UPPER OCEAN VARIABILITY OF THE EQUATORIAL INDIAN OCEAN AND ITS RELATION TO CHLOROPHYLL PIGMENT CONCENTRATION

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1. ABSTRACT

Hydrographic data from the upper ocean together with atmospheric data and satellite data are used to understand the variability of upper ocean and its relation to surface chlorophyll in the Equatorial Indian Ocean. The sea surface temperature showed a strong semi-annual signal with peak warming in April and cooling in July-August. Both mixed layer depth (MLD) and barrier layer thickness (BLT) showed a weak annual signal. The deep MLD during summer was due to the combined effect of strong winds and low net heat flux while shallow MLD in winter was driven by weak winds and net precipitation. A strong correlation of chlorophyll with SST was seen in the western EIO compared to central and eastern EIO. Our study indicated that the lack of seasonality in the chlorophyll pigment concentration, away from the western boundary, arises due to the lack of processes that could supply nutrients from subsurface.

2. INTRODUCTION

Equatorial Indian Ocean (EIO) is different from other equatorial regions of the world ocean because of the reversal of the wind system twice a year and due to which the surface current reverses semiannually. In the EIO the currents during winter and summer are westward while that during spring and fall are eastward. The organized strong westerly winds at EIO which occurs during the transition periods (April-May and October-November) between the southwest and northeast monsoon seasons, drive strong eastward surface jet with velocities of 1 m/s [1]. These Equatorial jets, which were also evident from the drifting buoys measurements [2, 3], are equatorially trapped and approximately 500 km wide. Unlike the Pacific and Atlantic, the equatorial undercurrent exists only during winter (December- March) in the Indian Ocean. The equatorial undercurrent is driven by zonal pressure gradient generated by the westward wind stress at the surface due to the prevailing trade winds [4]. In addition to the above, EIO is also characterized by intra-seasonal variability and propagation of waves such mixed Rossby-gravity waves, Kelvin waves and Rossby waves [5]. Another distinction of EIO is the lack of equatorial upwelling, unlike the equatorial Pacifica and Atlantic oceans [6]. A cursory look at the satellite-derived chlorophyll pigment concentration shows that equatorial Indian Ocean away from the coastal boundaries is a 'biological desert' with least chlorophyll concentration compared to any other region in the northern Indian Ocean [7].

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3. DATA USED

In the present study we used temperature and salinity data from 3 different sources – Hydro-cast, CTD (conductivity-temperature-depth) and Argo. Hydro-cast and CTD data were extracted from the World Ocean Data base 2005 [17] during the period 1919-2004 and Responsible National Oceanographic Data base (RNODC) during the period 1972-2006. Argo data were extracted for the period 2002 to 2008. Meteorological data were extracted from National Oceanographic Centre, UK (http://www.noc.soton.ac.uk/ooc/CLIMATOLOGY/noc11.php). In addition to the above data, chlorophyll pigment concentration from SeaWiFS (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml) during the period 1997-2007 were also analyzed in the domain 5°N-5°S and 40°-100°E to understand the seasonal variability of the upper ocean and its relation to satellite derived chlorophyll pigment concentration.

4. RESULTS

4.1. Basin-averaged seasonal cycle and its spatial dependence

In order to understand the seasonal cycle of equatorial Indian Ocean the ocean-atmospheric parameters were basin averaged and analyzed. To decipher the spatial dependence of the observed seasonal cycle, the EIO was further divided into three domains – western (45-55°E), central (70-85°E) and eastern (90-100°E) EIO and each of the above parameters were further studied in the respective domain.

The basin-averaged sea surface temperature (SST) in the EIO showed semi-annual variability with primary peak during April-May with a value of 29.8°C and secondary peak during October-November with SST of 28.6°C (Fig.1a.). The minimum SST was 28.3°C, which occurred during January and July-August.

The SST in western EIO showed strong semi-annual variability with high SST during April and November and low SST during July-August. The annual variability in SST was 3.5°C. In the central and eastern EIO, SST showed weak annual variability with amplitude of 1°C.

The basin averaged sea surface salinity (SSS) showed a weak annual variability of 0.3 psu with low salinity of 34.7 psu during March and comparatively high salinity of 34.9 psu during October-November (Fig.1b).

The SSS in western EIO showed weak annual signal with average salinity of 35.5 psu. In central and eastern EIO surface salinity showed weak annual signal with lower salinity of 34.5 and 34 psu respectively. Thus, the surface salinity in the western EIO was 1.5 psu higher than that of eastern EIO.

The basin averaged mixed layer depth (MLD) showed an annual signal, with deep mixed layer during June-August and shallow mixed layer from October to May (Fig.1c). The deepest MLD was 35m while the shallowest was 20m. The mixed layer depth from eastern EIO to western EIO showed a maximum variability of 15m, which occurred during January-February.

The basin averaged barrier layer thickness (BLT) showed a week annual signal of less then 15m with thinnest BLT during April and thickest during August. Barrier layer showed annual signal in the western EIO while in the eastern EIO it showed a semi-annual variability. A thick barrier layer was observed in the eastern EIO compared to western EIO.

To understand the atmospheric forcing responsible for the observed upper ocean variability, atmospheric data on net heat flux, momentum flux and fresh water flux were analyzed. The net heat flux showed a semi-annual variability similar to that of SST with maximum heat gain during February–April followed by September–November (Fig.1e). The maximum heat gain was 110 W/m^2 while minimum was about 30 W/m^2.

Wind speed showed semi-annual variability with high wind speed during June-July-August followed by January–February while low wind speed was observed during March-April and November-December (Fig.1d).

The fresh water flux (E-P) showed net precipitation in the EIO except during February-March where it showed net evaporation (Fig.1f). The highest precipitation was 6 cm/month, which occurred during November- December while net Evaporation was to the tune of 1 cm/month and occurred during February-March.

5. DISCUSSION

The high SST during April-May and October-November was driven by the net heat gain whereas upwelling along the western boundary drove the low SST during July-August. The variation in sea surface salinity was closely related to the variation in fresh water flux. The basin averaged E-P showed an excess precipitation of about 6cm/month during winter. In addition to this the north equatorial current transports low salinity waters from the eastern equatorial Indian Ocean towards west and by the end of winter/ beginning of spring the surface salinity in most part of the entire EIO become low. The deep MLD during summer (June-September) was due to the combined effect of strong winds and low net heat flux while the shallow MLD in winter was driven by the weak winds and negative E-P. The barrier layer was thickest in the eastern EIO compared to both central and western EIO, which was closely linked to the presence of low salinity water.

As it is well recognized that the variability in the chlorophyll biomass is related to the upper ocean variability we analysed remotely sensed chlorophyll pigment concentration from SeaWiFs in EIO to decipher its seasonal cycle. Further the relationship of chlorophyll biomass with SST and MLD was explored.

The basin averaged chlorophyll pigment concentration showed a weak annual cycle with highest concentration during August–September (0.24 mg/m^3) and lowest concentration during April (0.12 mg/m^3). In the western EIO the chlorophyll pigment concentration showed semi-annual variability with high chlorophyll during July-August-September followed by secondary peak during January-February while lowest chlorophyll was observed during March-April-May and November. The highest chlorophyll *a* was about 0.4-0.5 mg/m^3 and lowest was about 0.1 mg/m^3. In the central EIO chlorophyll concentration remained almost uniform (0.1-0.2 mg/m^3) without much variability, while in the eastern EIO chlorophyll showed an increasing trend from July to December and it increased from 0.2 mg/m^3 during July to 0.4 mg/m^3 during December.

Chlorophyll showed strong correlation with SST while that with MLD was poor (Fig.2.). The chlorophyll a showed a strong correlation with SST in the western EIO while correlation of chlorophyll with SST in central and eastern EIO was poor. Thus, the study indicated that the lack of strong biomass away from the western boundary arises from lack of nutrient supply from subsurface.

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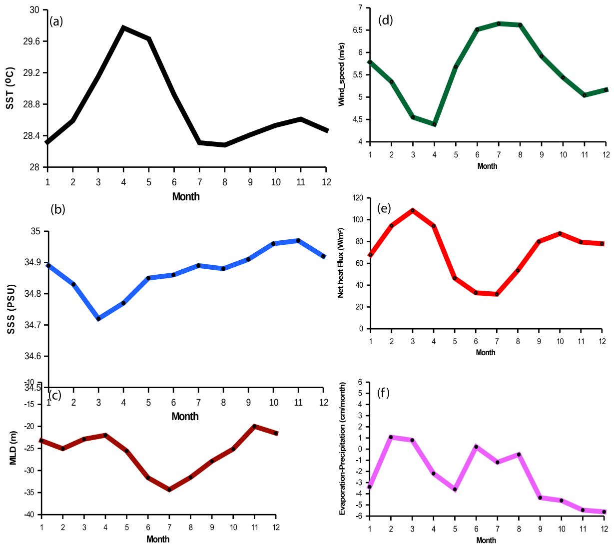

Figure.1. Basin averaged (a) SST, (b) SSS, (c) MLD, (d) Wind speed, (e) Net heat flux and (f) Evaporation-Precipitation in the Equatorial Indian Ocean (5°N-5°S, 40°E-100°E)

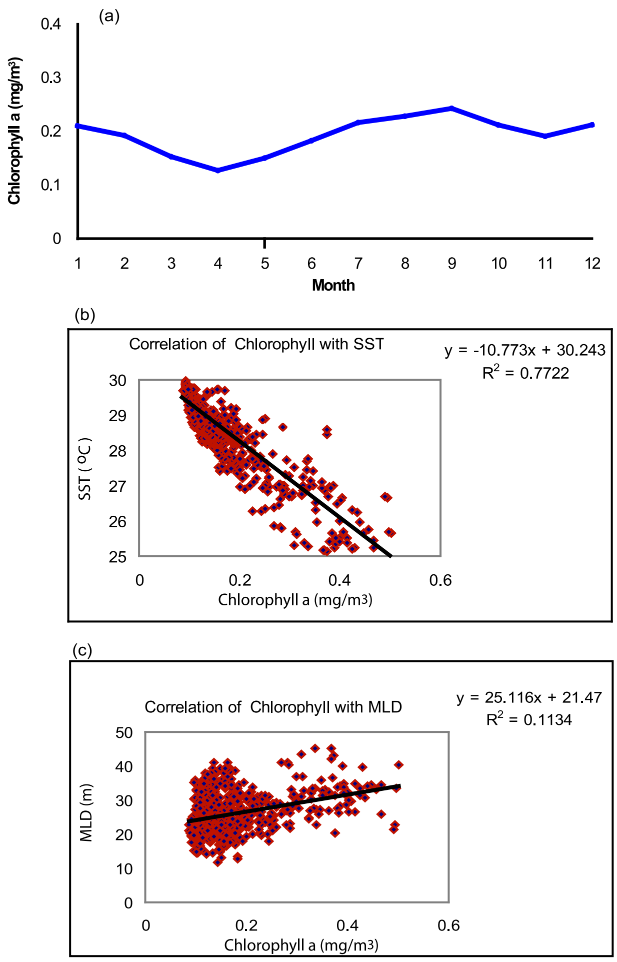

Figure.2. (a) Basin averaged chlorophyll a (mg/m³), (b) Correlation of chlorophyll with SST and (c) Correlation of chlorophyll with MLD in the equatorial Indian Ocean.