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Inter-annual and decadal variability of sea surface temperature (SST) over Indian Ocean

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सार – हिन्द महासागर के समुद्र सतह तापमान (एस. एस. टी.) में द्विध्रुव (डाइपोल) का पता लगने के उपरांत भूमंडलीय जलवायु के संदर्भ में हिन्द महासागर का महत्व बढ़ा है। समुद्र सतह तापमान समुद्र की जलवायु को नियंत्रित करने वाला एक महत्वपूर्ण महासागरीय प्राचल है। समुद्र सतह तापमान की इस महत्ता को देखते हुए इस शोध–पत्र में 1961 से 1998 की अवधि के दौरान (*i*) भूमध्यरेखीय हिन्द महासागर (5° उ. – 5° द. और 50° पू. – 100° पू.) तथा (*ii*) उत्तरी हिन्द महासागर (5° उ. – 20° उ. और 50° पू. – 100° पू.) में समुद्र सतह तापमान की अंतः वार्षिक तथा अंतः मौसमी परिवर्तनशीलता की जाँच की गई है। भारत की चार मानक मौसम वैज्ञानिक ऋतुओं नामतः शीत ऋतु, (जनवरी – फरवरी), मानसून पूर्व ऋतु (मार्च – मई), दक्षिण–पश्चिम मानसून ऋतु (जून – सितम्बर) और मानसूनोतर ऋतु (अक्तूबर – दिसम्बर) में हिंद महासागर के इन्हीं क्षेत्रों के समुद्र सतह तापमान में विसंगति के मानों का आकलन किया गया है । अंतः वार्षिक तथा दशकीय समय–मान पर विभिन्न मानक सांख्यिकीय विधियों और पद्धतियों का उपयोग करके समुद्र सतह तापमान में मौसमी विसंगति में परिवर्तनशीलता की जाँच की गई है और प्राप्त हुए परिणामों की परस्पर तुलना की गई है। हिंद महासागर के उक्त दोनों क्षेत्रों में समुद्र सतह तापमान में विसंगति में चारों ऋतुओं में, 1961–98 के दौरान और विशेष रुप से 1970 के दशक के मध्य के बाद से वृद्धि की अधिक स्पष्ट प्रवृत्ति देखी गई है ।

ABSTRACT. With the discovery of a dipole in Indian Ocean Sea Surface Temperature (SST), the Indian Ocean has been gaining an increasing importance in the context of global climate. SST is one of the important oceanic parameters controlling the ocean climate. In view of this importance, an attempt has been made in this study to examine the inter-annual and inter-seasonal variability of SST over (*i*) Equatorial Indian Ocean (5° N - 5° S and 50° E - 100° E) and (*ii*) North Indian Ocean (5° N - 20° N and 50° E - 100° E), during the period 1961-98. The values of seasonal SST anomaly over these sectors of Indian Ocean are computed for the four standard meteorological seasons over India, *viz*., Winter (January - February), Pre-monsoon (March - May), SW Monsoon (June - September) and Post-Monsoon (October - December). The variability of seasonal SST anomaly is examined, using various standard statistical methods and procedures, on inter-annual as well as decadal time-scale and the results are inter-compared. The SST anomaly over both the above sectors of Indian Ocean, for all the four seasons, shows an increasing trend during 1961-98, more particularly and prominently, after mid-1970s.

Key words – Sea Surface Temperature (SST), Indian Ocean, Trend.

1. Introduction

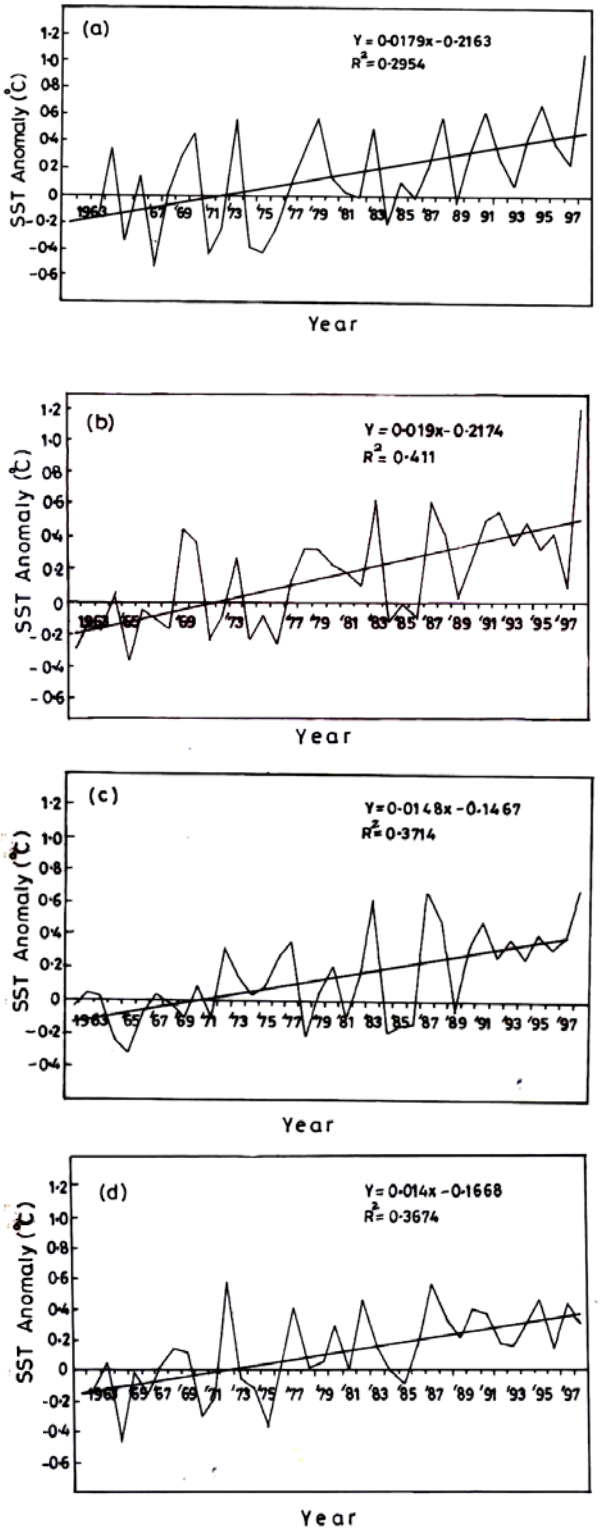
Indian Ocean constitutes a part of the major ocean basins of the globe, besides the Pacific and the Atlantic Oceans. The phenomenon of occurrence of El-Nino (anomalous warming of the eastern and central equatorial Pacific Ocean), has invited considerable attention, world over, since mid-1970s. The importance 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); Sikka (1980), among others]. 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 [Chandrashekhar and Kitoh (1998); Saji *et al*. (1999); Webster *et al*. (1999); Yu and Rienecker (1999)]. The inter annual variability in Indian Ocean is different too; little coherent behaviour has been identified in it until now, in contrast to the Pacific and the Atlantic Oceans where several modes of variability have been evident [Anderson (1999)]. One possible explanation for the apparent lack of variability of

Indian Ocean region is the different relative location of the major precipitation and through the release of latent heat, the associated atmospheric heating regimes. Meehl (1987) has discussed the annual cycle and inter annual variability in tropical Indian Ocean and Pacific Ocean. He has suggested that 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. 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. They relate the ocean temperature distribution to increasing rainfall over east Africa and reduced rainfall over Indonesia and to the associated shift in atmospheric heating patterns. 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. In their recent study, Singh and Sarker (2003) have observed that, during the period 1985-98, the SST in the coastal region of north Indian Ocean shows an increasing trend in all the seasons and the SSTs in the Island regions, during winter season, show decreasing trend. Singh (1999) has reported a significant increasing trend in the SST values over the Arabian Sea during May. Also, Singh (1998) has reported positive SST anomaly values over south Arabian Sea (0-10° N) and negative SST anomaly values over north Arabian Sea (10-25° N). Gnanaseelan, *et al*., (2003) have made an attempt to simulate the SST fields over north Indian Ocean (20° S - 25° N, 35° E - 115° E) and have concluded that a simple numerical model is capable of such simulation. The model used by them could also successfully simulate the observed dipole in SST over Indian Ocean during the years 1997 and 1994. 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 view of this importance of Indian Ocean, an attempt has been made in this study to examine the inter-annual, inter-seasonal and decadal variability of SST over (*i*) Equatorial Indian Ocean (5° N - 5° S and 50° E - 100° E) and (*ii*) North Indian Ocean (5° N - 20° N and 50° E and 50° E - 100° E), during the period 1961-98.

2. Data and methodology

The data of monthly SST over Indian Ocean (5° S - 20° N and 50° E - 100° E) for the period have been obtained from Comprehensive Ocean Atmosphere Data Sets (COADS). These data are obtained for mean monthly summary SST values over the part of the Indian Ocean



Figs. 1(a-d). Inter annual variability of seasonal SST anomaly over equatorial Indian Ocean for (a) Winter season (b) Pre-monsoon season, (c) SW monsoon season and (d) Post monsoon season (1961-98)

bounded by 5° S - 20° N and 50° E - 100° E, on 2° × 2° Latitude-Longitude grid. From these data, for each grid, the mean seasonal SST anomaly values are computed for the following four meteorological seasons over India, *viz*., Winter (Jan-Feb), Pre-monsoon (Mar-May), SW Monsoon (Jun-Sep) and Post-monsoon (Oct-Dec), for each year during the period of study, 1961-98. The anomaly values are computed as being departures from the respective mean values for the period 1961-98. These SST anomaly values are further averaged over the following two regions of the Indian Ocean *viz*., (*i*) Equatorial Indian Ocean (5° S - 5° N and 50° E - 100° E) and (*ii*) North Indian Ocean (5° N - 20° N and 50° E - 100° E). The variability of seasonal SST anomaly is examined, using various standard statistical methods and procedures, on inter-annual as well as decadal time-scale. The series of seasonal SST anomaly values, thus obtained, are also subjected to Statistical Trend Analysis, to assess for existence of trend, if any. The trend analysis has been carried out based on the method of least squares. The results of these analyses are presented in the following section.

3. Discussion

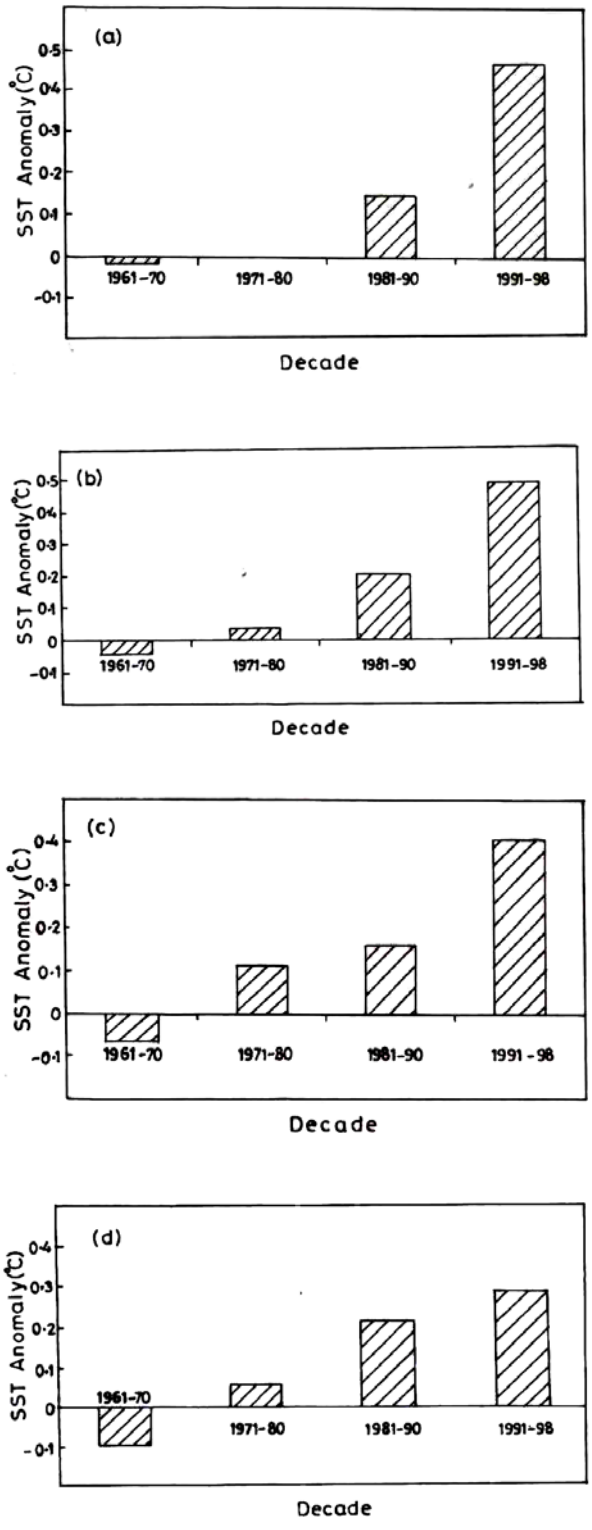
3.1. *Variability of SST over Equatorial Indian Ocean*

3.1.1. *Inter annual variability*

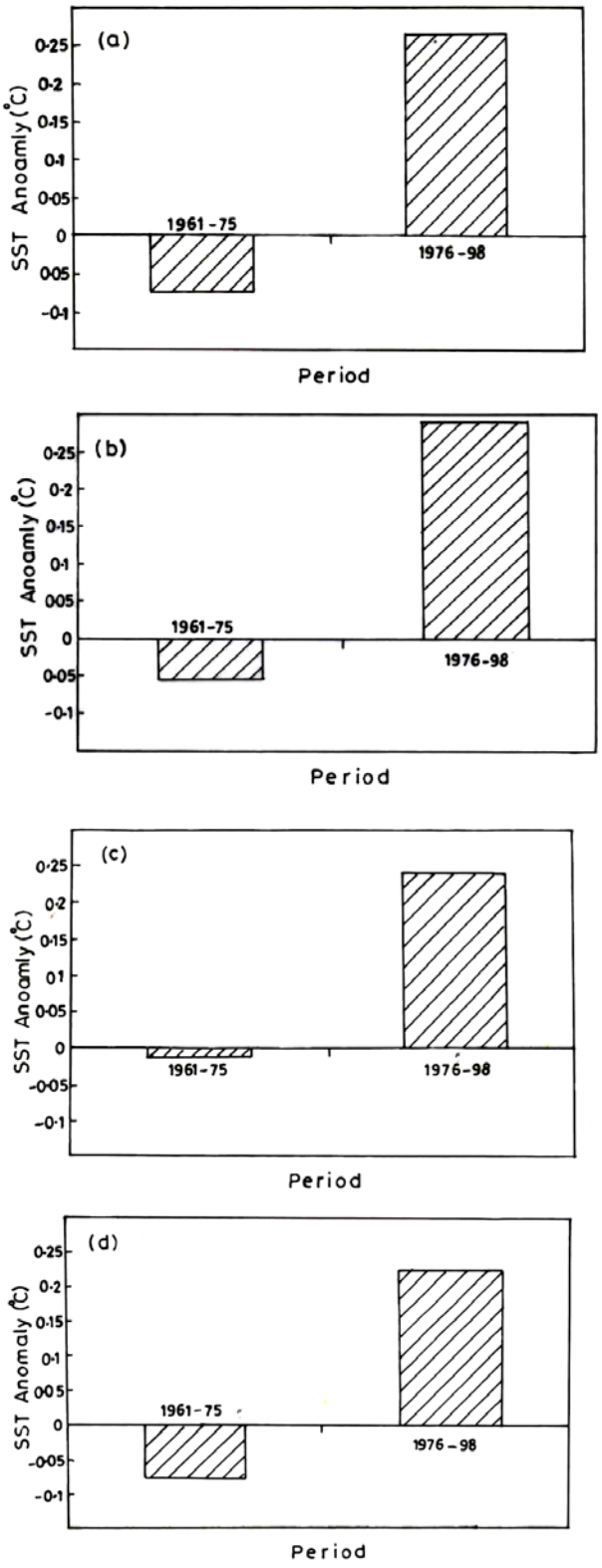
Figs. 1 (a-d) depicts the Inter annual variability of SST anomaly over Equatorial Indian Ocean, for the four meteorological seasons over India, *viz*., Winter (Jan-Feb), Pre-monsoon (Mar-May), SW Monsoon (Jun-Sep) and Post-monsoon (Oct-Dec), respectively, for the period 1961 to 1998. As is evident from this figure, the seasonal SST during all the four seasons is characterized by a high degree of interannual variability. Also, it is seen from this figure that the seasonal SST shows an increasing trend in its value during the period 1961-98, which is statistically significant at 5% level of significance.

3.1.2. *Decadal variability*

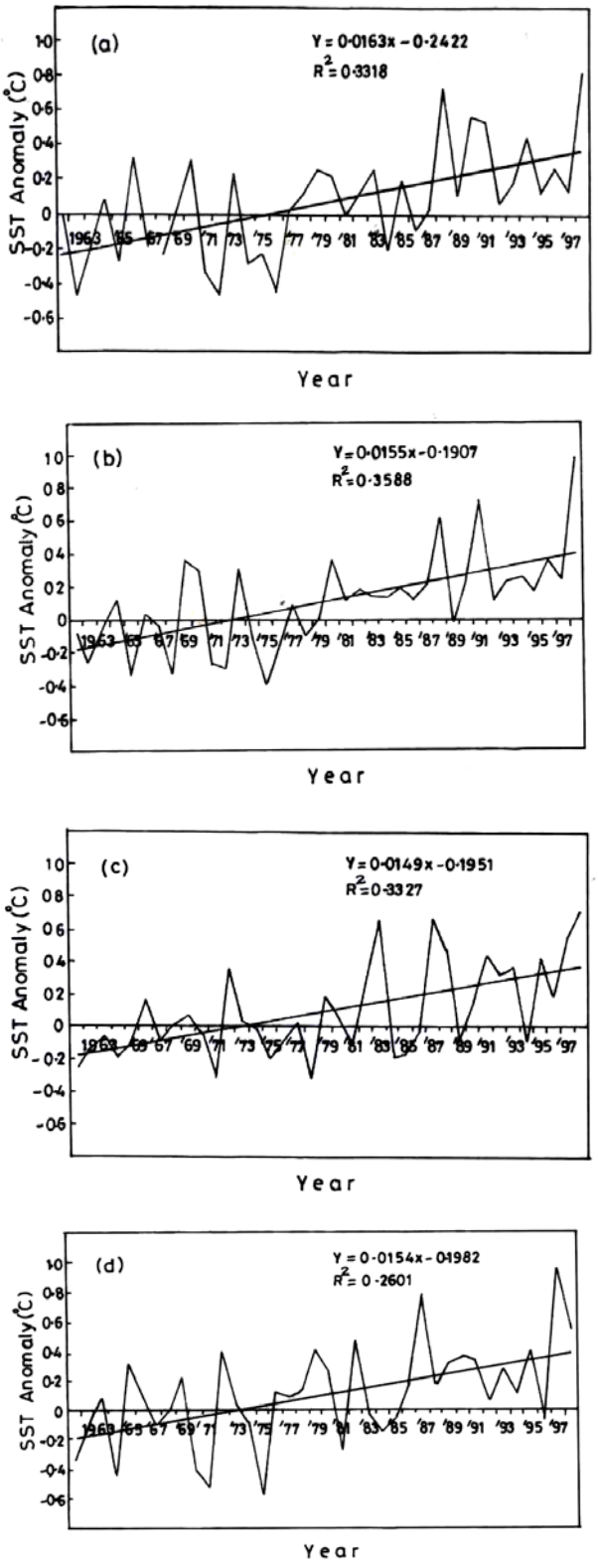
Figs. 2 (a-d) depicts the decadal variability of SST anomaly over Equatorial Indian Ocean, for the four seasons, *viz*., Winter (Jan-Feb), Pre-monsoon (Mar-May), SW Monsoon (Jun-Sep) and Post-monsoon (Oct-Dec), respectively, for the period 1961 to 1998. It is observed



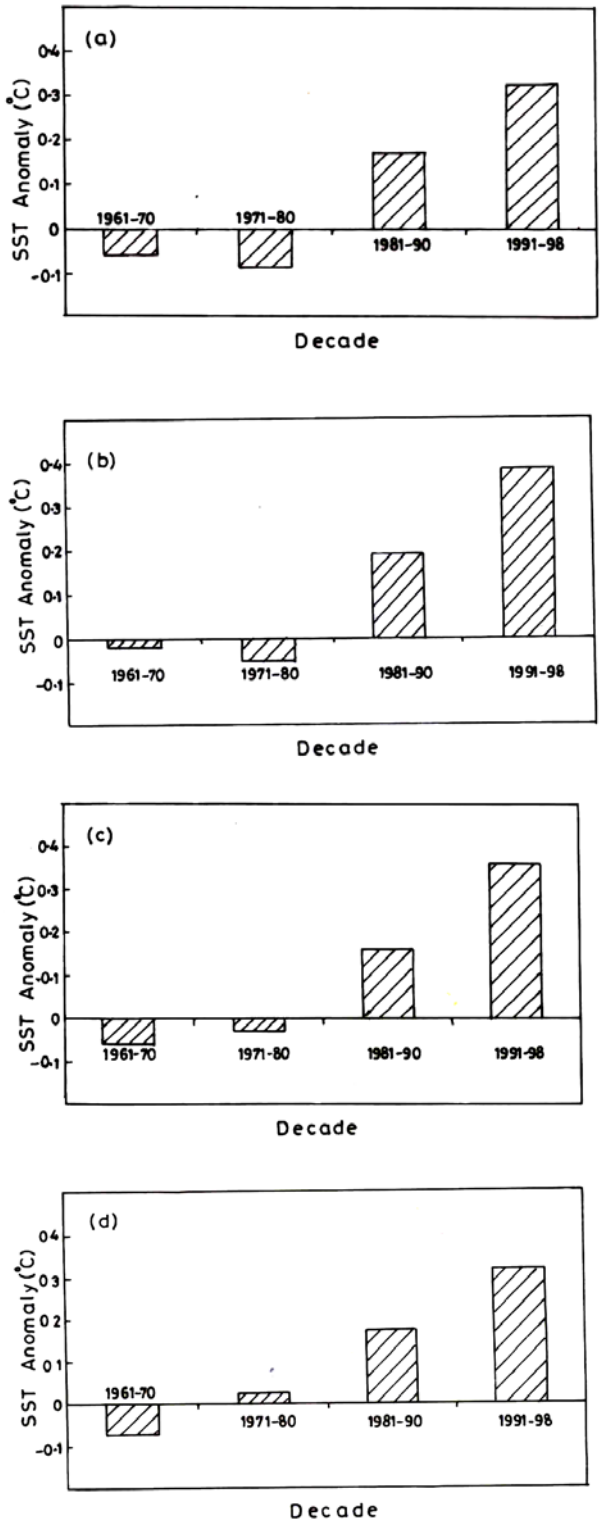
Figs. 2(a-d). Decadal variability of seasonal SST anomaly over equatorial Indian Ocean for (a) Winter season, (b) Pre-monsoon season, (c) SW monsoon season and (d) Post monsoon season (1961-98)



Figs. 3(a-d). Variability of SST anomaly over equatorial Indian Ocean for pre-global warming period (1961-75) and Post-Global warming period (1976-98) (a) Winter (b) Pre-monsoon (c) SW monsoon and (d) Post monsoon season



Figs. 4(a-d). Inter annual variability of seasonal SST anomaly over North Indian Ocean for (a) Winter season, (b) Pre-monsoon season, (c) SW monsoon season and (d) Post monsoon season (1961-98)



Figs. 5(a-d). Decadal variability of seasonal SST anomaly over North Indian Ocean for (a) Winter season, (b) Pre-monsoon season, (c) SW monsoon season and (d) Post monsoon season (1961-98)

that, the seasonal SST anomaly for all the four seasons is negative during the decade 1961-70 and for all the other decades, *viz*., 1971-80, 1981-90 and 1991-98, the seasonal SST anomaly is positive. During Winter season, however, the SST anomaly during the decade 1971-80 is zero, indicating normal SST values. The decadal SST anomaly values depict a progressive rise for the progressing decades, with the part of the last decade (1991-98), exhibiting the highest value of decadal SST anomaly among all other decades under study.

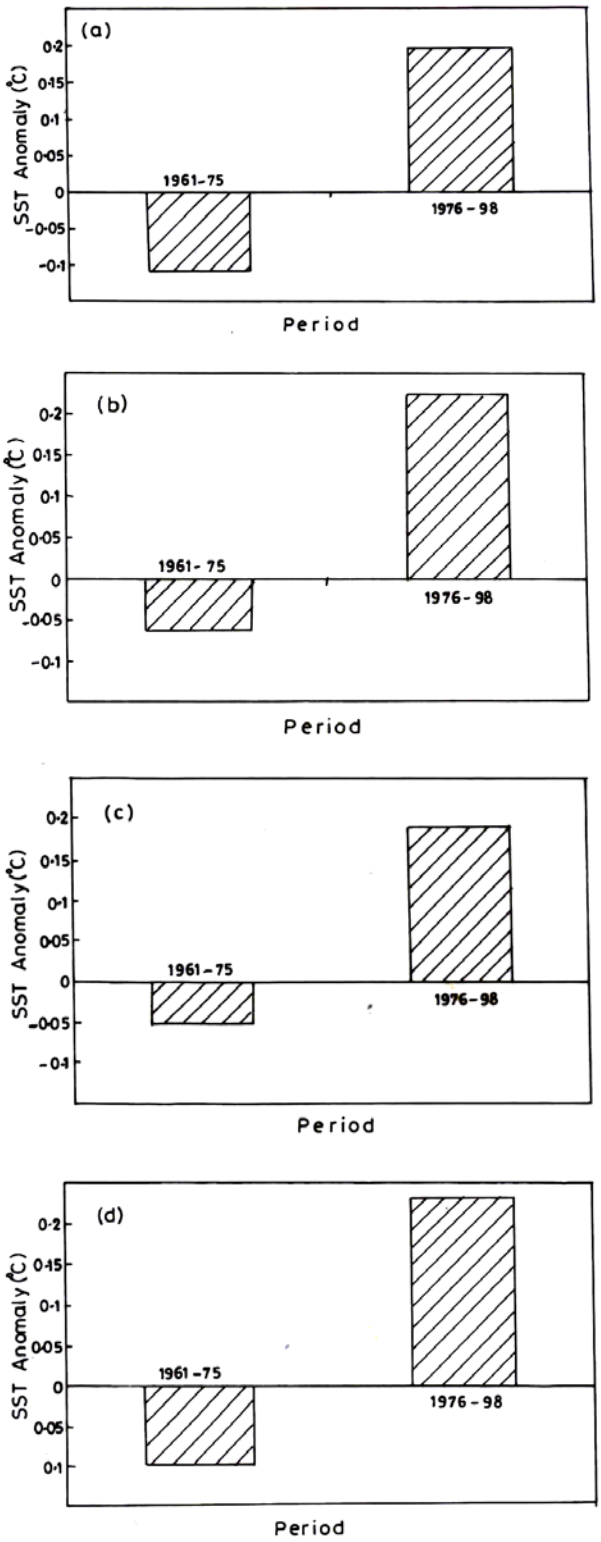
3.1.3. *Variability of SST anomaly for pre and post global warming period*

According to Inter Governmental Panel on Climate Change (IPCC) Third Assessment Report (TAR), there is an evidence of occurrence of global warming since mid-1970s. With this backdrop, the variability of seasonal SST over Equatorial Indian Ocean has been analysed for two separate periods: Pre-Global Warming Period (1961-75) and Post-Global Warming Period (1976-98). Figs. 3 (a-d) depicts this variability. It is observed that, the seasonal SST anomaly for all the four seasons, during the period 1961-75, is negative, while, that during the period 1976-98, is positive. It is also clearly evident from this figure that, there is a paradigm shift in seasonal SST anomaly value, for all the four seasons, after 1975, *i.e*., during the Post-Global Warming Period. The highest value of change of seasonal SST anomaly value from Pre-Global Warming period to Post-Global Warming period is observed for the Pre-monsoon season.

3.2. *Variability of SST over North Indian Ocean*

3.2.1. *Inter annual variability*

Figs. 4 (a-d) depicts the Inter annual variability of SST anomaly over North Indian Ocean, for the four seasons, *viz*., Winter (Jan-Feb), Pre-monsoon (Mar-May), SW Monsoon (Jun-Sep) and Post-monsoon (Oct-Dec), respectively, for the period 1961 to 1998. As is evident from this figure, the seasonal SST during all the four seasons is characterized by a high degree of inter annual variability. Also, it is seen from this figure that the seasonal SST shows an increasing trend in its value during the period 1961-98, which is statistically significant at 5% level of significance.



Figs. 6(a-d). Variability of SST anomaly over North Indian Ocean for pre-global warming period (1961-75) and post-global warming period (1976-98) (a) Winter (b) Pre-monsoon (c) SW monsoon and (d) Post monsoon season

3.2.2. *Decadal variability*

Figs. 5 (a-d) depicts the decadal variability of SST anomaly over North Indian Ocean, for the four seasons, *viz*., Winter (Jan-Feb), Pre-monsoon (Mar-May), SW Monsoon (Jun-Sep) and Post-monsoon (Oct-Dec), respectively, for the period 1961 to 1998. It is observed that, the seasonal SST anomaly for the three seasons, *viz*., Winter, Pre-monsoon and SW monsoon seasons, is negative during the decades 1961-70 and for 1971-80, 1981-90 and is positive during 1991-98. For Post-monsoon season, the seasonal SST anomaly is negative during the decade 1961-70 and positive during 1971-80, 1981-90 and 1991-98. The decadal SST anomaly values depict a progressive rise for the progressing decades, with the part of the last decade (1991-98), exhibiting the highest value of decadal SST anomaly among all other decades under study.

3.2.3. *Variability of SST anomaly for pre and post global warming period*

Figs. 6 (a-d) depicts the variability of seasonal SST anomaly over North Indian Ocean for two separate periods: Pre-Global Warming Period (1961-75) and Post-Global Warming Period (1976-98). It is observed that, the seasonal SST anomaly for all the four seasons, during the period 1961-75, is negative, while, that during the period 1976-98, is positive. It is also clearly evident from this figure that, there is a paradigm shift in seasonal SST anomaly value, for all the four seasons, after 1975, *i.e*., during the Post-Global Warming Period. The highest value of change of seasonal SST anomaly value from Pre-Global Warming period to Post-Global Warming period is observed for the Post Monsoon season.

4. Conclusions

(*i*) During the period 1961-98, the seasonal SST anomaly values over Equatorial and North Indian Ocean, for all the four meteorological seasons over India, show statistically significant increasing trend.

(*ii*) There is a paradigm shift in seasonal SST anomaly value, over Equatorial as well as over North Indian Ocean, for all the four meteorological seasons over India, after 1975, *i.e*., during the Post-Global Warming Period. The

SST anomaly, for the period 1961-75, is negative indicating colder than normal SST and for the period 1976-98, is positive, indicating warmer than normal SST, for both the sectors of Indian Ocean.

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