

# Subseasonal variability of air sea interaction over the Indian Ocean and its influence on regional and subseasonal variability of the Indian monsoon

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## **Abstract**

Subseasonal variability of air sea interaction over the Indian Ocean and its influence on the regional and subseasonal variability of Indian monsoon is evaluated in this study. Contrary to earlier studies which take the All India Rainfall (AIR) for studying monsoon variability, this study shows the necessity for taking into account the spatial variability and does a regional study here. The air sea interaction over the Arabian Sea and Bay of Bengal, lying on both sides of the Indian subcontinent, are evaluated as they are found to be major sources of influence on monsoon variability. The Indian subcontinent is divided into different regions taking into account the regional variability in monsoon involved. Spatial distribution and correlation analysis between these regions show that precipitation over these regions varies in different proportions and are under different centers of influence. As the first step of this study, Intra Seasonal Oscillations (ISO) within 10-60 days in the Sea Surface Temperature (SST), surface latent heat flux, surface winds and outgoing longwave radiation (OLR) over the Arabian Sea and influence on precipitation over the Western Ghats (west coast of Indian subcontinent) are evaluated. SST and zonal winds in the south eastern Arabian Sea 6-8 days prior to the precipitation maximum are found to have maximum significant correlations with the Western Ghats precipitation. Composite analysis of the filtered SST, surface latent heat flux, surface winds and OLR shows that maximum SST is found to lag minimum evaporation by 6 days, minimum zonal winds by 8 days and minimum convection by about 10 days. Low convective activity, easterly wind anomalies (giving weaker total winds), and reduced evaporation lead the positive SST anomalies, consistent with the surface fluxes generating the SST anomalies. Following the warm SST anomalies there is enhanced convection, and a few days later, enhanced westerly winds and strong evaporation leading to negative SST anomalies. The converging winds 5 days prior to the active phase enhance the uplift of moisture and the potential for convective precipitation. This results in an active phase over the Western Ghats region.

## **1. Introduction**

The subseasonal variability of monsoon is delineated by active periods of heavy rainfall interrupted by drier periods of deficient rainfall. The dry and wet spells of the active and break conditions, often lasting for 2-3 weeks, represent subseasonal variations of the monsoon with time scales longer than synoptic variability (1-10 days) but shorter than season. This subseasonal variability interacts with the annual cycle influencing the seasonal mean and its interannual variability. It also modulates synoptic activity and cause spatial and temporal clustering of lows and depressions.

Arabian Sea and Bay of Bengal on either sides of the Indian sub continent in the north Indian Ocean, though having similar features, behave differently and have distinct characteristics [Shenoi et al., 2002]. Lying on both sides of the continent, they are found to influence the centers of precipitation variability over the Indian subcontinent largely. The moisture for the southwest monsoon, transported over to the continent, is gathered by evaporation from the Arabian Sea and Bay of Bengal and also transported from the southern hemisphere [Findlater, 1969; Saha, 1970; Cadet and Greco, 1987.a,b]. Arabian Sea is a principal source of the moisture flux across the

west coast of India resulting in periods of heavy orographically forced rainfall over the Western Ghats [Saha and Bavadekar, 1977; Rakhecha and Pisharoty, 1996]. The northwestward propagation of the tropical depressions formed over the Bay of Bengal has been associated with the rainfall over the Ganges – Mahanadi river basins [Murakami, 1976; Rakhecha and Pisharoty, 1996].

As the first step of this study, Intra Seasonal Oscillations (ISO) within 10-60 days in the Sea Surface Temperature (SST), surface latent heat flux, surface winds and outgoing longwave radiation (OLR) over the Arabian Sea and influence on precipitation over the Western Ghats (west coast of Indian subcontinent) are evaluated.

## **2. Data and analysis methods**

Availability of data from satellites like Tropical Rainfall Measuring Mission (TRMM) during recent years helps us to look into variabilities on all time scales from few days to interannual. The precipitation used is obtained from the Climate Prediction Center Merged Analysis of Precipitation (CMAP), SST from the TRMM Microwave Imager (TMI), surface flux and winds from the European Center for Medium range Weather Forecasting (ECMWF) and OLR from the National Oceanic and Atmospheric Administration (NOAA).

All available data between June 1 and Sept 30 for the years 1998 to 2002 are band pass filtered to retain periods between 10-60 days using a boxcar filter. We define the active phase as when the Western Ghats intraseasonal precipitation anomaly exceeds 2.0 mm/day and break phase as when the minimum of intraseasonal precipitation anomaly exceeds -2.0 mm/day. This definition is applied to all the other parameters for compositing based on active and break phases in precipitation. SST, surface latent heat flux, surface winds and OLR are composited based on identification of active-break phases in precipitation over the Western Ghats region. We identify 12 events or intra seasonal oscillations for the period 1998 to 2002 and composite them together.

## **3. Subseasonal variability of air sea interaction over the Arabian Sea and its influence on the Western Ghats subseasonal monsoon variability**

Region of pronounced intraseasonal variance in SST over the Arabian Sea is found to lie over the central and northern Arabian Sea (Fig. 1a, 1b). Although the magnitude of the composite anomalies is small, individual events can have SST anomalies over a range of 1°C-1.5°C. Shinoda et al. found out that even an SST change from 29.0°C to 29.5°C corresponds to a positive saturation specific humidity of 0.76 g/kg. For a wind speed equal to 4m/s, the latent heat flux increases by 11.5 W/m<sup>2</sup>, whereas the sensible heat flux increases by 3.2 W/m<sup>2</sup>, which is significant considering the amplitude of the composite sensible and latent heat flux variation associated with the intraseasonal variability.

Composites of SST and surface winds before and after an active phase are shown in figure 1. Time-latitude (Hovmoller) sections of SST, surface latent heat flux, surface winds and OLR for the Arabian Sea (60°E-70°E) are also constructed and examined in figure 2. 10days prior to an active phase, the south and central Arabian Sea [5°N-15°N, 60°E-70°E] is found to be warm and the northernmost Arabian Sea is cool. The winds during this period south to 15°N are north easterly (Fig. 1c). In the region where the climatological winds are westerly at the surface the easterly intraseasonal zonal wind anomalies correspond to reduced evaporation and surface warming and the westerly intraseasonal wind anomalies correspond to enhanced evaporation and

surface cooling. This SST warming due to reduced evaporation (Fig. 2 a and b) is noticed over  $12^{\circ}\text{N}$ - $16^{\circ}\text{N}$  at first and it propagates northward as the intraseasonal south westerlies gather strength. As the Arabian Sea warms, the weak southwesterly winds over the south western Arabian Sea gather strength and during the active phase and after (Fig. 1d), it flows across the basin with the north easterlies over the southeast Arabian Sea vanishing and confined to the north Arabian Sea. This results in a positive vorticity with low level convergence over the southeast Arabian Sea. The converging winds during the active phase enhance the uplift of moisture and the potential for convective precipitation. This results in an active phase over the Western Ghats region. Now, the negative convective anomalies and the southwesterly winds (Fig. 1d) during the active phase cool the SST over the south Arabian Sea. The SST over the northern Arabian Sea keeps warm due to weak winds and solar insolation. The SST pattern over the basin portrays a dipole pattern simultaneous during and after an active phase with warm SST over the north Arabian Sea and cool SST over the south Arabian Sea. This dipole pattern is sustained for about 10 days. The negative SST anomalies over the south Arabian Sea weaken the winds 10 days after the active phase and the convergence cell collapses.

The central Arabian Sea is found to show pronounced intraseasonal variability in SST (Fig. 2a). The intraseasonal SST events propagate from about  $8^{\circ}\text{N}$  to  $20^{\circ}\text{N}$  in 20 days at a speed of  $0.6^{\circ}$  per day. Intraseasonal variability in the surface winds and OLR is also found to be pronounced in the region  $8^{\circ}\text{N}$ - $12^{\circ}\text{N}$ . This region of maximum intraseasonal variability is selected and averaged to further compare the evolution of air sea interaction in figure 3.

Figure 3 shows the evolution of SST, surface latent heat flux, surface winds and OLR during an active and break phase. From the analysis of the evolution during an active phase (Fig. 3a), minimum SST is found to lag maximum evaporation by 6 days, maximum zonal winds by 8 days and maximum convection by about 10 days. The same relationship is found to hold for the break phase as well (Fig. 3b). Maximum SST is found to lag minimum evaporation by 6 days, minimum zonal winds by 8 days and minimum convection by about 10 days.

#### **4. Summary and conclusions**

The study shows that intraseasonal variability in the air sea interaction over the Arabian Sea influences the active and break phases of the monsoon over the Western Ghats. The central and northern Arabian Sea is found to show pronounced intraseasonal variability in SST and related air sea interaction. These intraseasonal events propagate northward from the central Arabian Sea. Low convective activity, easterly wind anomalies (giving light total winds), and reduced evaporation lead the positive SST anomalies, consistent with the surface fluxes generating the SST anomalies. Following the warm SST anomalies there is enhanced convection, leading to an active phase over the Western Ghats region. The warm SST anomalies, few days later, lead to enhanced westerly winds and strong evaporation leading to negative SST anomalies. This develops into a break phase and the cycle repeats. Thus a key to the Western Ghats precipitation sub-seasonal variability is the subseasonal variability in the air sea interaction over the Arabian Sea.

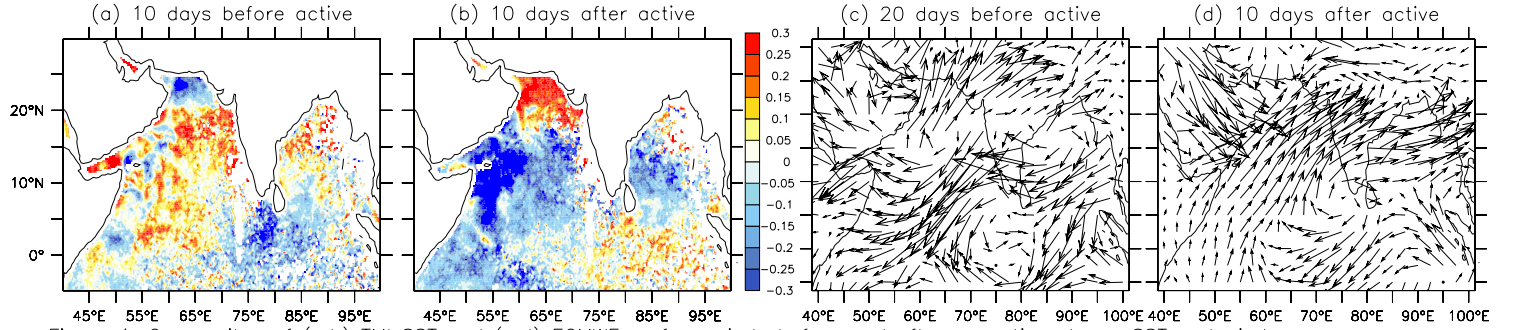


Figure 1. Composites of (a,b) TMI SST and (c,d) ECMWF surface winds before and after an active phase. SST and winds for June–Sept for years 1998–2002 are band pass filtered to retain periods between 10–60 days. Active phase defined as when precipitation is above 2 mm/day in the Western Ghats

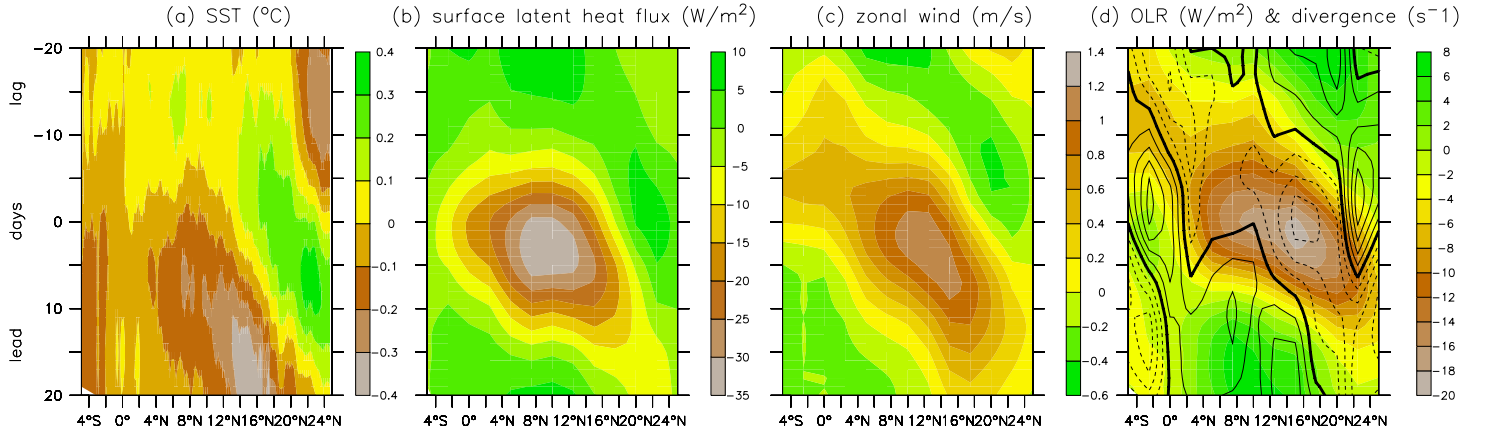


Figure 2. Time–latitude sections of (a) SST (b) surface latent heat flux (c) zonal wind and (d) OLR and divergence (contour, positive solid and negative dashed, contour interval  $0.25 \times 10^{-6} \text{s}^{-1}$ ) for the Arabian Sea ( $60^\circ\text{E}–70^\circ\text{E}$ ) during the evolution of an active phase

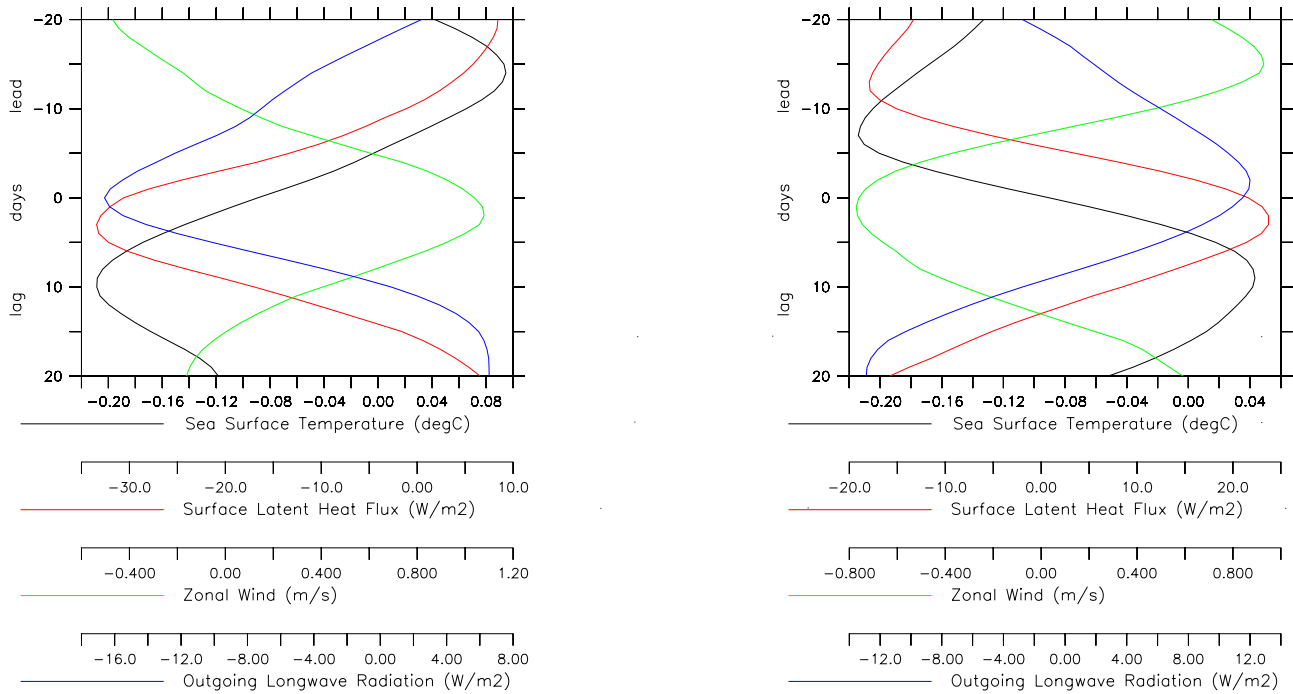


Figure 3. Summary of the temporal relationships of SST, surface latent heat flux, zonal winds and OLR for the central Arabian Sea ( $60^\circ\text{E}–70^\circ\text{E}$ ,  $8^\circ\text{N}–12^\circ\text{N}$ ) during the evolution of an (a) active phase and (b) break phase.