$) in the months of maximum biological production suggests a rapid transition of the area from high SST/low Chl to low SST/high Chl domain and phytoplankton blooms along the coast, specifically in the coastal waters of Cape Comorin. The empirical inverse relation provides insight to predict the change in SST with Chl in the exclusive economic zone of India where strong upwelling occurs.

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ACKNOWLEDGEMENTS

We thank the Director, Naval Physical and Oceanographic Laboratory (NPOL), Kochi for the facilities provided. Research Associateship (NPOL/A/EST/1/127/JRF/RA) from Defence Research and Development Organisation (DRDO), Ministry of Defence, Government of India through Naval Physical and Oceanographic Laboratory is sincerely acknowledged. Special thanks to the officers and crew of *INS Sagardhwani* for their help during sampling.

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In the present study, he has carried out the formulation of empirical relations, performed statistical analysis, preparation of figures and writing the manuscript with input from all authors.

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In the current study, he designed the research, conceptualised and formulated the objectives, carried out pilot studies, directed the analysis of data sets, provided statistical advice and approved the final manuscript.