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Outline of climate and oceanographic conditions in the Indian Ocean over the period 2002-2012

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Abstract

In this paper, we examine the trends of climate and oceanographic conditions from various perspectives. First, the trend of climate indicators and their impact on sea surface temperature (SST) and mixed layer depth (MLD) during the past 30 years are presented. Unlike the Southern Oscillation Index (SOI), the Indian Oscillation Index (IOI) has been shifting towards more frequent negative anomalies since the early 2000s. Whether this trend is related to an increased rate of warming observed in the Indian Ocean since the early 1980s needs further investigation. Negative IOI anomalies (below -1) are associated with a deeper thermocline in the West Indian Ocean and the full development of the MLD anomaly is reached 2 months after the IOI signal. Secondly, we investigate the variability patterns during the period 2002-2012 by a principal component analysis on SST, MLD and Sea Surface Chlorophyll (SSC) anomalies. The 3 variables are highly structured in space and the most developed anomalies over the study period are associated with the 2006-2007 Niño and the 2010-2011 Niña. Overall, SST and SSC exhibit two synchronized temporal phases. In 2002-2005, SST is below than normal and primary productivity (SSC) is enhanced. The year 2006 is a transition year, towards a phase dominated by higher SST and lower productivity for the rest of the period under study. Thirdly, we perform regional analyses of SST, MLD and SSC in five boxes of the Indian Ocean: the Somali Basin, the Maldives, the West Equatorial Indian Ocean, the Mozambique Channel and the East Tropical Indian Ocean. The major outcome is that the chlorophyll content has been decreasing over the period 2002-2012 in the first 4 areas (in a range of 20 to 38%). The years 2006-2007 often appear as the turning point between chlorophyll-enhanced (before) and chlorophyll-depleted (after) situations. By contrast, the chlorophyll content fluctuated with no trend in the East Tropical Indian Ocean, which is on average the less productive area. The inter-annual changes in primary productivity are often associated with the SST variability with productive (depleted) chlorophyll content being associated with cold (warm) SST anomalies.

Introduction

Anomalies and fluctuations of the oceanic environment need to be considered to better assess stock productivity and/or catchability changes. Environmental covariates are now commonly used to standardize CPUEs for stock assessment purposes in the different RFMOs. However, we need to understand the interplay between the major variables which are used in the GLMs. This can be achieved by reviewing the trends of the environmental factors of most ecological relevance. Several major anomalies occurred in the Indian Ocean, such as the El Niño events in 1997-98 and 2006-07, and the La Niña event in the 1998-99. The description of these events and their impact on tuna fisheries were presented at various tropical tuna working groups of the IOTC during the past 12 years (Marsac 1999, 2000, 2001, 2008).

In this paper, we undertake an update of the trend of climate and oceanographic indicators notably after a Niña event which developed during the second semester of 2010 and persisted in the early months of 2011. We focus on the inter-annual variability of the sea surface temperature (SST), mixed layer depth (MLD) and sea surface chlorophyll (SSC) over the period 2002-2012. The variability patterns are investigated at the ocean scale and regional analyses are performed in 5 areas which tuna fishing relevance. Such information may assist in the interpretation of CPUE trends during the 2012 working party on tropical tuna of the IOTC.

Data used

Atmospheric indices

The Southern Oscillation Index (SOI) is documented in many websites. A comprehensive analysis of trends of a number of climate and oceanic variables, and climate updates at a global scale are found in the Climate Diagnostics Bulletin of the CPC/NOAA at the following URL :http://www.cpc.noaa.gov/products/analysis_monitoring/bulletin/).

The Indian Oscillation Index (IOI) was introduced by Marsac and Le Blanc (1998). Similarly to the SOI, this index is the difference of standardized anomalies of the sea level pressure in two distant sites characterized by a dipole-like pattern, namely Darwin and Mahé (Seychelles) for the IOI. The series is updated monthly and the whole series, starting in 1951, is available with the author.

SST and MLD

The long-term trend of the SST is investigated with the Extended Reconstructed SST of the NOAA/NCDC which includes *in situ* data collected by ships and buoys. We now use the most recent version of the dataset (ERSST.v3b). The monthly analysis extends from January 1854 to the present, but because of sparse data in the early years, the analyzed signal is damped before 1880. After 1880, the strength of the signal is more consistent over time, however the data becomes more reliable after the 1940's.With a spatial resolution of 2 degrees of latitude/longitude, ERSST is suitable for long-term global and basin wide studies; local and short-term variations have been smoothed in ERSST (Smith et al, 2008). The monthly anomalies were calculated from a climatology established by the author over the period 1971-2000.

The study of the variability patterns and the regional environmental assessments was carried out with the outputs of the NOAA/NCEP Global Ocean Data Assimilation System, which provide fields of temperature, salinity, vertical velocity and current for 40 depth levels (5 to 4500 m), along a 1°longitude/0.33° latitude grid globally. The model outputs are produced monthly from January 1980 to the present. We call SST what corresponds to the first temperature level calculated by the model (at 5 m) and MLD, the depth of the 20°C isotherm obtained by interpolation between consecutive depth levels. The monthly anomalies were calculated from a climatology established for each variable by the author over the period 1980-2005.

SSC

The chlorophyll product of the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Earth Observing System (EOS) Aqua and Terra satellites was used to study the SSC trends. The original dataset is the Level-3 monthly composite at a 9-km resolution. In order to combine the analyses with SST and MLD, we generated a monthly Chlorophyll dataset at the same grid as the NCEP-GODAS model output (1°Lon/0.33° Lat) from the original 9-km dataset. The monthly anomalies were calculated from a climatology established by the author over the period 2003-2008.

Results

1- Climate forcing on SST and mixed layer depth

The atmospheric indices used are the Southern Oscillation Index and the Indian Oscillation Index (Marsac & Le Blanc 1998). The series for 1972-2012 are shown in Fig 1. Both series exhibit synchronised occurrences of negative episodes from 1972 to 2002. Negative (positive) SOIs denote El Niño (La Niña) events, and correspond to warm (cold) episodes in the Pacific Ocean. However, this synchrony is disrupted from 2002 onwards. Whereas SOI show more frequent positive events, the IOI gradually decreases, with more frequent strong negative events than during the previous period. A Niña event started to build up mid-2010 and peaked during the early months of 2011 then decreased. The current situation, mid-2012, is a neutral ENSO situation.

The secular trend (1900-2012) of the sea surface temperature is shown in Fig. 2 using the SST anomalies. The SST increase is noticeable all over the series, but the rate of warming increased substantially in the 1980s. The SST increase was 0.048°C per decade during 1900-1979 and 0.132°C per decade after 1980 (which is more than two fold that of the previous period). Whether the increased rate of warming of the ocean has any relation to the more frequent IOI anomalies needs further investigation. The warmest months in the recent period were: February 1988 (+0.57°C), January 1998 (+0.68°C) and February 2010 (+0.76°C). When we remove the trend from the original series, the warmest month ever recorded in the IO since 1854 (start of the SST reanalysis) is January 1998, which corresponded to the peak phase of an intense El Niño and positive Indian Ocean Dipole mode.

SST and IOI are strongly related through the air-sea interactions. Both series exhibit opposite phases with negative (positive) IOI associated with warm (cold) temperature anomalies. The combined plot presented in Fig.3 shows this overall coherence. We examined the effect of the IOI on the SST and mixed layer depth (MLD) changes in the West Indian Ocean. We selected the area 50°E-70°S/10°N-10°S for the SST; the area selected for the MLD was the corridor of highest MLD variability, 50°E-70°S/5°S-10°S (see section 2) which is also a major free-school fishing zone for purse seiners.

A Generalized Additive Model relating IOI and detrended SST anomalies explains 28% of the deviance. As the relationship is linear, this corresponds roughly to the percentage of variance explained in a linear model. By contrast, the relationship between the IOI and MLD anomalies is non-linear (Fig.4) showing a sharp deepening of the MLD once the IOI gets below -1. We tested different time lags between the IOI and SST anomalies and MLD anomalies. The maximum deviance for SST anomalies is obtained with no lag, whereas the maximum deviance with MLD anomalies is obtained 2 months after the IOI signal. This lag is likely to reflect the development of a passing wave from East to West which will induce an oscillation at the thermocline depth.

Deviance explained by GAMs relating IOI and SST anomalies, IOI and MLD anomalies, considering time lags ranging from 0 to 3 months. The maximum deviance is in bold.

Variable	**No time lag**	**Time lag**		
		1 month	**2 months**	**3 months**
SST anomalies (1951-2009)	**28.0%**	26.8%	21.4%	14.9%
MLD anomalies (1980-2009)	28.5%	33.7 %	**35.9%**	33.6%

The IOI depicts basin-scale climate processes which are also linked to the ENSO cycle. The IOI is strongly related to the Indian Ocean Dipole Mode Index (Saji et 1999, Webster et al 1999) as a result of interplay between SST, equatorial winds and sea level anomalies. During positive dipole modes, temperature increases in the west, easterlies become stronger at the equator and sea level anomalies are anomalously high in the west. Temperature and MLD anomalies during an El Niño/positive dipole, and reflected by negative IOIs, also lead to increased precipitations. The IOI was even used in epidemiological studies to explain cholera outbreaks on the African continent (Constantin de Magny et al, 2007a,b). The IOI could then be considered as an integrated index of climate variability which can also affects the habitat of large pelagic fishes.

2- Patterns of variability

We used the empirical orthogonal functions (EOF) to investigate the patterns of variability of the three variables selected in this paper. The EOF, a kind of principal component analysis, have been extensively used in meteorology and oceanography to analyze space and time trends in data sets (Lorenz 1956). The method represents the data as a sum of products of functions:

$$f(x,y,t) = \sum (Fi(x,y) \,.\, Gi(x,y)$$

where the Fi denote the data distribution in space and the Gi give the contribution of the respective space distribution at any given time. An infinite sum of functions will reproduce the current observations but, practically, the summation is truncated after the first few terms. The contributions of the sum are arranged in such a way that the first term (= first axis) accounts for more of the variance found in the observations than any other term. The second term accounts for most of the remaining variance and so on. The Eigen values that are calculated by this method have no unit and are proportional to deviations about the mean (standardized anomalies). The product of the spatial value (or coefficient) for the grid point (x,y) and the value at time t gives the sign of the anomaly for the triplet (x,y,t).

This results presented below are limited to the temporal and spatial components of the first EOF (EOF1) calculated in two distinct areas of the tropical Indian Ocean, from 10°N to 20°S : the West IO (40°E-80E) and the East IO (70°E-110°E). The two areas overlap in longitude in order to show the continuity of the pattern. Note however that the loadings between both EOFs are not comparable.

SST (Fig. 5): the greater SST variability in the WIO is found off the Somali coast (as a consequence of the upwelling), along the Seychelles-Chagos Thermocline Ridge (SCTR) located along 10°S. In the EIO, there is a clear pattern centred on 10°S/80°E. In the recent years, strong negative loadings are obtained from February-May 2008 and from Dec 2010-May 2011, denoting negative SST anomalies in the above mentioned areas. The latest strong positive loadings (warmer temperature) are observed from September to December 2011 in the West, and from October 2011 to May 2012 in the East.

MLD (Fig. 6): The greater MLD variability takes place in the SCTR, and a dipole is noticeable on both sides of a line joining 0°-50°E and 10°S-110°E. Basically, when the thermocline deepens in one region, it shoals in the other. Two major anomalies (of opposite signs) are observed in 2006-2007 and 2010-2011. In the SCTR (and beyond to the East), the most prominent thermocline deepening during 2002-2012 is seen during the 4th quarter of 2006 in the East and during the 1st quarter of 2007 in the West, when a strong negative IOI and positive dipole prevailed. This lag reflects the propagation of the anomaly from East to West. Simultaneously, there was a shallow thermocline in the north-eastern part of the basin. More recently, in the SCTR, the thermocline started to shoal in the East at the end of 2010 and then during the next months in the west. This event seems tightly associated to the IO Dipole Mode Index (Fig. 7), which reached a strong negative value in September 2010, and to a La Niña event (positive SOI) which developed during the second semester of 2010 (see Fig.1, top).

SSC : In the West, the highest SSC variability is found in the Somali basin and a meridional pattern between north (high variability) and south (low variability) of the SCTR is noticeable. In the East, the pattern found between 5°S-12°S and 75°E-85°E is that detected in the MLD spatial EOF1. Two distinct phases can be seen in the time series: a positive phase from 2002 to 2006, and a rapid shift to a negative phase from 2007 onwards. The only positive (and substantial) loading is observed early 2011, in relation with a positive SSC anomaly which started to develop in the East basin and slightly displaced to the south-west. The sharp 2006 shift is fuelled by the development of the 2007 El Niño and warm event in the WIO (associated to a negative SOI, a negative IOI and a positive IODMI). The lowest negative value of the West-EOF1 series is reached in December 2011 simultaneously to a very low IOI (although the SOI remains near 0). In the central Indian Ocean (5°S-12°S and 75°E-85°E) – right panel- elevated chlorophyll concentration started to develop in December 2010 and peaked in February 2011. This event, highlighted by Marsac (2011) at the 13th Session of the WPTT, remained in this position until May 2011, then moved southwards and vanished in November 2011 at the 20°S latitude.

The primary productivity is enhanced during the southwest monsoon which peaks in August. The combined plot of the SST and SSC's EOF1 (Fig. 9, top panel) shows an opposite pattern along the time series, in the two sides of the ocean, with two phases. From 2002-2005, SST is below normal (especially in the West, more variable in the East) and primary productivity (SSC) is enhanced. The year 2006 is a transition year, towards a phase dominated by higher SST and lower productivity. SST and SSC EOF1 are negatively and significantly correlated ($p<0.05$) as shown by the scatterplot (Fig. 9, lower panel).

3- Regional analyses

The Indian Ocean has been partitioned into 5 main areas: Somali basin (SOM), Maldives (MAL), west equatorial area (WEQ), east tropical area (ETR) and Mozambique Channel (MOZ). We computed the annual average of the SSC in each of these areas. Note that 2002 and 2012 are incomplete (2002 starts in July and 2012 ends in August), and therefore might not be strictly comparable to the other years. Three groups appear in terms of primary productivity: SOM and MOZ are the most productive areas (SSC : 0.30 to 0.50 mg/m3), then WEQ and MAL (SSC : 0.12 to 0.20 mg/m3), and lastly ETR being the less productive area (SSC around : 0.10 mg/m3). The second major observation is that all areas, except ETR, show an overall decreasing productivity over time. SOM exhibits a rapid decline from 2002 to 2007 then levels off about 0.3 mg/m3. The decline is lesser in the three other areas but still noticeable.

We examined the trends of SST, MLD and SSC in the different regions. Regions are presented according to the three groups exhibiting similar productivity patterns, as shown in the previous paragraph.

3.1 The Somali basin (Fig. 12)

The Somali basin is a hydrologically and biologically contrasted region. The coastal upwelling is active during the south-west monsoon, from June to September, when the current is flowing from South to North along the Somali coast. Offshore, two gyres are formed in association with the water advection from the upwelling: one between 2°S and 4°N, another one between 5° and 10°N (Swallow and Fieux 1982). The converging movement of surface waters towards the core of those gyres creates a downwelling and a deep thermocline (around 200 m). Therefore, it is not relevant to compute an averaged MLD in such a contrasted situation.

The intensity of the upwelling can be assessed by the trend of SST anomalies. We present the cumulated anomalies over the core of the southwest monsoon (July to August). In the series 2002-2012, negative anomalies (corresponding to cold SST and an active upwelling) in 2002-2004 were gradually replaced by positive anomalies from 2006 to 2011 onwards (with the exception of 2008). Then a negative anomaly occurred in 2012. An overall opposite pattern in the SSC trend can be observed: a productive phase until 2005 followed by a negative phase from 2006 onwards.

3.2 The Mozambique Channel (Fig. 13)

Annual values are presented for this region. The SST trend increases over the period 2002-2012, peaking in 2011with a cumulated anomaly of 6.6°C. Only one year (2008) had a cold SST anomaly. The MLD anomalies fluctuated, showing strong positive anomalies (i.e. deeper thermocline) corresponding to the El Nino/positive dipole event peaking in 2007. The SSC trend exhibits two phases: above than normal productivity from 2002-2005 then below than normal productivity from 2007 onwards (except a small positive anomaly in 2012, noting that 2012 covers only 8 months of the year).

3.3 The West equatorial Indian Ocean (Fig. 14)

The analysis is focused on the core of the north-east monsoon, December to February, when free schools are harvested by the purse seiners. This area is also a major spawning ground for yellowfin tuna during that season. The value assigned to the year *y* is an average of $December_{y-1}$ to $February_{y}$. SST anomalies exhibit two phases: a warmer period from 2002 to 2007 when the highest anomaly was obtained (matching an El Nino/positive dipole) and a rather cooler (or about the average) period after 2008. The MLD anomalies denote a situation of a shoaling thermocline from 2002 onwards, with the exception of 2007 when the deep thermocline wave triggered by the 2006-2007 El Nino crossed the entire area. The thermocline remained at a depth of 70 to 80 m, which is about 15 metres shallower than normal. The SSC follows a declining trend. The maximum productivity was found during the 2003-2004 north-east monsoon (+18.5% increase about the 2002-2012 average) and lowest productivity occurred during the 2009-2010 (-17%) and 2011-2012 (-23%) north-east monsoons.

3.4 Maldives (Fig. 15)

The statistics are calculated for the whole year. SST cumulated anomalies are always positive over the study period (up to 4.1°C in 2003), except in 2005 (-2°C). Inter-annual MLD changes have a low magnitude in Maldives. The extreme values took place in 2007 with a shallow anomaly (an opposite signal compared to the west equatorial area) and in 2012, with a thermocline deepening of about 10 meters. The SSC trend does not show clear relationship with SST or MLD trends. There is a positive rate of change in chlorophyll content from 2003 to 2005, then negative rate of change after 2007, with an anomalously low productivity in 2012 (still keeping in mind that this statistics only covers 8 months of the year).

3.5 The East tropical Indian Ocean (Fig. 16)

The statistics are calculated over a 12-month period ranging from July (of the previous year) to June (of the current year). The rationale is that inter-annual anomalies, mostly related to ENSO/Dipole variability, start to build up during the second semester, reach a peak at the turn of the year, then decrease during the subsequent first semester. Hence, the anomalies can be better appraised during a 12-month period covering to consecutive half-years than during a standard year. We do not show the MLD anomalies as the area contains patterns of opposite variability, as shown by the spatial EOF1 (Fig. 6). The averaged-MLD over the area were therefore very close to 0 (range from -5.6 to +4.5 m). SST anomalies do not exhibit a particular trend, rather we found strong opposite anomalies, such as in 2009-2010 (+4°C cumulated anomaly) and 2010-2011 (-2.8°C cumulated anomaly). Not much can be said about the 2009-2010 anomaly, but the 2010-2011 anomaly was clearly related to a negative dipole event, coupled with a Niña event (see Figs 1 and 7). The SSC variability is well related with the SST variability, with warmer (colder) events corresponding to lower (higher) productivity. The peak anomaly of 24.6% increase of chlorophyll compared to the 2002-2012 average corresponded to a long and anomalously productive event already reported by Marsac (2011) and well shown in the spatial EOF1 (see Fig. 8). Unlike the 4 other areas, SSC fluctuates with no trend in the East Tropical Indian Ocean.

Summary

The main outcomes resulting from this analysis are:

1) A La Niña event associated with a negative dipole mode developed in the Indian Ocean mid-2010, peaked during the first quarter of 2011, then decreased. The situation in 2012 is a neutral ENSO situation, meaning no major large scale environmental anomalies once the long-term trend is removed.

2) The Indian Oscillation Index (IOI) is closely related to the Indian Ocean Dipole mode; SST anomalies in the West Indian Ocean occur simultaneously to low IOI values whereas a 2-

month lag is observed between a series of negative IOI (below -1) and the full development of a mixed layer deepening, likely because of the effect of a passing wave from East to West.

3) At the basin scale, the 1st EOF of SST and SSC exhibit two synchronized temporal phases. In 2002-2005, SST is below than normal and primary productivity (SSC) is enhanced. The year 2006 is a transition year, towards a phase dominated by higher SST and lower productivity for the rest of the period under study

4) A regional analysis of SST, MLD and SSC, reveals that the annual (or seasonal) average of the chlorophyll content has been decreasing over the period 2002-2012 in four areas (Somali basin, Mozambique Channel, Maldives, West Equatorial Indian Ocean). The sharpest decline is observed in the Somali basin (-38% from 2003 to 2011), suggesting a reduction of the upwelling intensity which contributes to most of the primary productivity of this region (this particular point would deserve further investigation). The decrease in chlorophyll content is around 20-25% in the other 3 areas. Only one area, the East tropical Indian Ocean, does not show any clear declining trend of productivity, noting this area is on average much less productive than the 4 other areas.

5) Regional analyses show that inter-annual primary productivity changes are often associated with the SST variability, with productive (depleted) chlorophyll content being associated with cold (warm) SST anomalies. This pattern is well observed in the Somali basin, the West Equatorial area, the Mozambique Channel and the East Tropical Indian Ocean). When a declining trend is observed, the years 2006-2007 often appear as the turning point from more productive to less productive situations.

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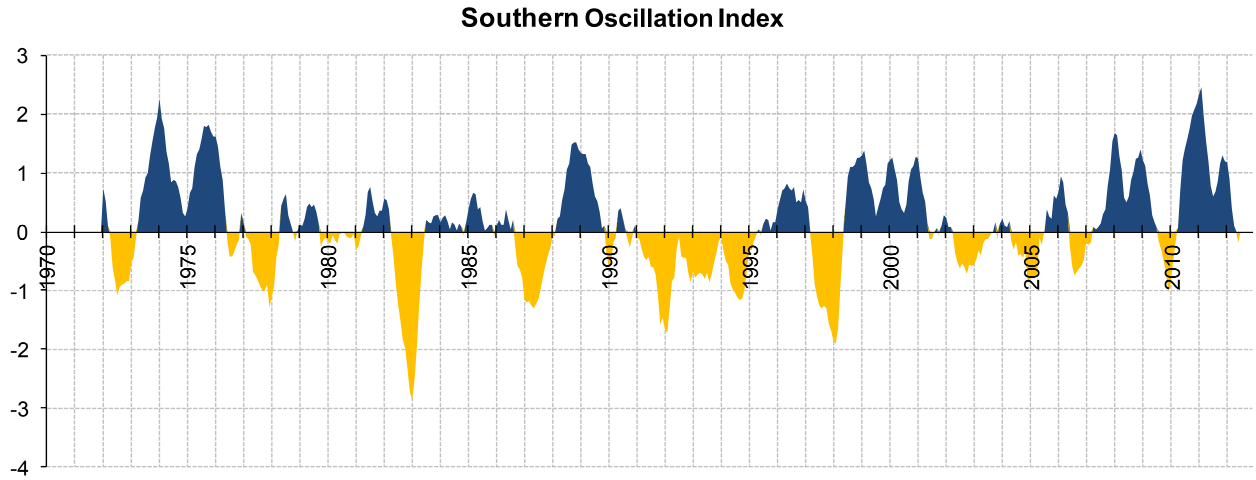


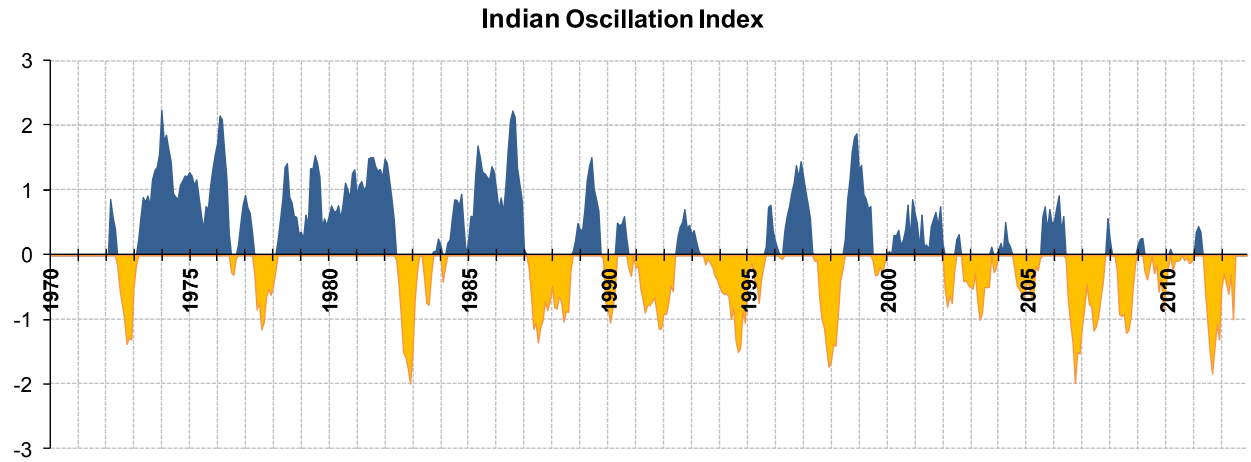


Fig. 1 – Southern Oscillation Index (top) and Indian Oscillation Index (bottom) over the period January 1972 – June 2012. The values plotted here are a 5-month moving average of monthly SOI/IOI

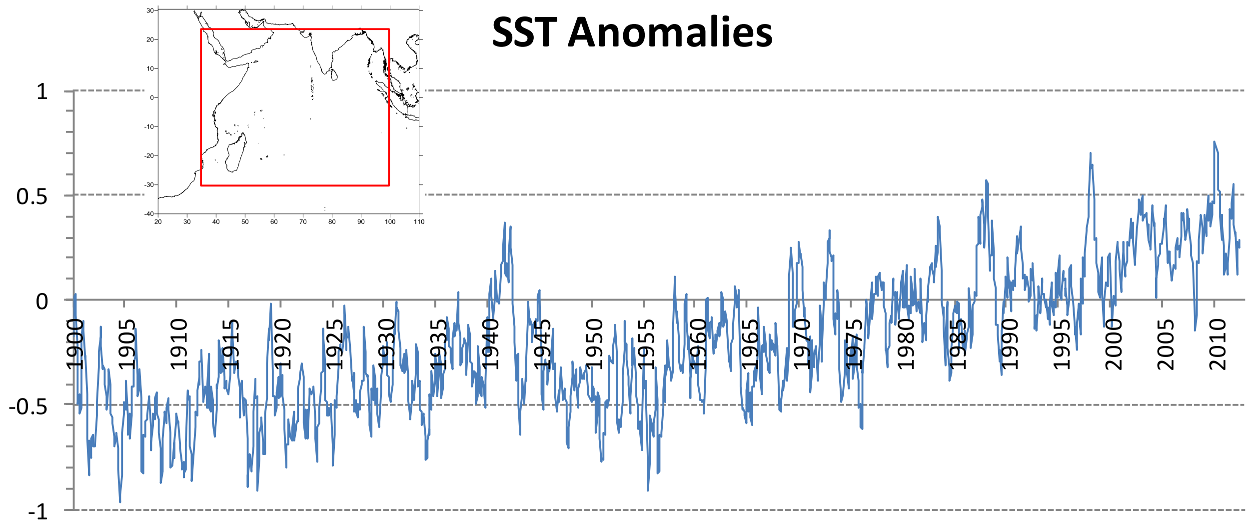


Fig.2 –Trend of SST anomalies over the whole Indian Ocean from 1900 to 2012

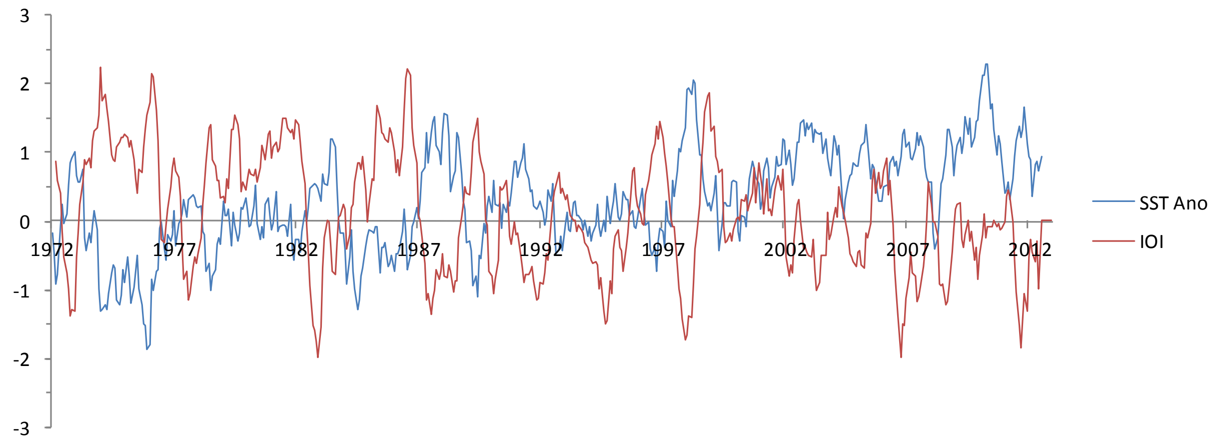
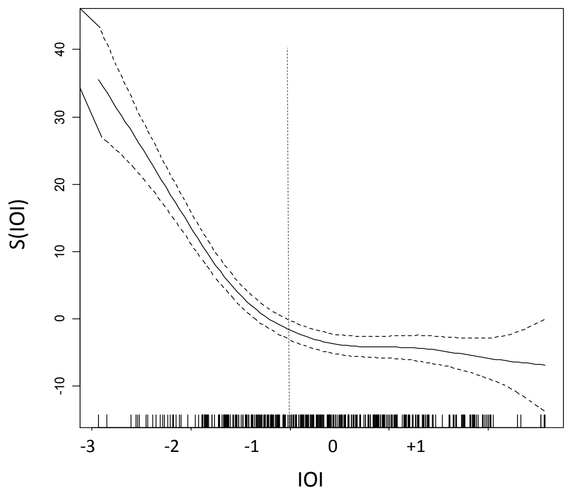


Fig.3 – Combined plots of SST anomalies and the IOI (the y scale corresponds to °C for the SST anomalies and to standard deviation for IOI)

Fig.4 – GAM regression showing the response of the MLD anomaly to a range of IOI values. The left part of the response curve (deep thermocline) corresponds to negative IOI values. Dotted lines indicate the 95% confidence interval. The bars along the x-axis indicate the density of observations. The threshold [IOI=-1] is shown by the vertical line



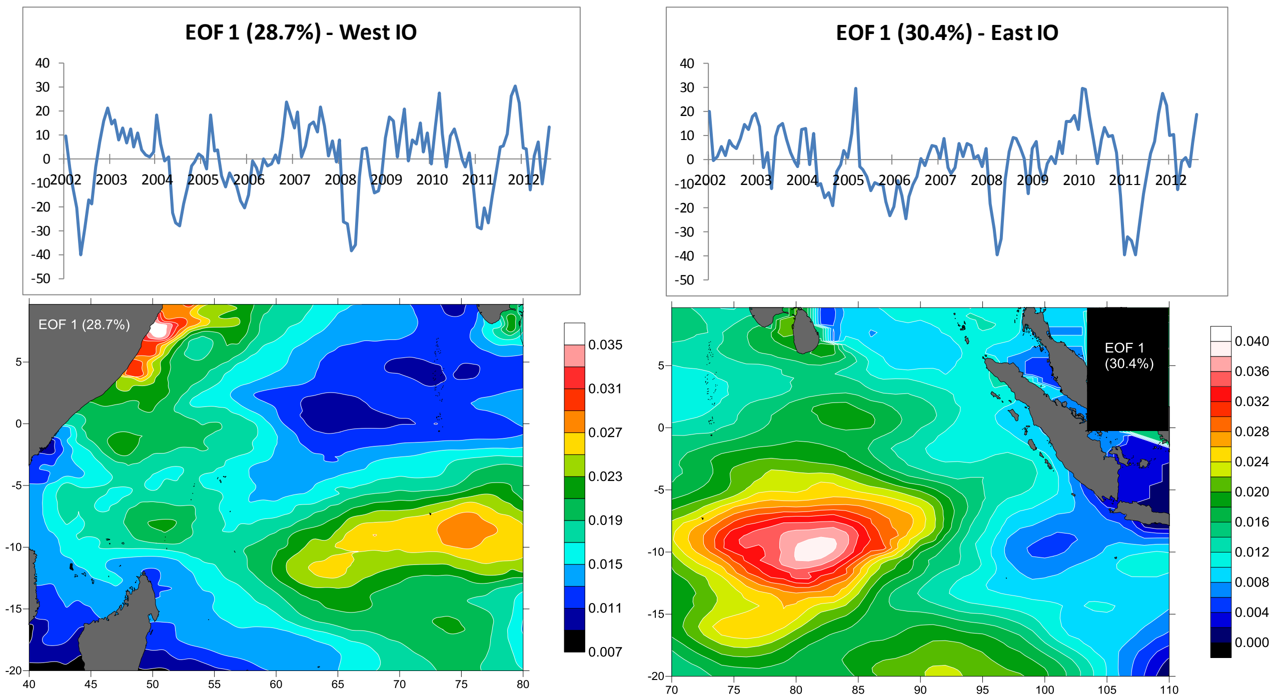


Fig. 5 – First EOF of the SST in the West (left) and East (right) Indian Ocean. Note the loadings are not comparable across the two EOFs

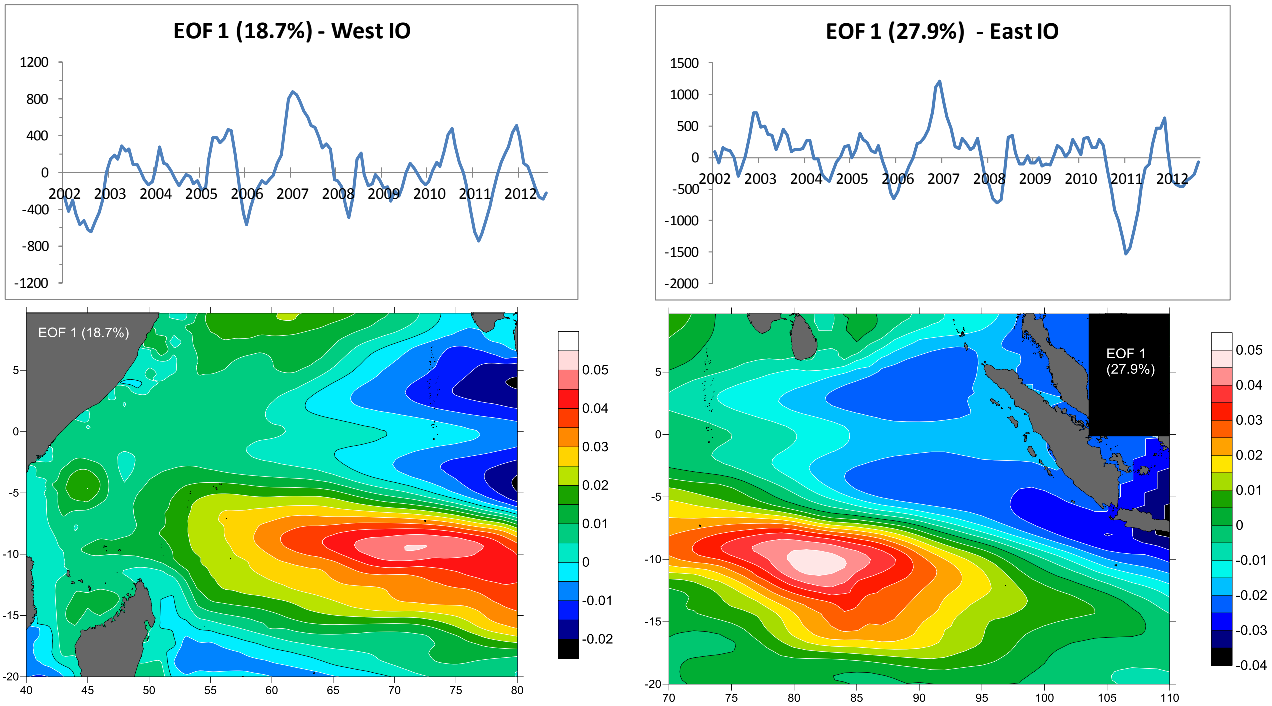


Fig. 6 – First EOF of the Mixed Layer Depth (20°C isotherm depth used as a proxy) in the West (left) and East (right) Indian Ocean. Note that the loadings are not comparable across the two EOFs

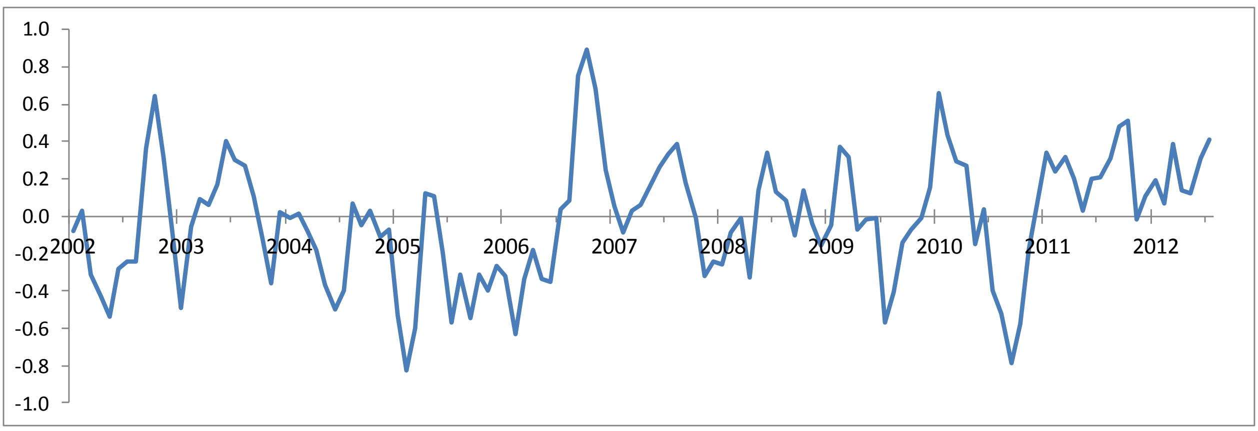


Fig 7 – Monthly series of the Indian Ocean Dipole Mode Index, Jan 2002-Jul 2012 This series has been calculated by the author, from the ERSST-v3 dataset.

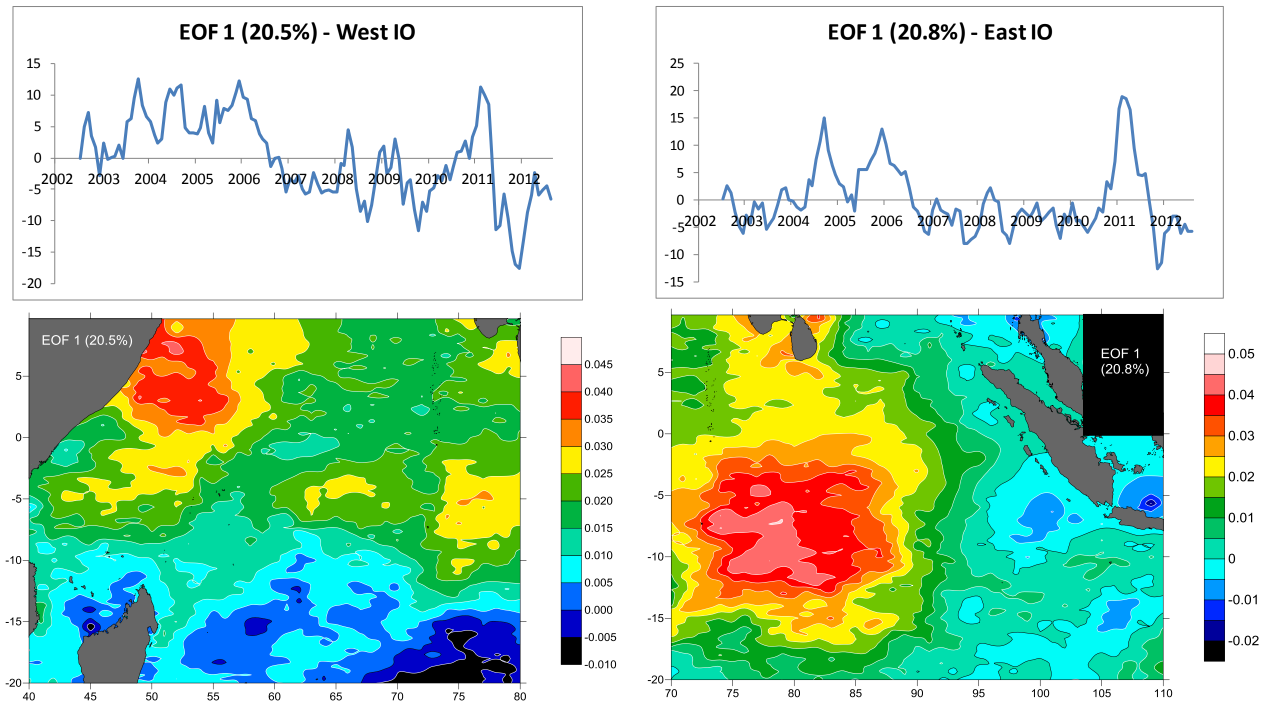


Fig. 8 – First EOF of the Sea Surface Chlorophyll in the West (left) and East (right) Indian Ocean. Note the loadings are not comparable across the two EOFs

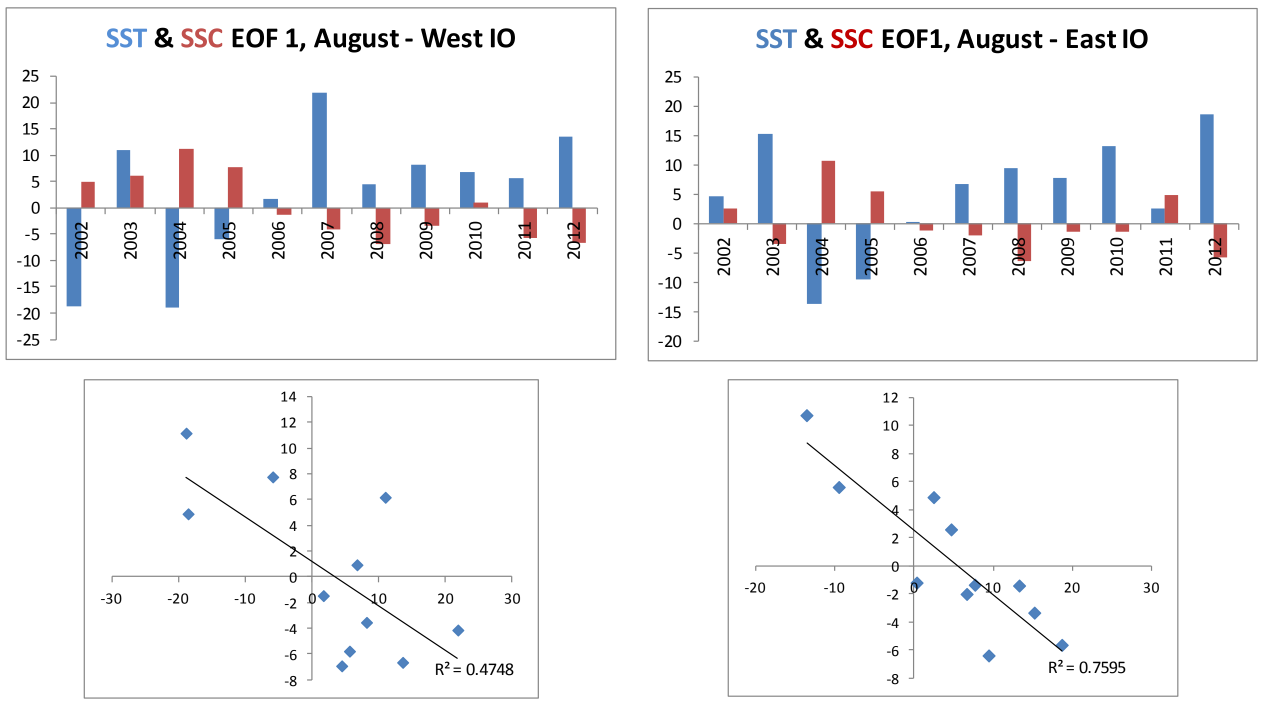


Fig.9 – Combined series (top) and scatterplot (bottom) of the 1st EOF of SST and SSC, in the West (left) and East (right) Indian Ocean, during August.

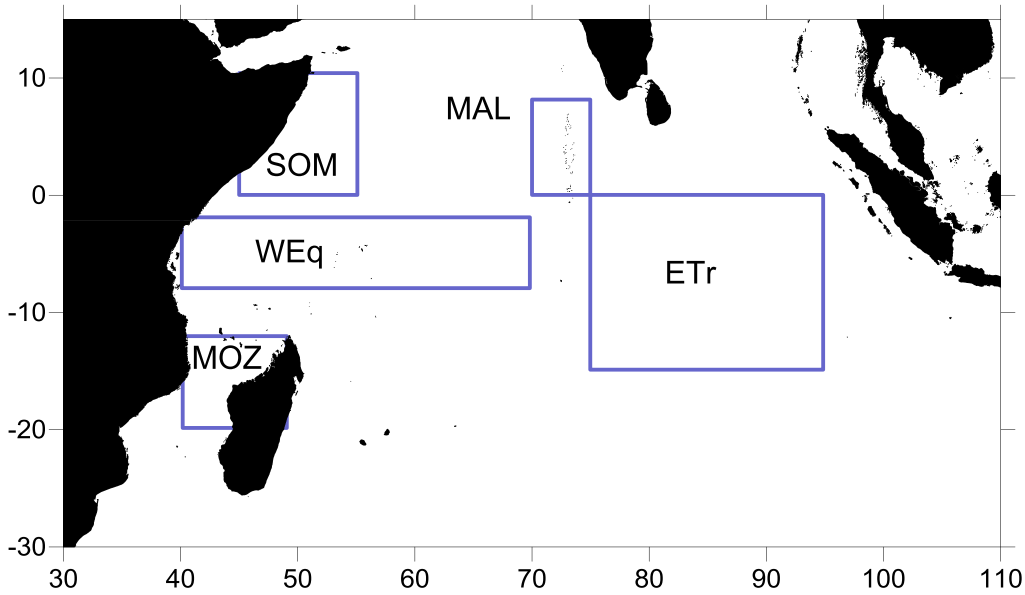


Fig.10 – Areas used for regional analyses

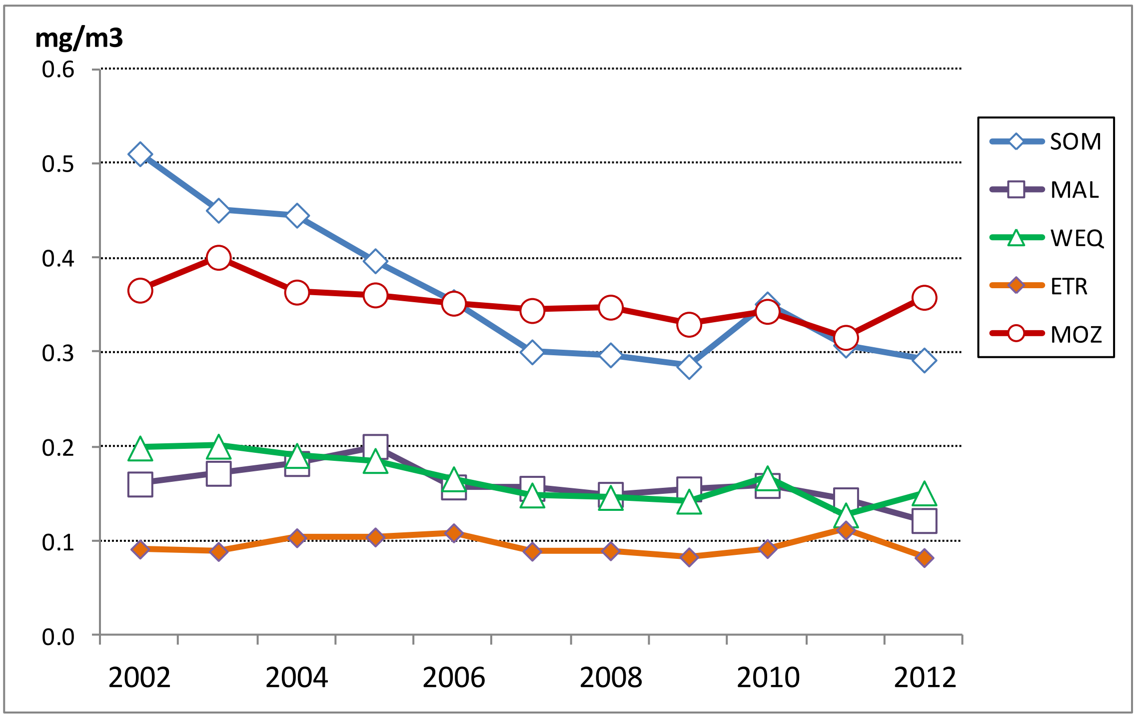


Fig.11 – Yearly trends of Sea Surface Chlorophyll by area, 2002-2012. Note that both 2002 and 2012 are incomplete (2002 starts in July and 2012 ends in August)

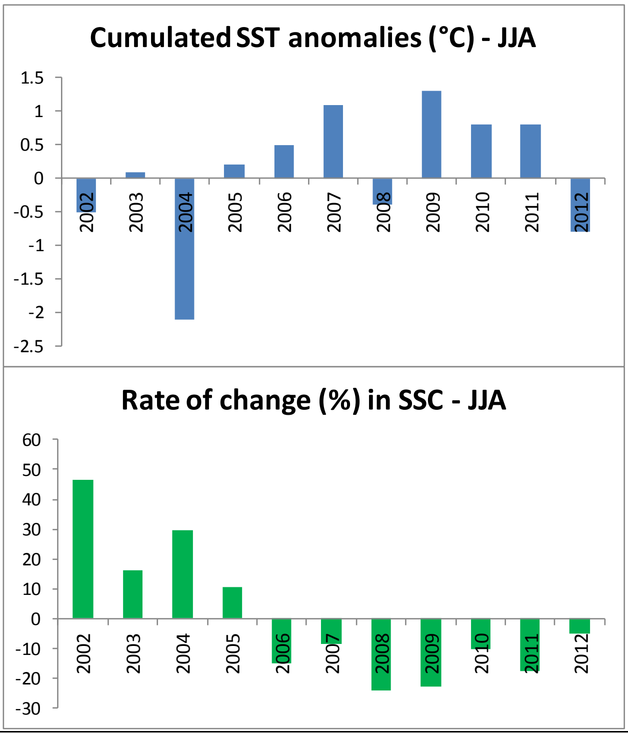


Fig. 12 – SST and SSC trends during the south-west monsoon, average June to August, in the Somali basin. SST anomalies are cumulated over the season, SSC is expressed as rate of change about the 2002-2012 average, June to August.

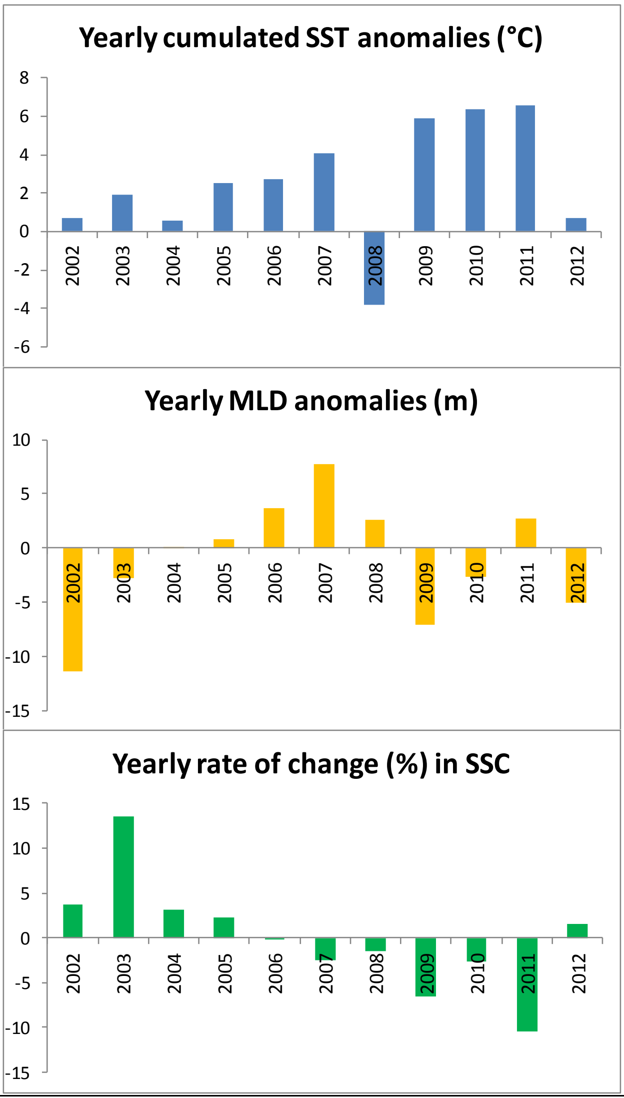


Fig. 13 – SST, MLD and SSC trends in the Mozambique Channel. SST anomalies are cumulated over the year, MLD anomalies are the annual mean and SSC is expressed as rate of change about the 2002-2012 annual average. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

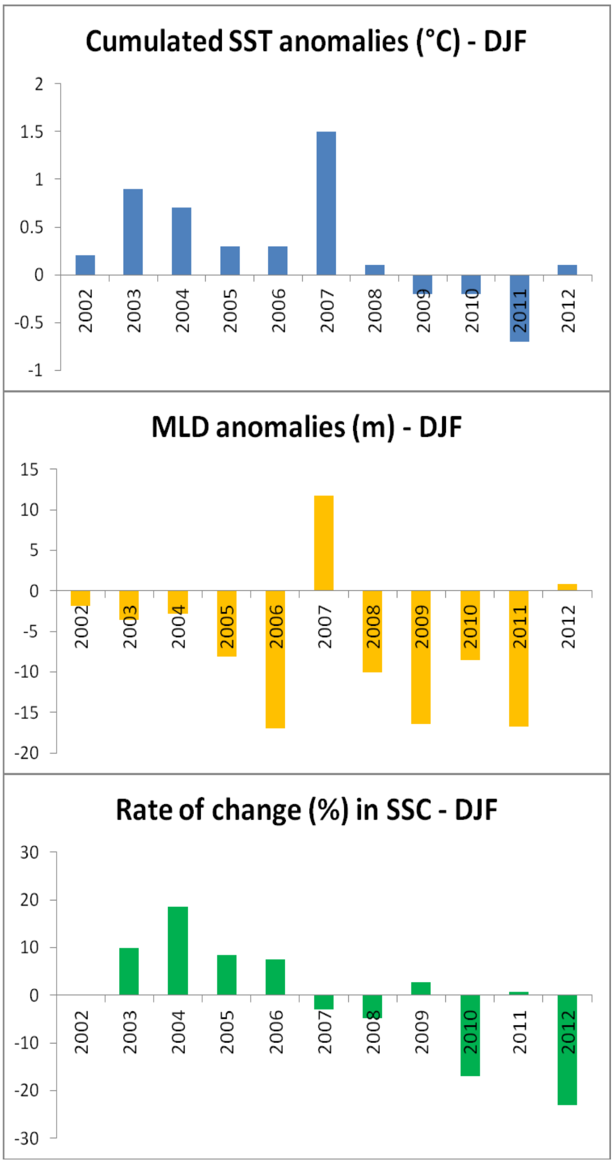


Fig. 14 – SST, MLD and SSC trends in the West Equatorial area, during the core of the north-east monsoon (December to February). SST anomalies are cumulated over the season, MLD anomalies are the mean over the season and SSC is expressed as rate of change about the 2002-2012 average for the season. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

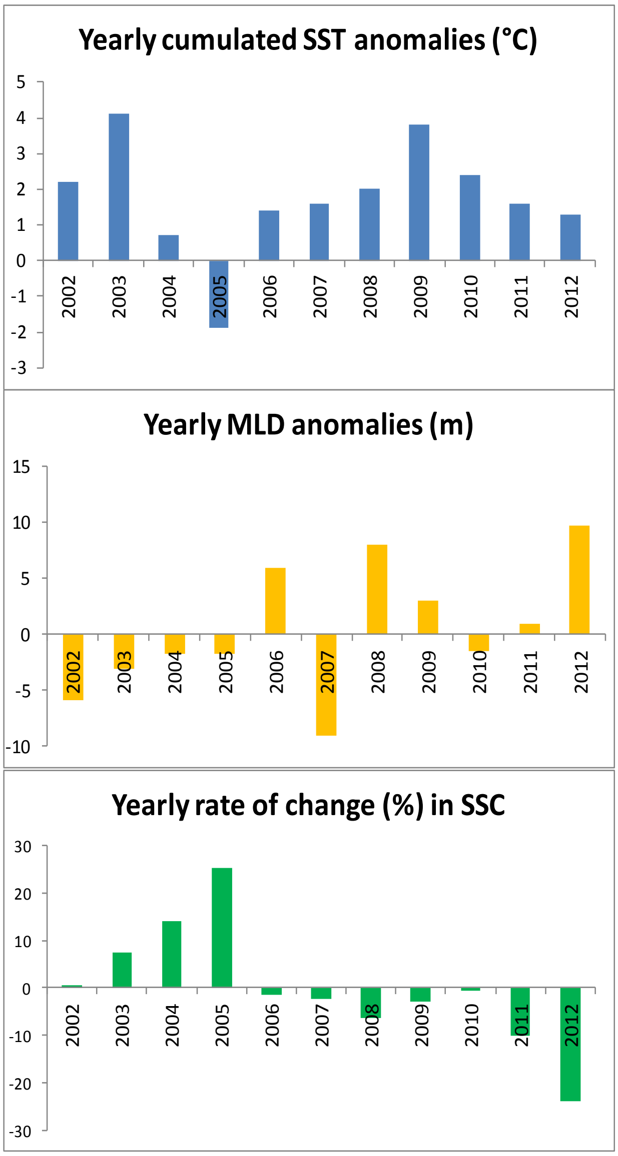


Fig. 15 – SST, MLD and SSC trends in the Maldives. SST anomalies are cumulated over the year, MLD anomalies are the annual mean and SSC is expressed as rate of change about the 2002-2012 annual average. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

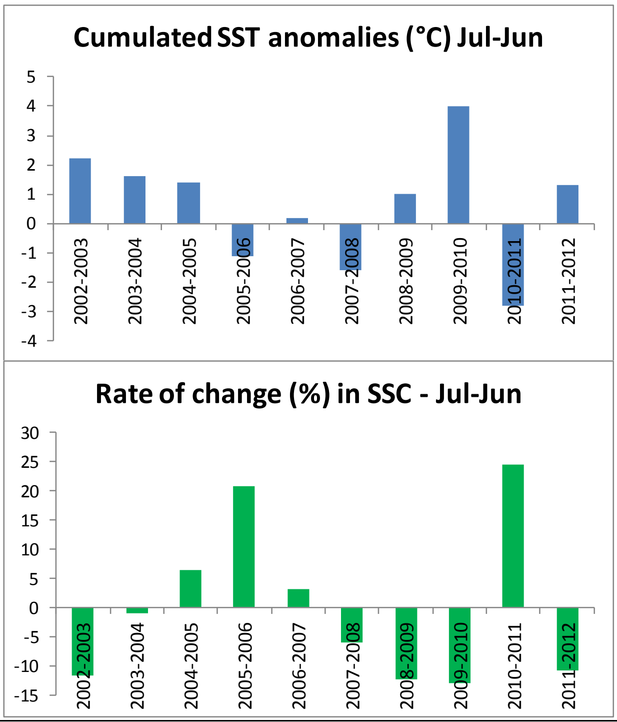


Fig. 16 – SST and SSC trends in the Eastern Tropical Indian Ocean, 12-month average from July (of the previous year) to June (of the current year). SST anomalies are cumulated over the 12-month period and SSC is expressed as rate of change about the 2002-2012 for the same period.