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Interannual variability of the Arabian Sea warm pool intensity and its association with monsoon onset over Kerala

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सार – इस षोध पत्र में अरब सागर के उष्ण कुंड की तीव्रता, दक्षिणी दोलन (एस. ओ.) और मानसून के आरम्भ होने के मध्य पाए गए संबंधों पर विचार–विमर्ष किया गया है। इनसे प्राप्त परिणामों से यह पता चला है कि लक्ष्यद्वीप के निकट सागर में उष्ण कुंड की तीव्रता की चरम सीमा केरल में मानसून के आरम्भ होने की तारीख के साथ उल्लेखनीय रूप से सहसंबंधित है। अप्रैल–मई में उष्ण कुंड क्षेत्र में उष्ण समुद्र सतह तापमान (एस. एस. टी.) की विसंगतियाँ केरल में देर से आरम्भ हुए मानसून के साथ संबद्ध है। हालांकि इस संबंध के कारण और इसके प्रभाव का पता नही चल पाया है। मार्च माह के दक्षिणी दोलन सूचकांक (एस. ओ. आई.) सामान्यतः अप्रैल माह में घटित होने वाले तीव्रता की चरम सीमा के पूर्वानुमान के संकेत उपलब्ध करा सकता है।

ABSTRACT. In this paper the relationships between the Arabian Sea warm pool intensity, Southern Oscillation (SO) and the monsoon onset have been discussed. The results show that the peak intensity of the warm pool in the Lakshadweep Sea is significantly correlated with the monsoon onset date over Kerala. Warmer Sea Surface Temperature (SST) anomalies in the warm pool region during April-May are associated with delayed monsoon onset over Kerala though the cause-and-effect relationship is not known. The Southern Oscillation Index (SOI) of March can provide predictive indications of the peak intensity of the warm pool which, normally occurs during April.

Key words – Arabian Sea warm pool, Sea Surface Temperature (SST), Southern Oscillation Index (SOI), Monsoon onset, Anomaly, El Nino.

1. Introduction

It is believed that the enhanced heating of the stratified upper ocean off southeast coast of India leads to the formation of the Arabian Sea warm pool (Bruce *et al.*, 1994; Shankar and Shetye, 1997; Shankar, 1998). The Arabian Sea warm pool is associated with intense convection during the onset phase of the summer monsoon and the formation of inset vortex (Krishnamurti *et al.*, 1981; Kershav, 1985). There is a sudden decrease of SST in the warm pool region during the monsoon onset (Singh and Hatwar, 2005; Hareesh Kumar *et al.*, 2005; Gnanseelam *et al.*, 2005). The warm pool collapses completely after the monsoon onset and the SSTs continue to fall in this region till August when SST minimum is observed.

There seems to be an intriguing relationship between the SSTs in the warm pool region during pre-monsoon and the monsoon onset over Kerala. It is believed that the warmer SST anomalies in the warm pool region are conducive for formation of onset vortex. The main aim of the present study is to determine and document the relationship between the peak intensity of the warm pool (maximum SST) during pre-monsoon and the monsoon onset over Kerala. The lag relationship between the Southern Oscillation and the peak intensity of the warm pool has also been looked into. As the peak intensity of warm pool occurs during pre-monsoon it can provide predictive indications of monsoon onset over Kerala.

2. Data and methodology

The SST climatology for the warm pool region has been prepared from the NOAA-AVHRR gridded SST data (1985-98) obtained from the NASA Physical Oceanography Distributed Active Archive Centre at the Jet Propulsion Laboratory, California, U.S.A. The satellite based SST climatology due to its very high resolution (~ 9.28 km) is suitable for the study of SST variability over a localized zone such as Arabian Sea warm pool due to paucity of conventional SST observations. SOI and the dates of monsoon onset have been obtained from the Australian Bureau of Meteorology and India Meteorological Department respectively.

3. Results and discussion

3.1. *Annual variation of SST in the warm pool*

The location of selected stations in the warm pool region is depicted in Fig. 1. The annual variation of SST

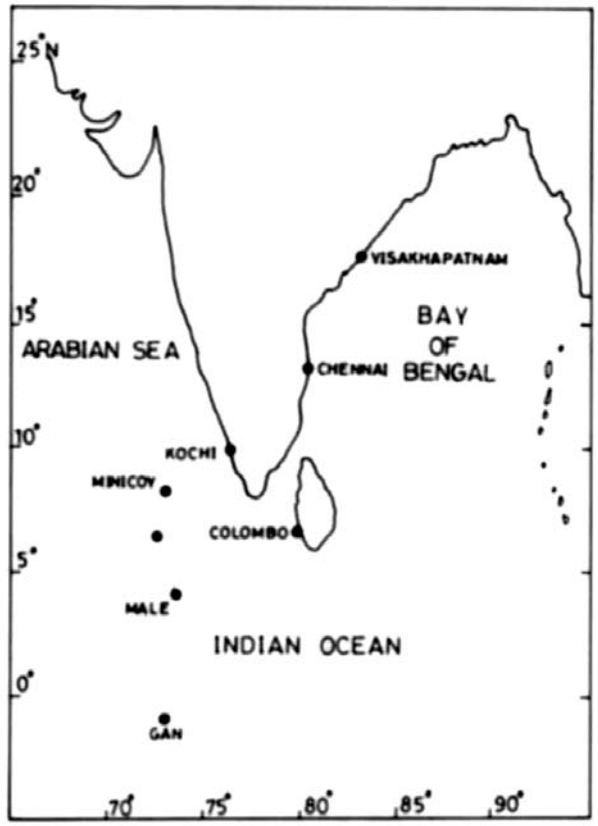

Fig. 1. Location of stations

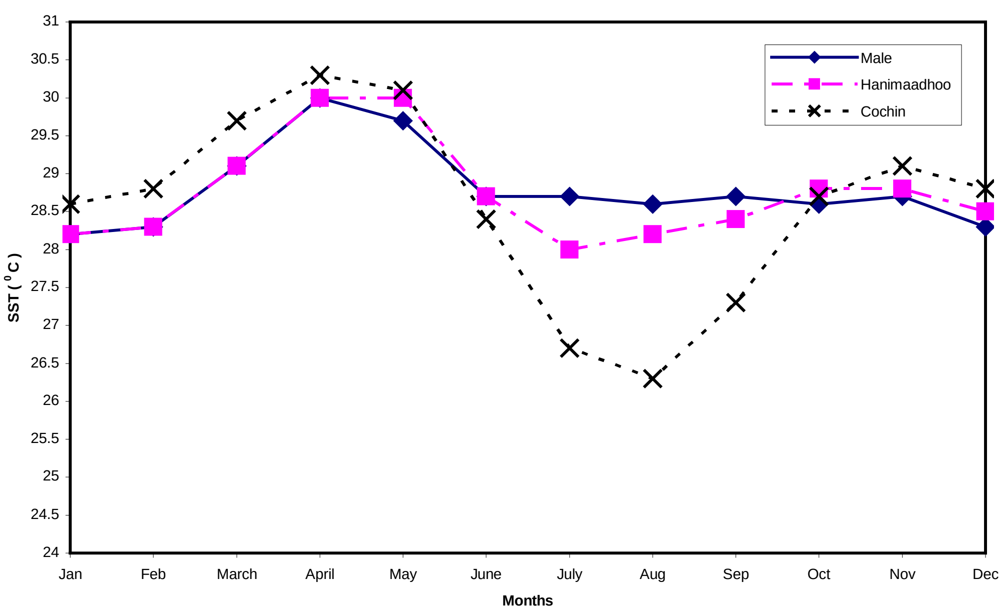

Fig. 2. Annual variation of Sea Surface Temperature (SST) in the warm pool region in the southeastern Arabian Sea

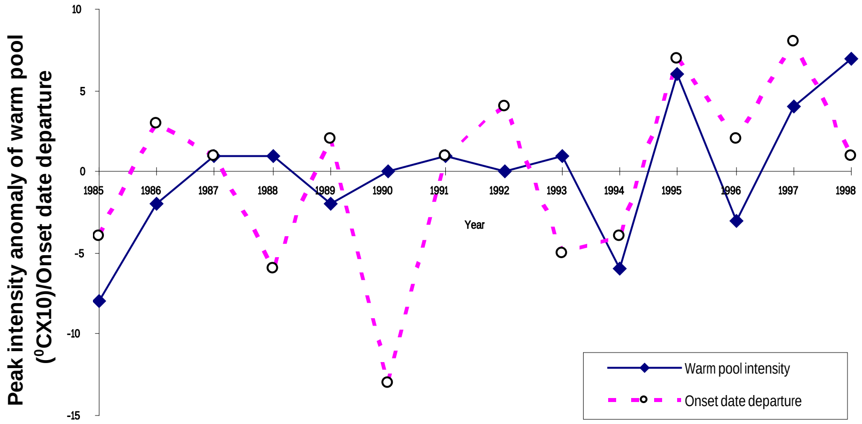

Fig. 3. Interannual variability of peak intensity of warm pool and monsoon onset date over Kerala

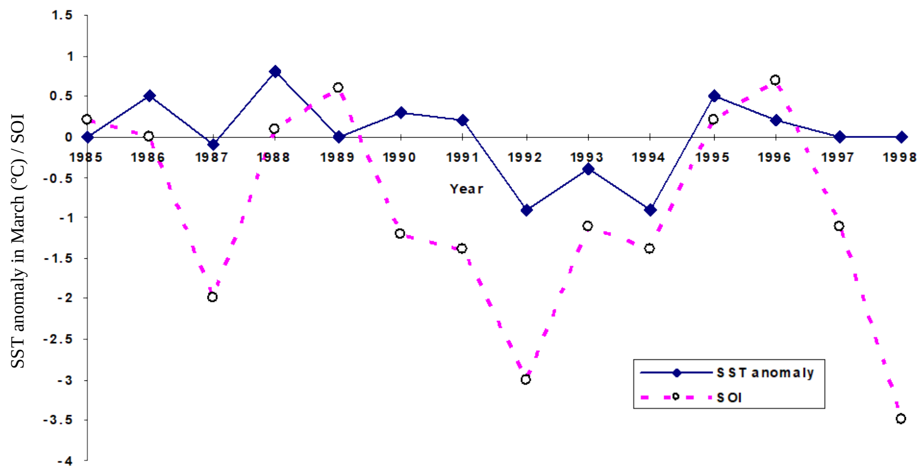

Fig. 4. Interannual variability of SST in Kerala coast (Cochin) alongwith corresponding SOI

in the warm pool region has been presented in Fig. 2. Annual SST variation in the warm pool region clearly shows that there is a sudden increase in SSTs after February. The SSTs in warm pool region continue to increase till April when maxima is observed. Off Kerala coast (at Cochin) there is a slight fall in SST during May but toward south (at Hanimaadhoo and Male) the average SSTs for April and May are nearly same. During June there is sudden decrease in SSTs throughout the warm pool region which is due to monsoon onset. Thus two main features of spatio-temporal variability of SST in the warm pool region are: The warm pool attains its peak intensity during April and maximum SST in the warm pool region occurs off Kerala coast. The SSTs in the warm pool region decrease towards south during the pre-monsoon. After the monsoon onset the minimum SSTs are observed off Kerala coast and SSTs increase towards south.

3.2. *Recent trend in the peak intensity of warm pool and its relationship with monsoon onset over Kerala*

Interannual variability of warm pool intensity and its recent trend along with monsoon onset dates over Kerala are displayed in Fig. 3. The average SST in the warm pool

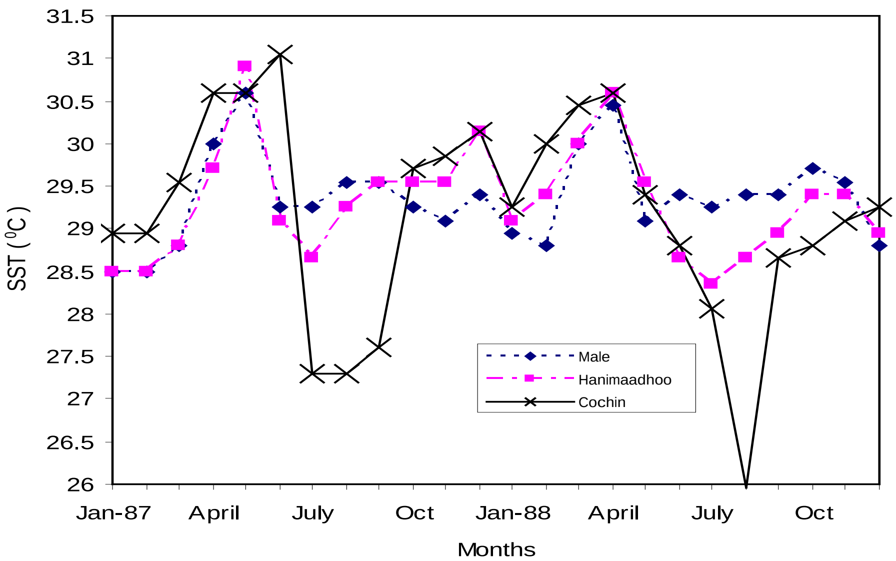

Fig. 5. SST variation in the warm pool region during El Nino/La Nina epochs of 1987-1988

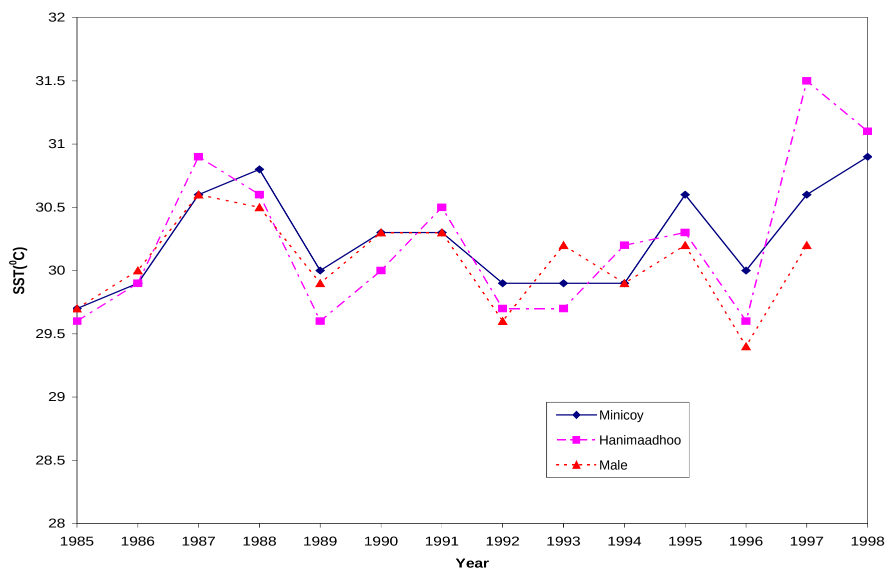

Fig. 6. Variability of peak intensity of the Arabian Sea warm pool at different locations during the period 1985-1998

region off Kerala coast has increased in recent years. The warm pool intensity has shown an uptrend at other locations also (Fig. 6). The SST anomalies have been generally positive during 1990s (except 1994 and 1996) and the onset of monsoon over Kerala has also been generally delayed during the decade (except 1993 and 1994). During the 14 years period from 1985-1998 the earliest onset occurred in 1990 and the most delayed in 1997. The warm pool was more intense during 1997 and had normal intensity during 1990. The average SST in the warm pool off Kerala coast during April was 30.9° C in 1997 when the onset over Kerala was delayed by a week.

During 1995 also the warm pool was very intense during April with average SST of 31.1° C. Thus the warm pool intensity during April can provide some indication of monsoon onset over Kerala in advance.

The correlation coefficient between the peak intensity of warm pool and the monsoon onset over Kerala is + 0.54 which is significant at 97.5% level (No. of observations = 14). It shows that warm SST anomalies in the warm pool region during pre-monsoon are associated with delayed monsoon onset over Kerala. The association of warmer SST anomalies in the warm pool region during pre-monsoon with delayed monsoon onset over Kerala was confirmed with buoy observations collected in the warm pool region during Arabian Sea Monsoon Experiment (ARMEX), 2003. the buoy DS7 recorded maximum SST of 31.7° C on 18th April, 2003 during ARMEX. The average SST till second week of May, 2003 was 30.9° C (Joseph *et al*., 2005). The intensity of warm pool was observed during April, 2003. These observations show the SST anomalies in the warm pool region were highly positive (warmer) during 2003. The monsoon onset over Kerala occurred on 8 June during 2003, a delay of one week from the normal onset date. Thus the ARMEX data has also shown that an intense warm pool during 2003 was followed by delayed monsoon onset over Kerala.

3.3. *The association between SO and SST anomalies in the warm pool*

The interannual variability of SST anomaly off Kerala coast (at Cochin 0 and SOI are presented in Fig. 4. There seems to be an association between March SST in the warm pool region and SOI. Colder SST anomalies with negative SOI (El Nino). The correlation between March SST and SOI is +0.53 (significant at 95% level). Thus during negative phase of SO colder SST anomalies prevail in the warm pool region during March. But when we consider the correlation between March SOI and Peak intensity of warm pool during pre-monsoon, it is –0.41 (significant at 90% level). In other words during the negative phase of SO (El Nino epoch) colder SSTs prevail in the warm pool region during March but the warm pool becomes very intense before the monsoon onset. As discussed in previous section warmer SSTs in the warm pool region during April-May are associated with delayed monsoon onset over Kerala. Therefore colder SST anomalies in the warm pool during March would be associated with delayed monsoon onset over Kerala. In other words early peaking of warm pool (*i.e*.,) during (March-April) seems to be associated with early onset of monsoon onset over Kerala and delayed warming in the warm pool region is associated with delayed monsoon onset.

The intensity of warm pool during the ENSO epoch of 1987-88 for 24 months was examined to find out the association between El Nino/La Nina and the warm pool intensity. The SSTs in the warm pool region during the ENSO epoch at four stations *i.e*., Cochin, Minicoy, Hanimaadhoo and Male are presented in Fig. 5. There was a major monsoon failure in India during 1987 which happened to be a strong El Nino year. On the contrary 1988 was an excess monsoon rainfall year and it was a strong La Nina year. From Fig. 5. it is clear that the peak intensity of warm pool was observed in June at Cochin and in May at Hanimaadhoo during 1987. Thus there was a delay of two months in the attainment of peak intensity of warm pool off Kerala coast during 1987 which normally occurs in April. Therefore, a delay in the attainment of peak intensity of warm pool preceded the monsoon of El Nino year 1987. On the contrary, during the La Nina year 1988 the attainment of peak intensity of warm pool was normal, *i.e*., in April. A delay in the attainment of peak intensity of the warm pool seems to be associated with El-Nino years.

4. Conclusions

The study has brought out the following results:

(*i*) The intensity of the Arabian Sea warm pool during April-May is associated with monsoon onset over Kerala. Warmer sea surface temperature anomalies in the warm pool region during April-May are following by delayed monsoon onset over Kerala.

(*ii*) The intensity of warm pool has shown an uptrend during recent years.

(*iii*) The Arabian Sea warm pool is more intense during the negative phase of Southern Oscillation.

(*iv*) El-Nino/La Nina monsoon is preceded by warmer/ colder sea surface temperature anomalies in the warm pool region .

(*v*) The sea surface temperature anomalies in the warm pool region during March can provide useful indications ensuring monsoon.

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