

Climate change and biological productivity: Indian Ocean

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The Coastal Zone Color Scanner (CZCS, 1978-1986) and SeaWiFS (1997 – 2010) derived chlorophyll data were used to analyze decadal variability. Change in chlorophyll values over the two decades is examined in context of global reports of decline in chlorophyll over the period. The Reynolds Sea Surface Temperature (SST) data were analyzed for 30 years (1978-2011). The Arabian Sea and Bay of Bengal show increase in SST more in Arabian Sea (AS) than in Bay of Bengal (BOB). The relationship between chlorophyll and SST has been studied, which shows change in the pattern over a period of time, Arabian Sea shows a positive relationship between chlorophyll and SST during 1980's while an inverse relationship is observed during 2000's. Thus it is very important to understand the pattern of chlorophyll variability as well the interrelationship with SST over a long period to make out the impact of climate over the ocean biology.

[Key Words: Climate Change, Chlorophyll, Sea Surface Temperature, Decadal change, Indian Ocean]

Introduction

Satellite measurements of ocean color provide a means of quantifying ocean productivity on a global scale and linking its variability to environmental factors. The seasonal variation in mixed layer dynamics and upwelling is an important determinant of annual cycle of primary productivity in the AS¹. Nutrient limitation interacting with changes in light intensity and temperature can lead to seasonality in primary and secondary production. The climate signatures in the coastal time-series are stronger given more direct connections to primary productivity via changes in nutricline depth and local wind-driven processes that modify fluxes and stratification. Nitrogen fixation, dust deposition, and eddies are relatively unimportant to coastal PP. In coastal systems, strong bottom-up, nutricline-driven regulation dominates and leads to large variability and large-scale climate imprints². A Study³ revealed that even the phytoplankton cell size may vary on inter annual and decadal scales resulting in changes in food chain length and hence energy transfer to higher trophic levels. Further, a shift to smaller sized phytoplankton has been hypothesized as a response to ocean

warming. Thus, this approach, estimating phytoplankton cell size from remotely-sensed temperature and chlorophyll, has the potential to provide global monitoring of an aspect of phytoplankton community structure likely to be responsive to future climate change.

The inverse relationship between temperature and nutrients concentration occurs seasonally in surface waters to varying degrees depending upon the geographical locations⁴. It is also shown that that surface warming in the permanently stratified ocean regions is accompanied by reductions in productivity. Intra-annual variability in chlorophyll vis-à-vis SST shows inverse relationship in the AS at most of the locations however, the northwest AS showed positive relationship during October to December and a negative during January to April⁵. The BOB at the northeast locations showed positive relationship, whereas no definite assessment could be made for other locations due to narrow range of chlorophyll concentration. Therefore, an assessment of chlorophyll variability along with Sea Surface temperature (SST) in the AS and BOB over a period of decade and its comparison with the values two decades back may give an

idea of impact of climate change on chlorophyll and SST in this region.

Temporal changes in ocean biology from inter annual to decadal scales can be traced directly to dominant modes of variability in physical properties. The Satellite data was used to assess the chlorophyll and SST pattern over the period of time >20years. The CZCS (1978 –86) derived chlorophyll data was used as representation of 1980's while SeaWiFS derived (1997 – 2010) chlorophyll data is used as representation of 2000's situation. Change in chlorophyll values over the two decades is examined in context of global reports of decline in chlorophyll over the period. The impact of SST over a time frame of around 30 years (1978 to 2011) was assessed using Reynolds SST data provided by PODAAC, the relationship between chlorophyll and SST has been studied, to examine the pattern of relationship over a period of time.

Material and Methods

The changes in the chlorophyll pattern in the AS and BOB over the two decades, is studied using SeaWiFS derived chlorophyll data for the period 1997–2010 and CZCS derived chlorophyll data for the period 1978 – 86. The SeaWiFS derived level –3 processed data has been used. The Chlorophyll datasets were generated, using Ocean Color- 4 (OC4) algorithm⁶. Monthly average, chlorophyll images have been analysed. This is level-3 global gridded product with 9 km resolution. The Standard Mapped Images (SMI) generated from SeaWiFS data has been used. The Coastal Zone Color Scanner (CZCS) derived processed data of Chlorophyll has been used to understand the pattern during 1980's. This data has been obtained from DAAC, NASA, USA.

All the chlorophyll images were regenerated by using Ocean Color- 4 (OC4) algorithm. Therefore, the comparison is possible. The cloud free period data (September–April) has been used for the period of two decades (1980's and 2000's). The area under total AS and BOB were averaged and analyzed separately. The impact of SST over a time frame of around ~30 years (1978 to 2011) studied using Reynolds SST data provided by PODAAC. This is global data. Processing and analyse has been done using SeaDAS, ENVI, Panoply and HDF viewer software. Before classification, masking has been done for the values $>15.0 \text{ mg m}^{-3}$ (Chlorophyll) and $>50^\circ \text{ C}$ (SST) owing to land mask.

Results and Discussion:

The decadal analysis of chlorophyll shows that the values are higher in the AS and BOB (Fig.1 and 2) throughout the study period i.e. September to April during recent year's (2000's) as compared to that of the decade 20 years back (1980's). The Chlorophyll range is between 0.5–1.3 mg/m³ during 2000's, which is quite high as compared to that of 80's (0.4–0.9 mg/m³). Recent decade shows that BOB chlorophyll values from 0.5 to 0.7 mg/m³ whereas during 1980's chlorophyll ranges between 0.2–0.45 mg/m³. Southwest (SW) and Northeast (NE) monsoon are periods when new nutrients were at or above the saturation concentration for uptake.

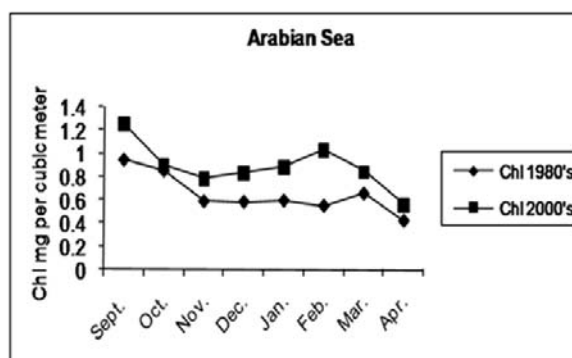


Fig.1 Seasonal pattern of chlorophyll in the Arabian Sea during 1980's and 2000's

The SST data analysis was done for three series of data representing 1980's, 1990's and 2000's which became possible due to

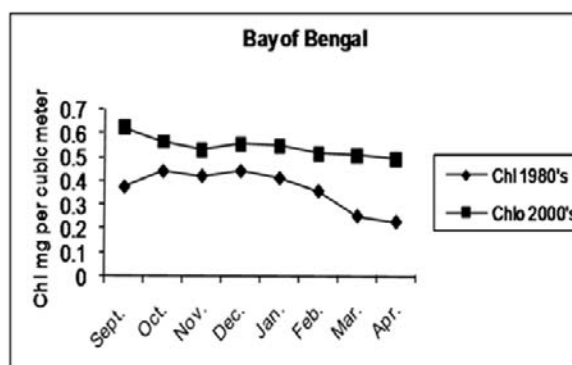


Fig. 2 Seasonal pattern of chlorophyll in the Bay of Bengal during 1980's and 2000's

availability of continuous data from PODAAC. This data was generated by averaging the SST values for 10 years' duration for each series for

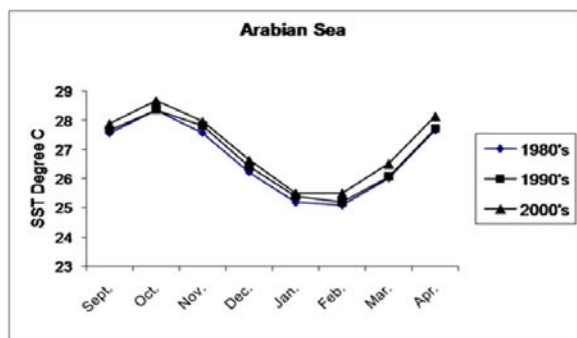


Fig. 3 Seasonal pattern of Sea Surface Temperature (SST) in the Arabian Sea during 1980's, 1990's and 2000's

the period September to April. Average SST shows gradual increase in the decade from 1980 to 1990 and sharper increase from 1990 to 2000 in AS (Fig. 3). The seasonal pattern remains same but more increase observed during February to April. The BOB shows in general slight increase in SST in the decades 1980 to 2000 except during the month December when its much higher during 1990 and again shows increase in 2000 (Fig.4).

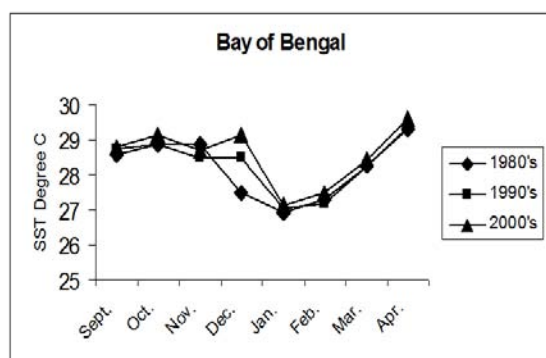


Fig. 4 Seasonal pattern of Sea Surface Temperature (SST) in the Bay of Bengal during 1980's, 1990's and 2000's

In order to understand relationship between chlorophyll and SST the average value for available chlorophyll during 1980's (1978 – 86) for AS was taken and SST value for the AS for the same period was calculated and chlorophyll value was regressed against the SST value for September to April. The results show positive relationship during 1980's (Fig. 5a). However, when data during 2000's is analyzed it shows somewhat different result. Chlorophyll shows inverse relationship till 28° C and then more or less constant (Fig. 5b). The BOB shows no clear pattern during 1980's (Fig. 6a). During 2000's the BOB shows higher chlorophyll with almost similar pattern (Fig. 6b).

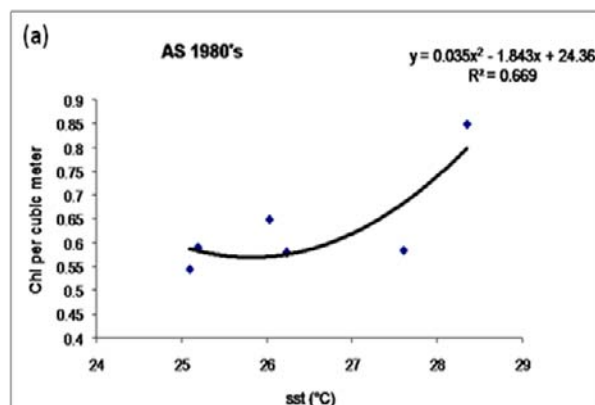


Fig. 5 (a) Relationship of Chlorophyll and SST in the Arabian Sea (AS) during 1980's

The observed Chlorophyll changes primarily reflect biomass changes due to dampened or increased nutrient fluxes to the upper-lit layers. The analysis reveals by ⁷ that the chlorophyll concentration is much higher in the northern and central AS during 2000's as compared to that during 1980's. An observation⁸ suggests that if coastal upwelling were increased as a consequence of global warming surface waters would be enriched not only in nutrients, but also in dissolved carbon.

Analysis of satellite and in situ time-series finds a global trend of increasing but unevenly distributed primary production. The analysis has shown a basin-specific response of phytoplankton,

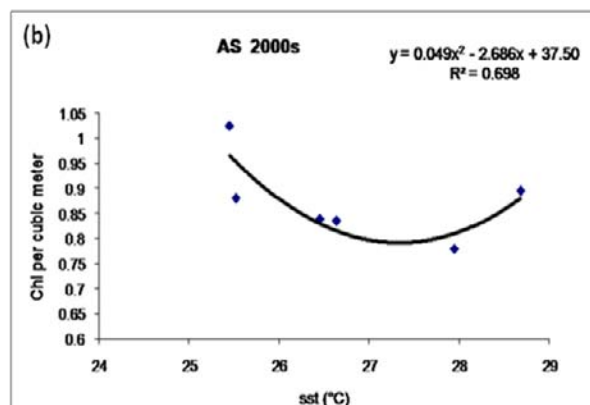


Fig. 5 (b) Relationship of Chlorophyll and SST in the Arabian Sea (AS) during 2000's

to large-scale climate oscillators Interaction between the main pycnocline and the upper ocean seasonal mixed layer is one mechanism behind this correlation⁹. However, the least productive oceanic habitats or the oligotrophic gyres in four of the world's major oceans are reported to be

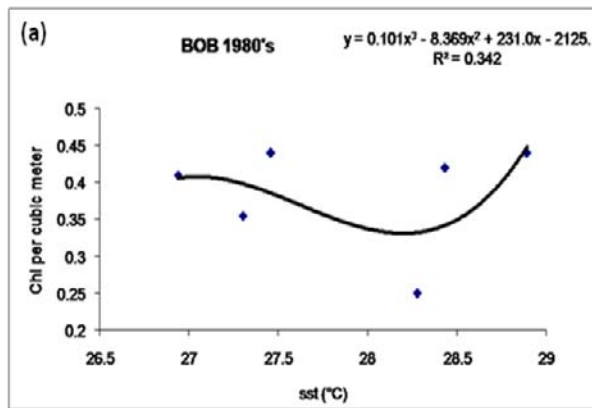


Fig. 6 (a) Relationship of Chlorophyll and SST in the Bay of Bengal (BOB) during 1980's

expanding since 1998 at average rates between 0.8%/yr and 4.3%/yr¹⁰. Our results show increase in chlorophyll concentration during 2000's as compared to that during 1980's. If due to any reason the stratification of the surface ocean gets changed then it may have potential effects on phytoplankton growth, at different spatial and temporal scales. Warmer waters, in general, are very stable near the surface, contain phytoplankton of small cell size and are very

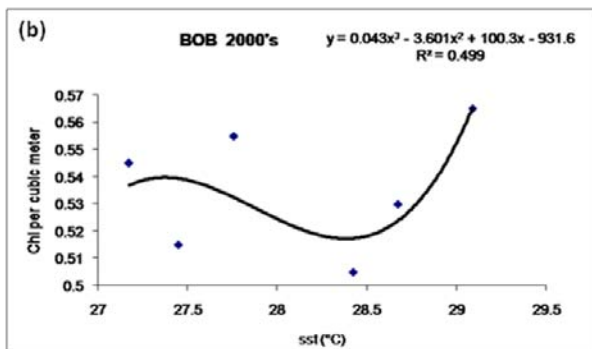


Fig. 6 (b) Relationship of Chlorophyll and SST in the Bay of Bengal (BOB) during 2000's

efficient at recycling nutrients and biogenic material in the upper ocean. The Sea Surface Temperature is altered through the heat loss or gain at the ocean surface and by mixing with water from below the surface or from advective horizontal mixing with water from another location. The high SST during April and October is driven by net heat gain. The study shows increase in chlorophyll concentration particularly in the northern AS and Northern BOB while there is increase in SST as well in this region. It seems though SST has increased to certain extent but nutrients are available in the northern region, which makes higher biological production possible.

This is also possible that species might have changed adapting to temperature. Water temperature also has a direct influence on phytoplankton growth and metabolic rates. Production increases with increasing temperature until a species-specific maximum is reached, after which rates decline rapidly¹¹. It is also observed that global chlorophyll concentrations indicated a decrease from the CZCS record to the present, of about 6%. Larger reductions occurred in the northern high latitudes¹². Conversely, chlorophyll in the low latitudes increased. It is reported that the "phytoplankton" has been declining globally over the 20th century and this is about 1% of the global average per year¹³. Strong chlorophyll Thermocline Depth correlation would be expected where nutrients are limiting and the thermocline is close to the surface, such as in tropics and in upwelling regions. A good correlation between both Chlorophyll and Sea Surface Height (SSH) has been clearly observed in Pacific¹⁴.

The physical control on surface biomass associated with MLD or TD controls on light and nutrients cannot account for chlorophyll variability associated with grazing pressure or Aeolian deposition of micronutrients. In one article [15] the impact of global warming on primary productivity is investigated and concluded that the dataset is not yet long enough to detect a global warming trend.

Conclusion

This study brings out few significant results/observation mainly, Chlorophyll values in the AS and BOB have increased substantially as compared to the values 2 decade back. The SST values in AS show gradual increase from 1980 to 1990 and sharp increase from 1990 to 2000. The BOB shows gradual increase from 1980 to 2000 except during December when it is much sharper increase from 1980 to 1990 and then to 2000. The relationship between chlorophyll and SST shows positive relationship during 1980's and an inverse relationship during 2000's¹⁵. This may be due availability of sufficient nutrients, along with the tolerance limit of phytoplankton for the increase in SST. Rising temperatures will also result in changes to the distribution of phytoplankton species¹⁶. Some species, adapted to warm temperatures and low nutrient levels (usually small picoplankton) will expand their range, whilst others that prefer turbulent, cool and nutrient-rich waters (mostly large phytoplankton, e.g. diatom species) may migrate pole ward as temperatures rise. These shifts in species composition may alter carbon export and the

availability of food to higher trophic levels. A statistical analysis of biogeochemical model output suggests that a Primary Productivity or Chlorophyll time series of ~40-year duration will be needed to distinguish a climate change signal from natural inter annual to decadal variability¹⁷. Whether these long-term trends caused by changes to Earth's climate, or are they responses to natural ocean cycles is still not fully understood. The length of time series of satellite ocean color measurements is right now not enough to understand the phenomenon completely, but recent results demonstrate that definitely the changes have occurred. Are these long-term trends caused by changes to Earth's climate, or are they responses to natural ocean cycles that are not yet fully understood.

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