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Outlook of ocean climate variability in the West tropical Indian Ocean, 1997-2008

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Abstract

The trend of the major environmental parameters during the decade 1997-200 is presented. The decade analysed is characterized by two large anomalous events related to the Indian Ocean Dipole (IOD) events that dramatically reduced the catch rates of the purse seine fleets in the West Indian Ocean (WIO). During the IOD events, the WIO shows above normal sea surface temperature, deeper than normal thermocline and depleted chlorophyll concentration, denoting unfavourable foraging conditions in the surface layer. The most recent IOD event (2006-2007) did not reach the magnitude of that of 1997-98 but purse seine catches declined sharply from the previous years. Such a decline is undoubtedly related to anomalous environmental conditions affecting catchability, but the hypothesis of a reduced biomass after some years of very high catches may be an additional reason to this decline.

Introduction

Anomalies and fluctuations of the oceanic environment and tuna catches were observed in the Indian Ocean during the last decade (1997-2008). The 1997-98 ENSO reached a magnitude similar to that of the well-documented 1982-83 ENSO. In the Indian Ocean, the 1997 warming episode was even greater than that of 1982. This event is well documented in the literature, from ocean-atmosphere coupling to biological productivity (see e.g. Ragu et al 1999, 2000, Webster 1999). Another ENSO episode started to develop mid-2006, reached full magnitude in December, then decreased rapidly and disappeared by February (see the *Climate Diagnostics Bulletin* of the CPC/NOAA : http://www.cpc.noaa.gov/products/analysis_monitoring/bulletin/). The purse seine catch in the traditional fishery area located in the West tropical region of the Indian Ocean have collapsed from December 1997 to February 1998. Because the schools became virtually absent in the West, the fleet moved to the East tropical IO where environmental conditions induced by El Nino (shallow thermocline, chlorophyll-enriched waters) promoted good forage conditions, tuna concentration and vulnerability of the schools to the surface gears (Marsac & Le Blanc, 1999, 2000). Purse seine catch rates were back to normal in 1999. From 2003 to 2005, abnormal high levels of yellowfin tuna catch (450 - 500 000 t) were recorded in the Western area of the fishery whereas the average yearly production had been fluctuating in the range 300-350 000 t between 1995 and 2002. The average yellowfin catch level for 2003-2005 then represented a 45% increase from the average level for the period 1995-2002. In 2007, catch rates showed a dramatic decline, being 45% lower than in 2006 (from 25.1 to 15.3 t/d), although the fishing effort was distributed more or less in the same region (Fig. 1)

In this paper, we examine the trend observed in the oceanic environment of the West Indian ocean and provide some details on the environmental anomaly that developed by the end of 2006 and early 2007. For this specific aspect, we shall refer to observations made during the CIRENE oceanographic cruise that covered the region located south-east of Seychelles (3°S-8°S / 55 – 67°E), a part of the SCTR (Seychelles-Chagos Thermocline Ridge), during January-February 2007 (Vialard et al, in press).

Atmospheric indices

The climate anomalies are driven by air-sea interactions occurring at various scales. Here we focus on the interannual variability that is well shown by atmospheric indices, such as the SOI or the IOI (Marsac & Le Blanc 1998).

The SOI is a tracer of the ENSO cycle that develops primarily in the Pacific. It corresponds to the difference of standardized anomalies of sea level pressure between Tahiti and Darwin (Australia). The IOI uses the same principle between Darwin and Seychelles (Fig. 2). The IOI is more correlated than SOI to the SST anomalies in the West Indian Ocean (Fig. 3 & 4). During the last decade, the strongest negative anomalies of the IOI correspond to the highest SST anomalies found West of 70°E, i.e. late 1997-early 1998 and late 2006-early 2007.

These anomalies are associated with the so-called dipole mode event (Saji et 1999, Webster et al 1999) that may or may not occur in phase with the ENSO events (Fig. 5). The strongest SST anomaly occurs when El Niño is combined with a positive IOD and when La Niña with negative IOD (Meyers et al 2007). During a positive IOD, SST is anomalously cold in the East and warm in the west. The cold eastern pole is the consequence of a stronger than normal upwelling off the coast of Java triggered by remotely forced easterlies (Yamagata et al 2004). The shallow thermocline anomaly starts in May, then grows during the summer monsoon, reaches a maximum in September-October and vanishes in the early following year. Because of zonal SST gradient and sea level pressure between East and West of the basin, air-sea interactions are generated and the phenomenon is maintained by westward propagating Rossby waves.

It is clear that a dipole event coupled to a mild El Nino developed during the second half of 2006 and first months of 2007, with a clear signature in sea level anomaly propagating westwards, SST anomalies in the West, enhanced cyclonic activity and above-average rainfall West of Indian during the following south-west monsoon.

Ocean temperature

During the last decade, the averaged SST field in the WIO provides evidence of a significant variability at the interannual scale (Fig.6). The warmest year is 1998 and the second ranked is 2007. There is also a clearly above-normal SST in 2003. In 2006-2007, as for most IOD events, the SST anomaly disappeared rapidly (by December) along the Equator. By contrast, these anomalies lasted until May 2007 along the SCTR.

The trend of yearly average of MLD (mixed layer depth) points out particular situations in 1997, 1998 and 2007, denoting deep thermocline (Fig. 7). When considering only the warm season, when the Dipole-related anomalies are the most developed, only two years (1998 and 2007) are particularly noticeable. The deep thermocline observed at the yearly scale in 1997 is due to the fact that the anomaly grew up substantially during the second half of the year, when this anomaly did not reach the same magnitude in 2006. The deepening of the mixed layer is consistent with the positive sea level anomalies propagating from East to West during an IOD event south of the Equator, associated with positive sea surface temperature.

The CIRENE measurements (Vialard et al, in press) early 2007 show a clear deepening of the thermocline from a vertical profile at 8°S, 67°30’E (Fig. 8a). The deepening of the mixed layer is consistent with the positive sea level anomalies propagating from East to West during an IOD event south of the Equator, associated to positive sea surface temperature (Fig. 8b). The thermocline slope between 3°S and 9°S was inversed. The normal situation is a rise from north to south (from 90 m at 3°S to 60 m at 9°S) and the CIRENE section at 67°S points out a deepening in the same direction (100 m at 3°-5°S to 120 m at 9°S). As a consequence, a strong positive temperature anomaly was detected at 80 m, up to 7°C (Fig. 8c).

Sea surface chlorophyll (SSC)

In the 1997-98 IOD, the spatial pattern of SSC was reversed from the normal one (Fig. 9), with low productivity off Somalia and in the Seychelles region, and anomalously high content of chlorophyll in the East, off Sumatra coast. In the season 2002-2003 and even more in 2003-2004, the productivity in the region stretching from the African coast (Kenya-Tanzania) to the Chagos archipelago was notably enhanced compared to the normal situation (Fig. 10 a,b,c). During the 2006-2007 IOD event, negative SSC anomalies were recorded East of Seychelles and the Somali basin, whilst positive SSC anomalies were found in a restricted region off the Tanzanian coast (Fig. 10d).

In 2007, the particular deep thermocline anomaly had a consequence in the vertical distribution of chlorophyll content as shown by CIRENE measurements (see Fig. 8b). Overall, the biological productivity of the surface layer decreases in the WIO during the marked Dipole events.

Consequence on purse seine catch rates

During the 1997-98 Dipole event, Marsac & Le Blanc (1999, 2000) showed that the eastward shift of the purse seine fishing grounds was due to unfavourable conditions in the traditional western fishing grounds, namely a deepening of the thermocline and a decreased biological productivity at the sea surface. In this case, the forage disperses in deeper layers, and tuna do not congregate in free schools at the surface. The December-February period, the North-West monsoon, is known as the core spawning season for yellowfin leading to huge school concentrations at the surface. Those schools were not found in late 1997-early 1998; the purse seine fleets discovered new school concentrations in the East Indian Ocean where an anomalous shallow thermocline was present as a consequence of the ENSO-Dipole event.

In 2006-2007, there was not spatial shift of the purse seine fishery, and the fleet recorded very low catch rates in the WIO.

Between those two dipole events, there was an enhanced biological productivity that peaked in 2003-2004. The corresponding high catches were due to a particular concentration of tuna schools between Seychelles (55°E) and the East African coast. This concentration lasted must longer than normal. We observed similar decadal trend between purse seine CPUEs and chlorophyll content (Fig. 11), suggesting that favourable foraging conditions prevailed for top predators. Huge concentrations of mantis shrimp were detected during those events, this prey representing over 90% of the stomach content of the tuna sampled from the purse seine catches (Marsac et al 2006).

Therefore, the decline in catch rates observed in 2007 might be due to several reasons :

- a decreased catchability, for environmental reasons such as deep thermocline and depleted (or scattered) forage conditions in the mixed layer. Tuna might have responded in staying in deeper layers, making them less vulnerable to the purse seine gears.
- A consequence of very high level of catches in the years 2003-2005 that might have reduced the stock biomass
- A combination of both effects.

In 2008, the environmental conditions have returned to normal.

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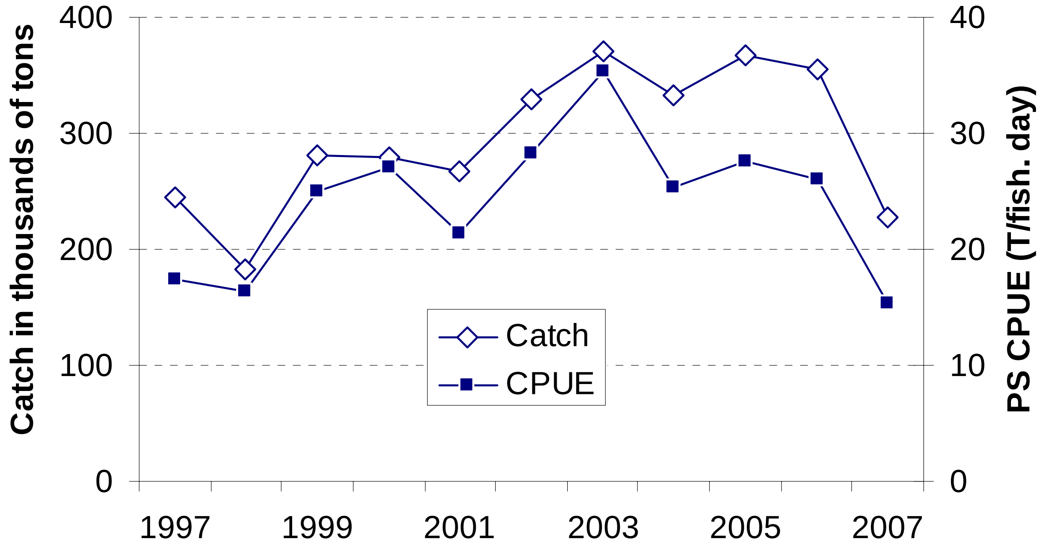

Fig. 1 – Trend of purse seine Catch and CPUE 1997-2007 in the West Indian Ocean (west of 80°E)

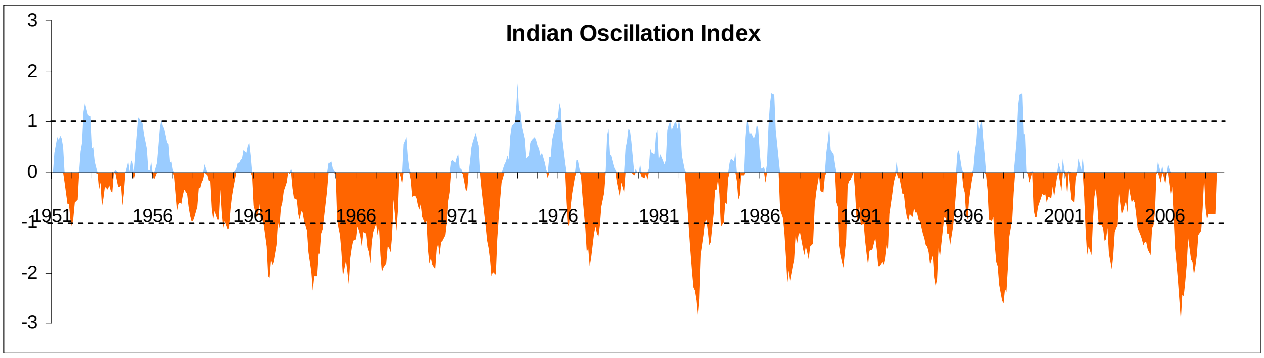

Fig. 2 – The Indian Oscillation Index, Jan. 1951 to July 2008. The negative (positive) values reflect warm (cool) situations. The dashed line (+1 and -1) is used to distinguish minor and major events.

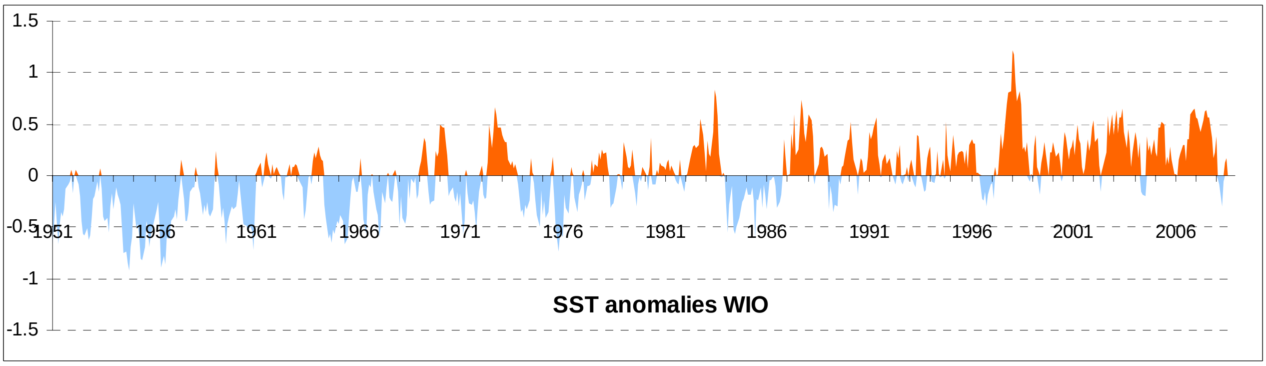

Fig. 3 – Sea Surface Temperature anomalies (from NCAR ersstv2) in the West Indian Ocean, Jan. 1951 to July 2008. Note the increasing and continuous trend throughout the series

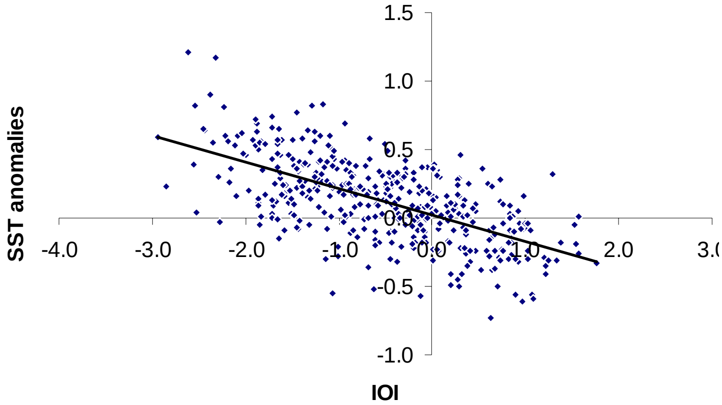

Fig. 4 - Scatterplot of IOI versus SST anomalies, denoting the good inverse correlation between these two parameters (r = -0.63, n= 437, 1972-2008)

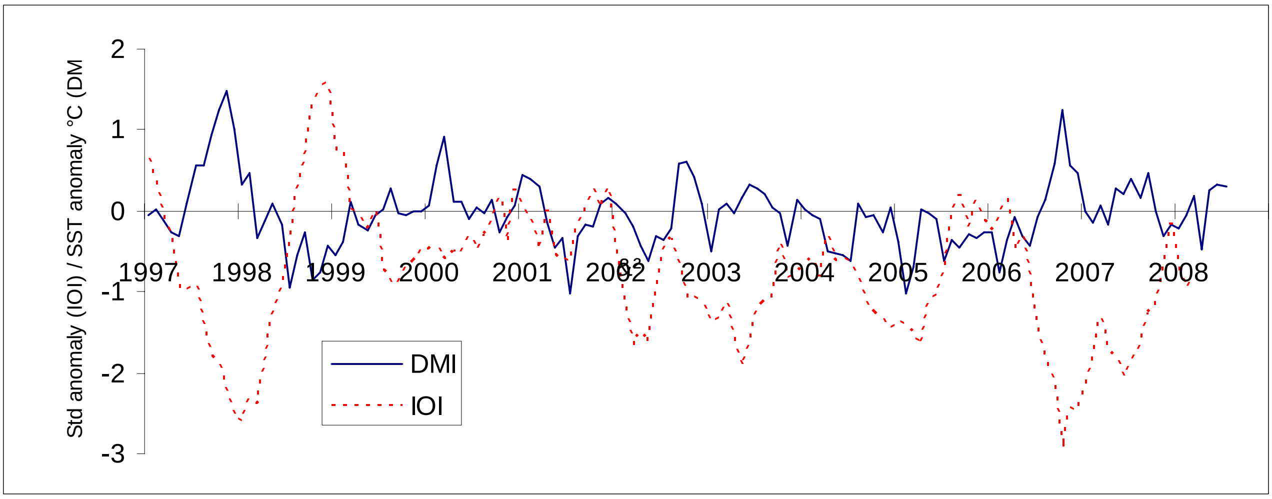

Fig. 5 – Series of Dipole Mode Index (DMI) and IOI, Jan 2007 – August 2008. Note that the highest DMI values occur in phase with the lowest IOI values.

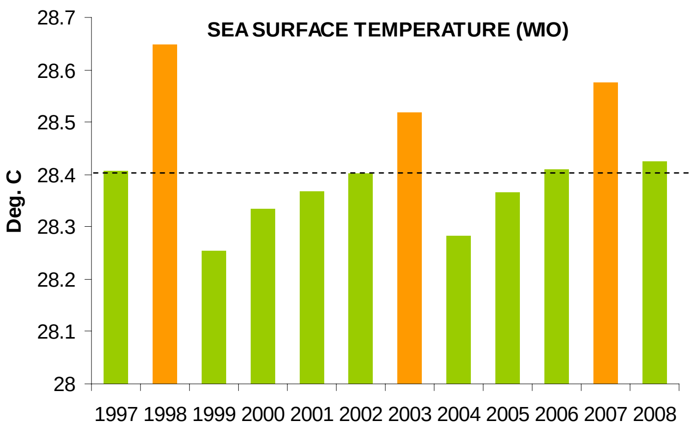

Fig. 6 – Trend of Sea Surface Temperature in the West Indian Ocean, 1997-2008. The dashed line indicates the decadal average (Note than in 2008 the average is for Jan-Aug).

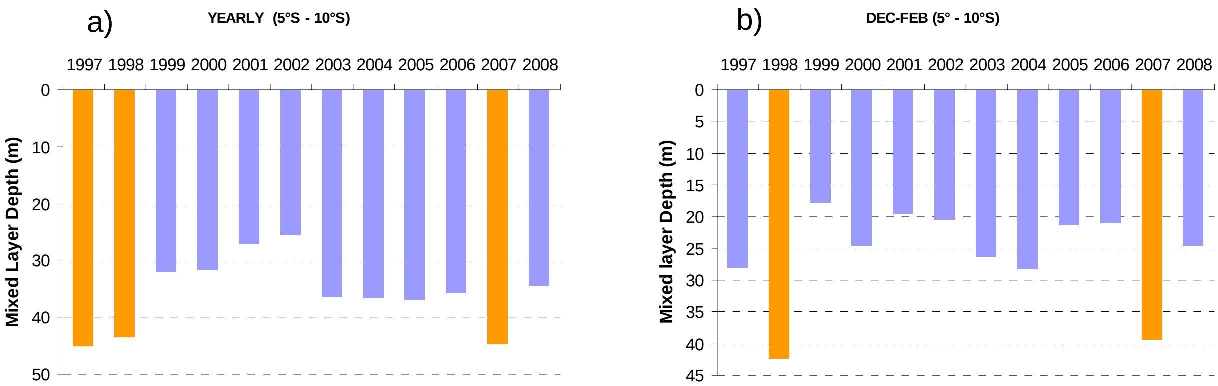

Fig. 7 – Trend of the depth of the mixed layer (in meters) between the latitudes 5°S-10°S in the WIO. a) yearly average, b) average for the north-West monsoon (Dec-Feb).

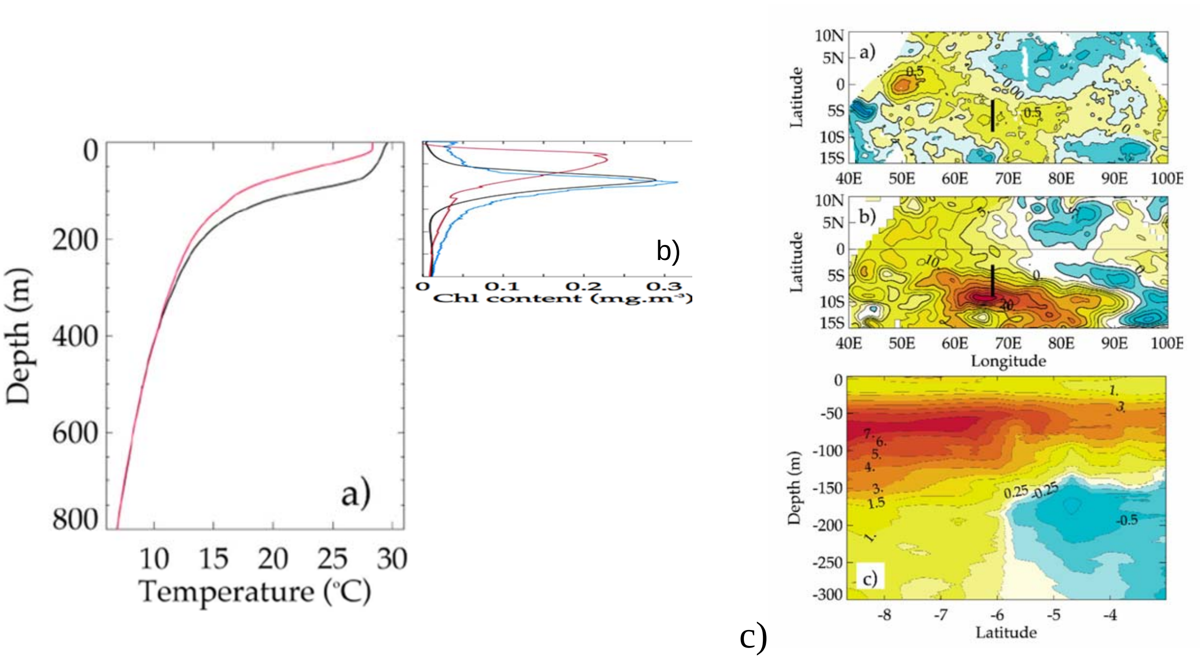

Fig. 8 - a) Vertical profile of temperature at 67°30'E, 8°S, Jan-Feb 2007 : CIRENE profile (black) and climatology from World Ocean Atlas (red). b) Vertical CTD profile of chlorophyll (black) and vertical density gradients (blue CIRENE, red climatology). d) Sea surface temperature (TMMI), Ssalto/Duacs sea level anomaly anomaly , temperature difference between CIRENE XBT section and climatology along 57°E. From Vialard et al, in press.

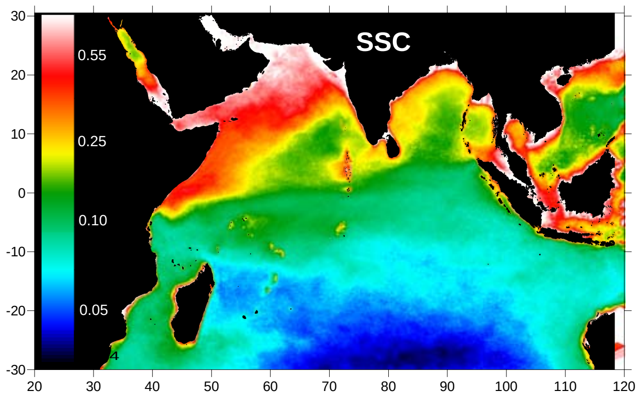

Fig. 9 – Average patterns of sea surface chlorophyll during the northwest monsoon (December to February).

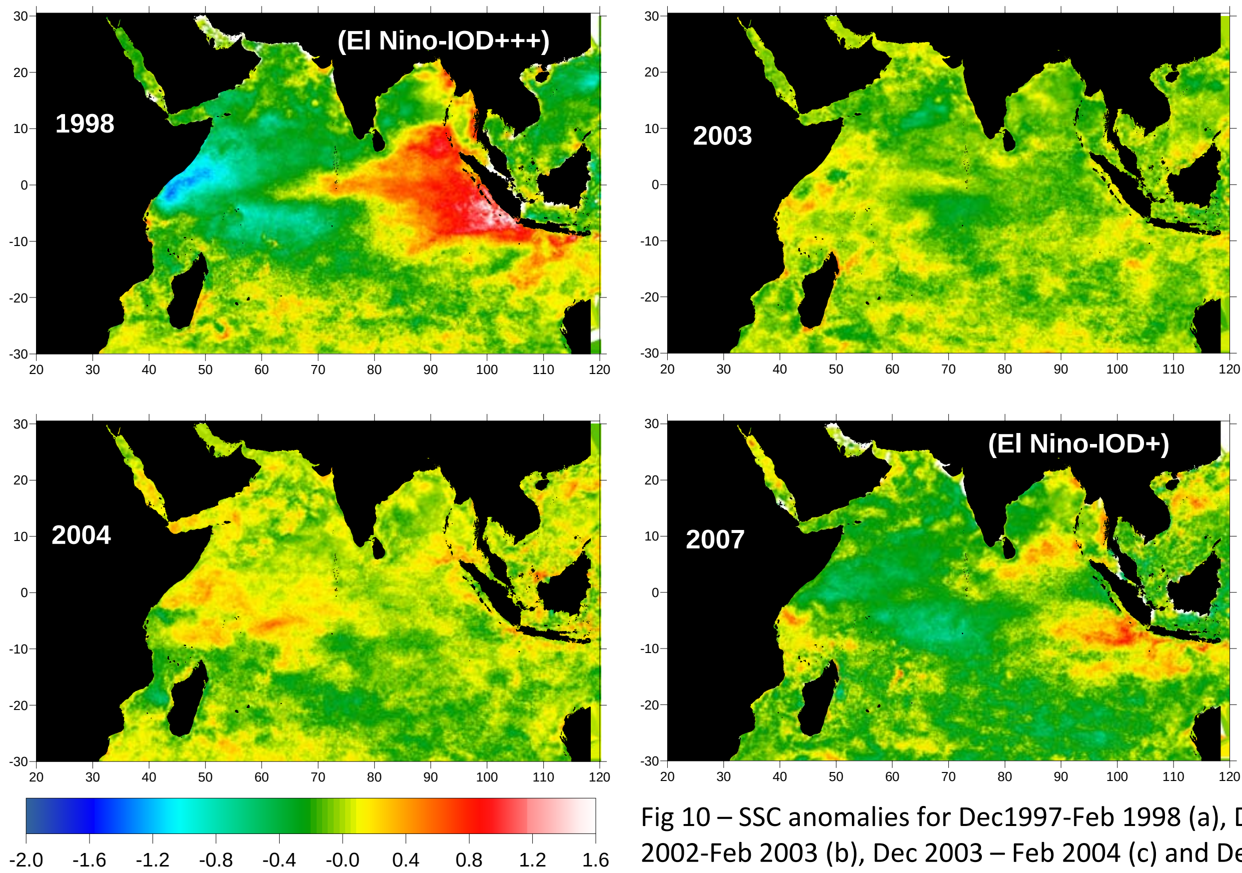

Fig 10 – SSC anomalies for Dec1997-Feb 1998 (a), Dec 2002-Feb 2003 (b), Dec 2003 – Feb 2004 (c) and Dec 2006-Feb 2007 (d). The anomalies are computed from log-transformed values of SSC concentration.

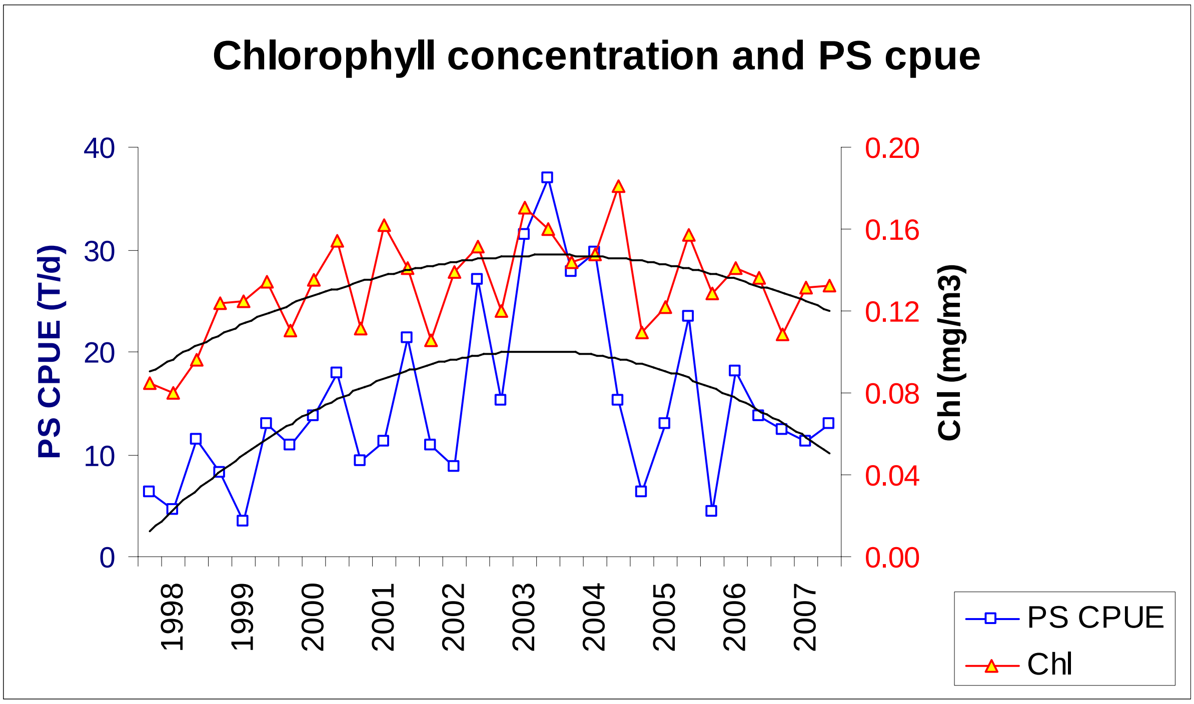

Fig. 11 – Trend of PS CPUE and Chlorophyll concentration (as derived from SeaWiFS data) in the west Indian Ocean. The data displayed are the monthly values for Dec to Feb (northwest monsoon) from Dec 1997 to Feb 2007.