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Variability of sea surface temperature field over Indian Ocean during 2002 and 2004

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ABSTRACT
The role of Indian Ocean in climate variability has been extensively documented in the literature. During 1997, the year that witnessed the strongest El-Nino of 20th Century, significant warming was observed also over the Indian Ocean [Medha Khole (2000)]. There exist complex and interesting inter-relationships between Sea Surface Temerature (SST) over the Pacific and Indian Ocean basins and All India Summer Monsoon Rainfall (AISMR) [Medha Khole & De (2001), Rejeevan, Medha Khole & De (2000)]. In recent times, 2002 was the first all-India drought year, ranking fifth of the most severe droughts over India, after a continuous spell of 14 good monsoons which followed the previous all-India drought year of 1987. The seasonal rainfall (June-September) for the country as a whole, during 2002, was 19% below normal with 29% area of India experiencing drought conditions. The month of July reported the worst rainfall deficiency of 49% (IMD 2004). The rainfall of 1997, in spite of a major El Nino and considerable warming in the Indian Ocean, since January 1997 till December 1998, has been near normal. The inverse relationship between EI-Nino and AISMR, though, not one-to-one and has been weakening in recent years, remains one of the important parameters controlling the variability of AISMR. During 2002, the values of anomalies of SSTs over Nino 3 (5° N-5°S, 150° W- 90° W), Nino (5° N-5° S, 160° W-150° W) and Nino 1 + 2 (0-10° , 90° W- 80° W) regions of the Pacific Ocean exhibited warming during the Indian Summer monsoon season (June-July-August-September), however, the SSTs over Nino 1+2 region of the Pacific were colder than normal during this period. This warming pattern over Pacific Ocean is, thus, anomalous in nature. It was, therefore, considered interesting to analyse the variability of SST field over Indian Ocean during the phase of warm SSTs over the Pacific Ocean. With this backdrop, the cycle of evolution of SSTs over Indian Ocean (20° S - 25° N, 50° E - 100° E), during the period January 2001 to December 2003, has been analysed in this paper. Its relationship with the deficiency of AISMR during 2002 has also been assessed. It has been observed that the SST over Arabian Sea (5° N - 20° N, 50° E - 80° E) was colder than normal during June and September, 2002 while it was warmer than normal during July and August, 2002. The further details of SST variability are extensively discussed in the paper.

INTRODUCTION

Ocean and atmosphere are closely linked and interact on different space and time scales to produce weather and climate on the planet. Early studies by Sir Gilbert Walker established the role of pressure oscillation in the far eastern regions of the equatorial Pacific in modulating the monsoon rains during the summer monsoon (June-September) over the Indian sub-continent. He coined a term known as the Southern Oscillation Index or SOl. Later studies by Bjerknes (1969), Rasmusson & Carpenter (1983), Mooley & Parthasarathy (1984) and several others revealed a close connection between the warming of Eastern Equatorial Pacific (EEP) and the negative phase of the SOl. In the last decade, a similar feature known as the Indian Ocean dipole has also been characterized as one of the controlling factors of the Indian Summer Monsoon Rainfall (ISMR). However, it seems that, there does not exist a one to one relationship between the warming patterns in the Pacific and the Indian Ocean and the seasonal precipitation during Indian Summer Monsooon (ISM). Medha Khole (2000) and Rajeevan, De & Prasad (2001) have studied some features of monsoon variability and the related Sea Surface Temperature (SST) variations during recent years of the last century. The increasing trends in SST over the equatorial Indian Ocean and Bay of Bengal and the Arabian sea and their association with the cloud cover have been reported by Rajeevan, Medha Khole & De (2000). The cloud cover over the northern Bay of Bengal exhibits a decreasing trend, while that over

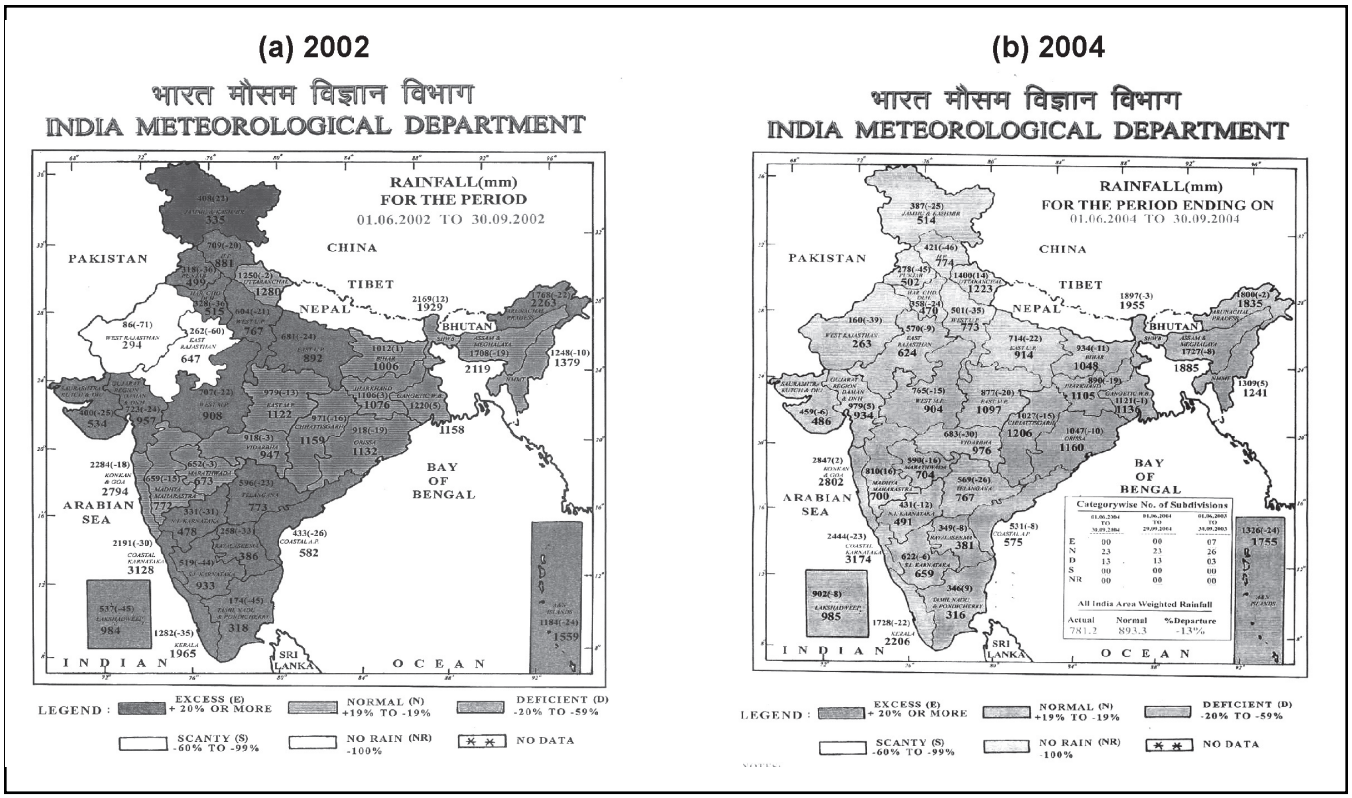

Figure 1. Spatial Distribution of Seasonal Summer Monsoon Rainfall over India.

Table 1. Sequence of warming of Pacific Ocean

(a) 2002 Warming Event

	Region		
	Nino 1+2	Nino 3	Nino 4
Warming began	October 2002	March 2002	June 2001
Peak of SST Anomaly reached	December2002	November2002	November2002
SST Anomaly became 0 or negative	January 2003	April 2003	-

(b) 2004 Warming Event

	Region		
	Nino 1+2	Nino 3	Nino 4
Warming began	October 2004	August 2004	SST Anomaly positive from June 2001 to Dec. 2005
Peak of SST Anomaly reached	November2004	December 2004	-
SST Anomaly became 0 or negative	January 2005	February2005	-

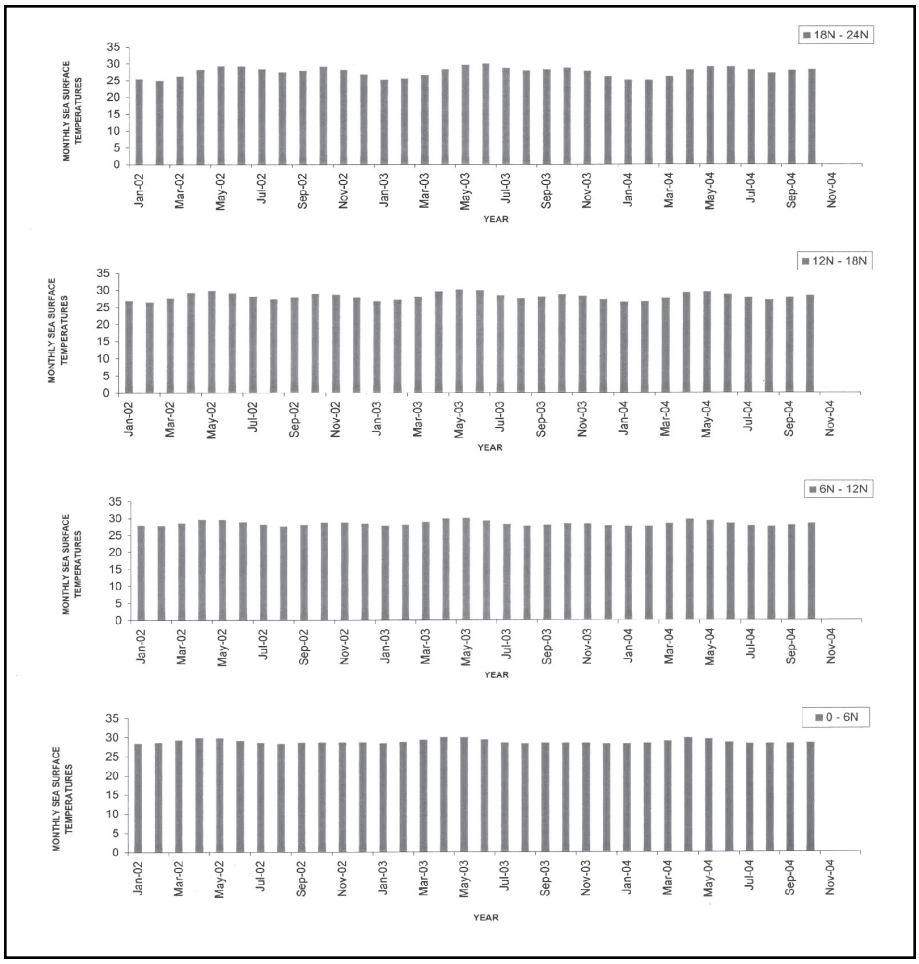

Figure 2. Monthly Sea Surface Temperatures averaged over four different latitudinal zones over Indian Ocean for the period 2002-2004.

equatorial Indian Ocean exhibits an increasing trend. The paper discusses the monsoon variability during 2002 and 2004 in conjuration with the SST changes.

DATA AND METHODOLOGY

The data for the study were obtained from Climatic Diagnostic Bulletin of India Meteorological Department (IMD) and data of SST were obtained from the National Data Centre of IMD and NOAA-CIRES Climate Diagnostics Center. The data of rainfall and details of Outgoing Long wave Radiation (OLR) for the years 2002 and 2004 were obtained from the NCEP reanalysis, NOAA-CIRES Climate Diagnostics Center. The rainfall distribution of the years 2002 and 2004 are shown in Fig. 1(a) and Fig. 1(b), respectively. The SST values in the Indian Ocean have been obtained in the form of a latitudinal section shown in Fig. 2.

DISCUSSION AND CONCLUSIONS

The seasonal monsoon rainfall in 2002 was -19% below the Long Period Average (LPA) and for 2004 was -13% below the LPA. The drought of year 2002 was due to a very large defect (-51%) occurring in July, while the rainfall during other three months was near normal. On the other hand, during 2004, July and September had moderately subdued rainfall. A comparative statistics for some major droughts is given below:

The year 2004 witnessed 4 monsoon depressions, 2002 had no depressions, in 1987 there were three, in 1979, five and in 1972, there were six monsoon depressions. In addition, there were 1, 3 and 4 Cyclonic Storms during 1987, 1979 ad 1972, respectively. Now we discuss the temporal pattern of SST distribution during 2002 and 2004.

From Fig.3 and Table 1a, it is observed that, the SST anomalies in 2002 were negative during winter in Nino

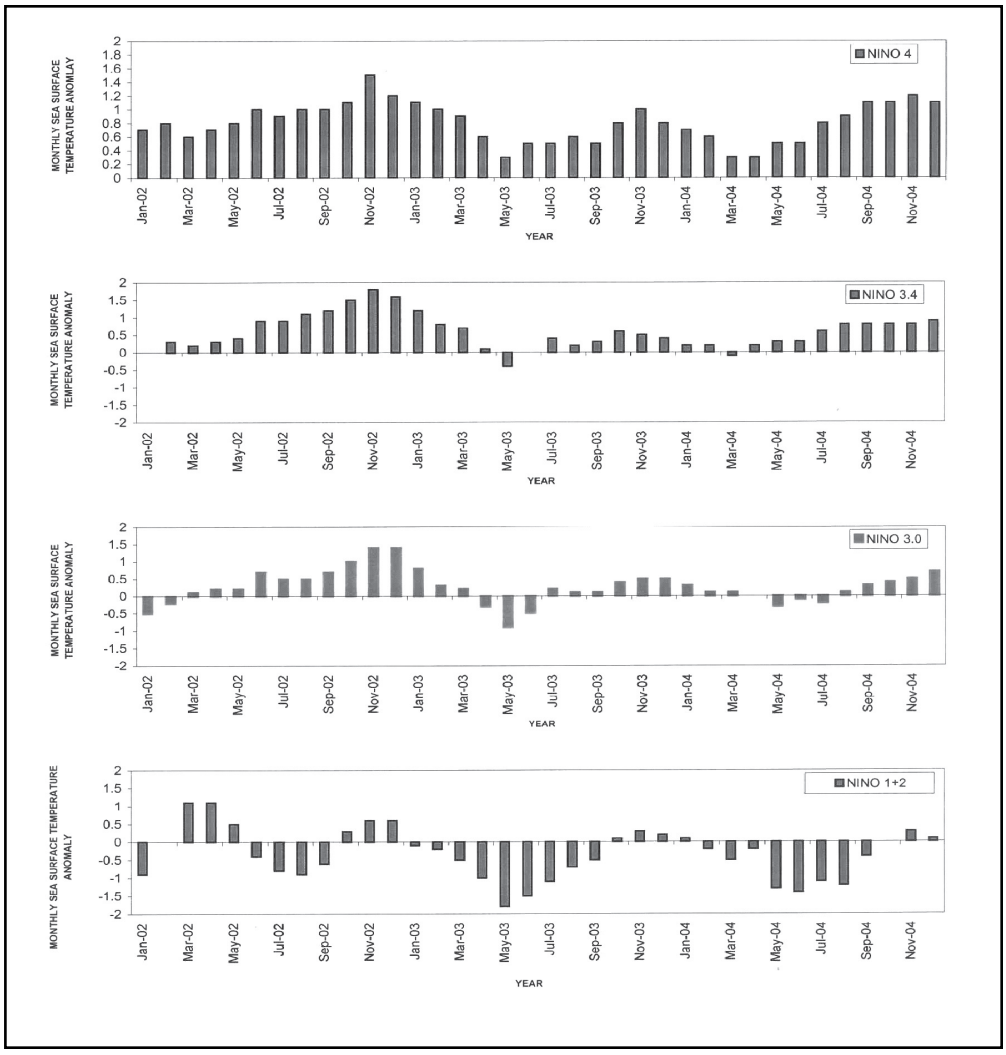

Figure 3. Monthly Sea Surface Temperature Anomaly averaged over four different latitudinal zones over Pacific Ocean for the period 2002-2004.

(1+2), Nino 3 and Nino 3.4 but from March onwards, they showed warming trends which continued in Nino 3 and Nino 3.4 till November. In the region Nino (1+2), a cooling trend was observed from May till August, which was a departure from the conventional cooling pattern. The SST anomalies in 2004 were slightly positive from April onwards and showed an increasing trend in Nino 3-4 and Nino 4. While in region Nino 1+2; there was cooling from April to August. A slight warming was seen in September and October, though the anomalies were negative from February till September 2004. In Nino 3 region, the SST anomaly values were negative during May to July 2004 and the SSTs showed warming trend since August 2004, which continued till December 2004 (Table 1b).

For the Indian Ocean, we have averaged the SST values in latitude strips of 0-6° N, 6-12° N, 12-18° N and 18-24° N. In the belt 0-6°N, the temperature rose from winter in 2002 till April and then cooling till August, followed by a slight rise in SST till November. In the next belt (6-12° N), there is a sharp rise in March followed by a slight cooling starting in May. The cooling in June is sharp which continues till August. This is followed by rise in SST till November, similar to that observed in 0-6° N belt. In the next two belts, the SST peaked in May 2002 followed by cooling (falling SST's) till about August and a rising trend till October.

In 2004, the pattern of SST variations in these four belts of the Indian Ocean is similar to that

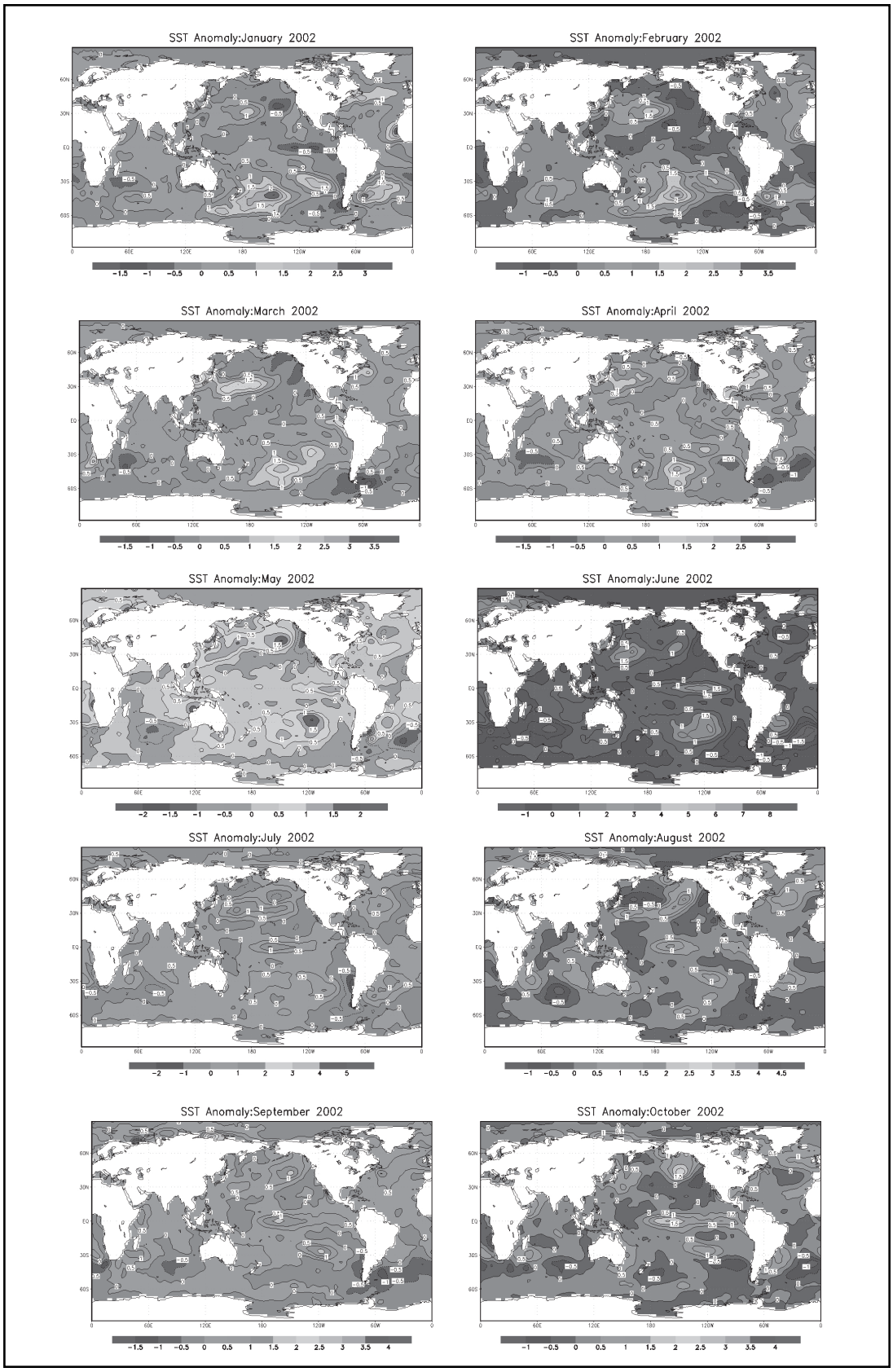

Figure 4. Latitude-Longitude sections of monthly SST Anomaly (Deg. C) during 2002

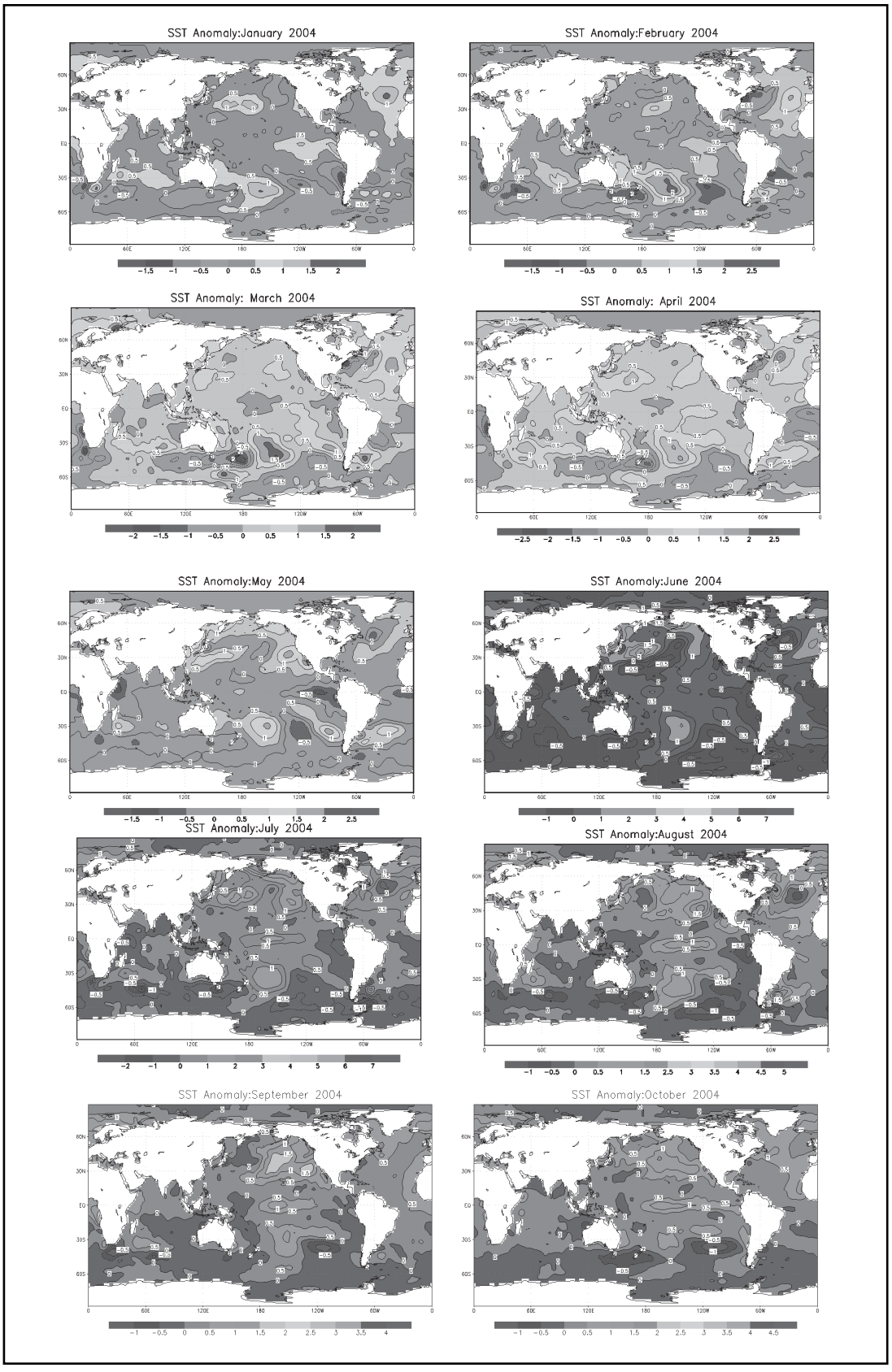

Figure 5. Latitude-Longitude sections of monthly SST Anomaly (Deg. C) during 2004

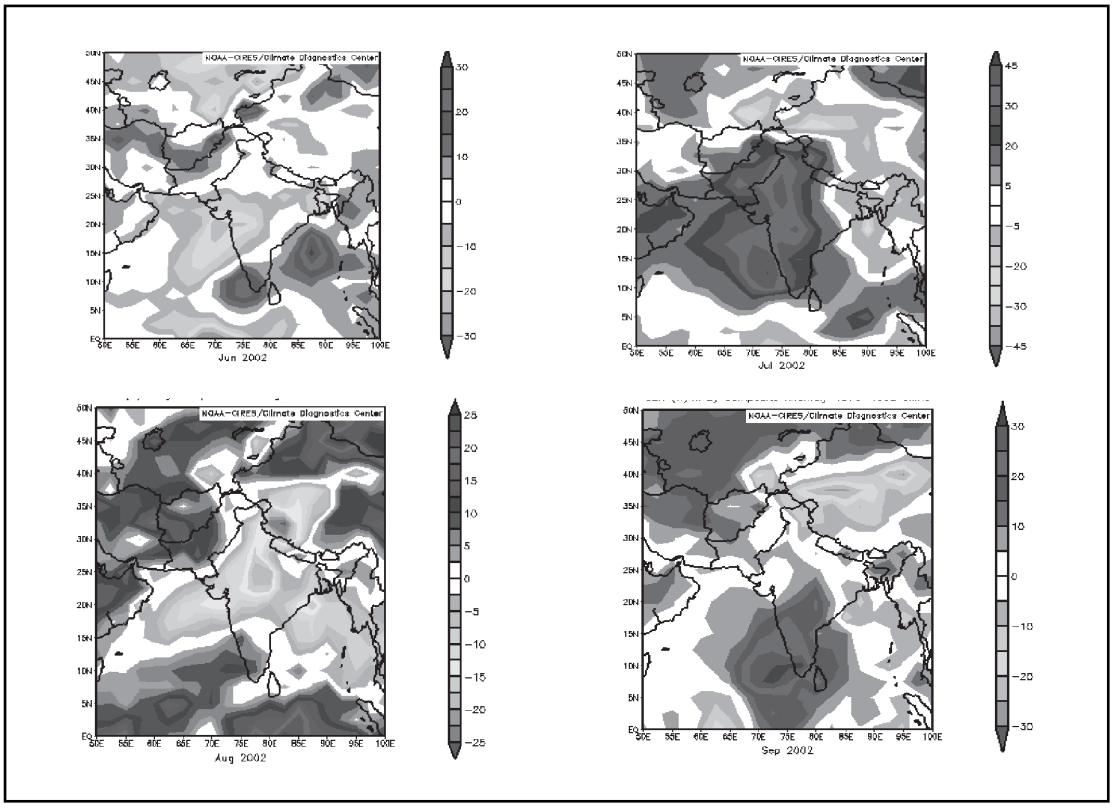

Figure 6(a). Monthly OLR Anomaly (Watts/sq.m.) during Indian Summer Monsoon season of 2002

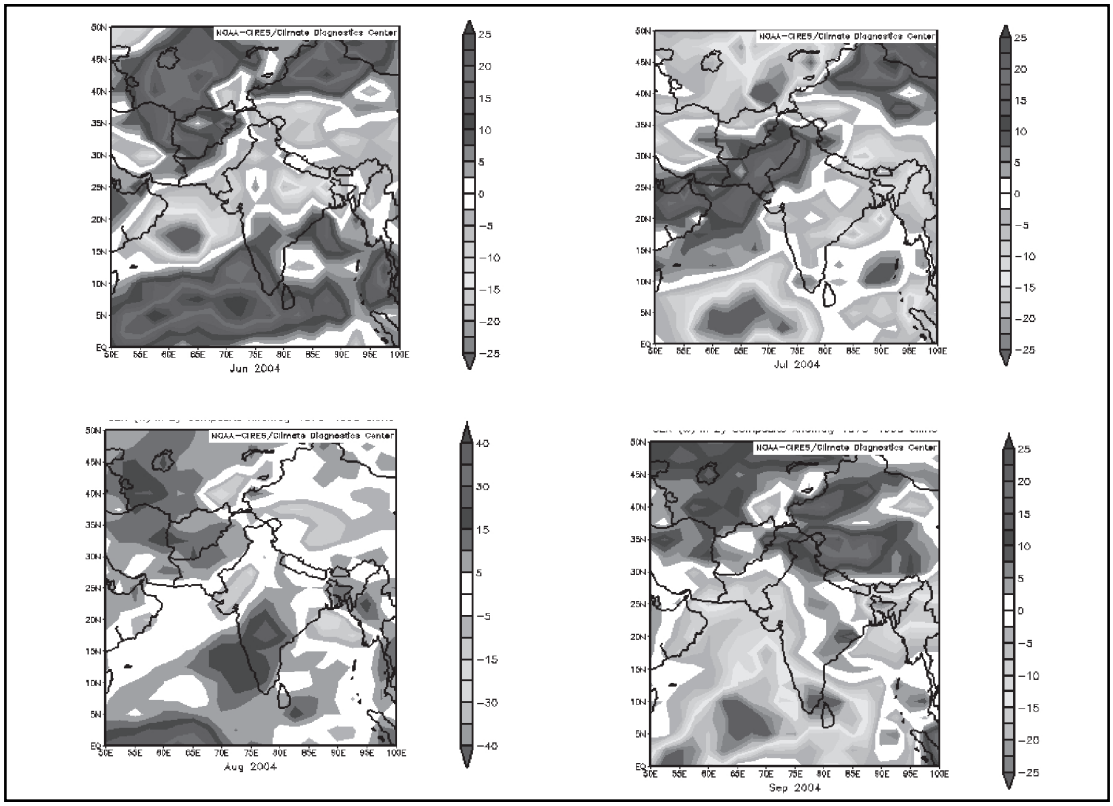

Figure 6(b). Monthly OLR Anomaly (Watts/sq.m.) during Indian Summer Monsoon season of 2004

seen in 2002. The monsoonal cooling which is quite significantly seen in the fall of SST values from June to July is present in both of these years (Fig.2). It is interesting to note here this is a feature which was not seen in the major ENSO year of 1997. The rise of SST in 1997 remained unabated during the entire summer monsoon [Madhu Khole (2000)].

During May 2002, considerable warming (SST Anomaly values $>1^0$C) is observed over Northern Pacific Ocean, which is not observed during May 2004. During the months of June, July and August, the cooling of SSTs over Northern Indian Ocean (Arabian Sea and Bay of Bengal) is more pronounced than that in the year 2002 (Fig.4 and Fig.5). The monthly OLR Anomaly distribution (Fig. 6) indicates that during July 2002, the OLR Anomaly values over the entire India are positive indicating suppressed convection, whereas, during July 2004, the OLR Anomaly values over the peninsular India are negative indicating enhanced convection over that region. Also, during August 2002, the convection over central and northern peninsular India is enhanced and during August 2004, the convection over central and peninsular India is suppressed, as indicated by positive OLR Anomaly values. On the other hand, during September 2002, the convection over peninsular India is suppressed and during September 2004, the convection over peninsular India is enhanced.

Thus, in the context of SST variations in the Pacific and the Indian Ocean 2002 and 2004 did not appear to be associated with a major warming episode. Sikka (1999) has discussed the major droughts in India for the last 12 decades where in he has pointed out that each drought has its own signature and may not be triggered by the same physical mechanism. The difference of SST temporal variation patterns between 1997, 2002 and 2004 stands out. This could be due to changing relationship between monsoon rainfall and oceanic parameters like the Pacific and the Indian ocean SST.

We may summarize the important conclusions:

1) The monsoonal cooling of the Indian Ocean was not suppressed during drought years of 2002 and 2004; the amount of cooling was lower than that observed in 2003.

2) The above was in sharp contrast to 1997, during which, the ENSO event resulted in a near normal rainfall during the ISMR, but the monsoonal cooling was absent over the Indian Ocean.

3) The significantly large rainfall deficiency in 2002 during July was also not seen in the temporal changes in SST.

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