MAUSAM, **54**, 4 (October 2003), 829-836

551.526.6 : 551.513.7 (267)

Variability of sea surface temperature over Indian Ocean during El-Nino and La-Nina years

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(*Received 19 March 2002, Modified 9 October 2002*)

सार – हाल ही में किए गए अनेक अध्ययनों में भूमंडलीय जलवायु परिवर्तनशीलता में हिन्दमहासागर के महत्व के विषय में बताया गया है। इस शोध–पत्र में एल नीनो और ला नीना वर्षों के लिए हिन्दमहासागर (10°द.–20° उ., 50° पू.–100°पू.) के यौगिक समुद्र सतह तापमान की परिवर्तनशीलता का विश्लेषण किया गया है। इस विश्लेषण के लिए, लिए गए आँकड़े 1961–97 की अवधि के हैं। इस विश्लेषण से यह पता चला है कि एल नीनों (ला नीना) वर्षों के लिए हिन्दमहासागर के यौगिक समुद्र सतह तापमान शीतऋतु के दौरान शीतलन (तापन) और उत्तर मानसून ऋतु के बाद तापन (शीतलन) को दर्शाता है।

ABSTRACT. Many recent studies have brought out the importance of Indian Ocean in global climate variability. In the present study, the variability of composite Sea Surface Temperatures (SSTs) over Indian Ocean (10º S - 20º N, 50º E - 100º E) for El-Nino and La-Nina years is analysed. The data period is 1961-97. It is observed that, the composite SSTs over Indian Ocean for El-Nino (La-Nina) years show cooling (warming) during winter season and warming (cooling) during post-monsoon season.

Key words – Sea surface temperature, Indian ocean, El-Nino and La-Nina years.

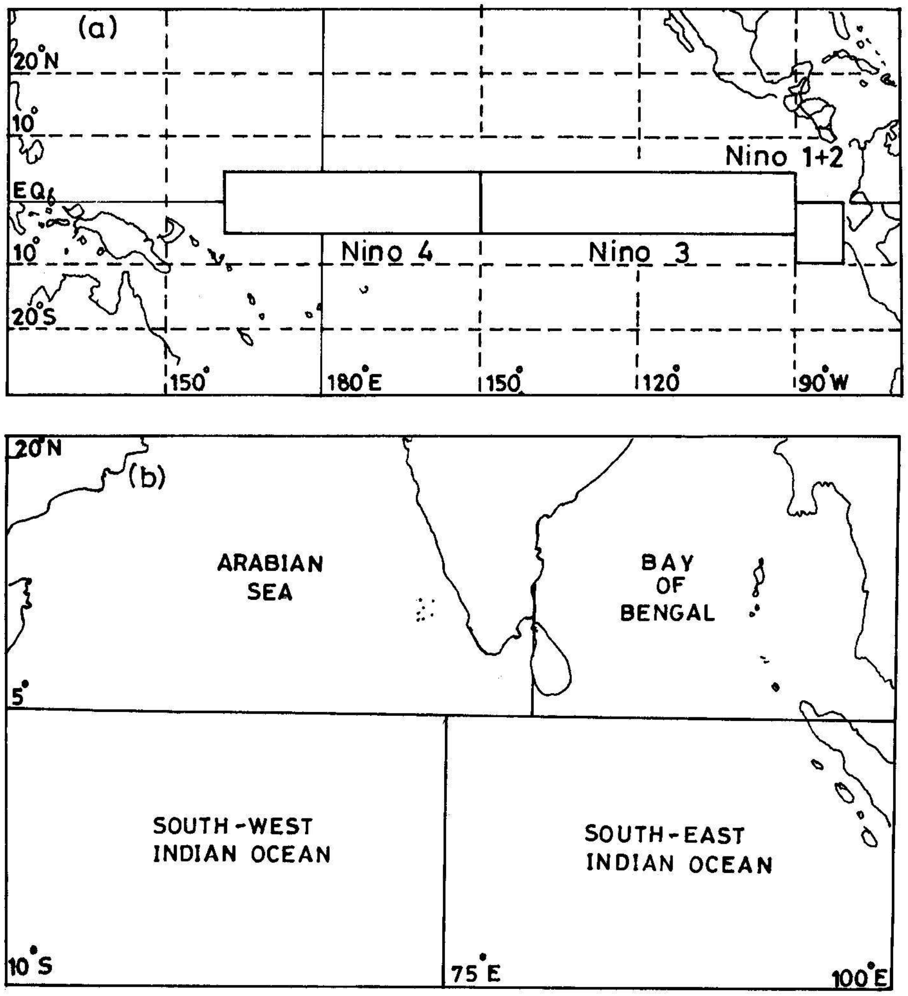
1. Introduction

The phenomenon of occurrence of El-Nino (anomalous warming of the eastern and central equatorial Pacific Ocean), has invited considerable attention, world over, since mid-1970s. The importance of changes in Sea Surface Temperature (SST) over the equatorial Pacific Ocean in global climate variability is extensively documented in the form of relationship between the El-Nino-Southern Oscillation (ENSO) and global climate anomalies [Walker (1923, 1924); Rasmusson and Carpenter (1982,1983); Ropelwski and Halpert (1987, 1989, 1996); Shukla (1987); Mooley and Paolino (1989); Kane (1997, 1998); Kripalani and Kulkarni (1997); Sikka (1980)]. Although usually not as extreme or extensive as in the Pacific Ocean, warmer oceanic temperatures and anomalous convection patterns do also occur in central Indian Ocean [Tourre and White (1995, 1997); Chandrashekhar and Kitoh (1998); Saji *et al*. (1999); Webster *et al*. (1999); Yu and Rienecker (1999)]. Meehl (1987) has discussed the annual cycle and inter-annual variability in SST over tropical Indian Ocean and Pacific Ocean. He has suggested that the inter-annual anomalies in the tropical Indian Ocean initiate over the Indian monsoon region during the northern summer and propagate southeastwards from northern summer to winter. Nagai *et al*. (1995) have shown that the major inter-annual variability in the Indian Ocean is related to ENSO. Ju and Slingo (1995) have shown that SST anomalies in Indian Ocean tend to be in phase with those over the central and eastern Pacific. Webster *et al*. (1999) have shown that in the second half of 1997 (the year of the most severe El-Nino event of the 20th century), anomalies in SST developed in Indian Ocean (cold in the east and warm in the west), a state known as Indian Ocean dipole. Saji *et al*. (1999) have identified a dipole mode in the equatorial Indian Ocean, which explains 12% of the SST variability in the Indian Ocean. Thus, the Indian Ocean is assuming increasing importance and relevance in global climate variability in recent years, particularly so, after the 1997 El-Nino event.

In this backdrop, the analysis of variability of composite SST over the Indian Ocean (10° S – 20° N, 50° E – 100° E), during the El-Nino and La-Nina events during the period 1961-97, is presented in this study.

2. Data and methodology

During the period 1961 to 1997, there have been 7 El-Nino events [Quinn (1987), Rasmusson and Carpenter (1983)] and 8 La-Nina years [Van Loon and



Figs. 1(a&b). (a) Graphical depiction of the three Nino regions of Pacific Ocean and (b) Graphical depiction of the four regions of Indian Ocean

Shea (1985)]. These events are listed in Table 1. The three Nino regions of the Pacific Ocean, *viz*., Nino 1+2 (0°- 10° S, 150° W-90° W), Nino 3 (5° N-5° S, 150° W-90° W) and Nino 4 (5° N-5° S, 160 °E-150° W) regions are depicted in Fig. 1(a). In order to study the variability of SST over Indian Ocean during these events, the data of SST over Indian Ocean, covering the area, 10° S-20° N, 50° E-100° E, have been utilized. The Indian Ocean region (10° S-20° N, 50° E-100° E) is divided into four sectors, *viz*. Arabian Sea (5° N-20° N, 50° E-80° E), Bay of Bengal (5° N-20° N, 80° E-100° E), South-West (SW) Indian Ocean (10° S-5° N, 50° E-75° E) and South-East (SE) Indian Ocean (10° S-5° N, 75° E-100° E), [Fig. 1(b)]. The maps of composite SST anomalies over Indian Ocean for El-Nino and La-Nina years are prepared and analysed, for examining the SST variability over Indian Ocean. For this purpose, the monthly SST data over Indian Ocean (10° S - 20° N, 50° E-100° E), based on the surface marine observations archived by the India Meteorological Department (IMD), have been used. These SST data have been grouped into

TABLE 1

El-Nino and La-Nina years during 1961 to 1967

El-Nino years	La-Nina years
1965	1964
1969	1966
1972	1970
1976	1973
1982	1975
1987	1978
1997	1983
–	1988

5° × 5° latitude-longitude grids and monthly SST anomaly values for each of these grids have been computed with respect to the mean SST for the base period 1961-97, for the respective grid. For each grid, the composite SST anomalies for El-Nino and La-Nina years during 1961-97

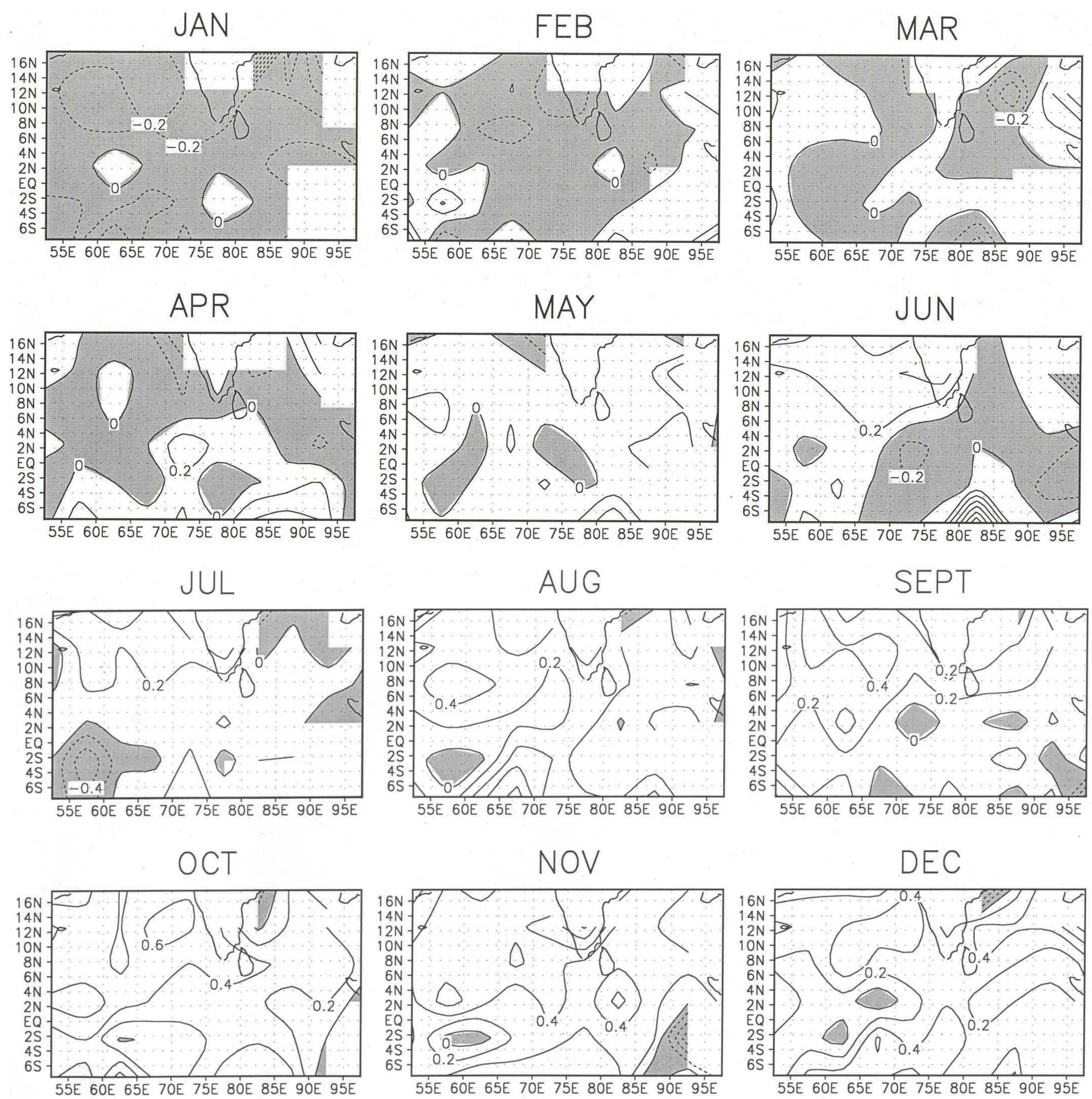


Fig. 2. Latitude-longitude sections of monthly composites of Indian Ocean SST anomalies for the El-Nino years (1961-97). Contour interval is 0.5. Area of negative SST anomalies indicating cooling is shaded

have been computed for all the twelve calendar months. The maps of these composite SST anomalies are then prepared and analysed. Figs. 2 and 3 depict these maps for El-Nino and La-Nina years respectively. For analysing the temporal variability of SST over Indian Ocean, the evolution of composite SST anomaly over the Nino 3 region (5º N-5º S, 150º W-90º W) and that over the four sectors of the Indian Ocean, *viz*. Arabian Sea, Bay of Bengal, South-West (SW) Indian Ocean and South-East (SE) Indian Ocean, [Fig. 1(b)] for El-Nino and La-Nina years, from previous year Y (-1) to the succeeding year Y (+1) through the concurrent year Y (0), is analysed. El-Nino phenomenon is considered as the anomalous warming of SST over Pacific Ocean. The warming over Pacific is generally expressed in terms of SST anomaly values averaged over the three 'Nino' regions as defined earlier. Out of these three regions, Nino 3 region is considered as being a broad representative region of Pacific Ocean to describe El-Nino phenomenon. Nino 1+2 region is too small/narrow a region to be broadly representative of an area to depict a large – scale oceanic phenomenon like El-Nino. Also, Nino 1+2 region being a highly localized region, warming in this region may occur in absence of El-Nino as well, under the influence of

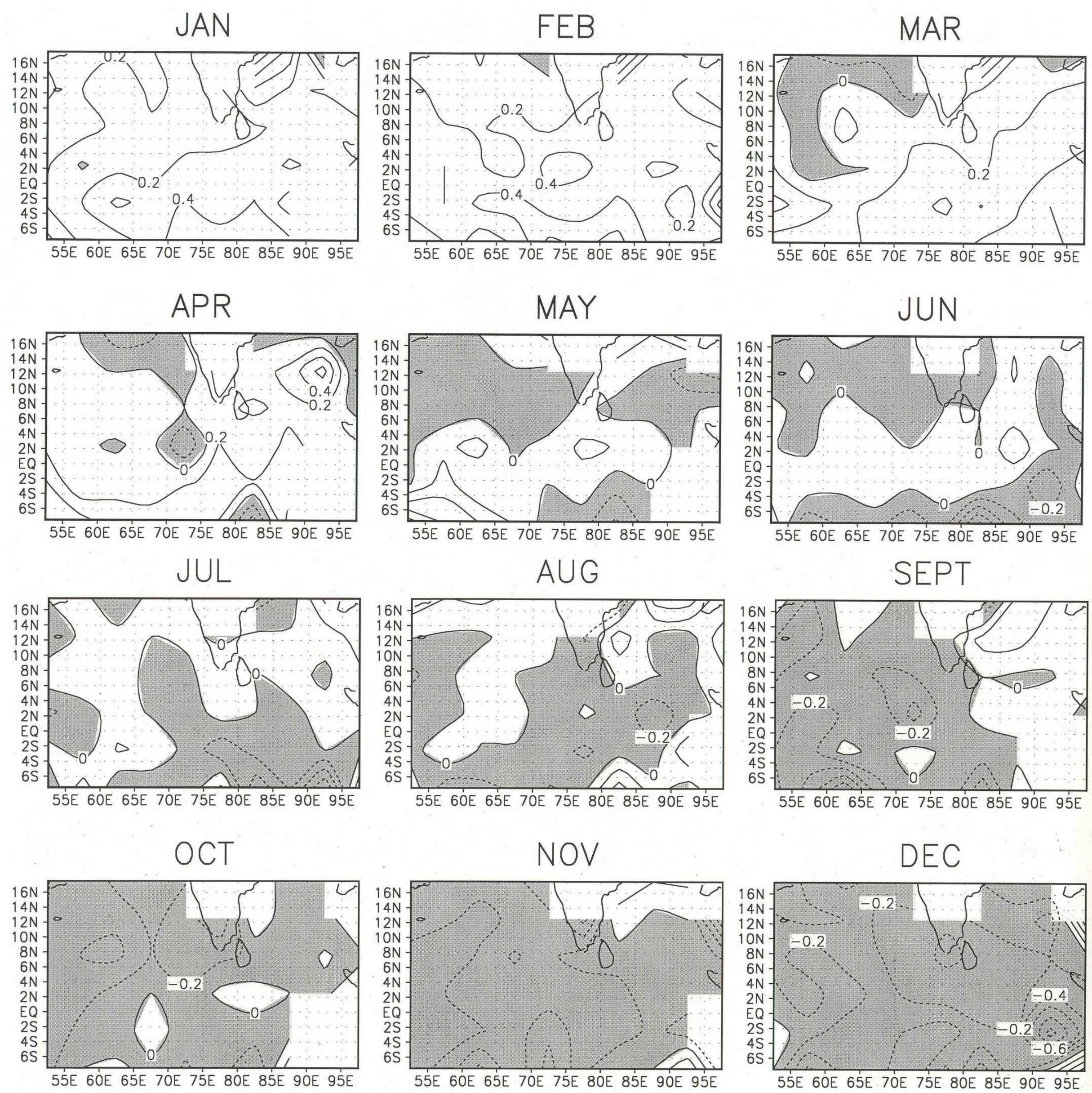


Fig. 3. Latitude-longitude sections of monthly composites of Indian Ocean SST anomalies for the La-Nino years (1961-97). Contour interval is 0.5. Area of negative SST anomalies indicating cooling is shaded

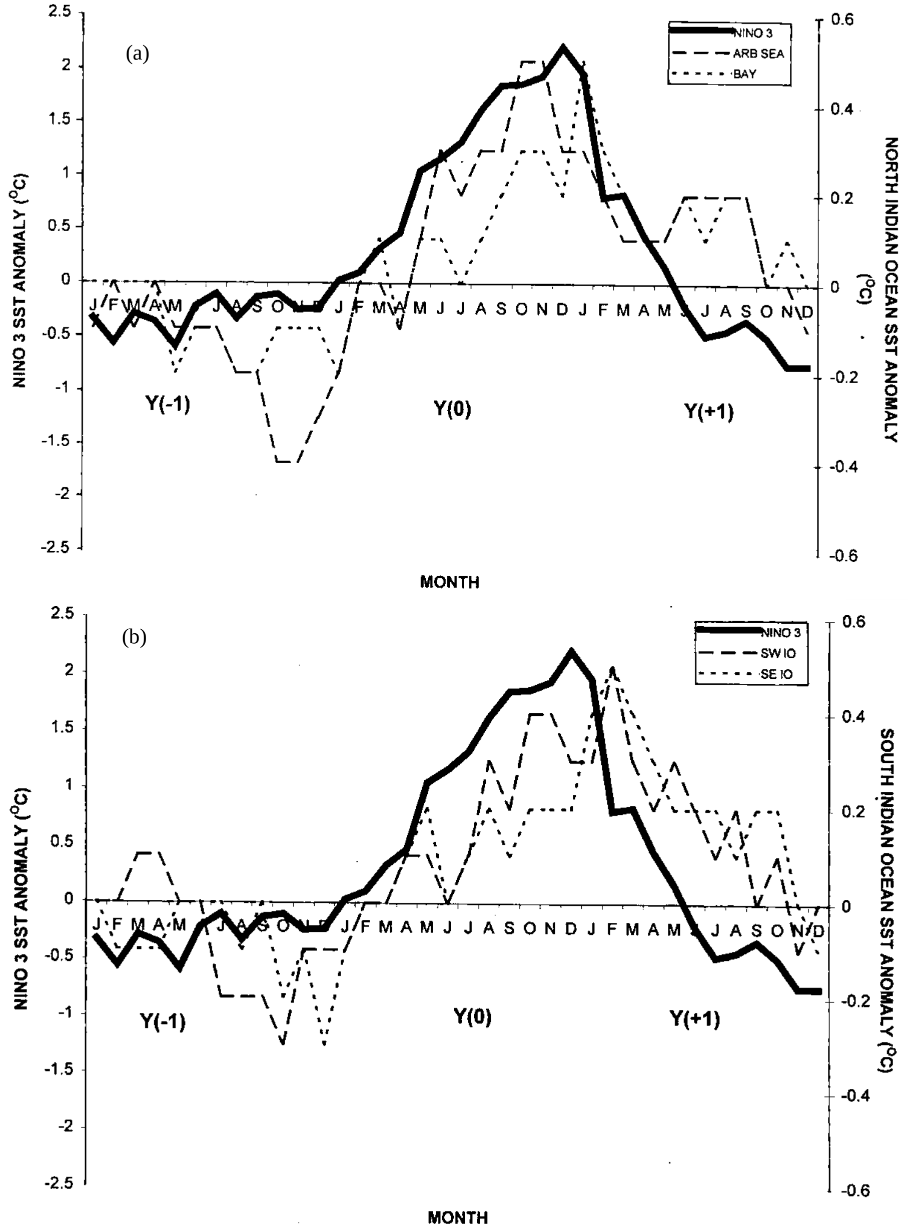
strong local currents. On the other land, Nino 4 region covers quite a large portion of the western Pacific Ocean, to the west of the International Date Line. As such, in the present study, Nino 3 region of the Pacific Ocean has been used as a representative area for El-Nino phenomena and the spatio – temporal variability of SST over Indian Ocean has been examined in its association. Nino 3 region has been used as a representative area of central and eastern Pacific Ocean for describing El-Nino phenomenon, in some other studies also (Thapliyal *et al*., 1998).

3. Discussion

3.1. *Spatial distribution*

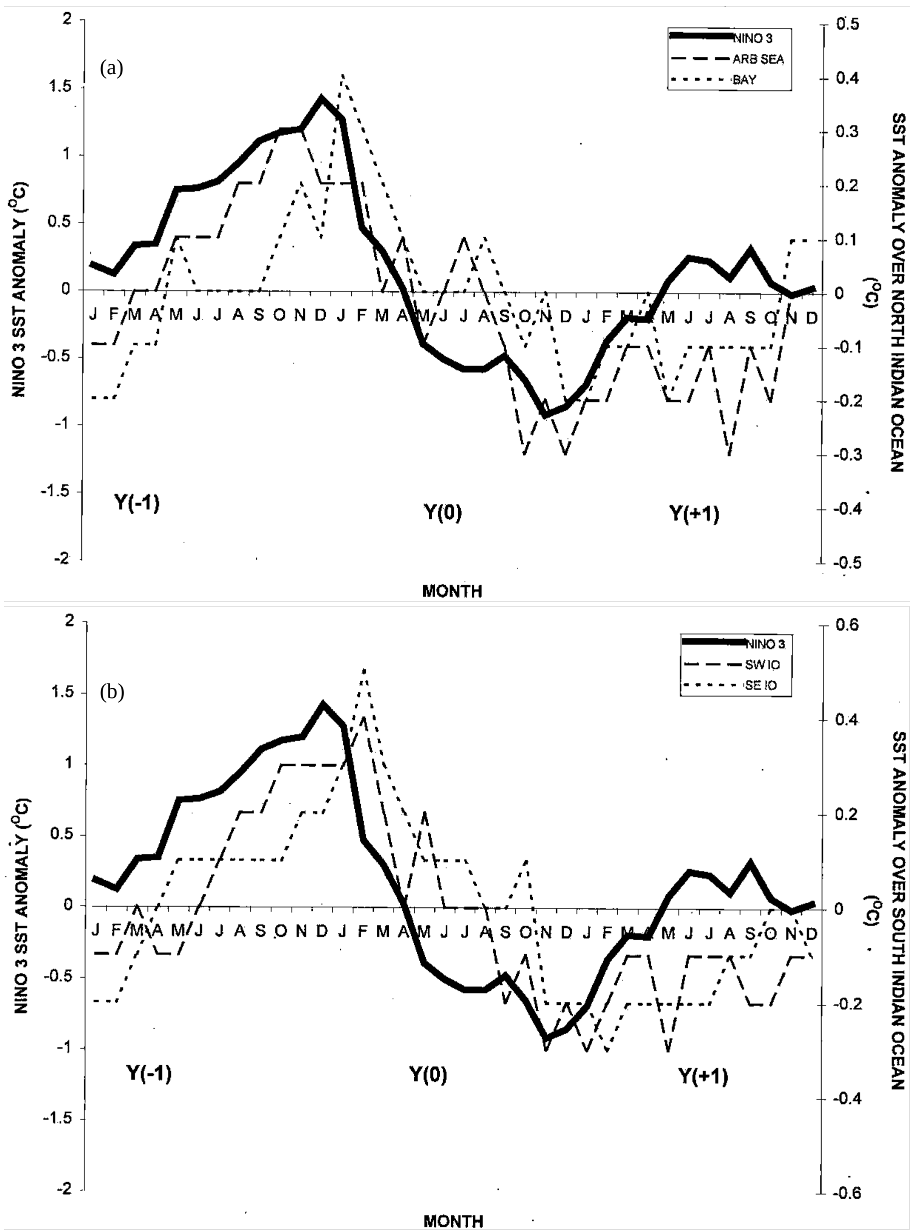
3.1.1. *El-Nino years*

Fig. 2 depicts the spatial distribution of the monthly composite SST anomalies for El-Nino years during 1961-97. These SST anomalies are computed for each of the grids on 5° × 5° scale over the region of Indian Ocean,



Figs. 4(a&b). (a) Temporal evolution of composite SST anomaly over Nino 3 region and north Indian Ocean for El-Nino years (1961-97) and (b) Temporal evolution of composite SST anomaly over Nino 3 region and south Indian Ocean for El-Nino years (1961-97)

10° S – 20° N, 50° E – 100° E; for all the twelve calendar months. It can be noted that, during January and February, most parts of the Indian Ocean show cooling. The spatial extent of this cooling is observed to decrease progressively during March to July. During June, significant warming is seen to be appearing over parts of Arabian Sea, with cooling persisting over parts of east-central Bay of Bengal and SE Indian Ocean. Warming is also observed over parts of the south-central Indian Ocean. During July, the cooling over Bay of Bengal and parts of south Indian Ocean reduces to a large extent and remains confined over extreme southwest Indian Ocean and northern Bay of Bengal. The Arabian Sea continues to depict warming. During August, the cooling further decreases and warming is dominant over the most parts of Indian Ocean. During September as well, dominant warming is observed over the north Indian Ocean with cooling over extreme southeastern Indian Ocean. During October also, dominant warming is observed over Indian Ocean with localized cooling over western region of Bay of Bengal. During November and December too, this warming is observed to persist. During November,



Figs. 5(a&b). (a) Temporal evolution of composite SST anomaly over Nino 3 region and north Indian Ocean for La-Nina years (1961-97) and (b) Temporal evolution of SST anomaly over Nino 3 region and south Indian Ocean for La-Nina years (1961-97)

cooling is observed over some parts of southeast Indian Ocean and during December, the cooling is observed over the extreme western parts of Bay of Bengal.

Thus, for the El-Nino years, during winter season, cooling is observed over the most parts of Indian Ocean. During the pre-monsoon season (March-April-May), the SST values close to the Long Period Average (LPA) values are observed, with beginning of appearance of warming. During the monsoon season, a gradual extension of warming over Indian Ocean is observed and during the post-monsoon season, the warming is dominant over the most parts of Indian Ocean. This suppresses the normal monsoonal cooling of these two basins.

3.1.2. *La-Nina years*

Fig. 3 depicts the spatial distribution of monthly composite SST anomalies for La-Nina years during 1961-97. The diagram has been prepared in a manner similar to that described in section 2. It is observed from this diagram, that, during January and February, significant warming is seen over the most parts of Indian Ocean. During March to May, the spatial extent of the warm area is observed to reduce and simultaneous appearance of cooling over parts of the Arabian Sea and the Bay of Bengal is observed in March. This cooling is observed to extend southwards till May. During June to August, the SSTs are close to their LPA values; over the most parts of the Indian Ocean, except over extreme northern Bay of Bengal, where warming is observed. In September, cooling is observed over parts of the Arabian Sea and the SW Indian Ocean, with warming persisting over the eastern region of Indian Ocean. During October, the warming is further reduced. During November, over the most parts of Arabian Sea and southwest Indian Ocean, significant cooling is observed; with a localized warming over extreme northern Bay of Bengal. During December, most parts of the Indian Ocean depict cooling.

Thus, for the La-Nina years, during the winter season, significant warming is observed over the Indian Ocean. During pre-monsoon season, the spatial extent of the warming is observed to reduce progressively. The values of SSTs over Indian Ocean during the monsoon season are close to the respective LPA values. During the post-monsoon season, significant cooling is observed over the most parts of the Indian Ocean.

3.2. *Temporal evolution*

3.2.1. *Monthly composite SST anomalies for El-Nino years*

Fig. 4(a) shows the evolution of composite monthly SST anomaly over Nino 3 region and that over north Indian Ocean (Arabian Sea and Bay of Bengal) for El-Nino years during 1961-97 from the previous year Y (-1) through the concurrent year Y (0) to the succeeding year Y (+1). The scales of primary and secondary Y axes of this diagram are different. It is seen from this diagram that, the magnitude of SST anomalies over the Arabian Sea and the Bay of Bengal is lower as compared to that over Nino 3 region. It is also evident that, the warming over Nino 3 region begins from February of Y (0), peaks in December of Y (0) and persists till April of Y (+1). However, over the Arabian Sea warming starts in May of Y (0) and peaks in October – November of Y (0), *i.e.* earlier to the peak warming over Nino 3 region. Thus, the rate of warming over the Arabian Sea is higher than that over Nino 3 region. The warming over the Arabian Sea persists till October Y (+1) as against the warming over Nino 3 region, which ceases in June of Y (+1). In case of the Bay of Bengal, warming begins in May of Y (0), later by 5 months than that over Nino 3 region. The peak of warming over the Bay is observed in January of Y (+1), a month later than that over Nino 3 region. The warming over the Bay of Bengal persists till December of Y (+1).

Thus, warming over the north Indian Ocean region begins later that over Nino 3 region by 3 months; the peak of warming is almost in phase with that over Nino 3 region and this warming persists till December of Y (+1).

Fig. 4(b) depicts similar evolution of SST anomalies over south Indian Ocean and Nino 3 region. It is observed that, over the SW and the SE Indian Ocean, the warming begins in April, two months later than that over Nino 3 region. It peaks in February of Y (+1), two months later than that over Nino 3 region and persists till October of Y (+1). The rate of warming over the SW and the SE Indian Ocean is almost the same as that over Nino 3 region. The magnitude of SST anomalies over south Indian Ocean is lower than that over Nino 3 region.

3.2.2. *Monthly composite SST anomalies for La-Nina years*

Figs. 5(a&b) depict the evolution of composite monthly SST anomalies over Nino 3 region and north Indian Ocean and south Indian Ocean, respectively for La-Nina years during 1961-97; from the previous year Y (-1) through the concurrent year Y (0) to the succeeding year Y (+1). The magnitude of SST anomalies over north and south Indian Ocean is lower than that over Nino 3 region, as indicated by the varying scales of the primary and secondary Y-axes of these diagrams. It is observed from Fig. 5(a) that, the cooling over Nino 3 region begins in May of Y (0) which persists till April of Y (+1) with the peak in November of Y (0). The Arabian Sea SST anomalies, however, show beginning of cooling from September of Y (0) (four months later than that over Nino 3 region). This cooling persists till October of Y (+1), with the peak in December of Y (0); only a month later than that over Nino 3 region. Over Bay of Bengal, cooling begins in October of Y (0) (five months later than that over Nino 3 region), and persists till October of Y (+1) with the peak in December Y (0) - January of Y (+1).

From Fig. 5(b), it is observed that, cooling over the SW Indian Ocean begins in September of Y (0) (five months later than that over Nino 3 region) and persists till December of Y (+1) with the peak in November of Y (0), simultaneous to the peak cooling over Nino 3 region and also in January and May of Y (+1). On the other hand, the cooling over the SE Indian Ocean begins much later, in November of Y (0) (by seven months later than that over Nino 3 region), which persists till December of Y (+1) with the peak in February of Y (+1), (three months later than that over Nino 3 region).

4. Conclusions

(*i*) The composite SSTs over Indian Ocean for El-Nino (La-Nina) years show cooling (warming) during winter season and warming (cooling) during post-monsoon season.

(*ii*) The composite SSTs over Indian Ocean for El-Nino (La-Nina) years show a warming (cooling) trend from the previous to the concurrent year.

Acknowledgements

The author is grateful to the anonymous referee for the valuable comments offered, for enhancing the quality of the manuscript. Thanks are due to Shri. S.R. Kshirsagar for assistance in computations and Smt. P.R Iyer for typing the manuscript.

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