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Outline of climate and oceanographic conditions in the Indian Ocean: an update to August 2015

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Abstract

Several descriptors of the ocean climate conditions are examined to depict the inter-annual trend and to track major changes that may affect the large pelagic ecosystem. We analyse climate indices (SOI, IOI, wind stress and rainfall), physical (SST, mixed layer depth) and biological (sea surface chlorophyll concentration) oceanographic variables, at the large (ocean basin) and regional scale (within specific areas that are relevant for tuna fisheries). The period considered is from September 1997 through August 2015. The ocean climate conditions seen in August 2015 reflect the early stage of development of a positive dipole mode, and further development in the wind, SST, Z20 and chlorophyll anomalies are foreseen during the fourth quarter 2015. The potential impact on purse seine and longline fisheries is discussed, based on two recent positive dipole events, a strong one in 1997-8 and a moderate one in 2006-07.

1 Data access and preparation

1.1 Climate 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.

The wind products (here, wind stress) are obtained from the Centre for Ocean-Atmospheric Prediction Studies based at the Florida State University. The data series starts in 1970 and is updated on a monthly basis. The current objective approach used to produce this data set treats the various types of observations (volunteer observing ships (VOS), moored buoys, drifting buoys) as independent, and objectively determines weights for each type of observation These long-term monthly fields are well suited for seasonal to decadal studies (© The University of Florida, 2014).

We also use rainfall data provided by the Climate Centre of the Seychelles National Meteorological Services National. Rainfall data are collected daily at the Pointe Larue International Airport and have been monthly averaged for 1972-2015.

1.2 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 (ERSST.v3b) which includes *in situ* data collected by ships and buoys. 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 monthly 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. 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.

1.3 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 Z20, 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).

2 Results and discussion

2.1 Climate indices

The climate indices used to track the inter-annual variability are the Southern Oscillation Index (SOI), the Indian Oscillation Index (IOI) (Marsac & Le Blanc 1998) and the Dipole Mode Index (DMI) (Saji et al, 1999). Since La Niña event which developed in 2010 through 2012 there was a gradual return to ENSO-neutral conditions in 2013-2014. An El Niño started to develop in March 2015 (sharp drop of monthly SOI values) and is still growing, as depicted by the recent negative SOI values (Fig. 1).

All models predict El Niño to continue into the Northern Hemisphere spring 2016 (95% chance) and all multi-models averages predict a peak in late boreal fall/early winter 2015 (ENSO alert system, Climate Diagnostic Bulletin Aug 2015, NOAA, USA). Typically, El Niño is strongest during the late austral spring or early summer, and weakens during late summer to autumn (Australian Bureau of Meteorology web site) and this is what forecasters predict for the current event. It is also widely agreed this El Niño would be a prominent one (Fig.2).

The occurrence of IOI negative values since 2014 through 2015 is consistent with the SOI trend. Both series are well correlated (r_{spear}= 0.39, $\alpha < 0.05$, n= 777). Since July 2015, DMI increased sharply into a positive mode, reflecting the setting up of a reversed SST temperature gradient across the tropical Indian Ocean (Fig. 3). The last positive dipole was observed in 2012 (simultaneously to negative IOI) but this was not related to any El Niño event. Overall, the correlation between DMI and IOI is significant (r_{spear}= -0.27, $\alpha < 0.05$, n= 777).

Rainfall records from the Seychelles International Airport (Belmont, com. pers) point out anomalous high values for 2015 (especially in August: + 175 mm above the 1981-2010 average of 122.5 mm). This is the second largest anomaly after that of August 1997 (+571 mm) when a strong positive dipole was building up. Furthermore, rainfall standardized anomalies follow an increasing trend through 2015, a similar trend to that measured for 1997. Situations found during negative dipole years (like 1990 and 1992) show a reversed rainfall trend through these years.

The current situation reflects a combination of a growing El Niño in the Pacific, and an emerging positive Indian Ocean Dipole in the Indian Ocean.

2.2 Long-term 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 1940-2015. SST decreased until the mid 50s, then levelled off during the 60s, then started to increase steadily since the 70s (Fig 4a, 4c). The most prominent positive anomalies over the whole Indian Ocean occurred in conjunction with the last 4 strongest El Niño events of the XXth century: 1972-73, 1982-83, 1986-87, 1997-98, as depicted by the detrended series of SST anomalies (Fig. 4b). During that period, sustained negative SST anomalies mirrored the positive anomalies. Since the 1997-98 Niño, the SST changes between warm and cold anomalies have been more frequent. Warm anomalies have lasted longer than cold anomalies. A sudden SST increase occurred in 2015.

2.3 Comparison of 2015 current conditions with past positive dipole events

In this section, the current ocean climate conditions found in August 2015 are compared with those of August of the years preceding strong positive dipole events. Four parameters are selected : zonal wind stress, SST, Z20 and surface chlorophyll. Thus, 2015 is compared with 1994, 1997 and 2006.

The common pattern for wind stress is that negative anomalies prevailed in the east and central tropical IO. Negative anomalies denote stronger easterlies, which at that time of the year, are trade winds blowing in a northwesterly direction (Fig. 5).

SST anomalies illustrate the development of a positive dipole situation, with negative anomalies (-1.5 to -3.5°C) in the East (Indonesia) and positive anomalies (+0.5 to 3°C) in the West (Africa). The temperature difference between both ends of the ocean basin is particularly strong in 1997 and 2006. In 2015, the positive anomalies are distributed over most of the central and western IO, whereas negative anomalies are only emerging along Java (Fig. 6).

The first common pattern for Z20 is a deep thermocline between 8° and 12°S (20 to 60m deeper than average), which develops west of 80°E along the Seychelles-Chagos Thermocline Ridge (an area with reduced mixed layer in normal conditions). It illustrates the development of a converging system with a positive sea level height anomaly, a dynamic structure which propagates westwards through the El Niño /positive dipole event (Webster et al 1999). The second common pattern is a thermocline shoaling along Indonesia. Actually these two major patterns are not reflected in all August snapshots displayed in Fig. 7. There is no deep thermocline in the west during August 2006, as the dipole developed in Sept-October. Likewise, the thermocline depth remains about the average off Indonesia in Aug 2015, and would likely develop from September on.

The sea surface chlorophyll distribution mirrors the SST distribution in September 1997 and August 2006 (note that Seawifs data became available in September 1997, thus replacing August for this specific map), with chlorophyll- depleted in the west (in association with warm water, deeper mixed layer) and chlorophyll-enhanced in the east (in association with cooler temperature and shallow thermocline) (Fig. 8). In 2015, such a situation is just being set up: chlorophyll depleted conditions are slightly developing in the west; as well as chlorophyll enhanced conditions South of Java.

The Hovmoller diagram presented in Fig. 9 displays the seasonal and interannual pattern of surface chlorophyll. During the onset of a positive dipole mode, the presence of cooler SST along Indonesia reduces the convection and leads to an easterly wind anomaly (negative) in the central basin. This wind anomaly drives westward currents at the equator, lifting the thermocline and cooling the surface in the east, thus reinforcing the initial anomaly (Saji et al, 1999). The thermocline dome created along Indonesia causes nutrient-rich waters to penetrate into the euphotic layer and boost the phytoplankton production.

The development of chlorophyll-enhanced conditions east of 90°E was maximal in the last quarter 1997; by contrast, highly chlorophyll-depleted conditions prevailed in the west for several months. Such a low chlorophyll status in the west has never been observed since then. Two other similar patterns occurred during the fourth quarter of 2006 and 2011, with elevated chlorophyll content off Indonesia and depleted conditions in the west, in relation to positive dipole events. Such a pattern has not been seen in August 2015.

Therefore, the ocean climate conditions seen in August 2015 reflect the early stage of development of a positive dipole mode, and we can expect further development in the wind, SST, Z20 and chlorophyll anomalies during the fourth quarter 2015.

2.4 Regional analyses

We used the same areas analysed in the three previous outlooks (Marsac 2012, 2013, 2014): Somali (SOM), Maldives (MAL), west equatorial area (WEQ), east tropical area (ETR). The only difference is for the MOZ area has been extended to the whole Mozambique Channel (12°S-25°S) (Fig. 10).

The series of yearly average of the surface chlorophyll concentration starts in 1998 (it started in 2002 in the previous outlooks) (Fig. 11). The major anomaly in the series is the exceptionally high chlorophyll content in 2002-2005 in the Somali area (Fig. 11) following chlorophyll-depleted conditions of 1997-98. Chlorophyll concentration also increased from 1998 to 2003 in the West equatorial area and from 1999 to 2003 in the Mozambique. Large fluctuations in chlorophyll occurred from 2009 on, with a slightly increasing trend. In Maldives and West Equatorial regions, there was an overall decline until 2013. Chlorophyll in the East tropical region has slightly declined all over the study period, except a positive anomaly observed in 2011. In all areas, a slight increase in chlorophyll is observed from 2014 to 2015.

Summaries of SST, Z20 and chlorophyll are given for each area, considering some specific months or seasons.

Somali (June-August, Fig. 12): the SST and chlorophyll anomalies fluctuate in phase, with cold (warm) years corresponding to high (low) primary productivity. The positive anomalies can be as high as 30-40% above normal (2002, 2004, 2013). During the growing phase of Niño events, the upwelling tends to be weaker than normal, as reflected by warm anomalies and depressed primary productivity. In 2015, SST anomalies are positive and chlorophyll content is lower than 2014.

Mozambique Channel (January-August, Fig. 13): like the Somali region, SST and chlorophyll fluctuate with roughly opposite anomalies. The chlorophyll enhancement is lesser than in the Somali region (maximum of +13%). Chlorophyll observations confirm that 2015 is a quite productive year.

West equatorial region (December-February, Fig. 14): the largest SST and Z20 anomalies occurred during the Niño/positive dipole events, in 1997-98 and 2006-07. Chlorophyll fluctuated largely, from -30% in 1997-98 to +20% in 2004. From 1998 on, chlorophyll went through a positive phase, then shifted into a negative phase after the 2006-06 positive dipole event. Chlorophyll anomaly is back on the positive side in 2015 and the mixed layer is slightly shoaling (10m above average).

Maldives (January-August, Fig. 15): Positive SST anomalies have prevailed in the Maldives since 1997 with no clear link with the ENSO/dipole signal.2015 appears as another warm year. Z20 fluctuates with no trend. By contrast, two regimes characterize the chlorophyll anomalies: positive phase for 1998-2002 and a negative phase during 2007-2014. Positive anomalies are back in 2015, but this single value is not a clue for a shift into a positive regime.

East tropical area ($July_{y-1}$ – $June_y$, Fig. 16): Positive SST anomalies prevailed during the study period except two years with negative signals (1999 and 2011), associated to Niña events. Chlorophyll anomalies exhibit two regimes, dominated by positive anomalies for 1998-200 (in relation to La Niña), and by negative anomalies for 2008-2015. The strong positive anomaly in 2011 among the dominant negative anomaly is again due to La Niña.

3 What possible response with respect to tuna fisheries in the forthcoming months

As a positive dipole is building up, and because current indicators would suggest it would become a strong event, we can try and build a scenario on the basis of what happened in 1997-98. The development of a deep thermocline between 5°S-10°S in the western part of the basin is likely to reduce the efficiency of surface gears, such as purse seine. From December 2015 through March 2016, the mixed layer may deepen by 60 to 80m below the average across the yellowfin spawning area where purse seiners operate during that season. Free schools would then become less abundant at the surface. In parallel, the phytoplankton concentration may decrease west of 55°E and more substantially along the coast of Africa. By contrast, more favourable conditions could emerge for the purse seine fishery east of 70°E-80°E, beyond Chagos, with shoaler thermocline and high potentially good foraging conditions for predators (enhanced primary productivity supporting the intermediate trophic level preyed upon by apex predators).

If the foreseen anomaly is not as large as in 1997, then the situation may mimic that of 2006. There was still a significant deepening of the thermocline in the west, but as it did not stretch out to the African coast, there were areas with shallow mixed layer in the westernmost part of the basin. The deep anomaly and poor foraging conditions would then favour the concentration of tuna close/within the East African EEZs.

If tunas are only pushed down the thermocline and not scattered in a wide area, both in depth and horizontally (with a resultant decreasing density), then the environmental anomaly should not negatively affect the longline fishery as much as the purse seine fishery.

Acknowledgements

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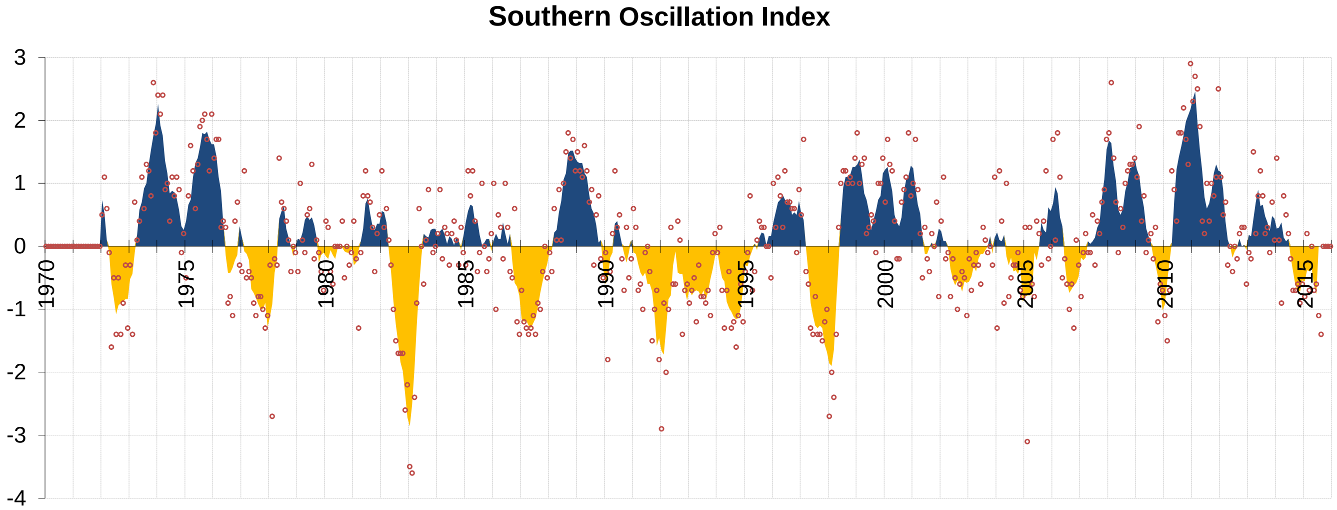


Fig.1 – The Southern Oscillation Index (SOI), January 1970 to August 2015. The shaded area represents the 5 month moving average, whereas observed monthly values are shown in red dots. Niños correspond to the extreme negative values whereas Niñas are described by the extreme positive values

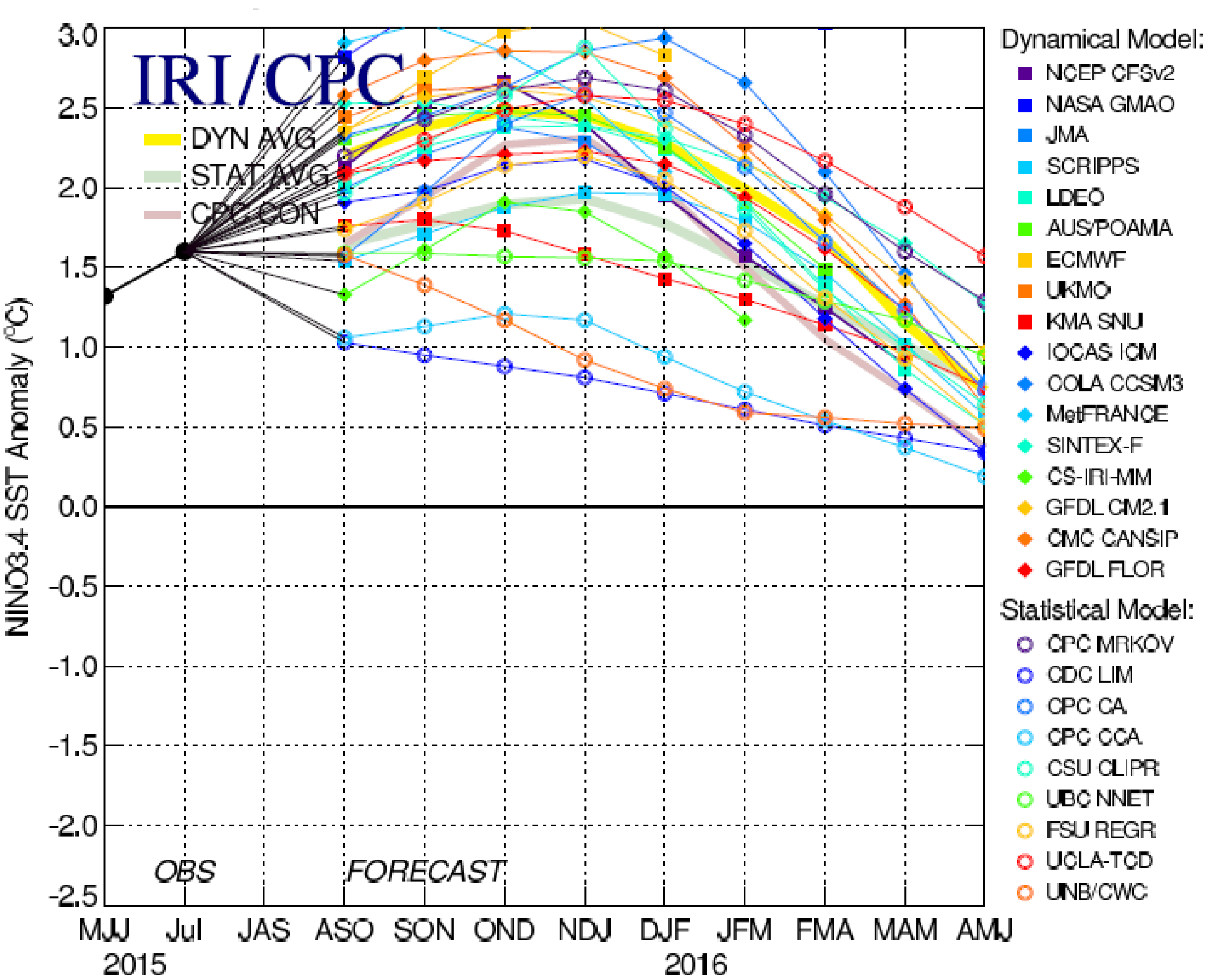


Fig.2 – Mid-Aug 2015 plume of Model ENSO predictions

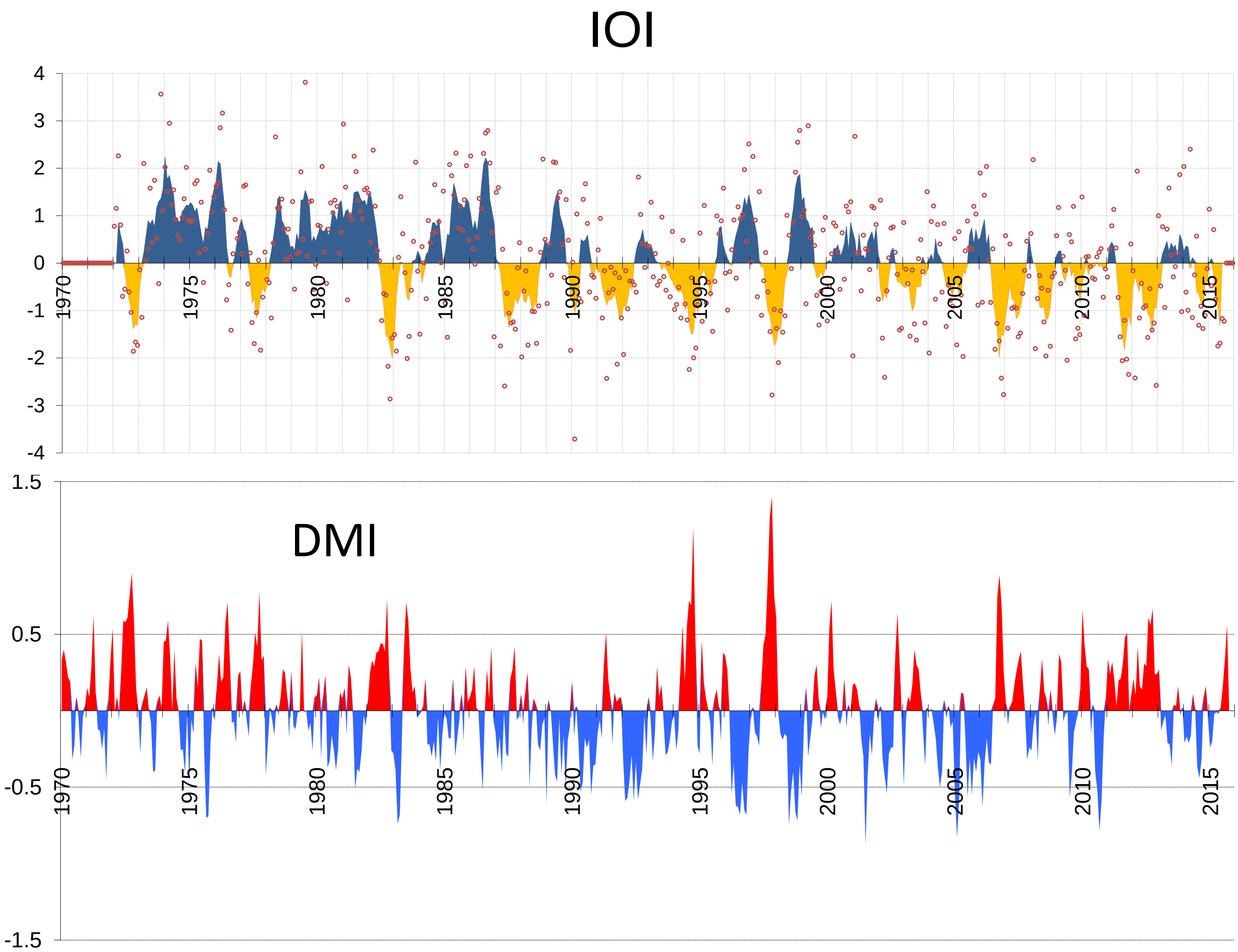


Fig. 3 - Indian Oscillation Index (top) and dipole mode index (bottom) over the period January 2002 – Aug 2015. The shaded area of IOI is a 5 months moving average whereas observed monthly values are represented in red dots. The DMI series is non-smoothed monthly values. Warm (cold) events are represented by negative (positive) IOI and positive (negative) DMI.

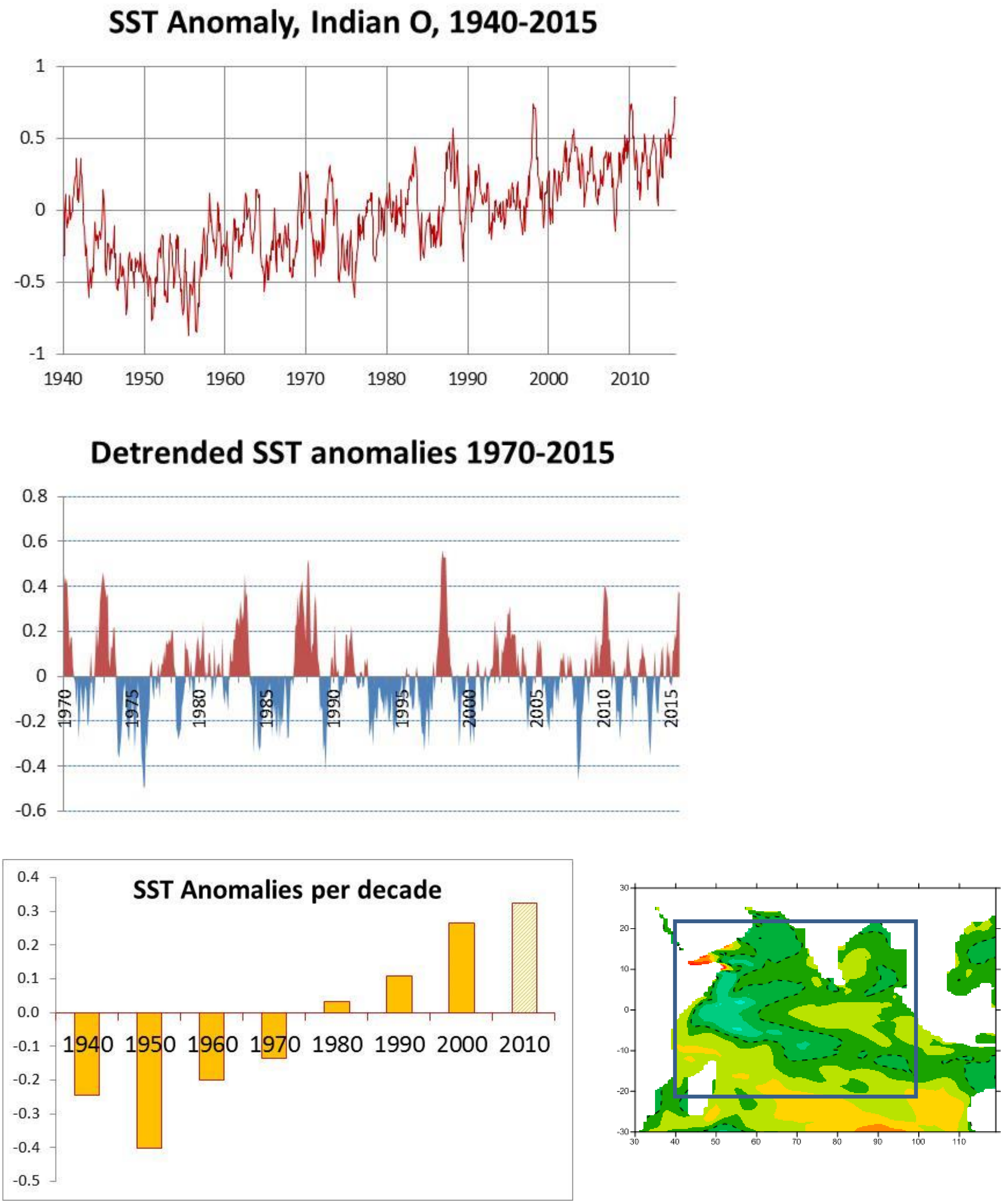


Fig. 4 – SST anomalies in the Indian Ocean measured from the ERSST v3b data set (Smith et al, 2008). a) monthly series Jan 1940-Aug 2015 (top); b) : monthly series Jan 1980-Aug 2015 (middle); c) average by decade (bottom). The square in the map indicates the limits of the area considered.

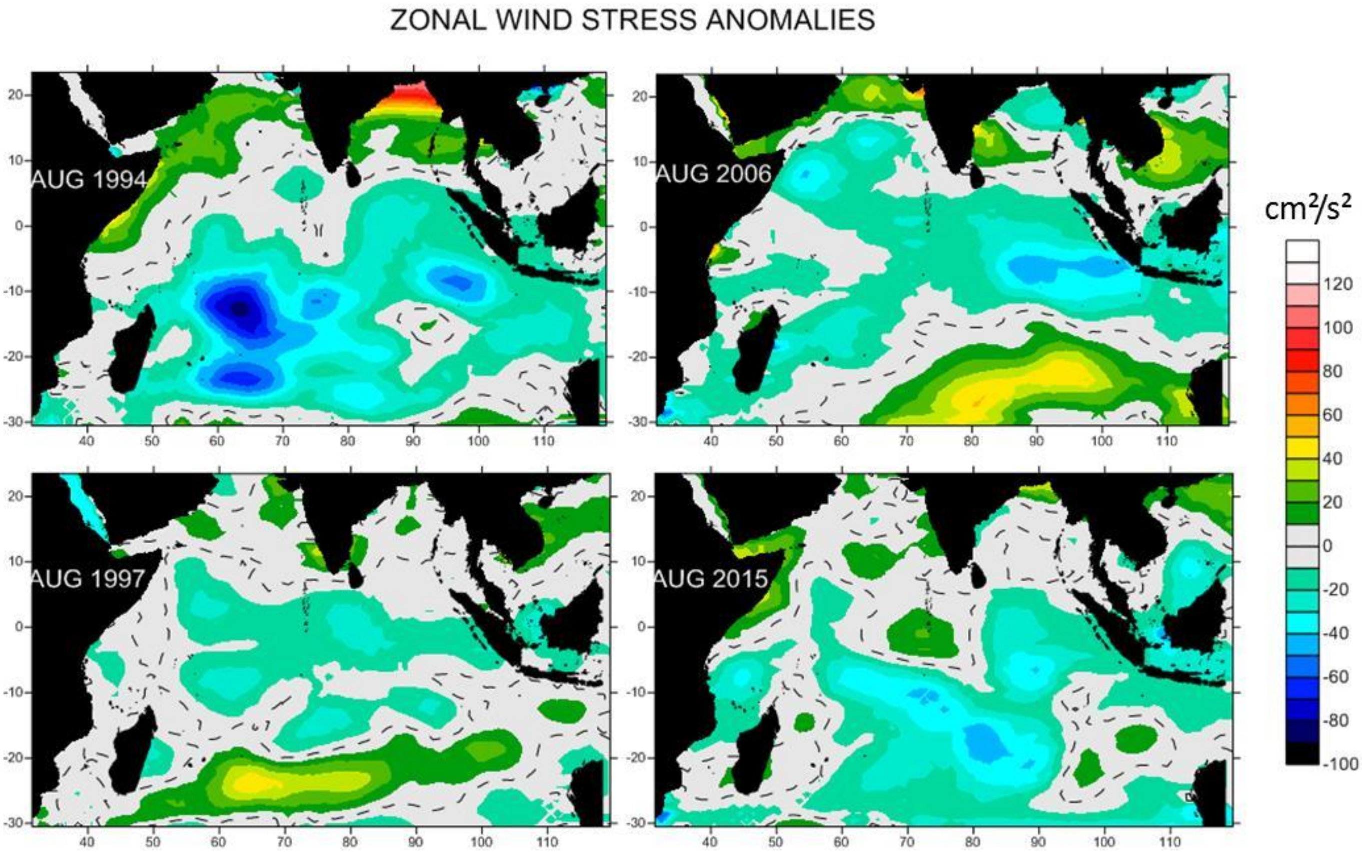


Fig. 5 – Distribution of zonal wind stress anomalies in August of 1994, 1997, 2006 and 2015. Negative anomalies denote stronger than normal trade winds below 10°S, and weaker than normal westerlies along the equator line and in the northern hemisphere. Grey shading indicates minor anomalies about the mean. It allows to highlight the more significant anomalies (colour shading).

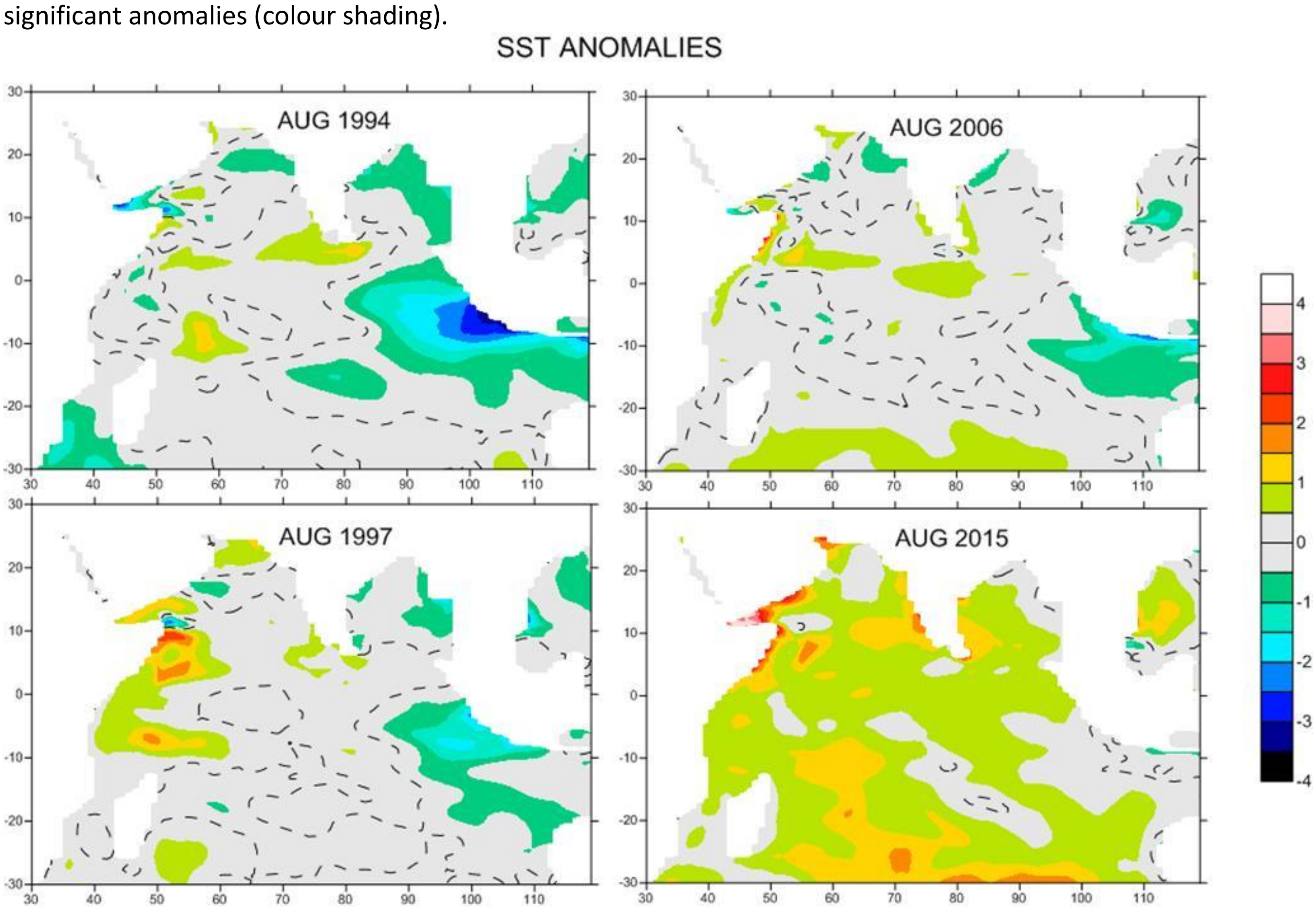


Fig. 6 – Distribution of sea surface temperature anomalies in August of 1994, 1997, 2006 and 2015.

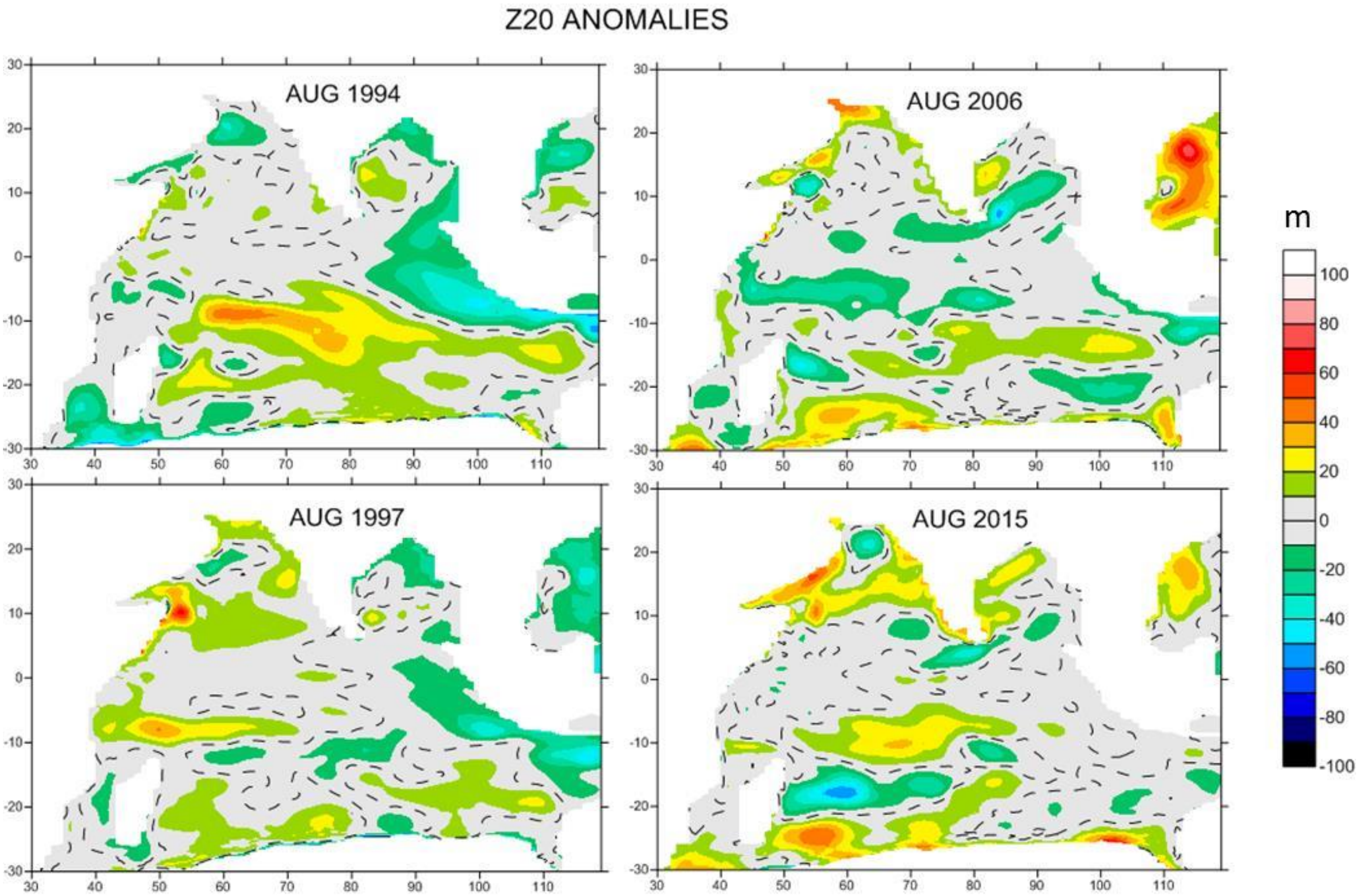


Fig. 7 – Distribution of mixed layer depth anomalies in August of 1994, 1997, 2006 and 2015

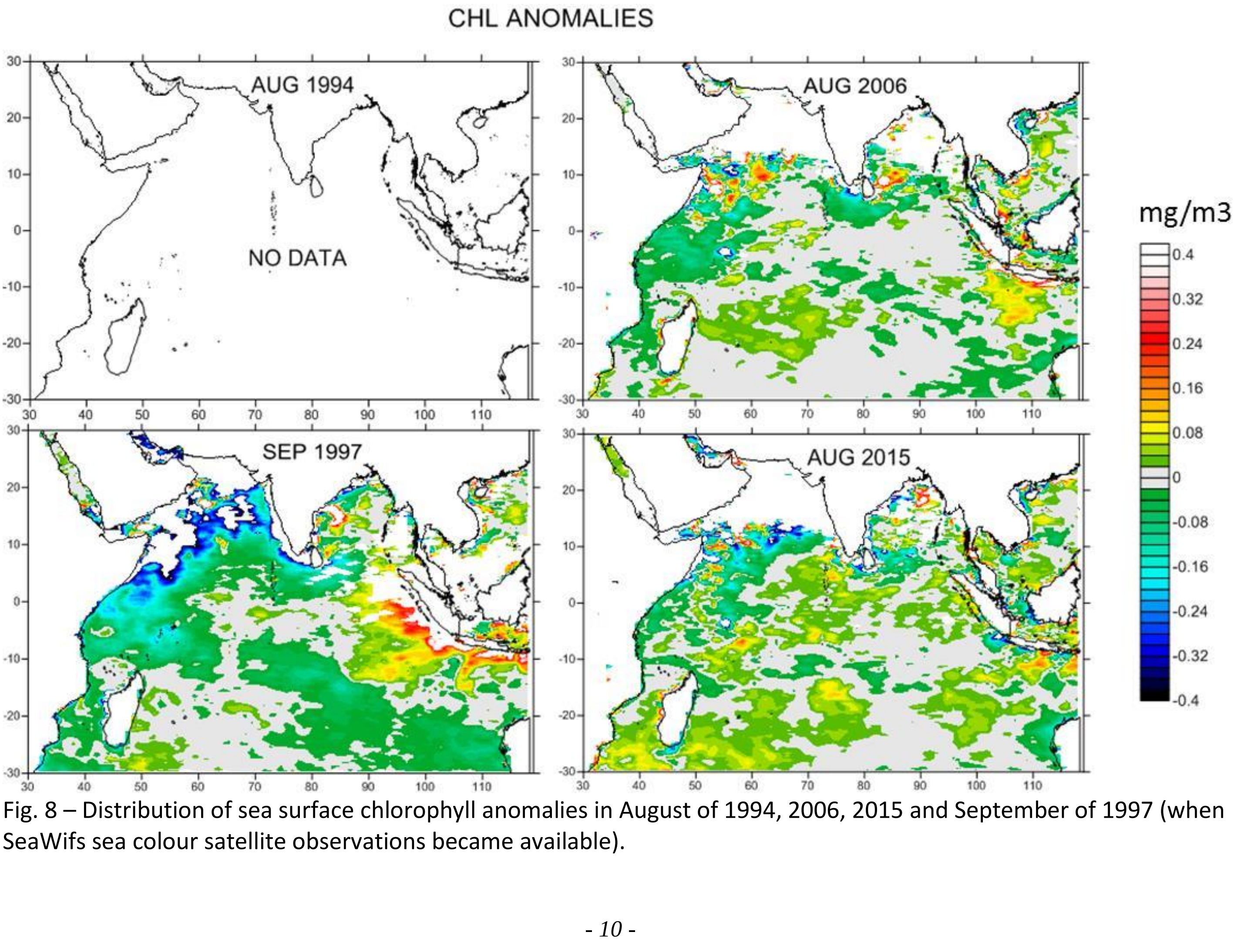


Fig. 8 – Distribution of sea surface chlorophyll anomalies in August of 1994, 2006, 2015 and September of 1997 (when SeaWifs sea colour satellite observations became available).

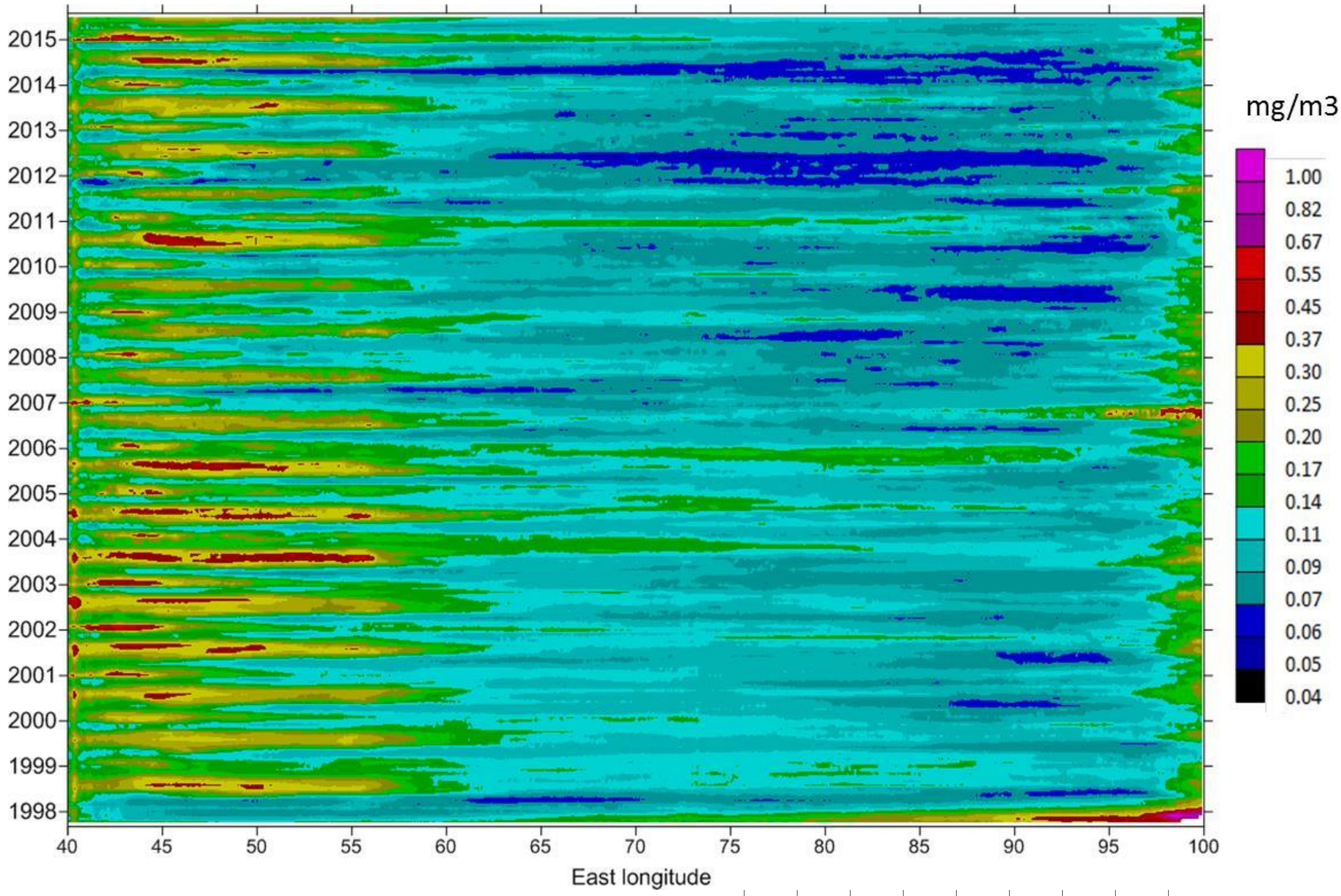
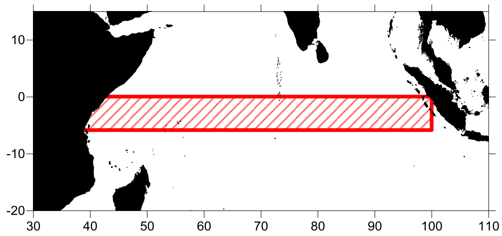


Fig. 9 – Hovmoller diagram of the monthly surface chlorophyll across the equatorial Indian Ocean (0°-5°S / 40°E-100°E) from September 1997 through August 2015.



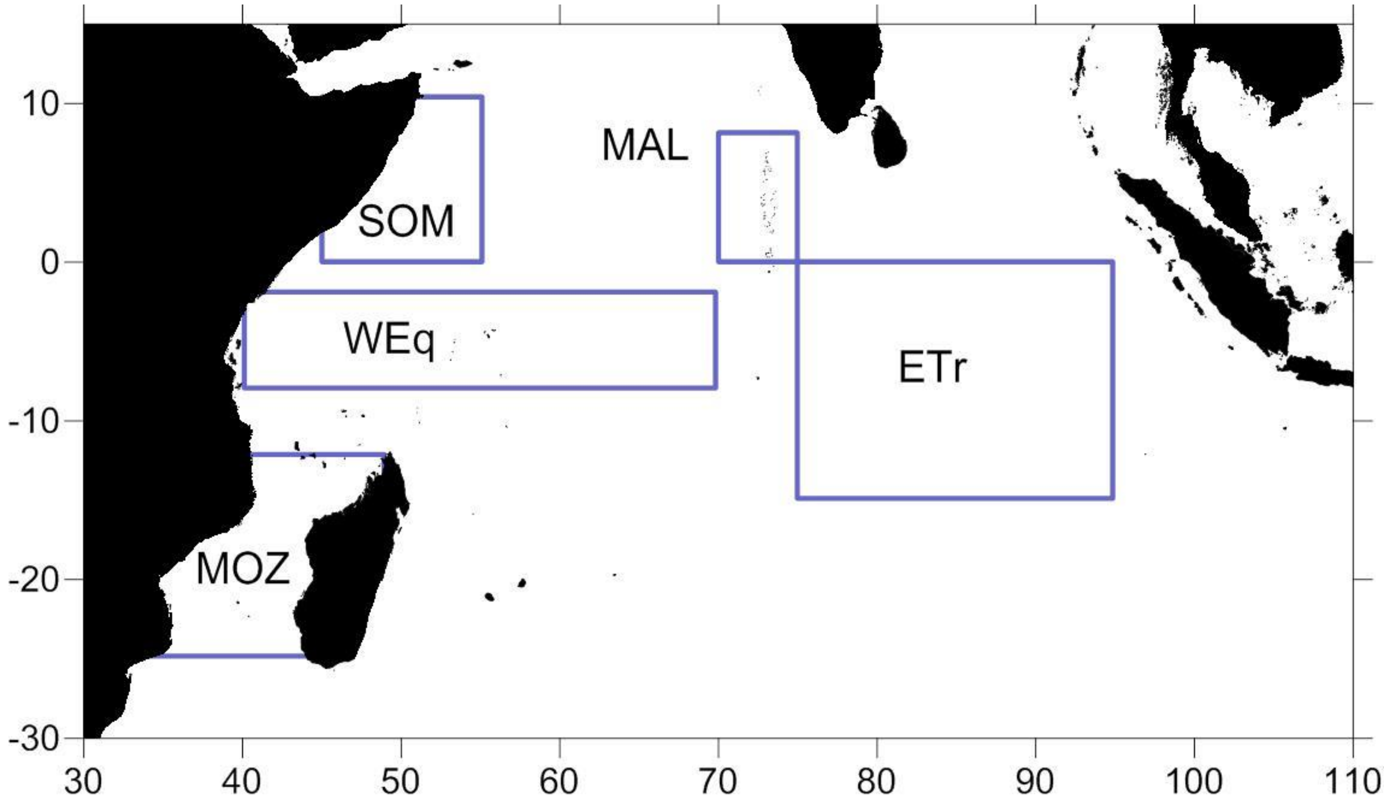


Fig. 10 - Area stratification used for the regional analysis.

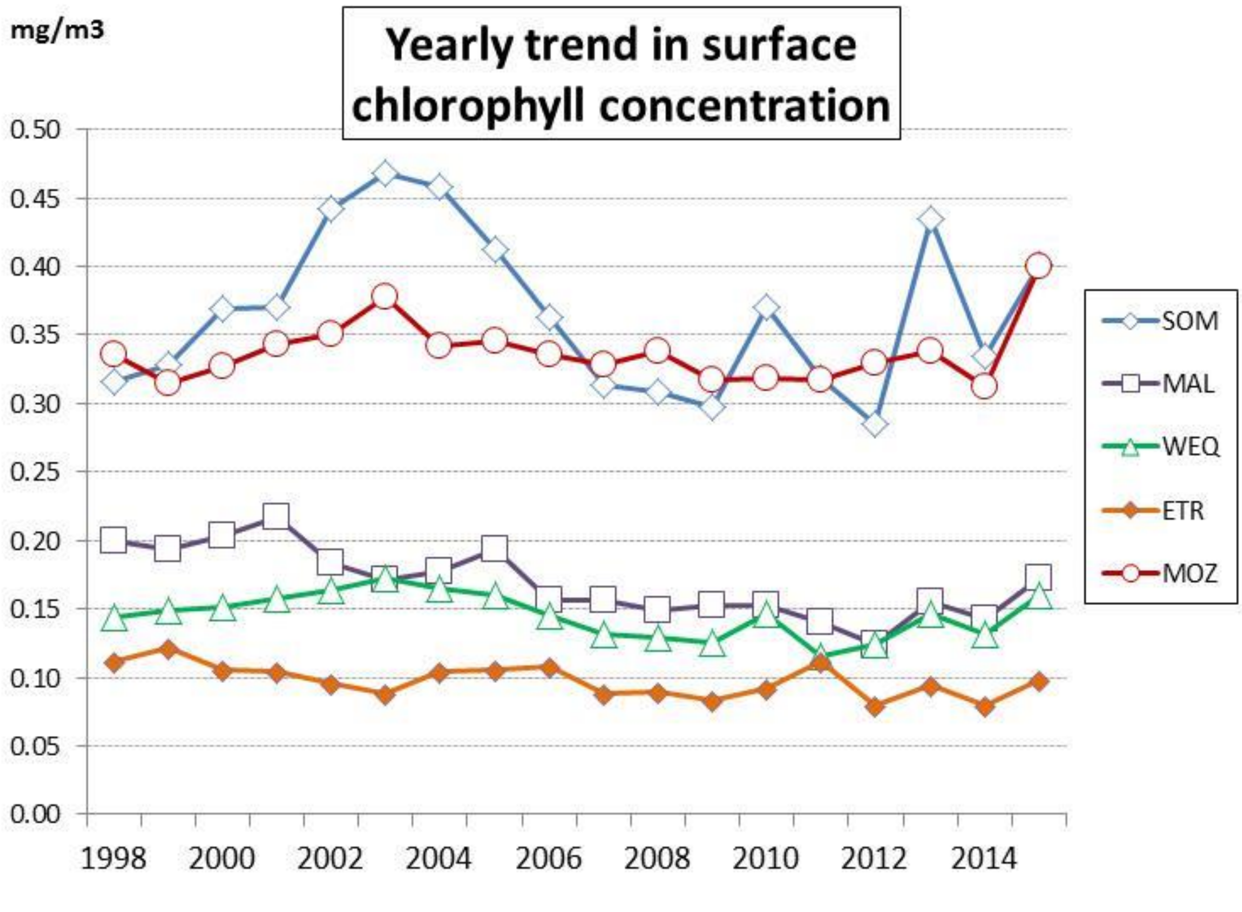


Fig.11 – Yearly trend of sea surface chlorophyll concentration measured by satellite, 1998-2015 (Seawifs 1998-2002 / Modis since 2003). Note that 2015 is incomplete (ends in August).

SOMALI

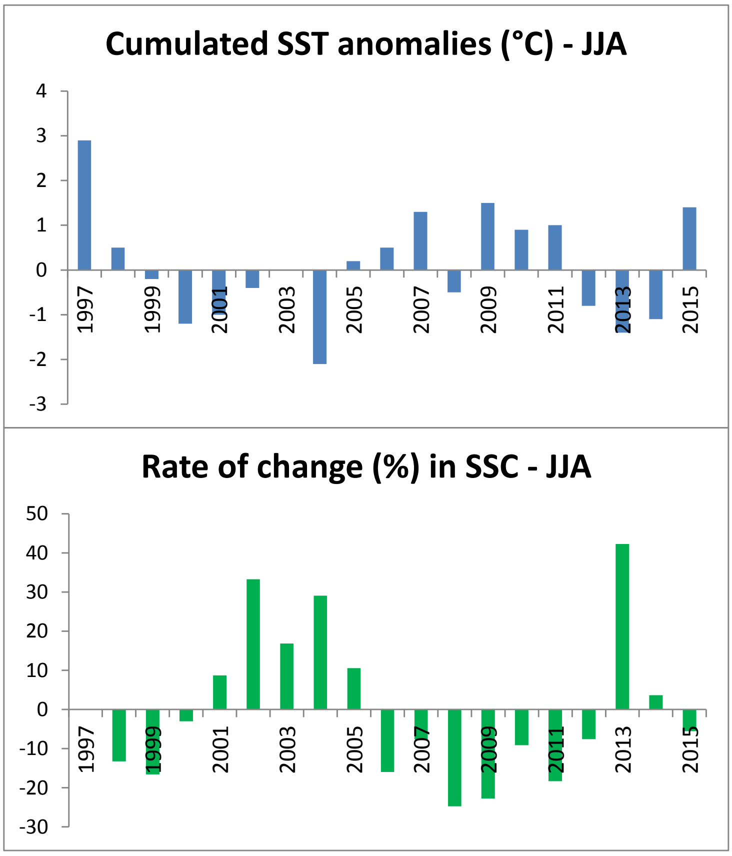


Fig. 12 – SST and surface chlorophyll (SSC) trends during the south-west monsoon, average June to August, in the Somali basin. SST anomalies are cumulated over the season. Chlorophyll is expressed as rate of change about the 1998-2015 average, June to August.

MOZAMBIQUE CHANNEL

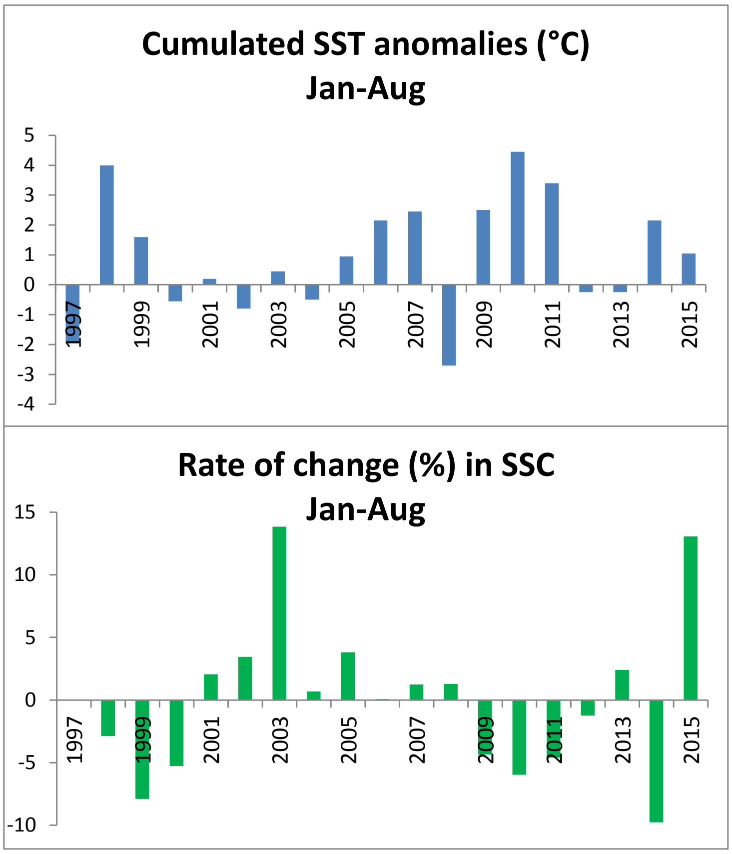


Fig. 13 – SST and surface chlorophyll (SSC) trends in the Mozambique Channel. Statistics are calculated for the period January to August. SST anomalies are cumulated over the period and chlorophyll is expressed as rate of change about the 1998-2015 for the study period.

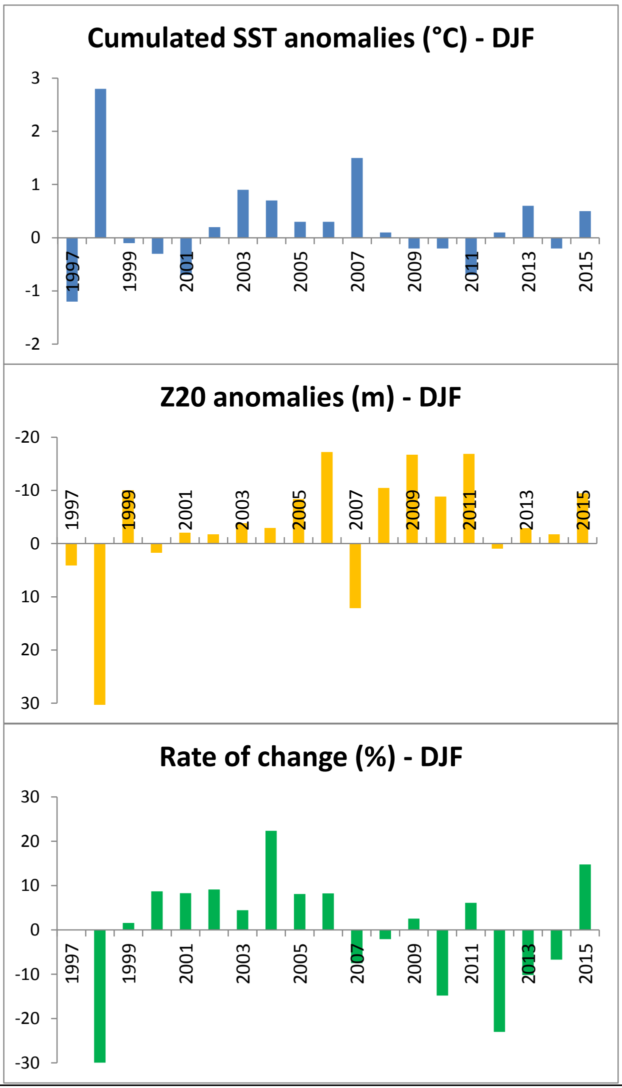


Fig. 14 – SST, MLD and surface chlorophyll trends in the West Equatorial area, during the core of the north-east monsoon (December to February). SST anomalies are cumulated over the season, MLD anomalies are the mean over the season and chlorophyll is expressed as rate of change about the 1998-2015 average for the season. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

WEST EQUATORIAL AREA

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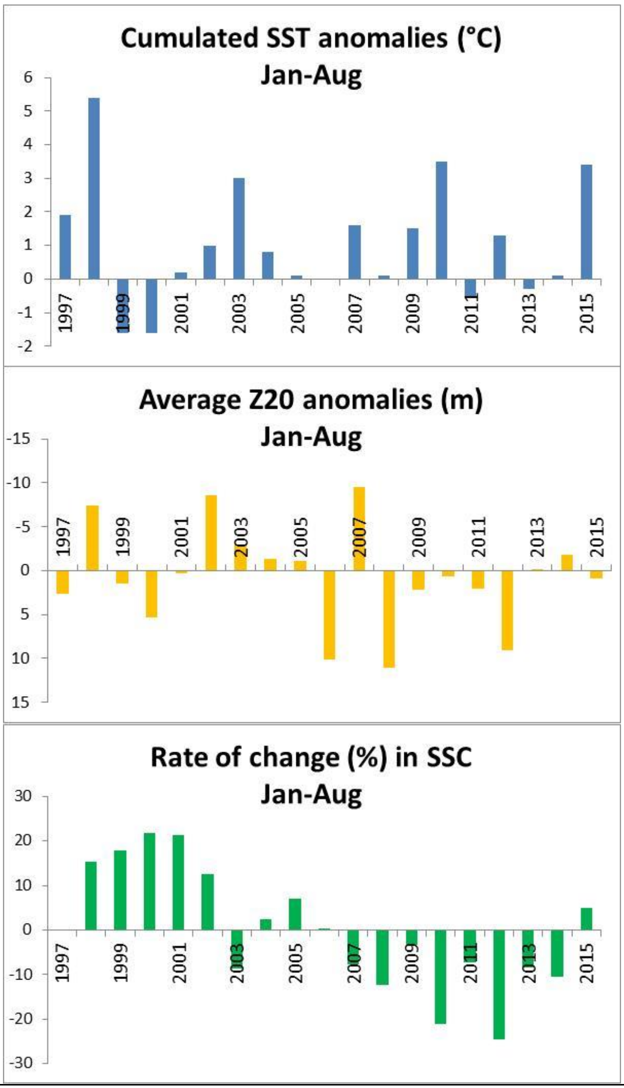
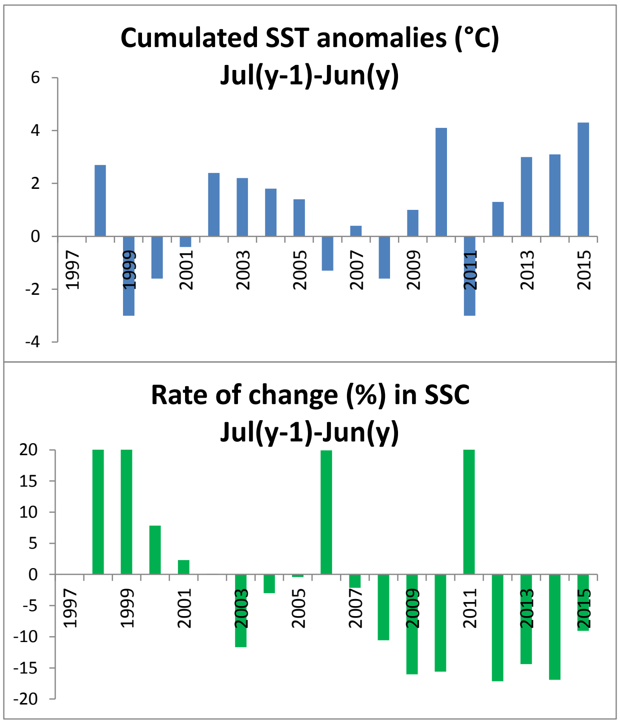


Fig. 15 – SST, MLD and surface chlorophyll (SSC) trends in the Maldives. Statistics are calculated for the period January to August. SST anomalies are cumulated over the period, MLD anomalies are the average over the period and chlorophyll is expressed as rate of change about the 1998-2015 for the study period. Negative (positive) MLD anomalies denote shoaling (deepening) of the thermocline.

MALDIVES



EAST TROPICAL AREA

Fig. 12 – SST and chlorophyll (SSC) trends in the Eastern Tropical Indian Ocean, 12-month average from July (of the preceding 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 1998-2015 for the same period.

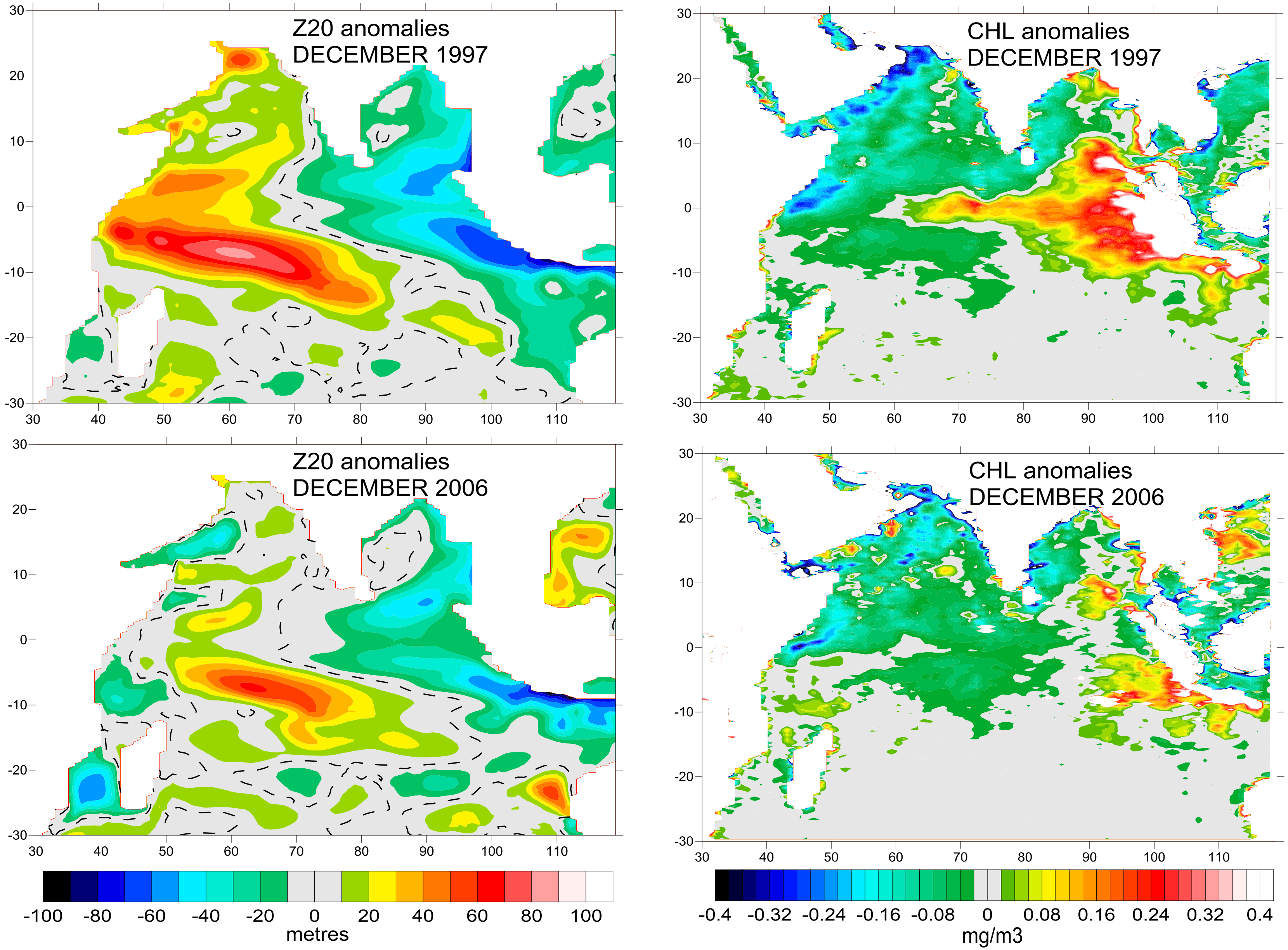


Fig. 13 –Maps of mixed layer anomaly (left panel) and surface chlorophyll anomalies (right panel) at the peak of two positive dipole events, a strong event in 1997 and a moderate one in 2006.