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# A Note on Arabian Sea Warm Pool and its Possible Relation with Monsoon Onset over Kerala

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***Abstract-*** The possible relation of the Arabian Sea Warm Pool (ASWP) with monsoon onset over Kerala is studied by utilizing the TRMM Microwave Imager data during the period 2007 - 2011 (5 years). The ASWP is a part of the Indian Ocean warm pool and forms in the Arabian Sea prior to the monsoon onset over Kerala (MOK) during the pre-monsoon months (April and May). The main focus of the present work is to look into the evolution of ASWP and its association, if any, with different types of MOK. The analysis revealed that there exist a lag of 16 days between the date of maximum intensity of ASWP and MOK. The ASWP started its dissipation immediately after attaining its peak intensity. It was also found that the extent and intensity of the ASWP showed large inter-annual variability. The number of warming events also showed large variability during these periods

***Index Terms***- Arabian Sea Warm Pool, Monsoon onset.

## I. INTRODUCTION

In the Arabian Sea, a pool of warmer water (>30$^o$C) is formed in the southeastern Arabian Sea every year prior to the onset of summer monsoon. This pool of anomalous water is the part of the famous Indo-Pacific warm pool. Several studies have been carried out to understand the mechanism responsible for the formation of the warm pool formed in the Arabian Sea and its characteristics (Seetaramayya and Master, 1984; Joseph, 1990; Rao and Sivakumar, 1999; Joseph et al., 2003; Deepa et al., 2007; Hareesh Kumar et al., 2009). However, the relation between the warm pool in the Arabian Sea and monsoon characteristics attracted only a few (Neema et al., 2011). In this paper an attempt has been made to document the characteristics of this warm pool in the Arabian Sea during normal and earlier monsoon years and its possible relationship with the Indian summer monsoon.

## II. DATA AND METHODOLOGY

The sea surface temperature data for the years 2007-2011 was obtained from the Tropical Rainfall Measuring Mission Microwave Imager sea surface temperature (SST) at 0.25$^o$x 0.25$^o$ grid resolutions (40$^o$E to 80$^o$E and equator to 25$^o$N). The monsoon onset date was obtained from the Indian Daily Weather Report. Ferret Data Visualization and Analysis software developed by PMEL (Pacific Marine Environmental Laboratory) of United States National Oceanic and Atmospheric Administration (NOAA) is used for analysis of the data. 3 and 5 day mean of SST maps are prepared in the region 45$^o$ – 80$^o$ E, 0$^o$ – 25$^o$ N for the period of April – May and few days after MOK. In this study, the warm pool is defined as the region where the SST is in excess of 30.5$^o$C. Details of the date of onset of monsoon over Kerala (MOK), date of attaining maximum temperature in the Arabian Sea, the core temperature and the area occupied by the warm pool are given in Table 1.

**Table 1: Details of the warm pool characteristics**

| Year | MOK | Peak Day | Core Temp | Area |
|---|---|---|---|---|
| 2007 | 28 May | 1 May | 31°C | South of 15$^o$N; west of 62.5$^o$E |
| | | | | South of 12$^o$N; east of 67.5$^o$E |
| | | **11 May** | **31°C** | **5$^o$ to 12$^o$N; west of 70$^o$E** |
| | | 26 May | 31.5°C | 5-20$^o$N; east of 67.5$^o$E |
| 2008 | 31 May | **15 May** | **31.5°C** | **3$^o$ to 12$^o$N; 63$^o$ to 70$^o$E** |
| | | 24 May | 31.5°C | 15$^o$ to 20$^o$N; east of 67$^o$E |
| 2009 | 23 May | 4 April | 31°C | South of 5$^o$N, east of 65$^o$E |
| | | **7 May** | **31.5°C** | **South of 10$^o$N, west of 75$^o$E** |
| | | 19 May | 31°C | South of 10$^o$N; east of 67.5$^o$E |
| 2010 | 31 May | 29 April | 32°C | South of 20$^o$N |
| | | **17 May** | **32°C** | **5-20$^o$N** |
| 2011 | 28 May | **12May** | **32°C** | **south of 12$^o$N; 50$^o$E- 67$^o$E** |
| | | 18 May | 31.5°C | 5$^o$-12$^o$N; 50$^o$-67$^o$E |

## III. Results and Discussion

In the year 2007, the monsoon onset over Kerala was on 28 May. The characteristics feature of 2007 is the formation and dissipation of the warm pool occur thrice in May (Fig. 1). The first one is observed on 1 May when temperature in excess of 30°C is evident in the western equatorial Arabian Sea, i.e. south of 15°N and west of 62.5°E (core temperature of 31°C) and another one in the southeastern Arabian Sea (SEAS), i.e. south of 12°N and east of 67.5°E (core temperature of 31°C). In the SEAS, the core of the warm pool is observed between 70° and 72.5°E, i.e. around the Laccadive Islands. After the decay of the first warm pool, temperature increases in the Arabian Sea leading to the formation another warm pool on 11 May between 5° to 12°N and west of 70°E with its core around 60°E (core temperature of 31°C). After attaining the maximum core temperature, the temperature drops by more than 1°C (~30°C) on 16 May and the area occupy by this isotherm also reduces. Between MOK and the date of maximum intensity of warm pool, there is a gap 16 days. Recently, Neema et al. (2011) reported a lag of two weeks between the MOK and the triggering of the decay of ASWP. Afterwards, it is interesting to notice temperature rise in the Arabian Sea leading to the formation of yet another warm pool in the SEAS, but slightly north of the first warm pool. It attains its maximum intensity on 26 May, when temperature along the west coast of India north of 5°N increases to values over 31.5°C and extends up to 20°N covering the eastern Arabian Sea. The dissipation of the warm pool starts by 31 May.

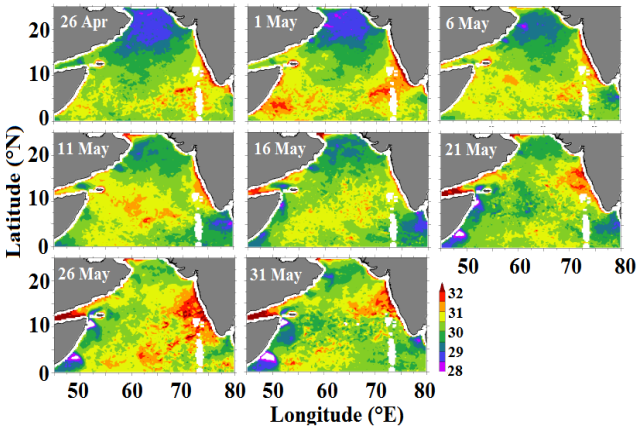


**Fig. 1 Evolution of warm pool during May 2007**

The sea surface temperature variation in the year 2008 was quite different from 2007. In this year the warm pool attained its maximum intensity on 15 May, with its core (~31.5°C) located between 63° to 70°E and 3° to 12°N (Fig. 2). The warm pool dissipated by 18 May. Here, it is interesting to notice the formation of a secondary warm pool in the eastern Arabian Sea with its core (31.5°C) located between 15° to 20°N and east of 67°E. In both cases, the core temperature is found to be nearly the same. As per the IMD records, the onset of monsoon over Kerala was on 31 May. In this case also, there is a lag of 16 days between MOK and the date of attaining maximum intensity. However, the cooling is slightly intense in the upwelling regions compared to 2007.

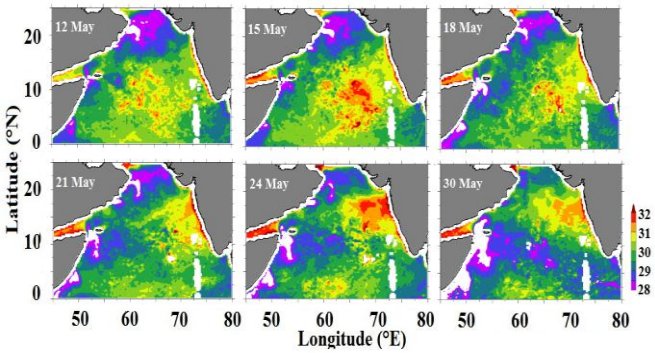


**Fig. 2 Evolution of warm pool during May 2008**

The evolution of warm pool in the year 2009 (Fig. 3) is quite different compared to other years. In this year, the warm pool was formed thrice in the Arabian Sea and each follows by a dissipation stage. The first warm pool is noticed on 4 April, located in the SEAS. The evolution of the second warm pool commences on 1 May and reaches its maximum intensity on 7 May. In this case, the core is evident on the western equatorial Arabian Sea, with a core temperature in excess of 31.5°C and dissipates by 16 May. In the Arabian Sea, temperature again increases and attains its maximum intensity on 19 May, with its core is centered slightly in the offshore regions of the southwestern equatorial Arabian Sea. Similar feature is noticed in the SEAS, south of 10°N and east of 67.5°E. After 22 May, dissipation triggers in the western Arabian Sea, but continue its existence in the SEAS. In this year, IMD reported the onset of monsoon on 23 May. Even though, temperature in the Arabian Sea attains its peak three times during the pre-monsoon season, the intensity of the one formed on 7 May is found to be very significant. In this case, also, there is a lag of 16 days between MOK (23 May) and the date of occurrence of the maximum intensity (on 7 May).

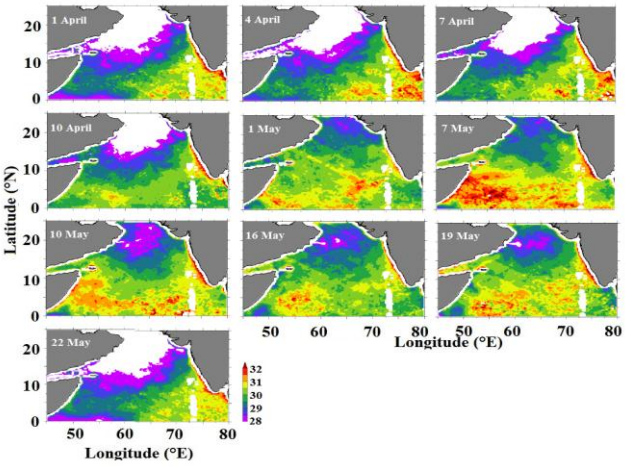


**Fig. 3 Evolution of warm pool during May 2009**

In the Arabian Sea, the maximum intensity and coverage of the warm pool is noticed in 2010. Compared to all years, average temperature in the Arabian Sea is found to be much higher in this year. Prominent warm pool is noticed in the central and equatorial regions from end of April. It attains its maximum intensity on 29 April (>30°C). On this day, the entire region south of 15°N is occupied by waters with temperature in excess of 30.5°C. On 2 May, even though the core temperature reduces to 31.5°C, the area occupied by the warm pool extends to the regions south of 20°N. This is a unique feature observed in the Arabian Sea. The probable reasons for this feature will be attempted later. Afterwards, the area occupied by this anomalous water decreases, but the temperature again increases and attains its maximum values on 17 May (>32°C). During this period, the anomalous water occupies the entire Arabian Sea north of 5°N. The onset of monsoon over Kerala, as reported by IMD, is on 31 May. Between MOK and the maximum intensity attains by the warm pool (31 May), there is a lag of 14 days. In all other years, the lag is found to be 16 days.

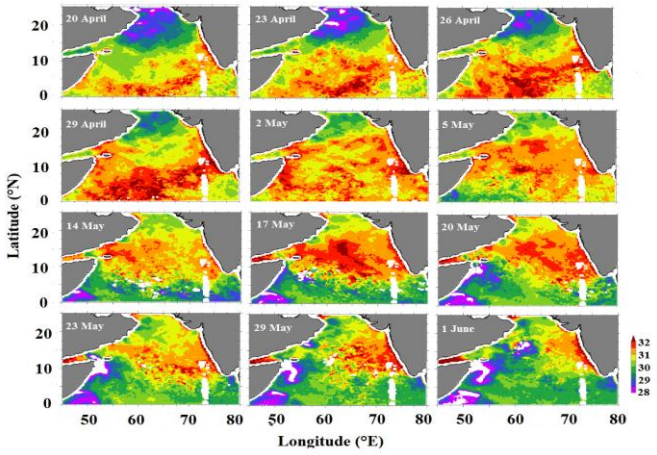


**Fig. 4 Evolution of warm pool during May 2010**

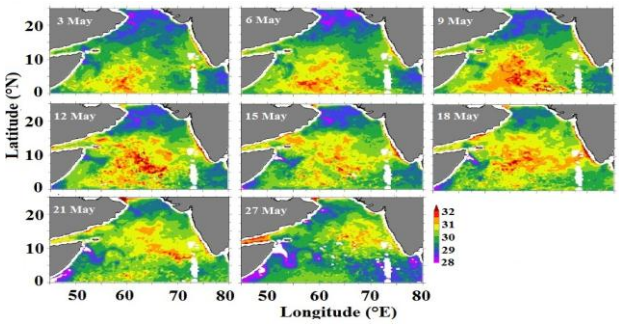


**Fig. 5 Evolution of warm pool during May 2011**

The characteristic feature of 2011 is the formation of the warm pool in the western equatorial Arabian Sea (between 50°E and 67°E; south of 12°N) on 3 May itself with a core temperature of 31.5°C (Fig. 5). The warm pool attain its maximum temperature (>32°C) on 12 May, with its core in the central equatorial Arabian Sea (between 60°-67°E and 5°-2°N). On this day, the entire region south of 15°N was occupied by the warm pool. After attaining the maximum core temperature, the surface layers started cooling by 15 May and the warm pool area dropped significantly. In this year, IMD reported MOK on 28 May. Between MOK and the date of attaining the maximum intensity of the warm pool, there is a lag of 16 days. By 27 May, the temperature in the equatorial Arabian Sea south of 10°N, dropped by more than 2°C compared to 12 May, when the intensity of warm pool was maximum. The drastic cooling observed off Somalia and the west coast of India was attributed to the prevailing coastal upwelling.

**Table 2.variability of MOK & Warm Pool**

| YEAR | MOK | Peak Day | Core Temp. | Location &area |
|---|---|---|---|---|
| 2007 | 28 May | 11 May | 31°C | 5°N to 12°N , west of 70°E |
| 2008 | 31 May | 15 May | 31.5°C | 3°N to 12°N, 63°E to 70°E |
| 2009 | 23 May | 07 May | 31.5°C | South of 10°N, west of 75°E |
| 2010 | 31 May | 17 May | 32°C | 5°N to 20°N |
| 2011 | 28 May | 12 May | 32°C | 5°N to 12°N, 50°E to 67°E |

## IV. Summary and Conclusions

In this paper, an attempt has been made to study the characteristics of the Arabian Sea Warm Pool (ASWP) and its possible relation with the monsoon onset over Kerala (MOK) utilizing TMI satellite data. The monsoon onset date was obtained from the Indian Daily Weather Report. Sea surface temperature in excess of 30.5°C is utilized to define the ASWP. In all the years, the ASWP is observed in the Arabian Sea during April and May. The analysis revealed significant inter-annual variability in the warming events in its number, area, location, time and peak core temperature in the Arabian Sea (Table 2.). The number of occurrence of these warming events varied between one and three. A lag of 16 days was noticed between the date of maximum intensity of ASWP and MOK. The ASWP started its dissipation immediately after attaining its peak intensity.

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