CLIMATE AND OCEANOGRAPHIC INDICES APPRAISING THE ENVIRONMENTAL FLUCTUATIONS IN THE INDIAN OCEAN

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ABSTRACT

This paper is an exploratory analysis of environmental indices that could be included in linear models for standardising CPUE indices of tuna stocks exploited in the Indian Ocean. Atmospheric and oceanographic indices are proposed and the degree if synchrony between the times series is studied using cross-correlation. Besides the well-known Southern Oscillation Index (SOI), we propose an Indian Oscillation Index (IOI) based on the difference of standardised sea level pressure anomalies between Mahe (Seychelles) and Darwin (Australia). Comparison between IOI/SOI and sea surface temperature anomalies (SSTA) is conducted in the equatorial region (0°-5°S) and in some tropical regions (Arabian sea, south Mozambique channel and two southern areas East and West of 75°E between 25°S-35°S). In the West equatorial areas, the IOI is better correlated to the SSTA than is the SOI, whilst SOI is better correlated to SSTA in the East equatorial areas (negative correlation in all cases). The IOI fluctuations are in phase and negatively correlated with the SSTA in the Arabian Sea and in the tropical south eastern area when SOI is leading by 12 to 13 months the maximum SSTA values. On the other hand, the SSTA in the South Mozambique channel and tropical south west area exhibit fluctuations with lower magnitude, and correlation with atmospheric indices is very weak. Along the equator, the inter-annual anomalies of the zonal wind stress in the Eastern area are leading by 2 months the SSTA variability in the West; this illustrates the remote wind forcing linked with the El Niño episodes. A clear positive relationship is also noticed at the equator, between the SSTA and the sea level dynamic topography anomalies (i.e. depth of mixed layer). Those indices are likely to be good predictors of the ocean conditions affecting catchability and distribution of the tuna populations in the Indian Ocean, in relation with strong inter-annual climate anomalies occurring during the ENSO warm phase.

INTRODUCTION

One of the recommendations of the second session of the IOTC Working Party on tropical tunas (September 2000) was to include environmental data in the calculation of apparent biomass. Estimating changes in abundance and catchability are key issues for reliable stock assessment analyses, and the environmental conditions are know to play an important role in those changes.

Commonly, CPUE indices for a given fishery are standardised using linear models where a set of factors are incorporated and their relative significance tested. The environmental effect is rarely introduced in those models although it is admitted that this would produce more accurate biomass indices.

Therefore, the question is "what type of parameter should be taken into account", provided that 1) we should focus on rather simple parameters, and that 2) these parameters should be reliable indicators of the ocean response to the climate forcing. In the present paper; we'll focus on several areas exploited by longline and purse seine fisheries, and we study different indices that can be used to trace the inter-annual environmental variability.

DATA AND METHODS

Two categories of variables are analysed :

- atmospheric variables : sea level pressure (SLP) and wind stress
- oceanographic variables : sea surface temperature (SST), sea level height

In order to depict better the variability, we'll use anomalies rather than absolute values of these variables.

DATA SOURCES

1- Sea level pressure

Atmospheric pressure at sea level are some of the data routinely collected by meteorological offices, on hourly or daily basis. We used monthly averages from two sites, Darwin (Australia) and Mahe (Seychelles). These sites have been chosen because they can give an indication on the ENSO related episodes. Opposite trends of SLP are generally observed from one side of the ocean to the other. Darwin data can be found online and data from Seychelles were kindly provided on request by the Meteorological Office.

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2- Wind stress

Pseudo wind stress data were downloaded by ftp from the Center for Ocean-Atmospheric Prediction Studies (COAPS) located at the Florida State University, Tallahassee. The database includes the zonal (East-west) and meridonal (north-south) components of the wind stress vectors, on a 1° grid, by month. Only the zonal components were used in this study.

3- Sea surface temperature

Data were downloaded from the Climate Prediction Center of the NOAA (NCEP-NWS). A series of monthly SST anomalies (SSTA) can be obtained on line on the NCEP web site, on user-defined geographic areas. The series starts in November 1981, and the latest data available were for May 2001.

4- Sea level height

Data were downloaded by ftp from the data base of the Austin Center for Space Research at the University of Texas (UT/CSR). This data base contains gridded sea level anomaly heights (SLA) observed by the TOPEX/POSEIDON satellite altimeter from 1992 to present. The sea level anomaly is the deviation of the sea surface away from a mean surface. The estimated accuracy of the sea level anomalies for a 1 degree grids in this data base is 3 to 4 cm over the entire ocean (Tapley et al, 1994)

DEFINITION OF SUBAREAS

We'll analyse indices in different subareas of interest with respect to purse seine and longline activities (fig. 1) :

- Arabian Sea (Arab) : longline fishery targeting exclusively yellowfin
- Equatorial subareas Ew, Ecw, Ece, Ee : purse seine fishery dominated by yellowfin and skipjack and longline fishery dominated by bigeye and yellowfin
- Southern Mozambique channel (Moz) : longline fishery with high species diversity (yellowfin, bigeye, albacore and swordfish)
- Southern Indian (South W and South E) : specifically albacore fishing grounds by longliners.

SST anomalies will be computed in each of these areas, whilst the sole equatorial region will be considered for the wind stress and sea level.

RESULTS

1- An atmospheric Indian Oscillation Index (IOI)

SLP monthly averages were processed to compute standardised anomalies in both locations (Darwin and Mahe). The standardised anomaly is the deviation between the SLP of a given month/year and the climatological mean of the corresponding month, weighted by the standard deviation of the series for the corresponding month. Then, we filtered the series by a moving average on 5 months. The data for Darwin are available on line on this format, but not the Seychelles data. The standardised anomalies for Seychelles were calculated from a climatology along the period 1972-90.

The Southern Oscillation Index (SOI) is a well known descriptor of the ENSO fluctuations, and SST anomalies in the Pacific Ocean are highly correlated with SOI. There are some deviations between SOI and SST anomalies in the Indian Ocean, and we defined another atmospheric index, more specific to the Indian Ocean, the Indian Oscillation Index (Marsac and Le Blanc, 1998) to assess its relevancy to SST anomalies. Similarly to the SOI, which is the difference of SLP standardised anomalies between Tahiti and Darwin, the IOI is the difference of SLP standardised anomalies between Seychelles and Darwin.

Both series show similar trend (fig. 2), because of the common reference to Darwin, and also the fact that phenomenon are rather symmetrical in both oceans, with below (higher) than normal SLP in Tahiti and Seychelles (Darwin) during the warm phase of ENSO . However, some differences can be noticed, such as an increasing IOI from 1984 to 1987 when SOI is about 0, negative IOI in 1988 during the development of the Niña (in the Pacific) when SOI is positive.

2- Wind stress anomalies at the equator

At the equator, winds blow predominantly from West to East. Hence, we only considered the zonal component of the wind stress and we computed standardised anomalies in each of the four sub-areas (fig. 3). Strong negative anomalies denote a weakening of the westerlies or even the transition to anomalous easterlies. In the easternmost area (Ee), they occur at the onset of the ENSO warm phase. However, western and eastern basins of the ocean exhibit different patterns: some strong negative anomalies, such as that of august 1989, was only recorded in the western basin (areas Ew and Ecw). The area Ee exhibits the clearest signal with respect to inter-annual variability and especially ENSO events.

3- SST anomalies (SSTA) at the equator

The SST (non standardised) anomalies for the four equatorial subareas are presented in fig. 4. The warm episodes related to ENSO (1983, 1987, 1992, 1997-98) appear on these series but with different magnitudes according to the area. The most striking feature is seen during the 1997-98 ENSO, with a strong negative anomaly in the easternmost subarea (Ee) preceding a strong positive anomaly that occurs 3 months later in the west (Ew). Since the larger magnitudes are observed in the westernmost and easternmost boxes, we have put emphasis on these two sub-areas. Standardised SSTA were computed and used as to reflect the variability of the ocean surface conditions in the equatorial zone, induced by inter-annual climate forcing (especially ENSO). They served as a reference to which series of three atmospheric variables, SOI, IOI and zonal wind stress anomalies will be compared.

4- Relationships between SSTA at the equator and atmospheric variables

- SOI and IOI

SSTA in the West are negatively correlated to SOI and IOI (fig. 5). Positive SSTA are associated with low SOI and IOI. Cross correlations show that SOI precedes SSTA by 2 months, whilst IOI is almost in phase (follows SSTA by 1 month). A higher correlation is obtained with the IOI.

In the East, SOI precedes SSTA by 6 months while IOI is leading SSTA by 4 months (fig. 6). Higher correlation is obtained with SOI.

- Zonal wind stress anomalies

The cross correlation between the SSTA in the West (area Ew) and the zonal wind stress anomalies in the east (area Ee) indicates a significant negative correlation with wind stress anomalies preceding SST anomalies by 2 months (fig. 7).

5- Relationships between SSTA in tropical sub-areas and IO I/SOI

Non standardised anomalies were used in the 4 tropical sub-areas (Arab, Moz, South W and South E, cf fig.1). Combined plots of these anomalies and SOI and IOI are given in fig. 8. Clear ENSO signals are found in the Arab and South Eastern sub-areas.

In the Arabian sea, there are two major warm periods, 1987-88 and 1998. IOI fluctuations are in phase with SSTA (but opposite in sign), when SOI is leading by 12 months (and following the anomalies by 8 months). The correlation is almost the same for both indices but the synchrony between IOI and SST anomalies makes it easier to handle in the Arab sub-area (fig. 9).

In the South East, anomalies are higher than for the other tropical sub-areas considered in this study. IOI is well in phase with SST anomalies, with a negative correlation. The highest correlation with SOI is found when this index precedes by 13 months the SSTA. For the same reason as for the Arab sub-area, IOI is easier to handle to explain fluctuations of the surface conditions in this area.

The two other tropical areas do not show a clear pattern of SSTA in relation with ENSO. Consequently, no significant correlation was found with SOI or IOI.

6- Relationships between SSTA and sea level dynamic topography

Sea level dynamic topography is much affected by ENSO. During the latest event, the sea level rose by more than 15 cm in the West (area Ecw). Stronger amplitudes were recorded in the East, with negative anomalies (-15 cm in December 1997) reversing rapidly to positive anomalies (+15 cm) six months later.

SSTA and sea level anomaly heights (SLA) fluctuate in phase and are positively correlated (fig. 10) in both equatorial areas considered (East and West). Hence, SOI and IOI are also correlated with SLA. In the West, SOI and IOI are in phase with SLA and are negatively correlated. In the East, there is a positive correlation with SOI and IOI following the SLA with a lag of 2 months.

DISCUSSION

SST is one of the most easy-to-get physical parameter and standardised anomalies can be used as good proxies of the surface ocean response to air-sea interactions (which is still a non fully understood issue). SSTA are correlated with SLP-derived indices, such as the SOI or the IOI, but the present study points out some differences with respect to the ocean basin (East or West) that is considered. In the West equatorial area, IOI is slightly better correlated to SSTA whilst the correlation is better with SOI in the East equator. However, in both cases, IOI is more in phase with SSTA than is SOI. IOI is following by 1 month SSTA in the West and leading by 4 months SSTA in the East. The wind remote forcing that occurs at the onset of an ENSO is well depicted by the zonal component anomaly of wind stress in the East: when the westerlies weaken and easterlies start to appear, SST negative anomalies appear in the West two months later.

In the tropical areas, only two areas exhibit a clear response to ENSO fluctuations (Arabian sea and South East). In the Arabian sea; Tourre and White (1995) had shown that positive SSTA appear during the early stages of an ENSO warm phase, and propagate eastward to the northern and equatorial Indian Ocean. In both areas, IOI is in phase with SSTA, and the correlation is almost the same as the SOI. We suggest that the in-phase characteristic could promote its use as an environmental descriptor in CPUE standardisation instead of the SOI.

In the equatorial region, the well marked ENSO signal makes that SSTA is also a good indicator of the subsurface conditions, especially depth of mixed layer. Positive sea level anomalies denote a deepening of the mixed layer and during the ENSO warm phase, the thermocline deepens in the West and becomes shallower in the East. At the same time, positive (negative) SSTA develop in the West (East). The SOI and IOI are also related (with opposite sign) to sea level anomalies. However, the comparison between SSTA and Topex SLA is made on a short period of time so that only the latest ENSO (the strongest ever recorded in the Indian Ocean) can been tested.

The use of these indices to assess the impact on stock abundance or catchability to gears should be tested. Taking the example of the purse seine fishery in the equatorial Indian Ocean, Marsac and Le Blanc (1999) had shown that the 1997-98 ENSO had impacted the strategy of the fleets, with a drastic shift of the fishing activity to the far East during the fourth quarter of 1997 and first quarter of 1998, while the catches are usually concentrated in the Western part at that season of the year. Then, it was suggested that the catchability to gears was promoted with a shallow thermocline. A recent analysis (yet unpublished) of SeaWIFs color data in the equatorial region indicates that a anomalous primary production bloom occurred in the Eastern equatorial region, in relation to the onset of the 1997 ENSO. The highest PS CPUEs were recorded from 3 to 4 months after the bloom. It is likely that not only the catchability was enhanced but the local abundance as well, due to favourable forage conditions that were generated by the primary production bloom.

CONCLUSION

This paper brings out time series of some climate and oceanographic indices that can be easily introduced in the standardisation procedure of the CPUEs of both purse seine and longline fisheries. This is still an exploratory work that should be completed with statistical analyses. SLP-derived indices can be used along with SSTA as factors of GLMs; IOI is recommended for the Western equatorial Indian ocean, Arabian sea and South East tropical area, whilst SOI should be used for Eastern equatorial Indian Ocean.

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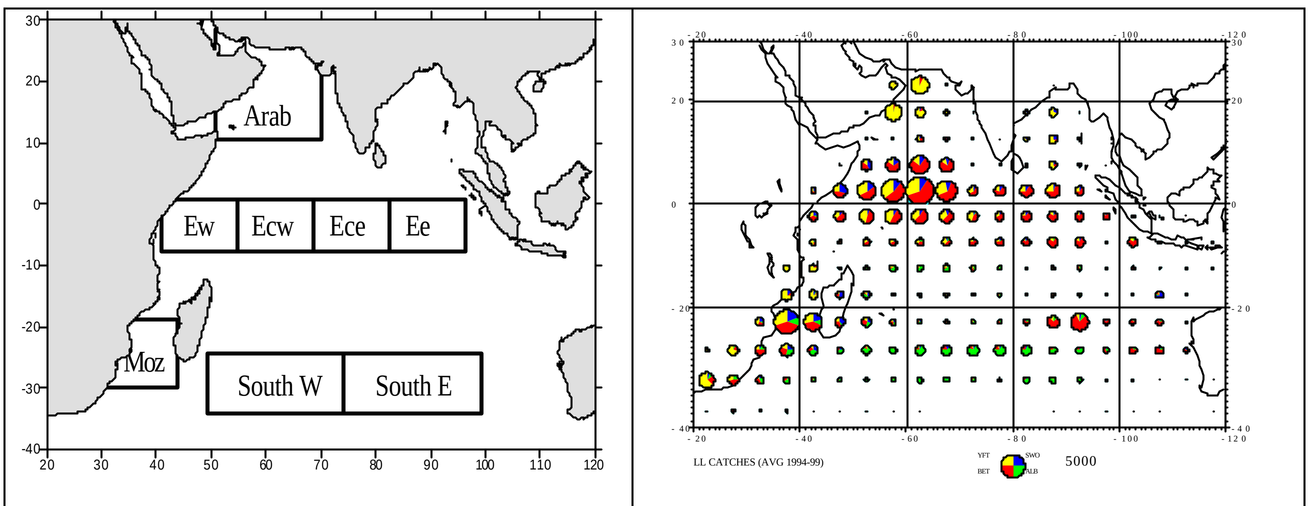


Figure 1. Geographical boundaries of sub-areas with respect to tuna fisheries (the map corresponds to lingline catches that are widespread in the whole Indian Ocean)

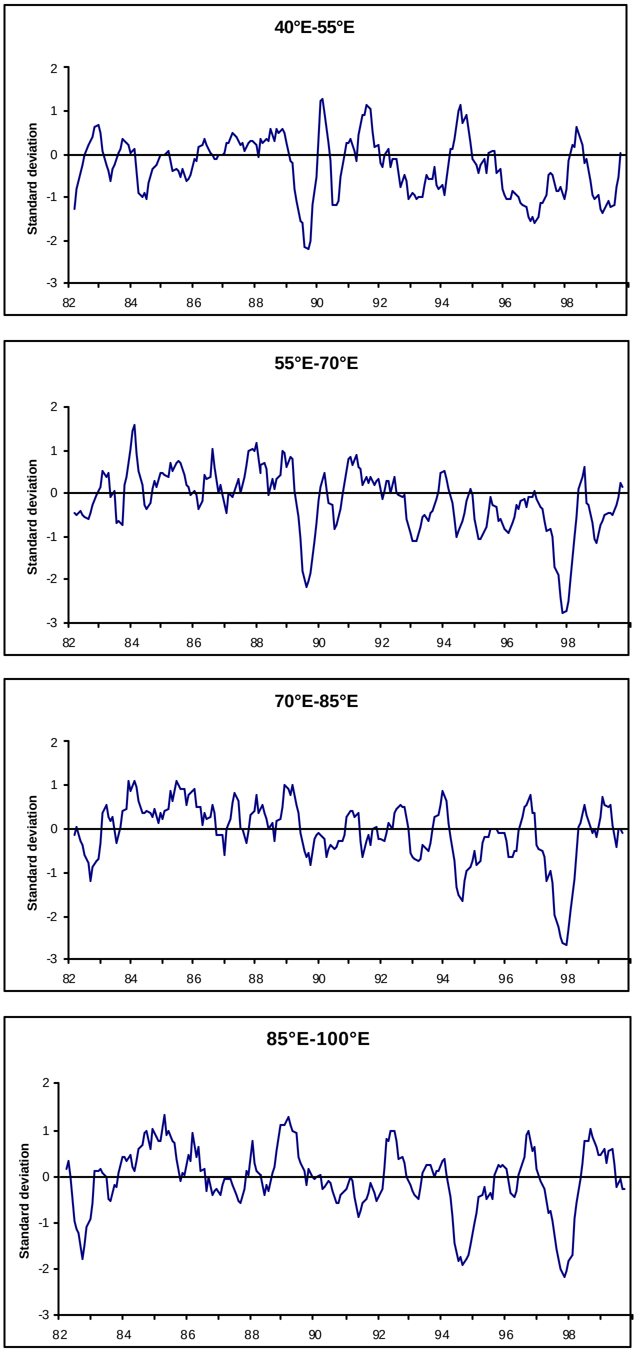


Figure 3. Wind stress anomalies in the four equatorial subareas

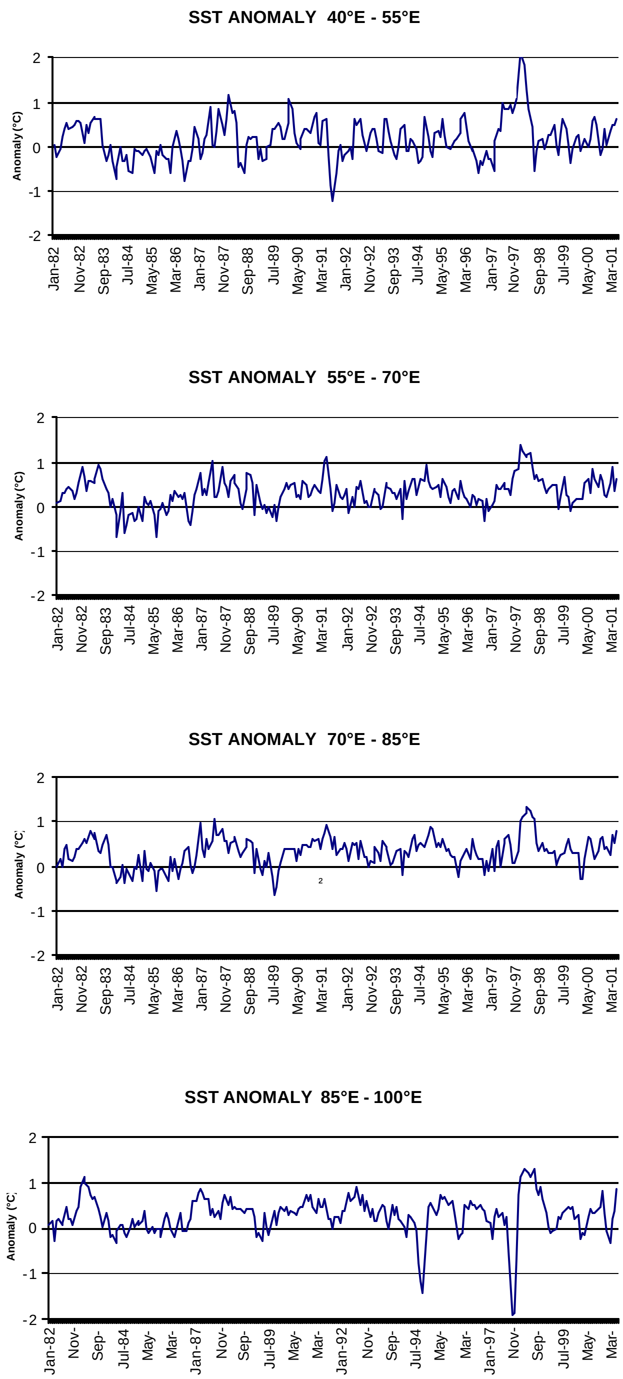


Figure 4. SST anomalies in the four equatorial sub-areas

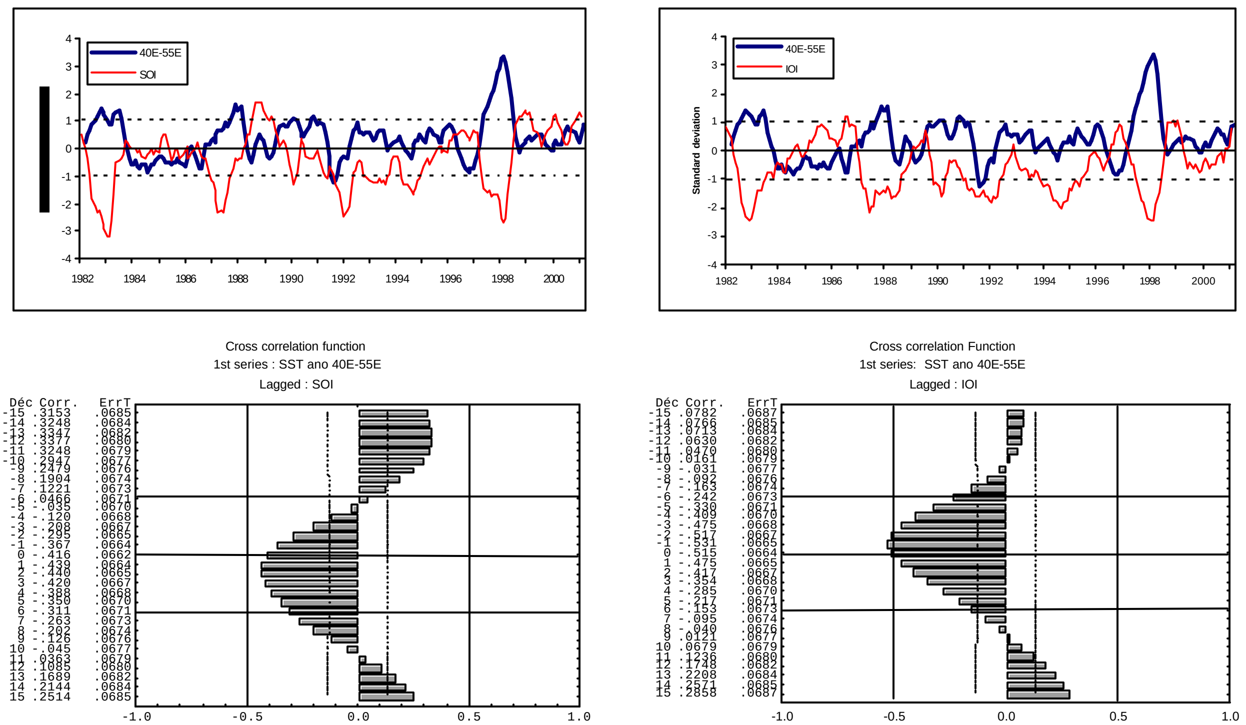


Figure 5. Combined time series and cross correlation between SST anomalies in the West equatorial region and SLP derived indices: SOI (left column) and IOI (right column)

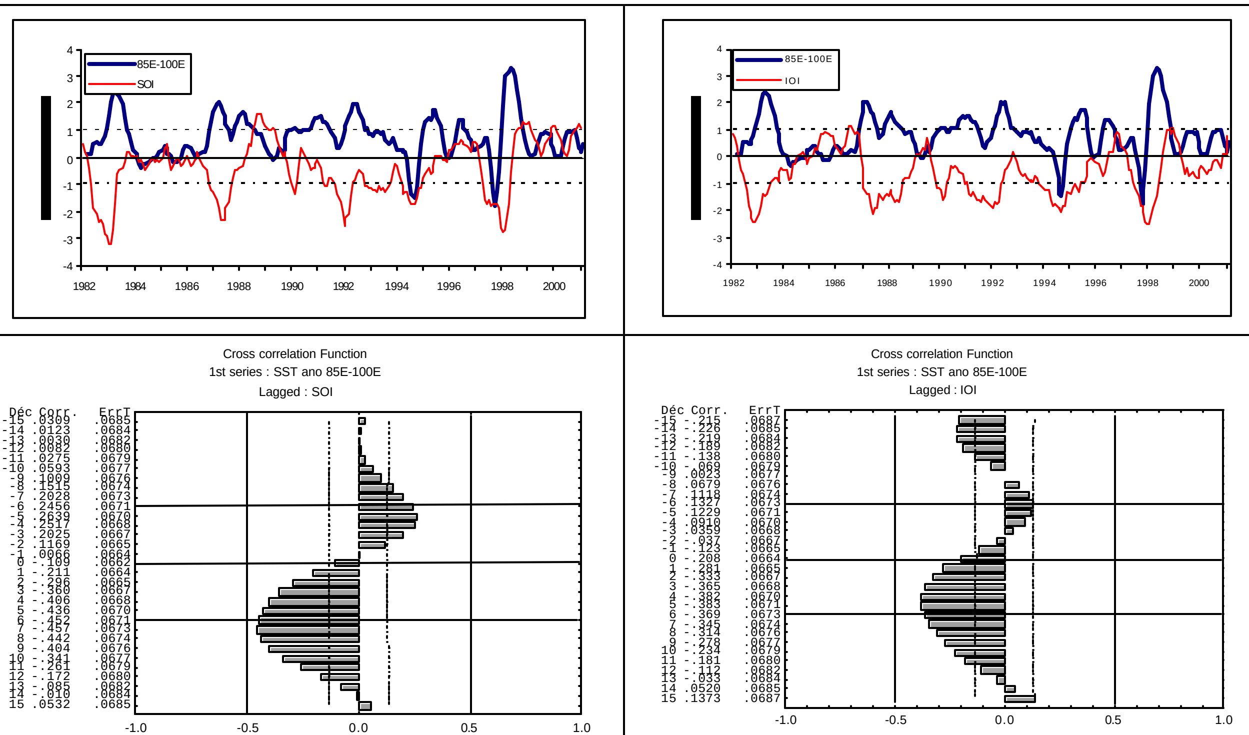


Figure 6. Combined time series and cross correlation between SST anomalies in the East equatorial region and SLP derived indices: SOI (left column) and IOI (right column)

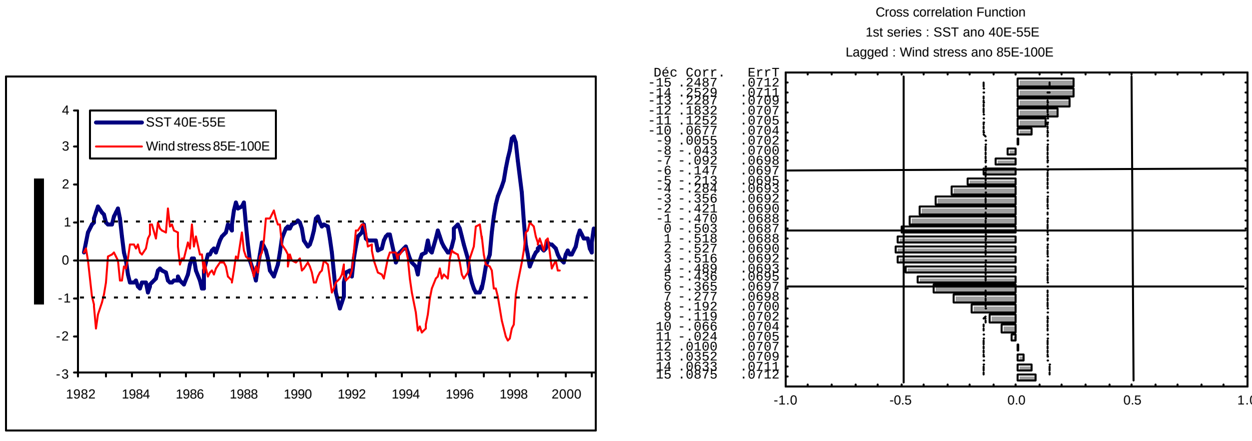


Figure 7. Combined time series and cross correlation between SST anomalies in the West equatorial region and zonal wind stress anomalies in the East equatorial region.

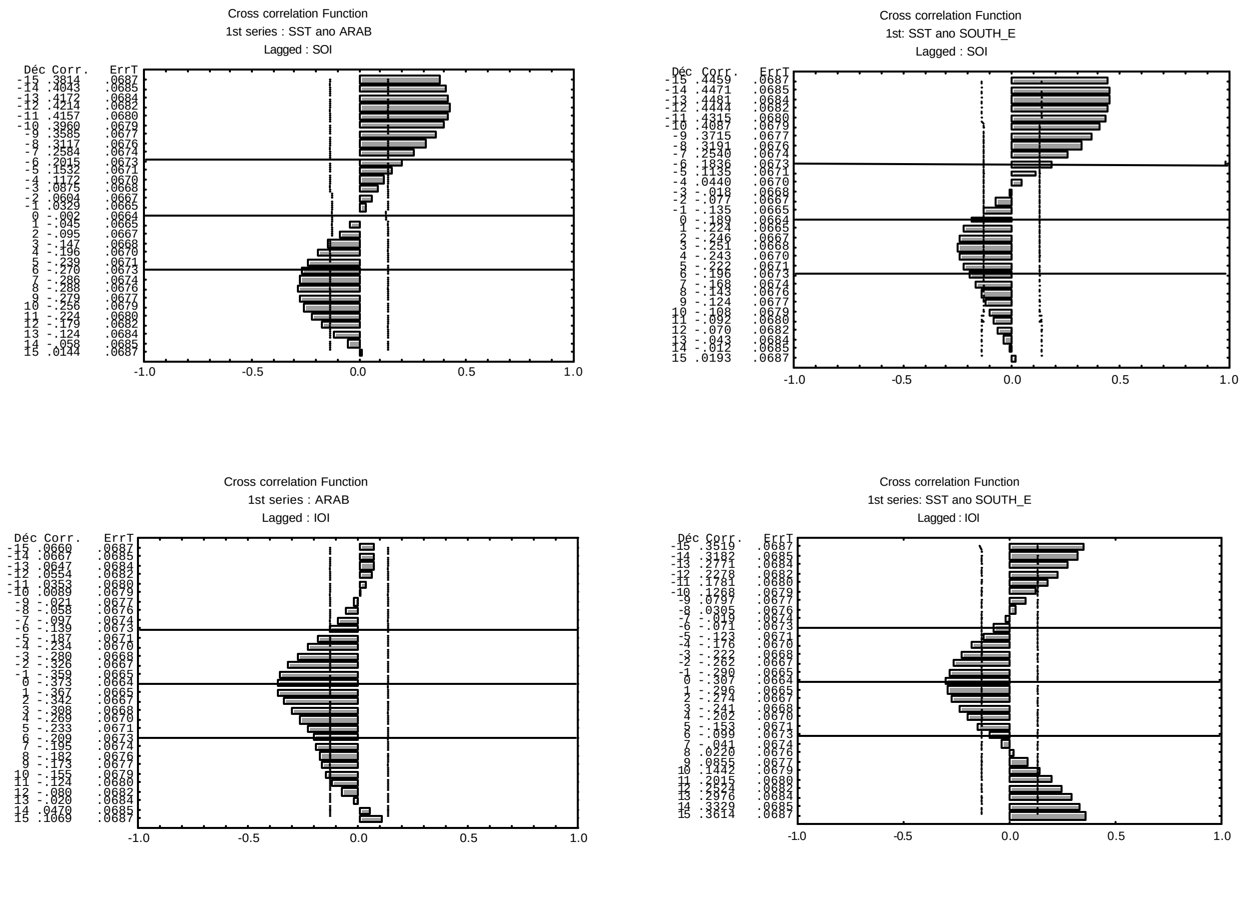


Figure 9. Cross correlation functions between SST anomalies and SLP/IOI in the Arabian Sea (left column) and in the South Eastern tropical area

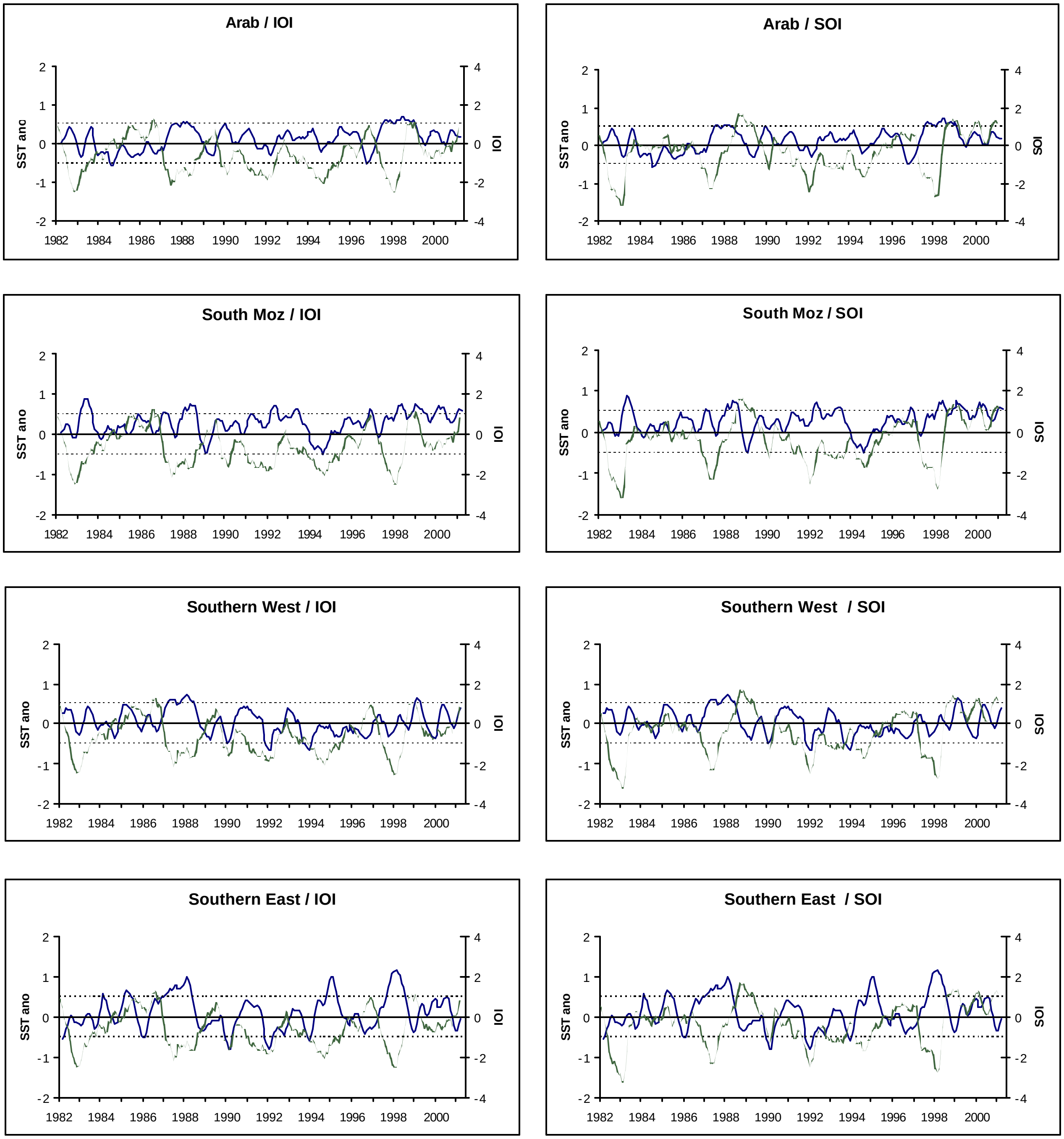
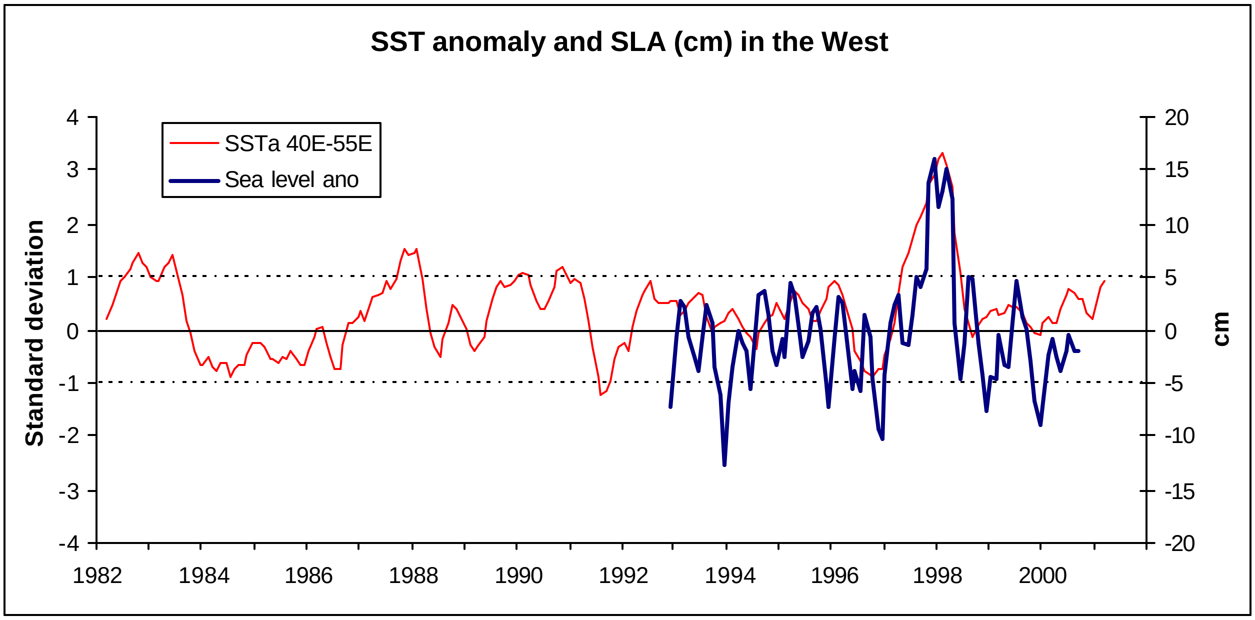


Figure 8. Combined plots of time series of SST anomalies in the four tropical sub-areas and SLP-derived indices: IOI (left column) and SOI (right column)



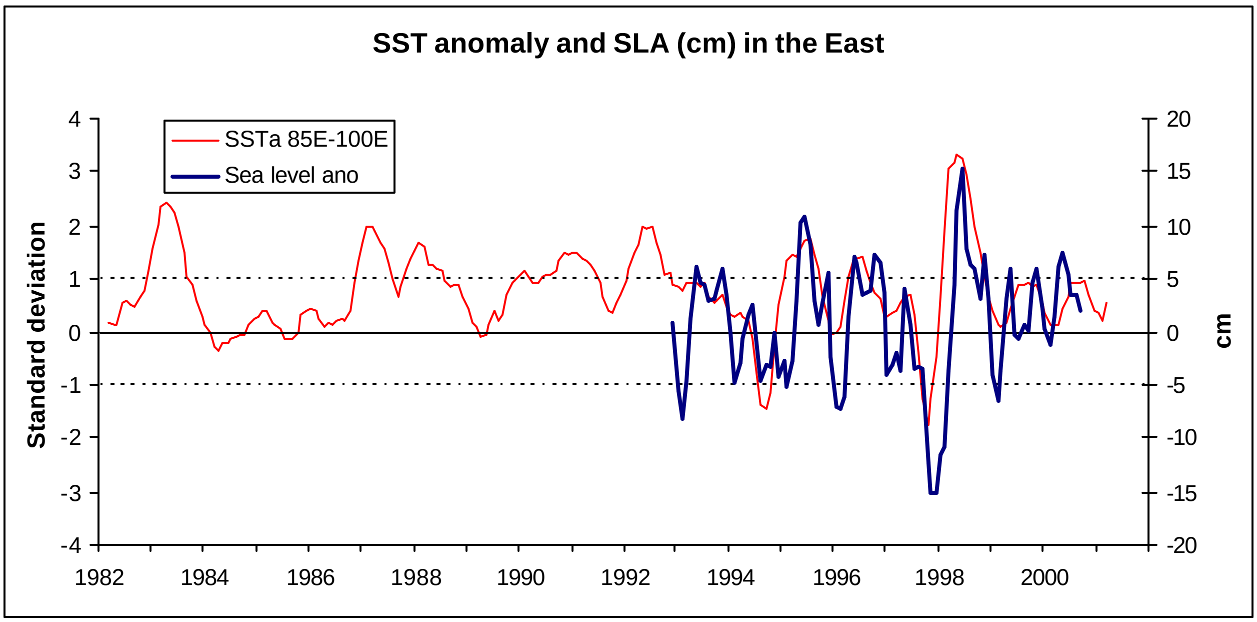


Figure 10. Combined time series between SST anomalies and the sea level height anomalies in the West and East equatorial areas of the Indian Ocean