Received: 15 November 2014


# Outline of climate and oceanographic conditions in the Indian Ocean: an update to August 2014

Francis MARSAC
IRD, ICEMASA
UMR 212 EME
University of Cape Town, South Africa

**Abstract**

*In this paper, we provide an update on the trends of climate and oceanographic conditions in the Indian Ocean, at both basin and regional scales. The ENSO cycle has been largely fluctuating between ENSO-neutral and Niña conditions during the past 4 year and is considered being in a neutral state in 2014. Forecast coupled models give a 58% chance that an El Nino will develop by the end of 2014, but there is consensus that, if it does so, it will be a weak event. The sea surface temperature (SST) of the whole Indian Ocean has increased by +0.68°C from the 1950s to the 2000s (50 years) and this warming is still ongoing. Investigating the patterns of inter-annual variability between the East and West regions of the Indian Ocean, we found a good coherence for SST whereas the sea surface chlorophyll (SSC) had more contrasted patterns. The magnitude of SSC anomalies is also greater in the West compared to the East. Regional analyses for 5 sub-areas of the Indian Ocean were performed. The Somali basin and the Mozambique Channel are the most productive of the 5 sub-areas studied. In the Somali basin, the SST pattern is not related to the ENSO cycle, and SST and SSC are well correlated through an inverse relationship. Negative SST anomalies and high SSC content were observed in 2013. This area is under the influence of the Somalian coastal upwelling. In the Mozambique Channel, SST was back to the 1980-2005 average in 2012-2013 and warm anomalies appeared in 2014. The SSC has been depleted during several years since 2008 and the depletion intensified in 2014. The West equatorial area (WEQ) and the Maldives (MAL) exhibit similar trends. SST was back to normal in 2013-2014, and the depth of the thermocline (Z20) has been around the 1980-2005 average since 2012 (in the WEQ) and 2013 (in MAL). In those sub-areas, SSC has been depleted since the 2007 El Niño and remained in a depleted mode since then. The East tropical area is the least productive area. The SST has varied greatly with some relation to the ENSO and Dipole cycle. SSC has been low since 2007 and was still in a depleted state in 2014. The only dramatic enhancement in SSC occurred in 2011 in relation with a La Niña event.*

## 1 Introduction

Two analyses of the climate and oceanographic conditions were presented at WPTT-14 and 15 for the period starting in 2002 and ending in 2012 and 2013 respectively (Marsac, 2012, 2013). In this paper we use the same variables (atmospheric indices, sea surface temperature, depth of thermocline and sea surface chlorophyll concentration) as in previous analyses. The data series are updated to August 2014 and further discussed. An analysis of the environmental influences on yellowfin CPUEs of the purse seine fleet in the west equatorial region is also presented.

## 2 Data used

### 2.1 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.

## 2.2 Sea surface temperature and thermocline depth

The long-term trend of the sea surface temperature (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). 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 (GODAS), 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. Here, we use the depth of the 20°C isotherm (Z20) as a proxy for the thermocline. Z20 is 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.

The Dipole Mode Index (DMI), that quantifies the Indian Ocean Dipole (Saji et al, 1999), is obtained by subtracting the SST anomalies between the West and East Indian Ocean. The west box is 50°-70°E/10°N-10°S and the east box is 90°E-110°E/0°-10°S  The ERSST dataset was used compute the DMI.

## 2.3 Sea surface chlorophyll

The chlorophyll product of the SeaWifs (1997-2002) and Modis (2002 to present) sensors were used to study the trends in sea surface chlorophyll (SSC). 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 re-gridded the level-3 dataset at the same spatial resolution as the NCEP-GODAS model output (1°Lon/0.33° Lat). The monthly anomalies were calculated from a climatology established by the author over the period 2003-2008. The transition between SeaWifs and Modis series was done by averaging values of both sensors over a common period of 6 months (July to December 2002).

# 3 Results and discussion

## 3.1 Atmospheric indices

The atmospheric indices used are the Southern Oscillation Index (SOI) and the Indian Oscillation Index (IOI) (Marsac & Le Blanc 1998). The most recent anomalous event was La Niña which developed in 2010-2011. Since this episode, there was a gradual return towards ENSO-neutral conditions which are currently prevailing (Fig. 1)

Most models predict El Niño to develop during October-December 2014 and to continue into early 2015. However, the available information and model forecasts have reduced confidence that El Niño will fully materialize. If El Niño does emerge, the forecaster consensus favours a weak event (Fig. 2). In summary, there is a 58% chance of El Niño during the Northern Hemisphere winter, which is favored to last into the Northern Hemisphere spring 2015 (CPC/IRI consensus forecast, updated 6 Nov 2014).

The IOI and DMI (5 months moving average) exhibit the same pattern, although IOI appears less noisy. Low IOIs and high DMIs have prevailed from the 2007 El Niño until 2012, whereas slightly positive (negative) IOIs (DMIs) have been seen since 2013. However, the weak magnitude of such change does not qualify for a significant anomaly (Fig. 3)

## 3.2 Basin-scale SST trend

Using the ERSST v3b dataset, we computed the average monthly SST anomalies over the whole Indian Ocean (40°E-100°E / 20°S-20°N) for 1940-2014. SST decreased during the first decade examined, then started to increase steadily from mid-1950s (Fig 4 a). The average SST anomaly was -0.42°C in the 1950s (compared to the 1971-2000 climatology) and was +0.27°C in the 2000s, that is a +0.68°C increase over 50 years (Fig 4c). During the 2000s, SST anomalies fluctuated in the range -0.19 / +0.55°C whereas those recorded from 2010 to 2014 were quasi all positive (-0.02 to +0.75°C) (Fig 4b). This underlines the still increasing SST over the Indian Ocean.

Using the NCEP/GODAS2 dataset, we examined the SST and SSC inter-annual variability in two large areas separated by the longitude 80°E, in order to investigate any difference of patterns from one side of the Indian Ocean to the other. Two opposite seasons were considered (Fig 5).

a) SST. We found a good coherence of the inter-annual variability patterns between West and East of the ocean, whatever the season, particularly since 2009, which is a steady warm phase. The magnitude of SST anomalies is also very similar during 2009-2014. The largest discrepancy is related to the 2006-2007 El Niño. During the developing phase of a Niño (Jul-Aug), a large thermocline dome is formed along Sumatra, causing the SST to decrease below normal. This is seen in Jul-Aug 2006. Then the Niño becomes fully developed in the West at the turn of the following year (Dec-Feb) with strong positive SST anomaly. This is seen from December 2006 to February 2007.

b) SSC. The SSC variability pattern is more contrasted between East and West. The magnitude of anomalies is also greater in the West compared to the East. The high productivity measured in the West in 2004 (and to a minor extent in 2003 and 2005) had no analogue in the East. The elevated positive anomaly found in the East in Jul-Aug 2006 is related to the thermocline dome mentioned earlier. The East-West coherence becomes greater from 2009 onwards, when negative SSC anomalies prevail. However, two events of positive SSC in both sides of the ocean occurred in Dec 2010-Feb 2011 (La Niña related) and Jul-Aug 2014.

We computed Hovmoller diagrams for a longitude strip (20S to 10°N, between 50°E and 55°E) in the West Indian Ocean. The highest variability in SSC takes place to the North of the equator line. The anomalies remain weak anywhere else (keeping in mind that local enhancements are not captured at the 1°lon / 0.33° lat resolution). The long episode of negative SSC anomaly spanning 2006-2012 appeared during the south west monsoon (middle of the year).At that time, the coastal Somali upwelling is the dominating feature enhancing chlorophyll production, but it has probably been weaker than normal during these years of low productivity. The situation reversed in 2013 but low anomalies happen again in the middle of 2014 (Fig 6a). The zonal pattern of the SST differs significantly from the SSC one. Warm anomalies are not restricted to a particular area and they span over all tropical latitudes instead (Fig 6b). A strong negative SST anomaly (around -2°C) occurred around 10°S, due to the local shoaling of the thermocline at the boundary between the south equatorial current and the counter equatorial current (Seychelles-Chagos thermocline ridge). The anomalous deep events of the thermocline (positive Z20 anomalies) correspond to the warmest episodes. The latitudes south of 5°S are the most affected by the Z20 variability (Fig. 6c).

## 3.3 Regional analyses

We used the same areas analysed in the two previous studies: Somali (SOM), Maldives (MAL), west equatorial area (WEQ), east tropical area (ETR) and Mozambique Channel (MOZ) (Fig. 3). We computed the annual average of the SSC in each of those areas. Note than 2002 and 2014 are not complete years, hence not strictly comparable to the rest of the series. Three groups appear in terms of chlorophyll content: SOM and MOZ are the most productive areas (SSC: 0.28 to 0.45 mg/m3), then MAL and WEQ (SSC : 0.12 to 0.20 mg/m3), and lastly ETR being the less productive area (SSC around : 0.10 mg/m3) (Fig. 7). The highest SSC contents were observed in 2003-2004 after which SSC declined rapidly in relation with the 2007 El Niño. However, low SSC (around 0.3 mg/m3) prevailed during 3 consecutive years, then again in 2011-2012 after a moderate increase in 2010. SSC was quite high in

2013 but declined again in 2014. MOZ and WEQ had a moderate SSC decline until 2011 then a slight increasing trend since then. The SSC content in MAL decreased from 2005 to 2012 then increased slightly in 2013. No trend was shown in ETR.

We examined the trends of SST, Z20 and SSC in the different regions. Regions are presented according to the three groups exhibiting similar productivity patterns, as shown in the previous paragraph. Here, we mostly discuss the situation in the last 2-3 years, until August 2014, as more a extensive discussion was given in Marsac (2012).

*3.3.1 The Somali basin (Fig. 8)*

The last 3 years of the series point out a return to colder than average conditions, after a period of warmer conditions from 2007-2011 (with the exception for 2008). The rate of change in SSC mirrors the SST trend, with depleted CHL associated to warmer conditions. Chlorophyll content dramatically increased in 2013, in parallel with colder SST anomaly, likely a consequence of the upwelling intensification. It does not appear any clear ENSO/IOD effect on the two variables studied.

*3.3.2 The Mozambique Channel (Fig. 9)*

To make years comparable from one another, we computed anomalies over the period January to August. SST returned to normal in 2012-2013 after 3 years of warm anomalies which also characterize the year 2014. Z20 anomalies have oscillated without trend and are about the average in 2014. Depleted SSC conditions, which have prevailed since 2009, strengthened in 2014 (10% below normal). It should be kept in mind that the mesoscale turbulence which affects the variables presented here, are not resolved in the GODAS spatial resolution.

*3.3.3 The West equatorial Indian Ocean (Fig. 10)*

For this area, we focus on the core of the north-east monsoon, December to February, when free schools mostly composed of yellowfin are harvested by the purse seiners. The value assigned to the year *y* is an average of $\text{December}_{y-1}$ to $\text{February}_{y}$. The SST fluctuated without trend since 2008, but a cold anomaly happened in 2011 in relation to La Niña. In 2014, the situation is about the average. After several years of shallow thermocline (2008-2011) when the thermocline remained at a depth of 70 to 80 m (15 metres above normal), the conditions were back to normal in 2012 and up to present. The Z20 fluctuations are well correlated to the ENSO cycle, with shallow thermocline associated to positive (Niña-like) SOI. Negative SSC anomalies have prevailed since 2007 (except very minor positive anomalies in 2009 and 2011, in relation to La Niña for the latter) and are still observed in 2014. Very low CHL content was observed in 2012 (22% below normal) which is opposite to the high CHL anomalies observed in 2004 (23% above normal). The SSC from December 2013 to February 2014 is 6% below normal.

*3.3.4 Maldives (Fig. 11)*

The statistics were calculated for January-August. Warmer conditions have mostly prevailed since 2002. These anomalies peaked in 2010, with a cumulated anomaly of 3.4°C. The conditions were back to normal in 2013 and 2014. The magnitude of changes in Z20 depth does not exceed 10 meters in Maldives. The most recent deepening was in 2012, and conditions were back to normal in 2013 and 2014. There is no clear relationship between SSC and SST or Z20. SSC has steadily declined since 2000 (not shown), from positive anomalies (22% above normal) to negative anomalies (26% below normal in 2012). The depleted event started in 2007 and is still occurring in 2014 (11% below normal).

*3.3.5 The East tropical Indian Ocean (Fig. 12)*

The statistics were 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/IOD 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 present the Z20 anomalies as the area contains patterns of opposite variability, as shown by the spatial EOF1 (Fig. 6 in Marsac, 2012). SST exhibits a large inter-annual variability. Warm anomalies have prevailed since 2009 up to 4°C cumulated anomalies), except for 2011 (-2.8°C) in relation to La Niña. The SSC variability is consistent with the SST variability, with warmer (colder) events corresponding to lower (higher) productivity ($R^2$=-0.40, p=0.05). The highest positive SSC anomaly was recorded in 2011 (20% increase from the 1998-2014 baseline). It corresponded to a long and anomalously productive event already reported by Marsac (2011) and well shown in the spatial EOF1 (see Fig. 8, Marsac, 2012). The situation was back to depleted situation after La Nina, and such situation is continuing in 2014 (13% below normal).

## References

Marsac , F. (2011). Outline of climate and oceanographic conditions in the Indian Ocean : an update to August 2011. Oral presentation at the 13th session of the WPTT, IOTC. IOTC-2011-WPTT13-Rev1.

Marsac, F. (2012). Outline of climate and oceanographic conditions in the Indian Ocean over the period 2002-2012. 14th session of the IOTC Working Party on Tropical Tunas, Mauritius, 24-29/10/2012. IOTC-2012-WPTT14-09, 16 p.

Marsac, F., Le Blanc, J-L. (1998). Interannual and ENSO-associated variability of the coupled ocean-atmosphere system with possible impacts on the yellowfin tuna fisheries of the Indian and Atlantic oceans. In : J.S. Beckett (Ed). ICCAT Tuna Symposium. *Coll. Vol. Sci. Pap*., L(1) : 345-377.

Saji, N.H. , Goswani, B.N., Vinayachandran, P.N., Yamagata, T. (1999). A dipole mode in the tropical Indian Ocean. *Nature* **401**: 360-363

Smith, T.M., Reynolds, R.W., Peterson, T.C., Lawrimore, J. (2008). Improvements to NOAA's Historical Merged Land-Ocean Surface Temperature Analysis (1880-2006). *J. Climate*,**2:** 2283-2296

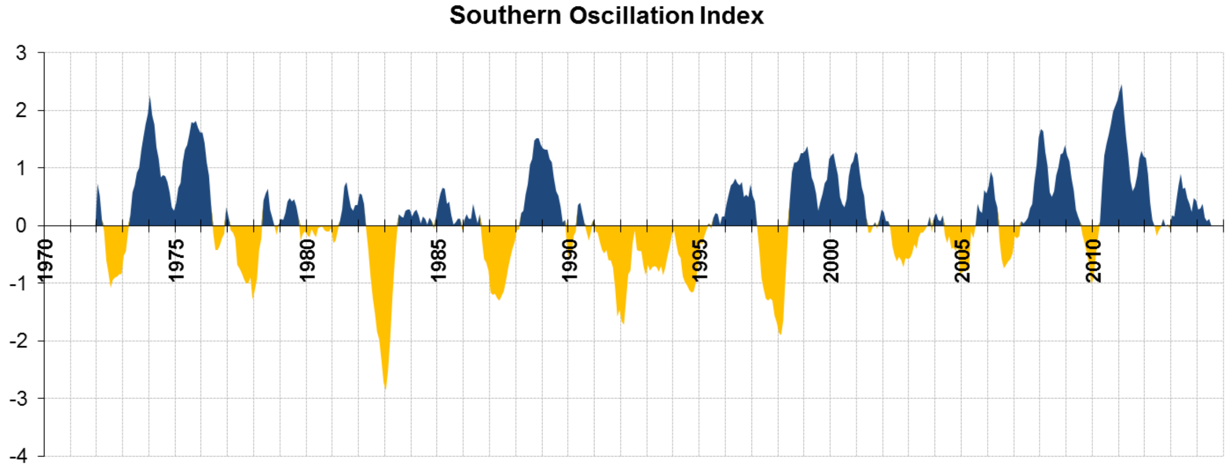



Fig.1 – The Southern Oscillation Index (SOI), January 1970 to August 2014 (the series is smoothed by a 5 month moving average). Niños correspond to the extreme negative values whereas Niñas are described by the extreme positive values

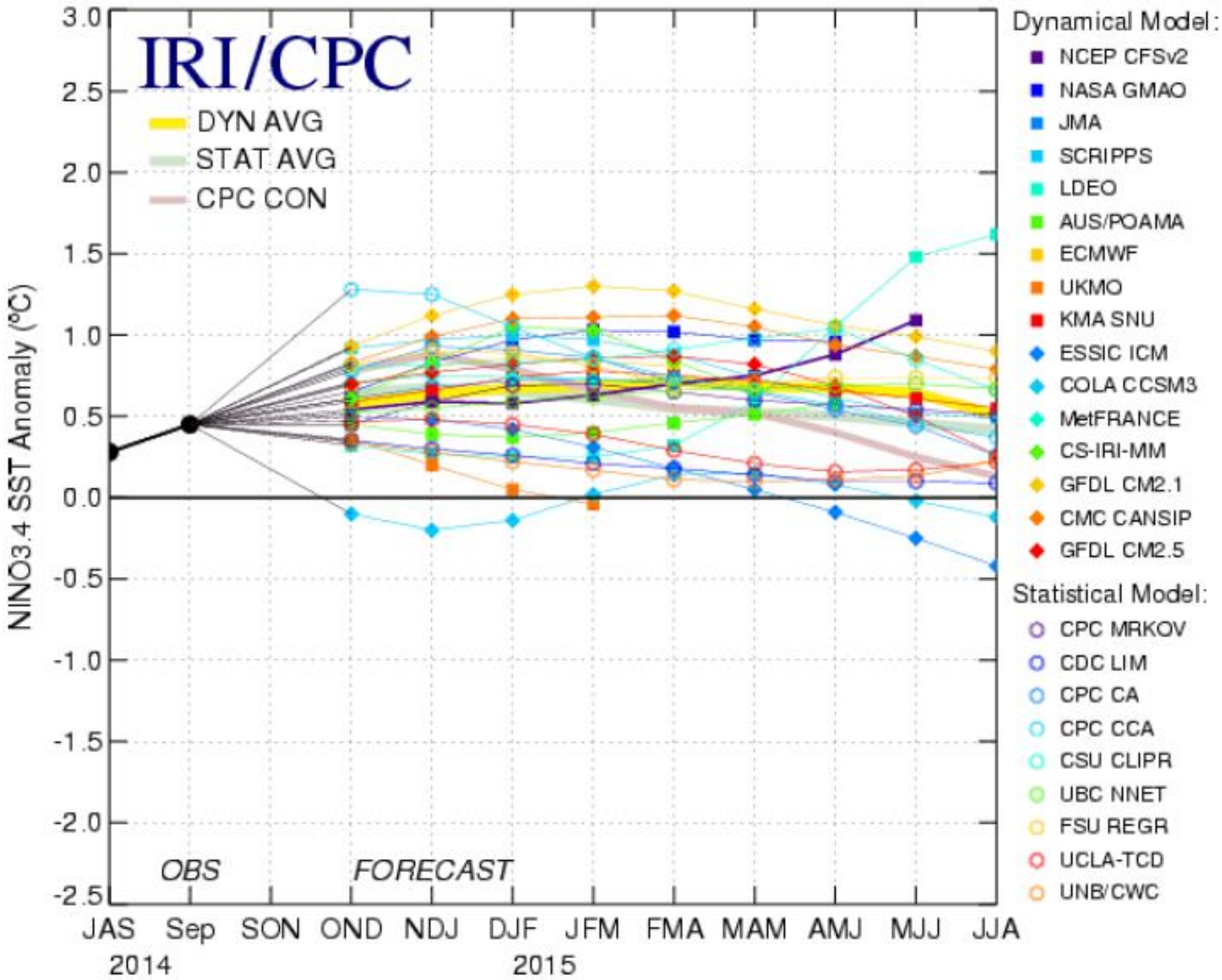



Fig.2 – Mid-Oct 2014 plume of Model ENSO predictions

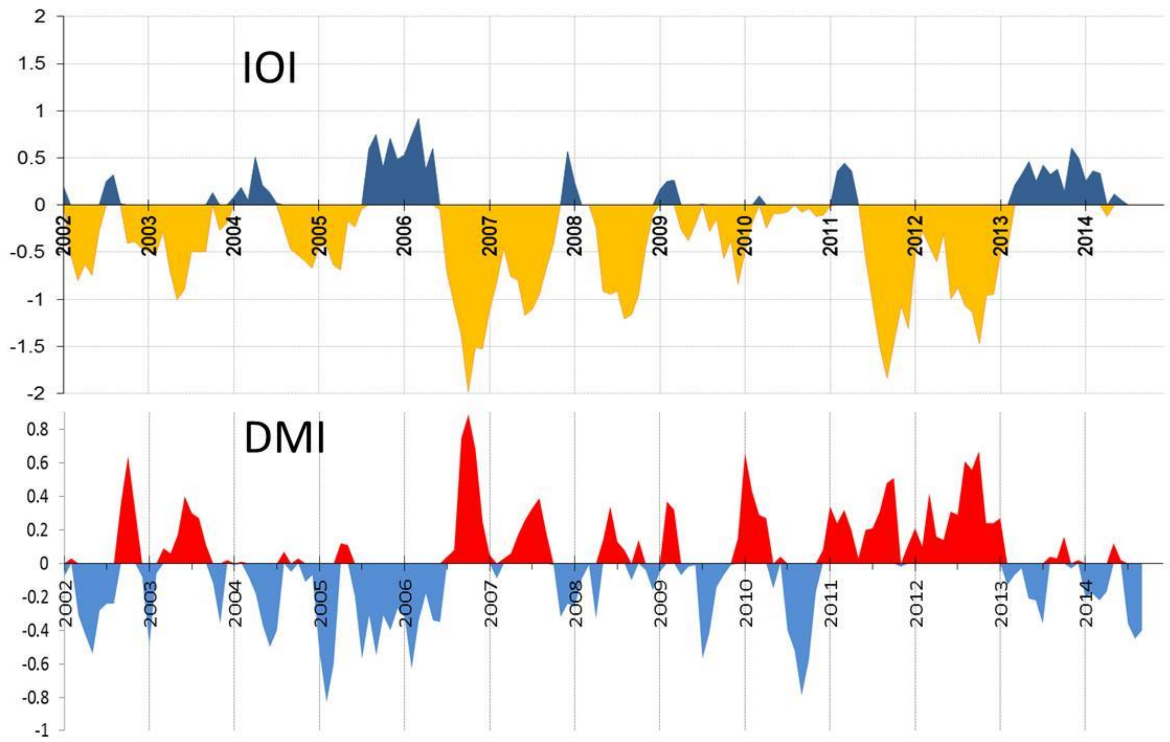



Fig. 3 - Indian Oscillation Index (top) and dipole mode index (bottom) over the period January 2002 – June 2014 (the series is smoothed by a 5 months moving average). Warm (cold) events are represented by negative (positive) IOI and positive (negative) DMI.

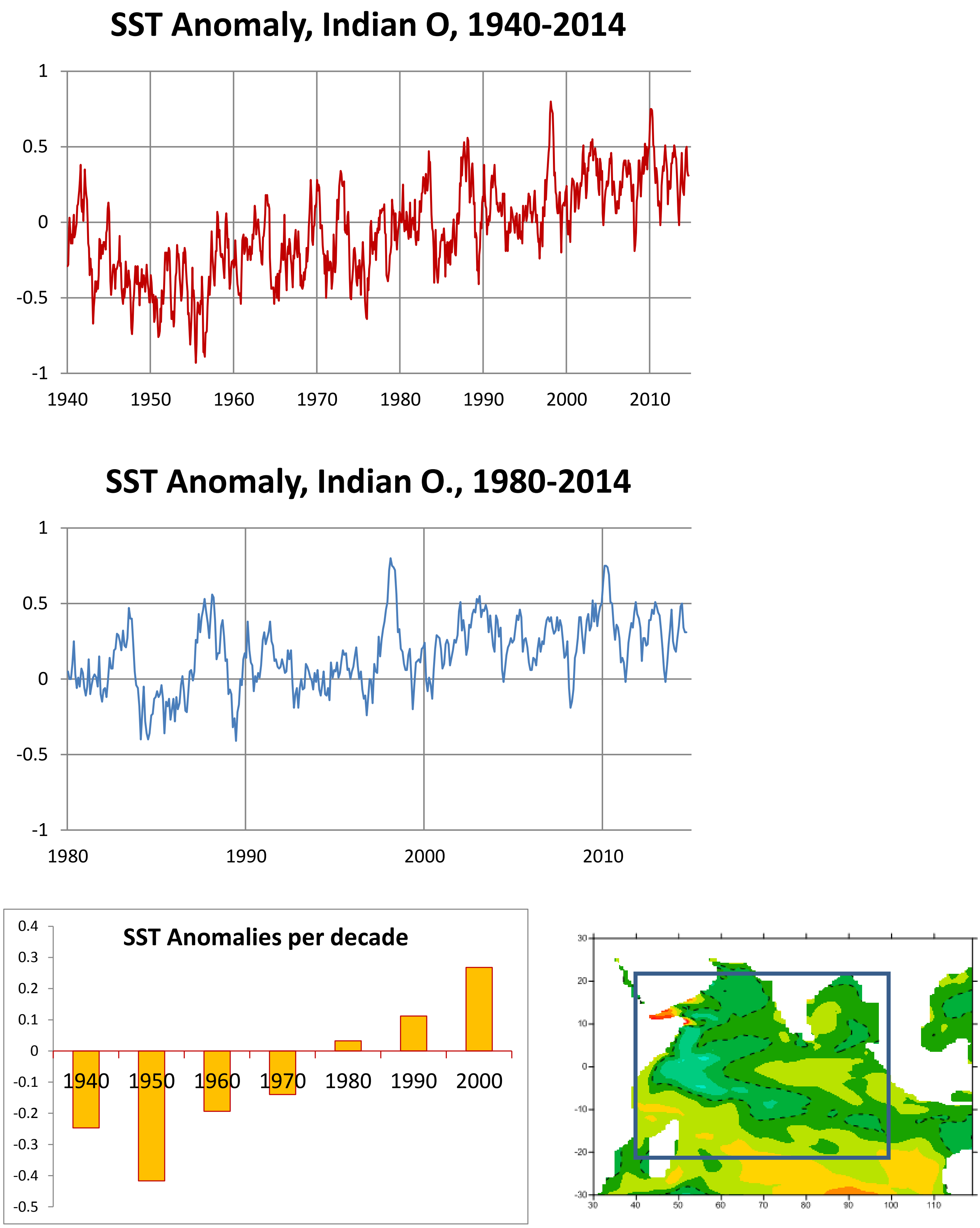



Fig. 4 – SST anomalies in the Indian Ocean measured from the ERSST v3b data set (Smith et al, 2008). a) monthly series Jan 1940-Aug 2014 (top); b) : monthly series Jan 1980-Aug 2014 (middle); c) average by decade (bottom). The square in the map indicates the limits of the area considered.

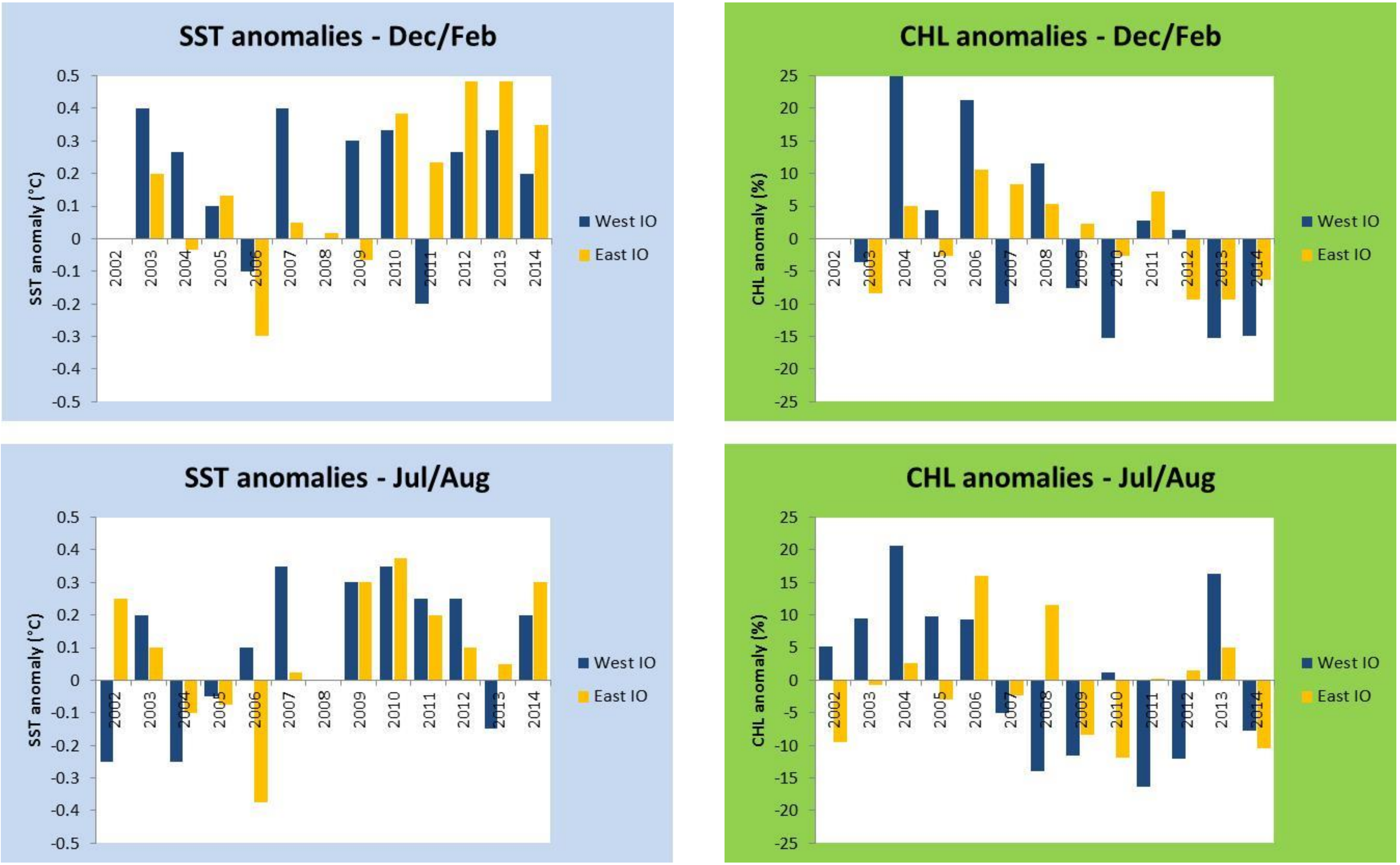



Fig. 5 – SST anomalies (from the climatology 1980-2005) and SSC anomalies (from a climatology 1998-2005) in two large areas of the Indian Ocean separated by the longitude 80°E. Two seasons are considered, December-February and July-August.

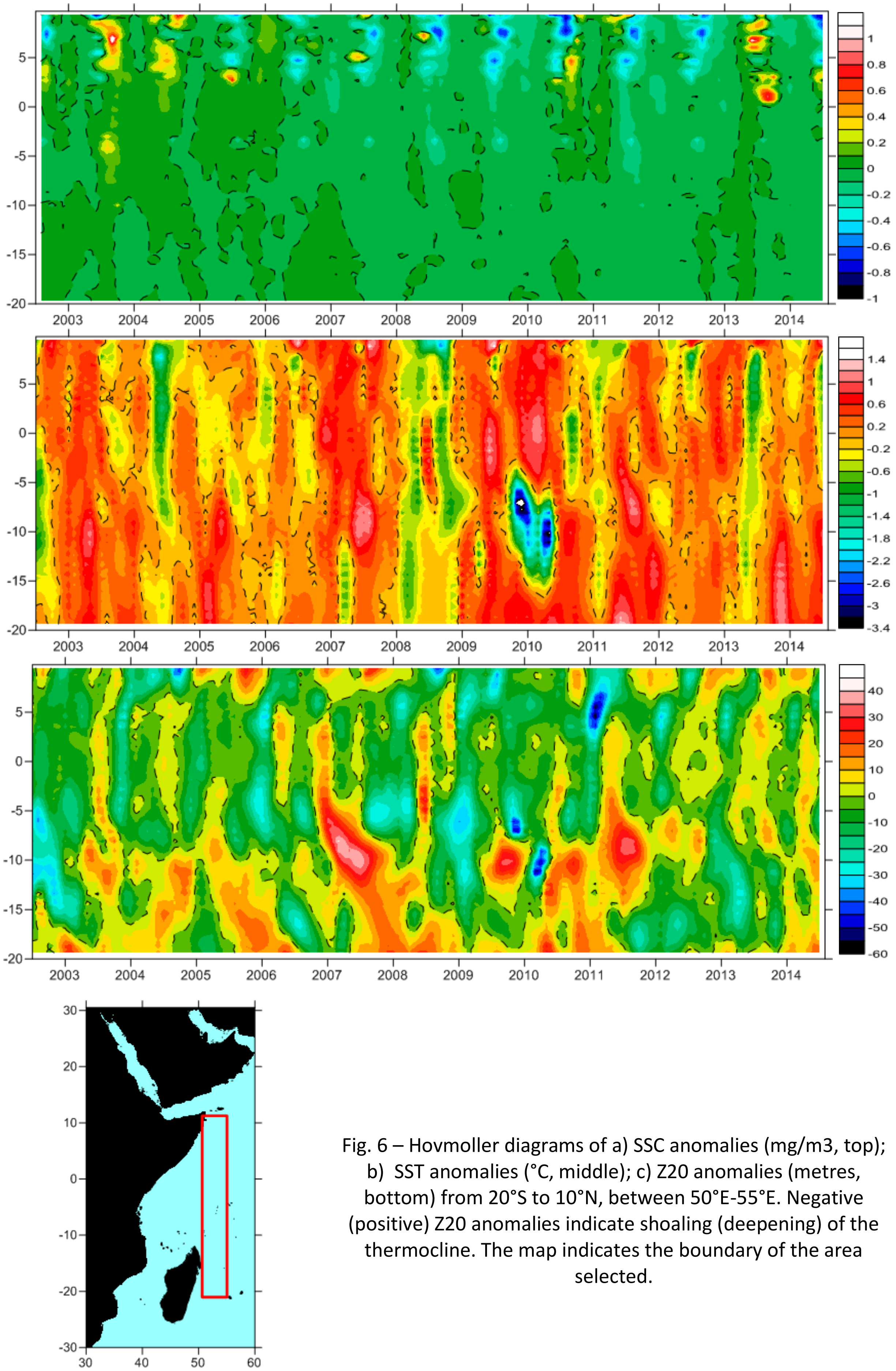



Fig. 6 – Hovmoller diagrams of a) SSC anomalies (mg/m3, top); b) SST anomalies (°C, middle); c) Z20 anomalies (metres, bottom) from 20°S to 10°N, between 50°E-55°E. Negative (positive) Z20 anomalies indicate shoaling (deepening) of the thermocline. The map indicates the boundary of the area selected.

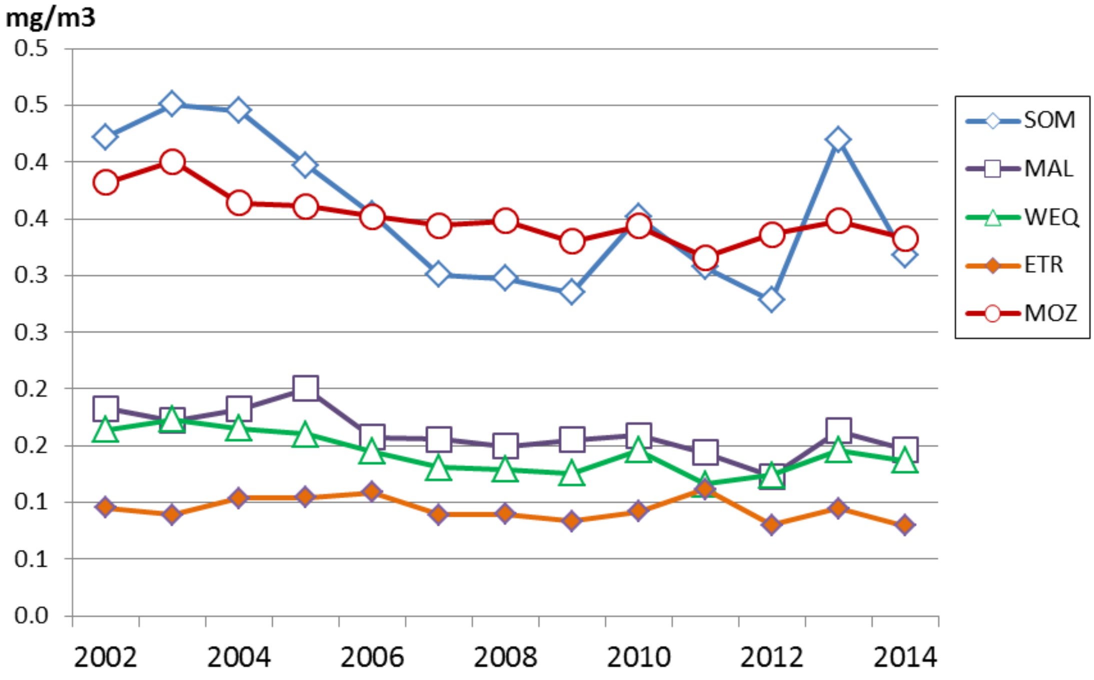
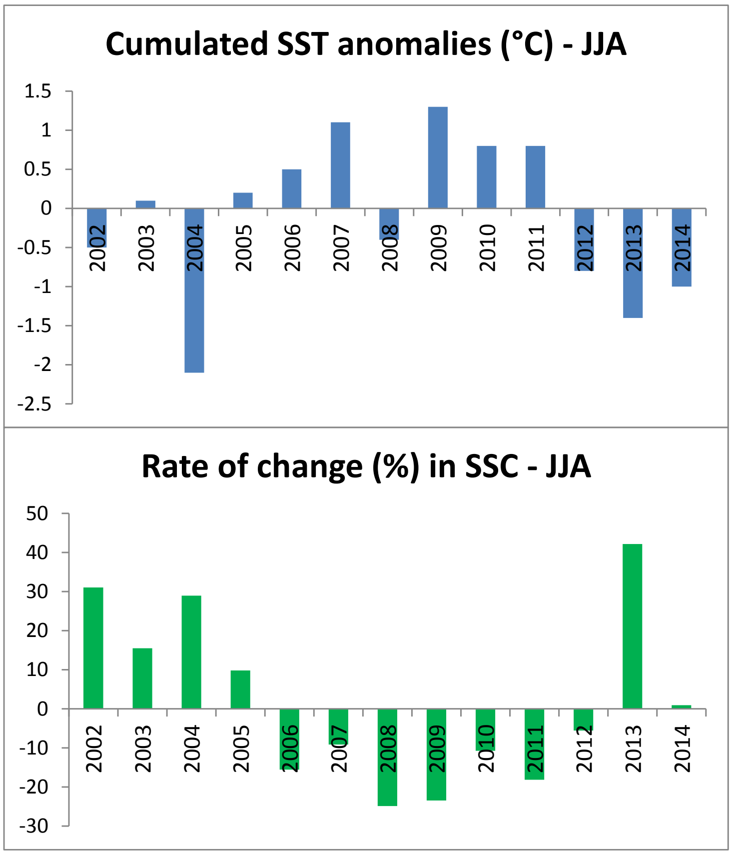
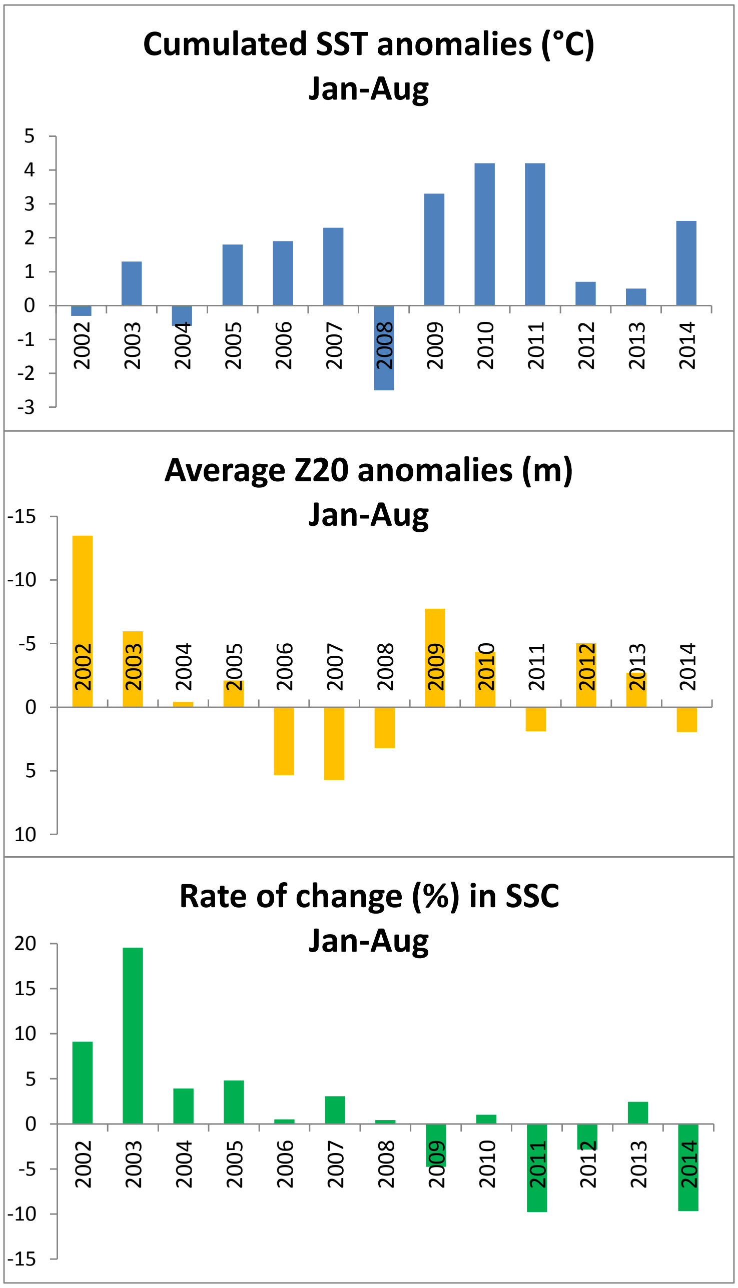



Fig.7 – Yearly trend of sea surface chlorophyll concentration, 2002-2014 (from Modis dataset). Note that both 2002 and 2014 are incomplete (2002 starts in July and 2013 ends in August).




SOMALI

Fig. 8 – 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 1998-2014 average, June to August.




# MOZAMBIQUE CHANNEL

Fig. 9 – SST, MLD and SSC trends in the Mozambique Channel. Statistics are calculated for the period January to August. SST anomalies are cumulated over the period, MLD anomalies are the average over the period and SSC is expressed as rate of change about the 1998-2014 for the study period. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

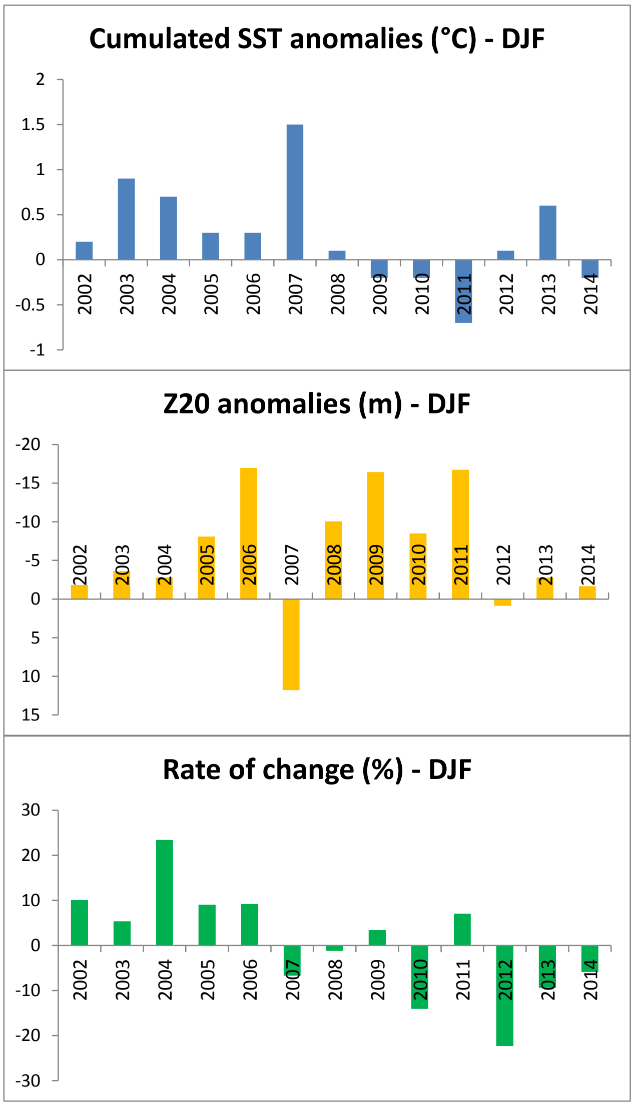



Fig. 10 – SST, MLD and SSC trends in the West Equatorial area, during the core of the north-east monsoon (December to February). SST anomalies are cumulated over the season, MLD anomalies are the mean over the season and SSC is expressed as rate of change about the 1998-2014 average for the season. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

WEST EQUATORIAL AREA

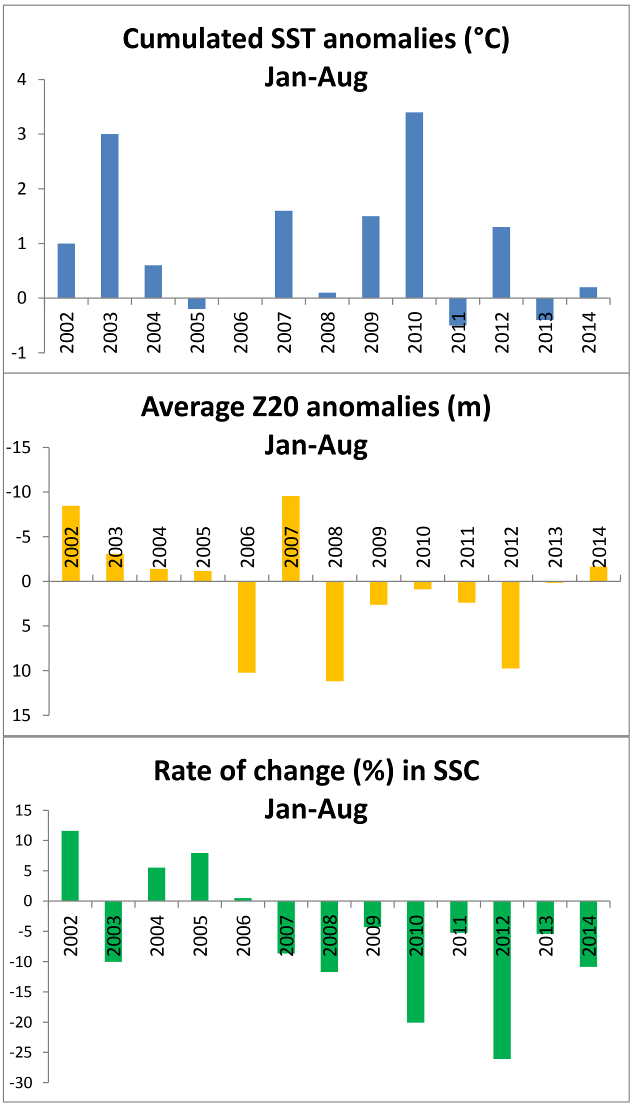
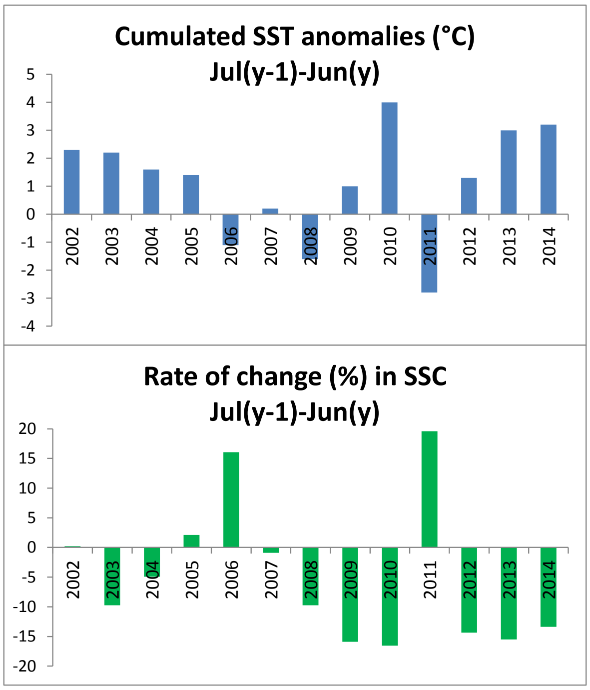



Fig. 11 – SST, MLD and SSC trends in the Maldives. Statistics are calculated for the period January to August. SST anomalies are cumulated over the period, MLD anomalies are the average over the period and SSC is expressed as rate of change about the 1998-2014 for the study period. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

MALDIVES

.




# EAST TROPICAL AREA

Fig. 12 – 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 1998-2014 for the same period.