Abstract

Over the last decade, our perception of the Indian Ocean has evolved from a climatically passive ocean to one having significant climatic influences, at timescales from intraseasonal to decadal. At intraseasonal time-scales, the Madden–Julian Oscillation (MJO) is the primary source of tropical atmospheric variability. The MJO forces a substantial thermodynamic response in the surface layers of the ocean by modulating the surface fluxes. Although the primary cause of intraseasonal SST variability within the region where the MJO is active comes from the surface fluxes, dynamical forcing still plays a substantial role.

In the case of Indian Ocean SST, the most striking feature is that strong intraseasonal variability is confined only in some regions though active MJO coupling all over the warm pool region. This spatial SST picture which elucidates the dynamic ocean response to MJO, inspires us to work on the detailed understanding of the process study using Ocean General Circulation model experiments. The main results are based on OGCM simulations forced by NCAR Corrected Interannual Forcing (CIAF) data sets from the Common Ocean-ice Reference Experiments (CORE). Several carefully designed sensitivity experiments are used to understand the processes in addition to exploring the same (not quiet successfully) with the observations.

The model simulation of the intraseasonal variability in the maximum SST variance over TRIO region during winter and Northern Indian Ocean compares well with observations. During Summer in addition to the known Bay of Bengal SST variability, upwelling regions in the Arabian Sea and their response to active/break cycle is explored. Major findings regarding the boreal winter oceanic intraseasonal oscillations, focusing on the thermocline ridge of southern tropical Indian Ocean (TRIO) are as follows.

- The time scale of the heat-flux perturbation, in addition to its amplitude, is important in controlling the intraseasonal SST signature, with longer periods favoring a larger response.
- The dynamic response of the ocean through entrainment at the intraseasonal timescale primarily controls the biological response.
- Ekman pumping does not contribute significantly (on average) to intraseasonal SST variability.
- Surface heat fluxes contribute to 70% of intraseasonal SST variability over the TRIO region, with shortwave flux (75%) dominating. Wind stress-induced entrainment and vertical advection contribute to 20% of the variability on average.

- Internal variability does not contribute significantly to the intraseasonal SST over TRIO region.

- Interannual variations of the subsurface thermal structure associated with Indian Ocean Dipole/El Niño events modulate the MJO-driven SST signature by up to 30%, mainly by changing the temperature of water entrained into the mixed layer. Amplitude and time-scale of the surface heat flux perturbation are however the main control the interannual variation of SST.

During summer, the northern Indian Ocean exhibits significant atmospheric intraseasonal variability associated with active and break phases of the monsoon in the 30-90 day band. We investigate mechanisms of the Sea Surface Temperature (SST) signature of this atmospheric variability and the major findings are:

- Concurrent with the northward propagation of atmospheric intraseasonal oscillations, the SST variations appear first at the southern tip of India (day 0), in the Somalia upwelling (day 10), Northern Bay of Bengal (day 19) and finally Oman upwelling (day 23), as the atmospheric intraseasonal oscillation moves Northward.

- The Bay of Bengal and Oman signals are most clearly associated with the monsoon active/break index, whereas weaker relationship prevails with the Somalia upwelling and the southern tip of India signals.

- Heat flux variations drive most of intraseasonal SST variability in the Bay of Bengal both from modeling (a 0.9 regression coefficient to SST intraseasonal variability, against ~0.25 for wind stress) and observations (0.8 regression coefficient); with ~60% of heat flux variations due to shortwave radiations and ~40% due to latent heat flux.

- Wind-stress variations contribute to ~70% to ~100% of SST intraseasonal variations in the Arabian Sea, through modulation of oceanic processes (entrainment, mixing, Ekman pumping, lateral advection) indicating a prominent role of dynamical oceanic processes in the Arabian sea.

- Internal oceanic variability (i.e. eddies) contributes considerably to intraseasonal variability at small-scale in the Somalia upwelling, but does not contribute to large-scale intraseasonal SST variability due to its small spatial scale and random phase relation to active-break monsoon phases.

Regional biodiversity and regional climate influenced by the interannual variation of intraseasonal events over southern tropical Indian Ocean. The strong off shore Ekman
transport forced by anomalous south-easterly wind along Sumatra-Java upwelling in the east equatorial Indian Ocean are responsible for inducing higher ch–a whereas the Ekman pumping anomaly shows varied phase relation with ch–a. In the case of TRIO region, both Rossby waves and local upwelling are responsible for lifting the phytoplankton from Deep Chlorophyll Maxima (DCM) to the surface in this region. In addition to changes in the underlying oceanic state over TRIO, MJO associated ocean dynamic response (mainly entrainment) is more prominent on the years when shallow thermocline is observed, thereby supporting the role of background thermocline in ocean response. The model sensitivity experiments revealed that both intraseasonal dynamical response and interannual forcing are responsible for the phytoplankton blooming in the western basin of STIO region, whereas the interannual forcing is mainly responsible for the blooming in the east.

Finally how diurnal cycle modulate intraseasonal SST associated with MJO can be examined by inclusion of the diurnal cycle in an OGCM. To quantify this impact over the TRIO region, we have designed different sensitivity experiments along with daily average short wave flux forcing in the OGCM control run (CTL). Mixed layer variability and the heat distribution during day time and night time are simulated and validated with observations from the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction program (RAMA) moored buoys in TRIO. The diurnal accounted model experiment shows that the intraseasonal cooling events are reduced to 18% of CTL and correspondingly the mixed layer is shallowed during the peak event. The additional surface flux available in the mixed layer warms the upper layer during the active phase of MJO along with reduced entrainment flux. In addition, 36% variance of diurnal cycle related to the contribution of short wave flux to the intraseasonal SST in the TRIO. In order to study the modulation of intraseasonal events by the diurnal cycles, we have excluded the impact of non-solar flux in the upper layers of the model from solar forcing and this makes the study different from the previous approaches of including mixed layer depth variation by non-solar components.