

## Is there impact of climate change on biological productivity in the Indian Ocean

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SeaWiFS derived eight days average, chlorophyll images for 10 years from 1997 onward have been analysed, representing the present situation. Few representative locations in the Arabian Sea and Bay of Bengal were studied to understand the chlorophyll variability. Chlorophyll values are generally higher during 2000's as compared to that of during the 1980's. In order to study the expansion or contraction of area under low or high chlorophyll region, the image was classified into three zones viz. oligotrophic, mesotrophic and eutrophic waters based on chlorophyll range. A comparison is made of average values from October to April in CZCS derived (1980's) and SeaWiFS derived (2000's) chlorophyll images. Chlorophyll concentration in the northwest Arabian Sea has increased significantly during the 2000's as compared to that of 1980's and the area under eutrophic zone i.e. chlorophyll rich waters has increased in spatial extent. An increase in chlorophyll concentration in this decade, as compared to two decades back, indicates a positive sign, against the reported global warming.

[**Keywords:** Chlorophyll, Phytoplankton, Ocean productivity, Oligotrophic, Eutrophic]

### Introduction

The observed reductions in ocean productivity during the recent post-1999 warming period provide insight on how future climate change can alter marine food webs<sup>1</sup>. Interannual changes in phytoplankton abundance are small relative to total standing stocks and require accurate, long-term measurements to detect. It is also clear from the current analysis that surface warming in the permanently stratified ocean regions is accompanied by reductions in productivity. Intraannual variability in chlorophyll vis-a-vis SST shows inverse relationship in the Arabian Sea at most of the locations. In the Northwest Arabian Sea a positive relationship during October to December and a negative during January to April is observed. In the Bay of Bengal at the northeast locations positive relationship is observed, whereas no definite assessment could be made for other locations due to narrow range of chlorophyll concentration. These observations in the Arabian Sea and Bay of Bengal for four years provide an additional dimension to the criteria required for delineating the oceanic zones<sup>2</sup>.

Seasonal variation in mixed layer dynamics and upwelling is an important determinant of annual cycle of primary productivity in the Arabian Sea<sup>3</sup>. Nutrient

limitation interacting with changes in light intensity and temperature can lead to seasonality in primary and secondary production. Ocean colour dataset provides the basis for temporal and spatial variability studies. Southwest (SW) and Northeast (NE) monsoon were periods when new nutrients were at or above the saturation concentration for uptake. Bulk of aquatic productivity (75%) occurs in the open ocean (gyre) systems, by virtue of their vast extent. Global chlorophyll concentrations indicated a decrease from the CZCS record to the present, of about 6%. Larger reductions occurred in the northern high latitudes. Conversely, chlorophyll in the low latitudes increased. Decreases ranged from about 9% in autumn (Oct–Dec) to nearly 11% in summer (Jul–Sep). No significant change was observed in winter (Jan–Mar) or spring (Apr–Jun)<sup>4</sup>. Large areas of the Indian Ocean showed substantial increases during all four seasons. Since 1998, the least productive oceanic habitats or the oligotrophic gyres in four of the world's major oceans have been expanding at average rates between 0.8%/yr and 4.3%/yr. Rate of expansion is greater during the winter in three of these oceans<sup>5</sup>.

The results also show that dampening the effect of interannual variability by averaging over two decades allows the decadal variability to be revealed and analyzed. Therefore, it can be anticipated that averaging over several decades may eventually reveal longer-term trends related to subtle changes in physical forcing. This emphasizes the critical importance of reanalyzing historical data. This important role of ocean physics indicates that the observed Chl changes primarily reflect biomass changes due to dampened or increased nutrient fluxes to the upper lit layers. Changes in the photo acclimation state of phytoplankton probably also intervene, without obscuring the global picture, however. Quantifying the respective role of both phenomena would require the parallel examination of Chl and other quantities more directly tied to biomass<sup>6</sup>. Have shown a basin-specific response of phytoplankton, to large-scale climate oscillators. Multi-decadal changes in global phytoplankton abundances are related to basin-scale oscillations of the physical ocean, specifically the Pacific Decadal Oscillation and the Atlantic Multi decadal Oscillation. This relationship is revealed in ~20 years of satellite observations of chlorophyll and sea surface temperature. Interaction between the main pycnocline and the upper ocean seasonal mixed layer is one mechanism behind this correlation.

The article by<sup>7</sup> reveals that “phytoplankton” has been declining globally over the 20<sup>th</sup> century. Phytoplankton decline is documented to be about 1% of the global average per year. This trend is particularly well documented in the Northern Hemisphere and after 1950, and would translate into a decline of approximately 40% since 1950. Since the early 1980’s, ocean phytoplankton concentrations that drive the marine food chain have declined substantially in many areas of open water in Northern oceans, according to a comparison of two datasets taken from satellites.

This study is undertaken to understand the effect of two decades on chlorophyll concentration in the Arabian Sea and Bay of Bengal using Satellite data. CZCS (1978–86) derived chlorophyll data was used as representation of 1980’s while SeaWiFS derived 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.

## Material and Methods

In order to analyse the change in chlorophyll pattern over the two decades time SeaWiFS derived chlorophyll for the period 1997 – 08 and CZCS derived chlorophyll for the period 1978 – 86 were used to understand the change in chlorophyll pattern.

SeaWiFS derived level-3 processed data has been used. Chl-a images were generated, by using Ocean Color-4 (OC4) algorithm<sup>8</sup>. Eight days average, chlorophyll images have been analysed. This is level-3 global gridded product with 9 km resolution. Standard Mapped Images (SMI) generated from SeaWiFS data has been used. Cloud free data (October-April) has been used for the period of 1997-2008. Costal Zone Color Scanner (CZCS) derived processed data of Chlorophyll has been used. This data has been obtained from DAAC, NASA, USA. Chl-a images, have been regenerated by using Ocean Color-4 (OC4) algorithm. Therefore, the comparison is possible. Ten years average data of 1979-86 from October to April has been analyzed. Monthly data was used for the analysis.

To understand the spatial and temporal distribution of Chl-*a* in the parts of the AS and the BOB, few locations (Fig. 1) were studied. Nine locations have been chosen in both the areas, which are of near coast, offshore and open ocean waters. CZCS and SeaWiFS derived chlorophyll images for the same period were studied to understand the change over the twenty years period (two decade) and seasonal variability in the Arabian Sea and Bay of Bengal. In order to avoid data unavailability due to cloud cover problem, the monthly data were averaged and the results were analysed on a seasonal (October to April) basis.

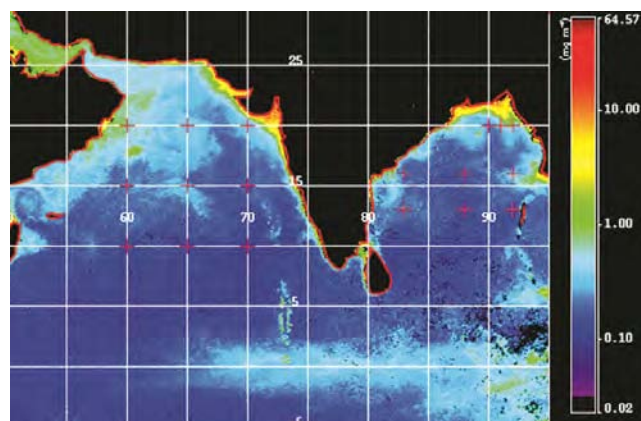


Fig. 1—SeaWiFS derived Chl-*a* image for November, 1997 showing studied locations in AS and BOB

Processing and analysis of the CZCS and SeaWiFS derived chlorophyll-a images has been done using ENVI-4.4 software. Before final classification, masking has been performed for the values  $>50.0 \text{ mg m}^{-3}$  owing to land mask. To examine the changes in 80's and 2000's, images were divided in to three different categories. To study the expansion or contraction of chlorophyll-a all area's sea waters divided in to three zones based on their Chlorophyll-a values. In the image analysis, sometimes the value goes up to  $7.0 \text{ mg/m}^{-3}$  in the Ocean which is considered as very high chlorophyll-a and some areas are covered by very low chlorophyll-a values ( $0.02 \text{ mg m}^{-3}$ ). So for this region of the globe we consider  $0.02 \text{ mg m}^{-3}$  as minimum and  $7.0 \text{ mg/m}^{-3}$  as maximum chlorophyll-a values. Based on this analysis we have divided the water in three zones. Oligotrophic water ( $0.02\text{-}0.3 \text{ mg/m}^{-3}$ ), Mesotrophic water ( $0.3\text{-}0.8 \text{ mg/m}^{-3}$ ) and Eutrophic water ( $0.8\text{-}7.0 \text{ mg/m}^{-3}$ ).

## Results and Discussion

### Decadal variability

#### Arabian Sea

The nine representative locations studied in the Arabian Sea show a pattern of generally higher chlorophyll in the northern Arabian Sea during 1997-06 (SeaWiFS derived) as compared to that during 1978-86 (CZCS era). However, in the southern locations not much difference is observed and values are close to each other. At  $20^\circ\text{N } 70^\circ\text{E}$  a northeast location in the Arabian Sea values are higher now as compared to 20 years back (CZCS era) throughout the study period. Large increase in chlorophyll values are observed particularly during, December to February (Fig. 2a). At  $20^\circ\text{N } 65^\circ\text{E}$ , another location in the northern Arabian Sea highest increase is observed in February (Fig. 2b). However, at  $20^\circ\text{N } 60^\circ\text{E}$  a northwest location in the Arabian Sea values are higher from December to March (Fig. 2c). Similarly at mid Arabian Sea locations ( $15^\circ\text{N } 70^\circ\text{E}$ ,  $15^\circ\text{N } 65^\circ\text{E}$  and  $15^\circ\text{N } 60^\circ\text{E}$ ) chlorophyll concentration is high with different degrees of magnitude particularly during December to March during the current period as compared to that of mid 80's (Fig. 3a,b,c).

Southern Arabian Sea does not show much of variation may be because the range itself is quite narrow (Fig. 4 a,b,c).

#### Bay of Bengal

Northwest locations in the Bay of Bengal show considerably high chlorophyll at present as compared

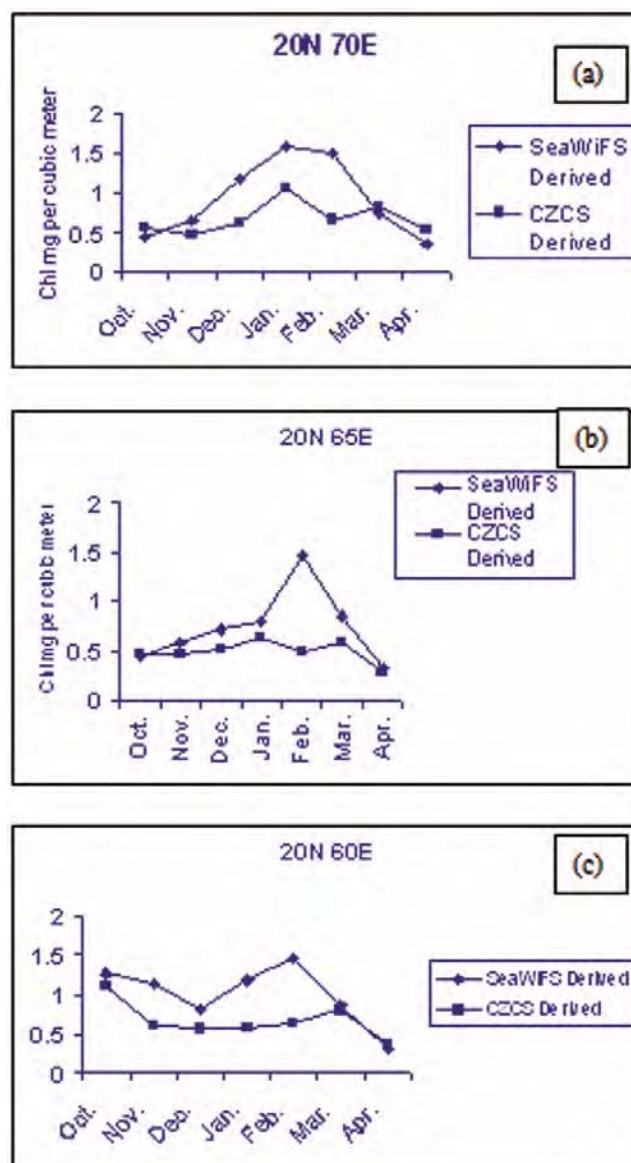


Fig. 2—Seasonal variability and Comparison of Chl-a values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 ( $20^\circ\text{N} - 70^\circ\text{E}$ ) (b) Location 2 ( $20^\circ\text{N} - 65^\circ\text{E}$ ) (c) Location 3 ( $20^\circ\text{N} - 60^\circ\text{E}$ )

to mid 80's (Fig. 5a,b,c) in general. However, at location c chlorophyll is lower during October, November and higher during February March. At mid ocean locations chlorophyll values are close to each other (Figs 6 & 7 a,b,c).

#### Analysis of Chlorophyll Zones

In order to understand the spread of different chlorophyll concentration zones within Arabian Sea and Bay of Bengal the sea water was classified into three categories viz. Oligotrophic ( $0.02\text{-}0.3 \text{ mg/m}^{-3}$ ),

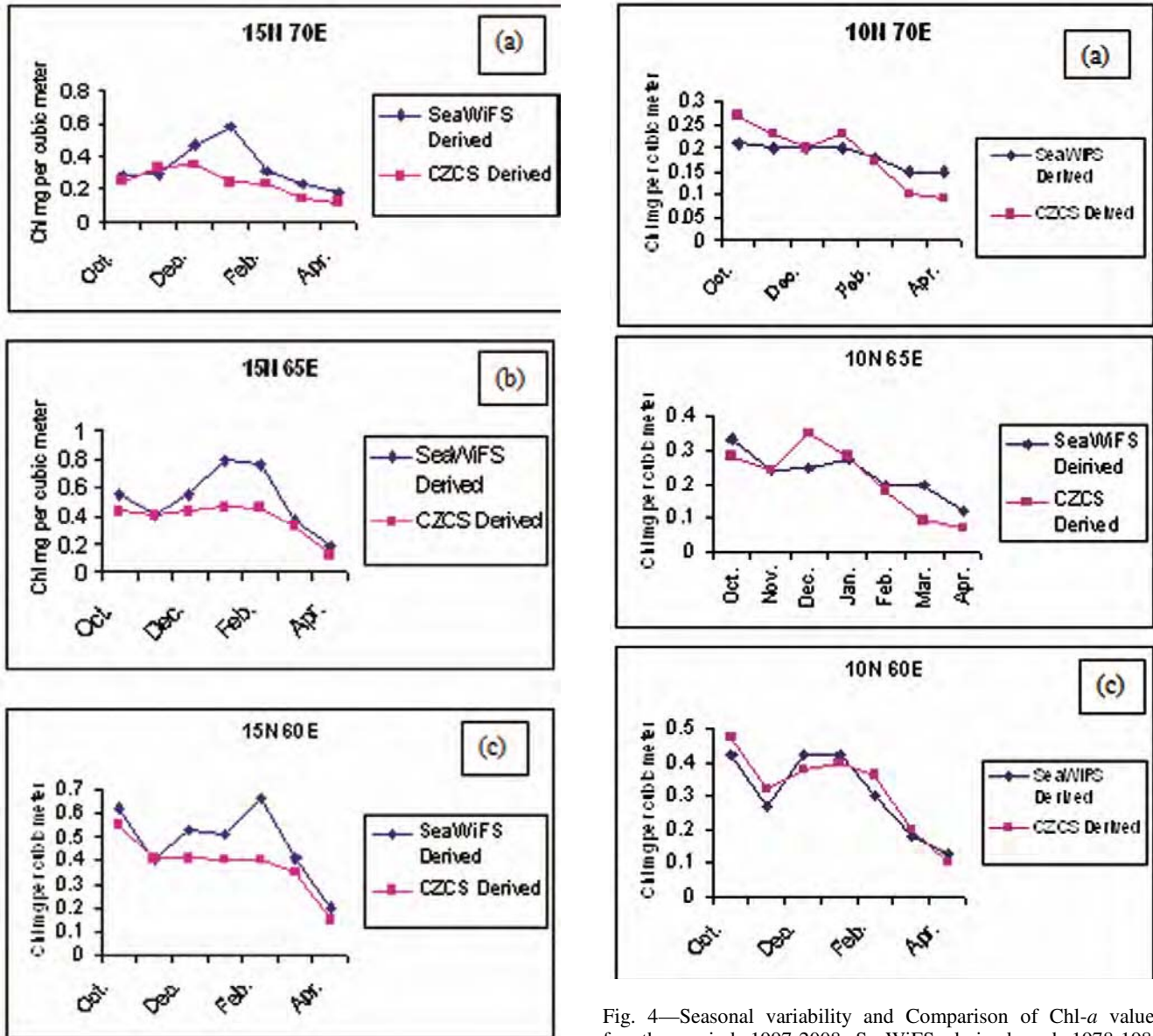


Fig. 3—Seasonal variability and Comparison of Chl-*a* values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 (15°N - 70°E) (b) Location 2 (15°N - 65°E) (c) Location 3 (15°N - 60°E)

Mesotrophic ( $0.3\text{--}0.8\text{ mg/m}^3$ ), and Eutrophic waters ( $0.8\text{--}7.0\text{ mg/m}^3$ ) and a comparison is made of seasonal and over the decade changes in the spread of these waters.

The Chlorophyll image derived from CZCS (1979-86) and the Chlorophyll image derived from SeaWiFS (1997-2008), for the period October to April was used to generate chlorophyll zones image. Seasonal analysis shows maximum increase is observed during November and February to April

Fig. 4—Seasonal variability and Comparison of Chl-*a* values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 (10°N - 70°E) (b) Location 2 (10°N - 65°E) (c) Location 3 (10°N - 60°E)

(Fig. 8) during recent years. Eutrophic waters show maximum increase from December to February (Fig. 9) as compared to that during 80's. The results show an increase in eutrophic waters during recent years as compared to that of 80's particularly in the Arabian Sea.

A chlorophyll image was generated for the period October to April for 1980's and recent years (Fig. 10). Here it is very clear that the eutrophic waters have increased substantially during the recent years particularly in the Arabian Sea. However, in the Bay of Bengal the mesotrophic waters seem to decrease to some extent.

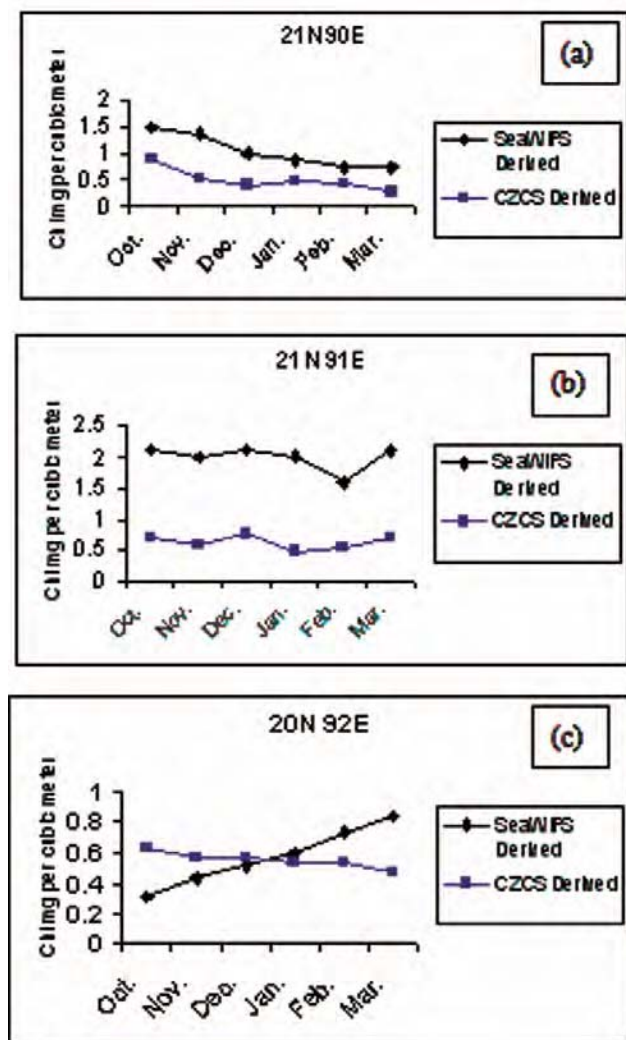


Fig. 5—Seasonal variability and Comparison of Chl-*a* values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 (21°N - 90°E) (b) Location 2 (21°N - 91°E) (c) Location 3 (20°N - 92°E)

The analysis over the period October to April shows that overall around 55% increase is observed in the eutrophic waters these days as compared to that during 1980's. And the mesotrophic waters show ~11.6% decrease. However, the mesotrophic waters have increased in Bay of Bengal.

Results show ~55% increase in eutrophic waters now as compared to 20 years back. At the same time mesotrophic waters show ~58% decrease indicating that eutrophic waters have increased by encroaching mesotrophic waters.

### Discussion

Our results based on the analysis of representative locations in the Arabian Sea and Bay of Bengal, show

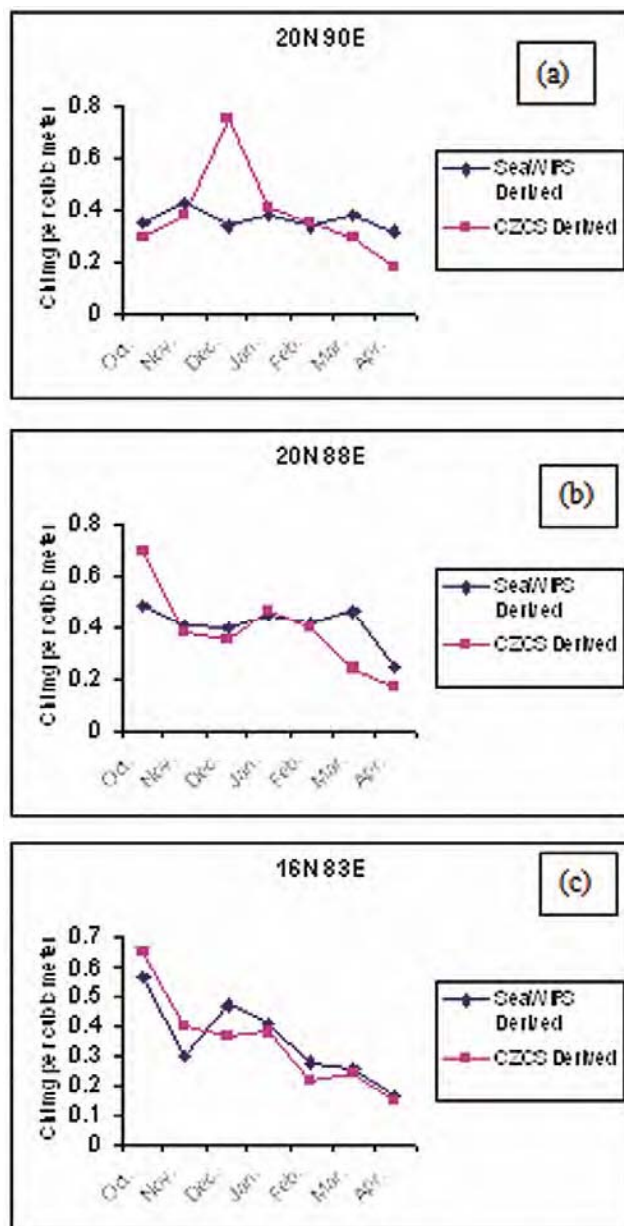


Fig. 6—Seasonal variability and Comparison of Chl-*a* values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 (20°N - 90°E) (b) Location 2 (20°N - 88°E) (c) Location 3 (16°N - 83°E)

that the chlorophyll concentration is much higher in the northern and central Arabian Sea during 2000's as compared to that during 1980's. This increase is more prominent during December to March. However, southern Arabian Sea does not show much change and as it is chlorophyll values are quite low here. If coastal upwelling were increased as a consequence of global warming<sup>9</sup>, surface waters would be enriched not only in nutrients, but also in dissolved carbon and

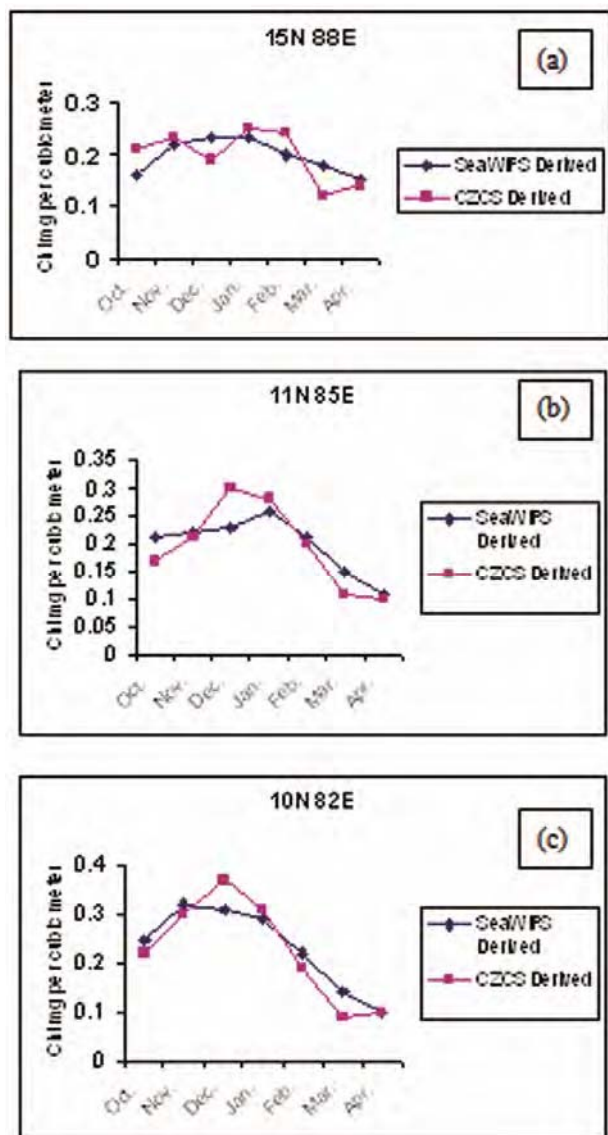


Fig. 7—Seasonal variability and Comparison of Chl-*a* values for the period 1997-2008 SeaWiFS derived and 1978-1986 CZCS derived data (a) Location 1 (15°N - 88°E) (b) Location 2 (11°N - 85°E) (c) Location 3 (10°N - 82°E)

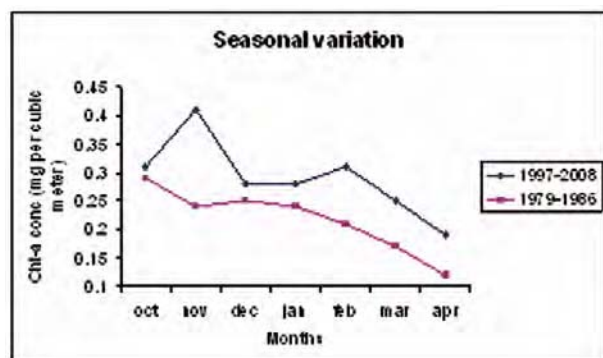


Fig. 8—Seasonal variation for two decade in Northern Indian Ocean

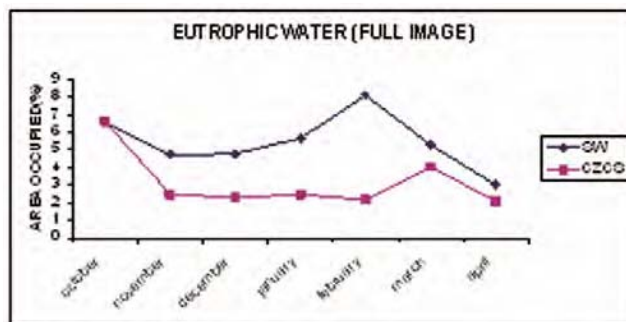


Fig. 9—Area Occupied by Eutrophic waters (0.8-7.0 mg per cubic meter) in  $10^3$  km in SeaWiFS and CZCS derived images

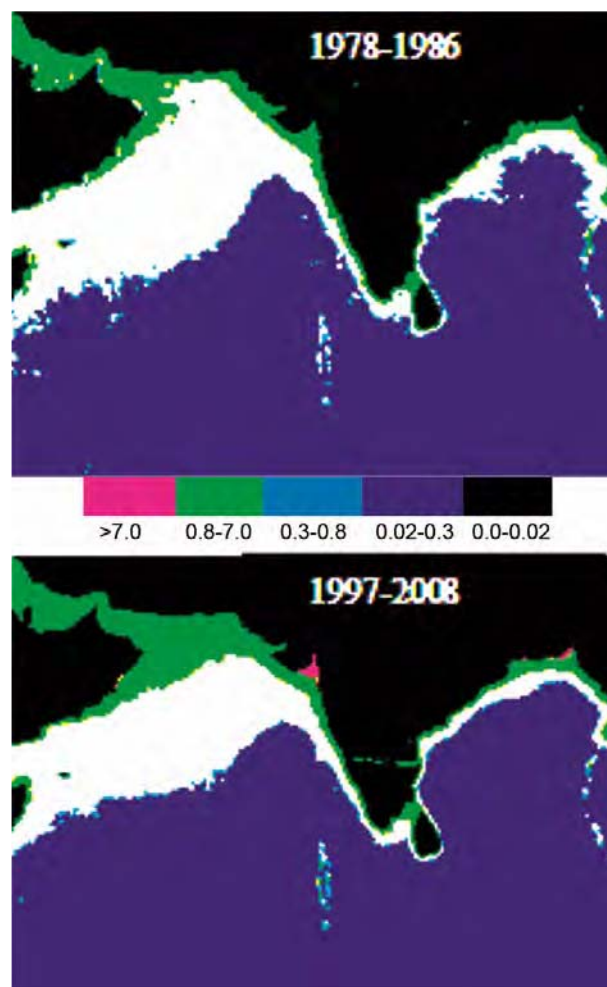


Fig. 10—Chl-*a* image of monthly mean from October to April (a) SeaWiFS derived image mean of 1997-2008 (b) CZCS derived mean of 1978-1986 showing zonation

this carbon might be sufficient for organic production (no need for carbon from atmosphere). Sarmiento *et al.* on the other hand argued that the general

warming trend by increasing stratification would reduce the flux of nutrients to the upper ocean and therefore, the effectiveness of the biological pump.

Bay of Bengal as well show high chlorophyll in the northern region while no significant difference observed in the southern part. The uniqueness of BOB lies in the tremendous freshwater influx it receives from the rivers draining the subcontinent. This high influx of freshwater brings a lot of nutrients. In the tropics and at mid-latitudes, phytoplanktons are often nutrient-limited. They grow when nutrients are made available within the upper layers through the upwelling of cold nutrient-rich water from below (or mixing with these deep waters). Therefore, any change of the overall stratification of the surface ocean has potential effects on phytoplankton growth, which may happen 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 efficient at recycling nutrients and biogenic material in the upper ocean. As a result, relatively little carbon sinks to deeper water.

Seasonal analysis of Oligotrophic, mesotrophic and Eutrophic Chlorophyll zones shows the maximum increase during November and February to April during recent years. Eutrophic waters show maximum increase from December to February as compared to that during 80's. The results show an increase in eutrophic waters during recent years as compared to that of 80's particularly in the Arabian Sea. A chlorophyll image for the period October to April for 1980's and recent years shows very distinctly that the eutrophic waters have increased substantially during the recent years particularly in the Arabian Sea. However, in the Bay of Bengal the mesotrophic waters seem to decrease to some extent<sup>4</sup> used data from 1998 to 2003 to show that phytoplankton amounts have increased globally by more than 4 percent. These increases have mainly occurred along the coasts. No significant changes were seen in phytoplankton concentrations within the global open oceans, but phytoplankton levels declined in areas near the center of the oceans, the mid-ocean gyres. Phytoplankton amounts have increased by 10.4 percent along global coast regions, where the ocean floor is less than 200 meters (656 feet) deep. Global warming may alter the biological production. This may be either via direct effects of temperature

and sunlight on growth rates, and metabolic processes, or via changes in ocean circulation, in particular the rate of upwelling. Warmer ocean temperatures increase stratification of the surface mixed layer, which inhibits the entrainment of nutrients from below to support ocean primary production. Results of <sup>6</sup> show that the multi-decadal Chlorophyll changes observed over the CZCS-to-SeaWiFS era appear related to basin-scale oscillations in the physical environment. These oscillations can alternately weaken or emphasize the possible effects of global warming, making difficult the identification of trends over short time series. It might be difficult to separate cause and effect. If we identify a trend in the past, this is not necessarily a reliable guide to the future behavior of such complex, non-linear systems. More detailed analysis of the component processes interaction is required for this.

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