Sub-seasonal Variability of Ocean Currents and Chlorophyll-a in the Bay of Bengal

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Abstract

The National Aeronautics and Space Administration (NASA) Ocean Surface Current Analysis Real-time (OSCAR currents) was used to identify sub-seasonal variability of satellite derived surface ocean currents in the Bay of Bengal (BoB). The pentad OSCAR data (5 day averages) were binned by the corresponding phase of the Madden-Julian Oscillation (MJO) to determine the MJO's effects on the surface ocean currents. Certain phases of MJO were found to have pronounced impacts on surface ocean currents during some months, but minimal impacts during others. Notably, during MJO Phases 2 and 6 the OSCAR surface ocean current anomaly pattern was coherent and suggested basinwide response to the MJO forcing. Future work will analyze MJO forcing on satellite derived sea surface temperatures (SSTs) and Chlorophyll-a (Chl-a) concentrations to more fully understand the upper ocean nutrient distribution and primary production response to direct MJO wind variability.

Study Area and Background

Prior studies found that surface ocean currents in the BoB exhibit pronounced seasonality due to a reversal in surface wind patterns associated with the Indian Monsoon (Vinayachandran, 2009; **Fig. 1**). In winter, the prevailing currents in the BoB feature two eddies, both with primarily clockwise flow, that develop in response to the northeast monsoon current intersecting with India and Sri Lanka. In summer, the mean BoB surface currents feature a single eddy with counter-clockwise flow (Potemra et al. 1991). However, there is a lag between the prevailing wind patterns and the ocean current reversal (Hacker et al., 1998). The purpose of this capstone project is to study the impact of MJO driven intra-seasonal surface ocean current variability in the BoB, with specific emphasis on whether the MJO projects a signal within the already complex Monsoon driven surface current reversal.

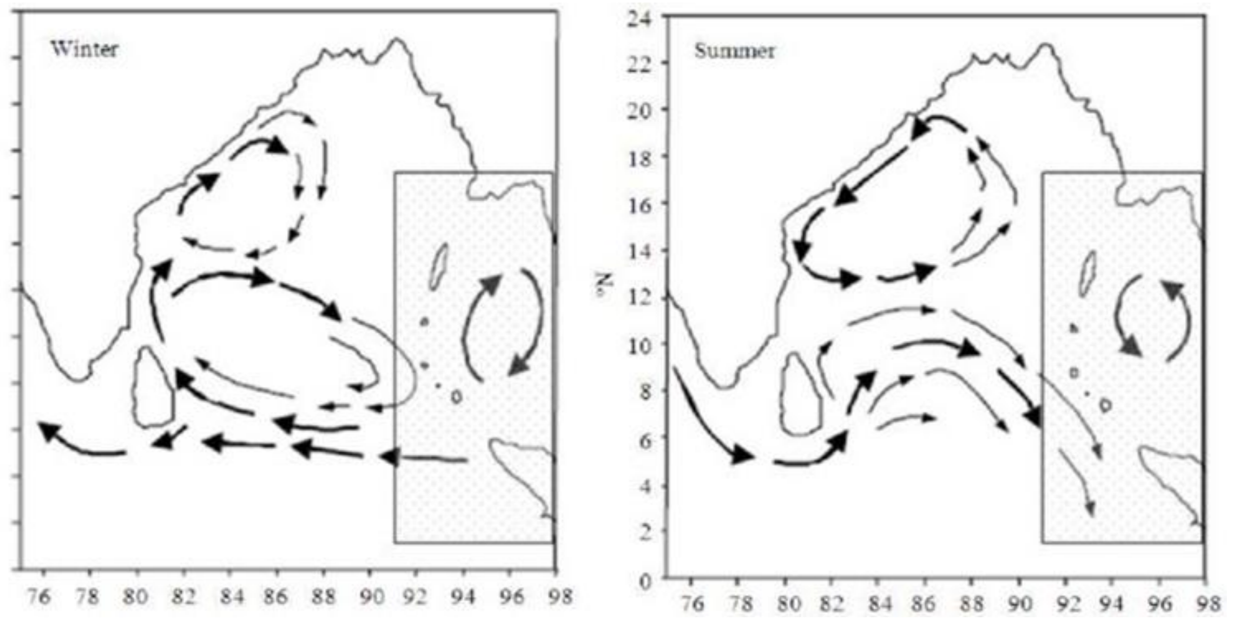

Figure 1: Mean surface ocean currents in winter (DJF) and summer (JJA) in the Bay of Bengal (Varkey et al., 1996). The ocean surface currents show a lagged seasonal reversal between the winter and summer months due to a change in surface wind stress from the Indian Monsoon.

Data and Methods

Pentad OSCAR (Bonjean and Lagerloef, 2002) u and v current components were binned by phase of the Real-time Multivariate MJO (RMM) index for six two-month pairings from 1993-2019. Anomalies were calculated by subtracting two-month means of u and v from the MJO averages. MJO phases 2 and 6 for the month pairs of Oct-Nov and Apr-May were selected for further study due after the preliminary analysis showed these month pairs had the strongest and most pronounced current reversal throughout the year. An example of the MJO driven mean surface wind field and cloud pattern during those phases is shown in **Figure 2**, while **Figure 3** shows MIDN 1/C Caballero and MIDN 1/C Swanson conducting the data intensive research and analysis.

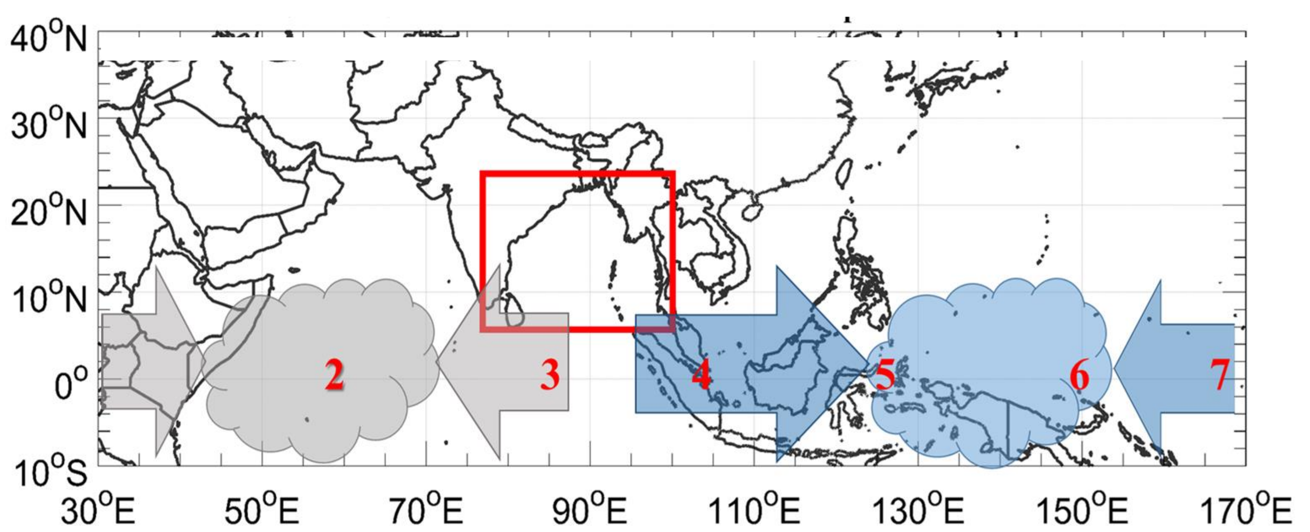

Figure 2 (above): Schematic of the general wind (arrows) and convention (clouds) pattern during MJO phase 2 (gray) and MJO phase 5/6 (blue). The red box indicates the BoB study area for this project. Approximate geographic location of MJO phases 2-7 are given by red numbers.

Figure 3 (left): MIDN 1/C Caballero and MIDN 1/C Swanson analyzing MJO driven variability of the Bay of Bengal (photo credit: B. Barrett, 2020).

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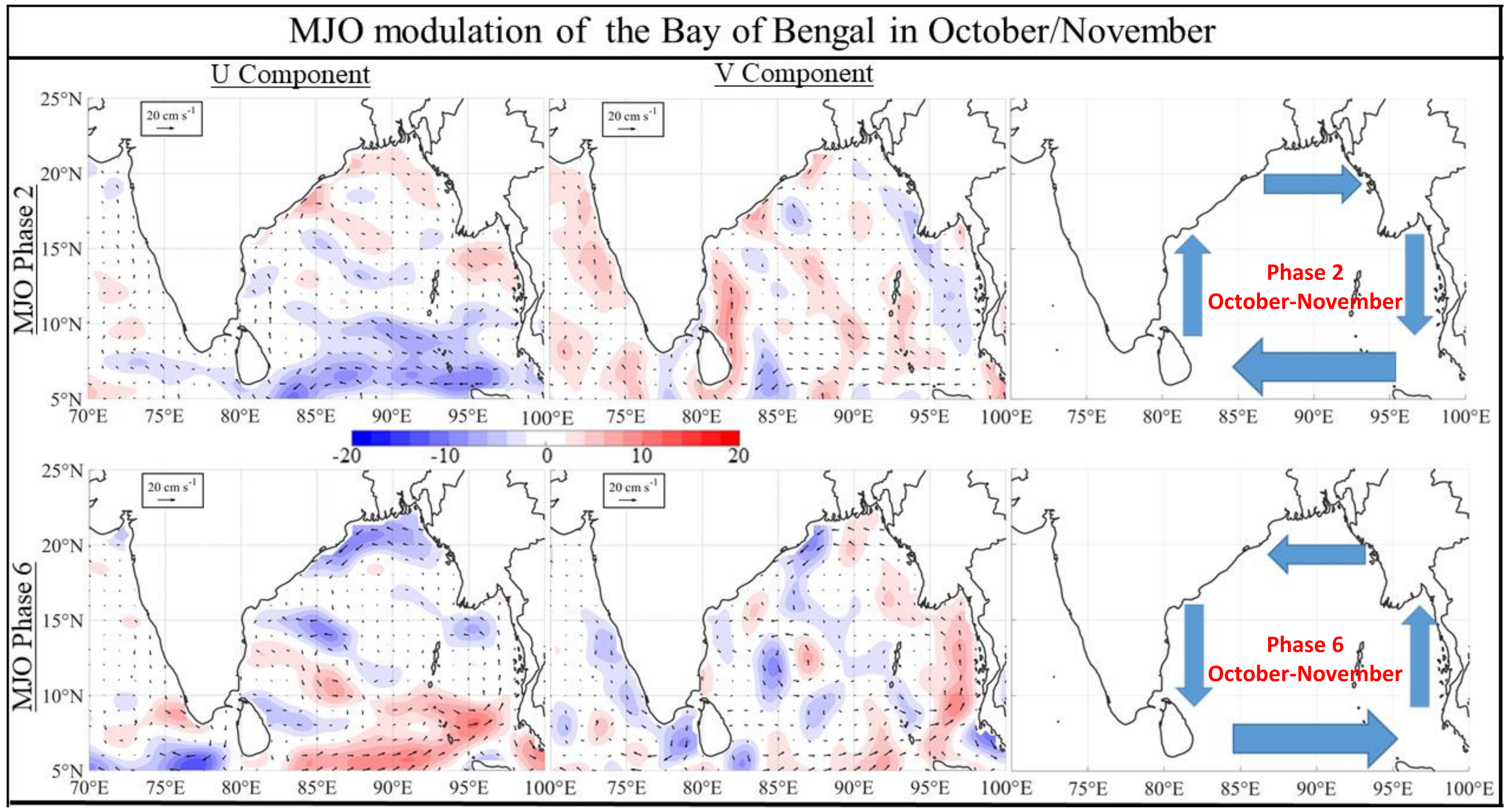
Results and Discussion



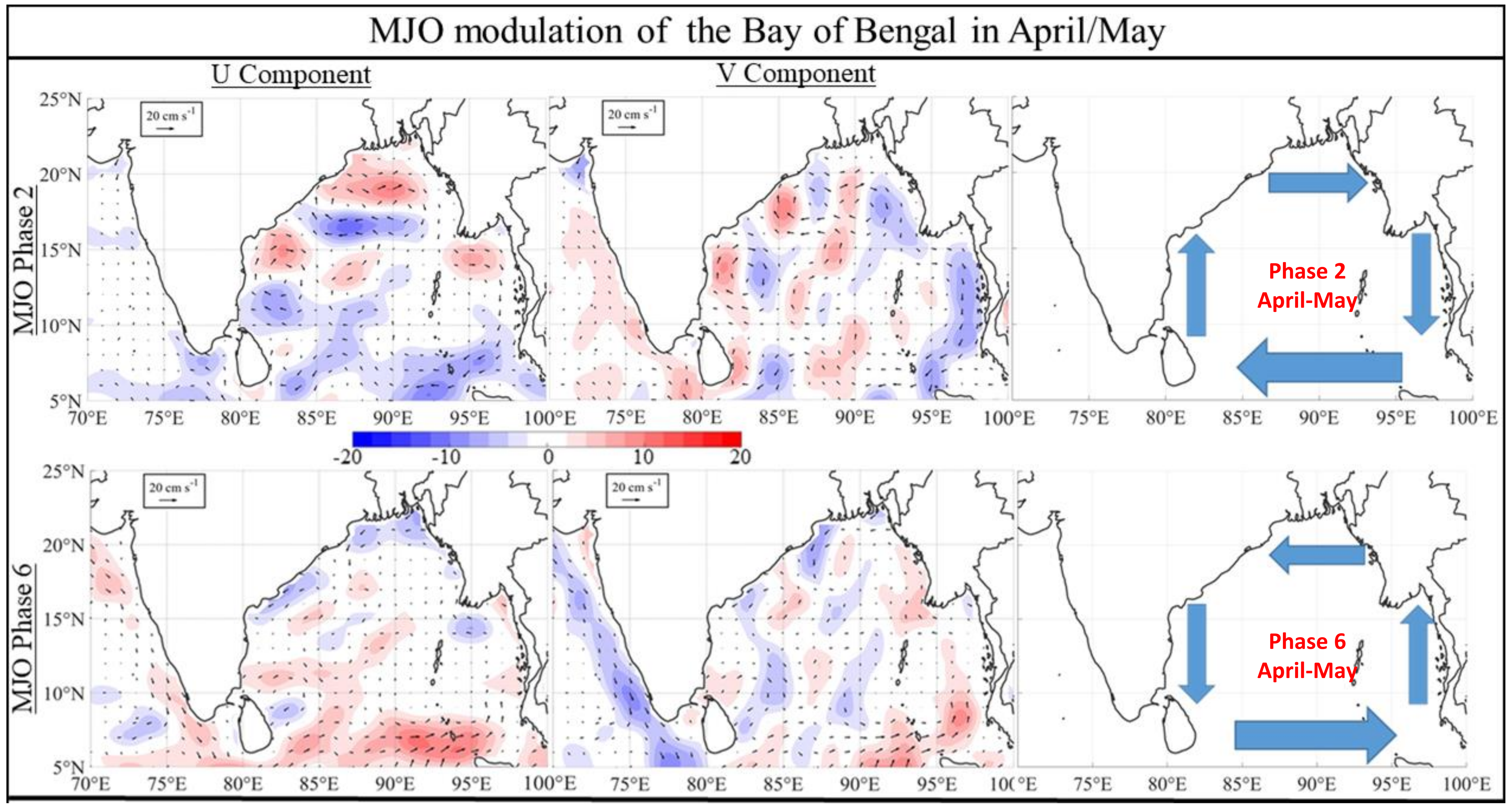


Figure 4A (Top). OSCAR current anomalies (color shading, in cm s^{-1}) in October and November for days during MJO phases 2 and 6; schematic diagrams (right column) summarize ocean current anomalies (blue arrows) corresponding to each particular MJO phase. **Figure 4B (directly above).** As in Figure 4, but for April and May.

October and November:
The sub-seasonal OSCAR surface ocean current anomalies in the BoB during October and November are opposite between MJO phases 2 and 6 (**Fig. 4A**). Specifically:

- **Phase 2:** During phase 2, the current anomaly is ~10 cm s^{-1} in the $+u$ direction near Bangladesh and 5-10 cm s^{-1} in the $-u$ direction near 5°N along 80° to 100°E. The v-component anomaly is relatively weaker (less than 5 cm s^{-1}) and is most pronounced in the southward direction along the eastern side of the BoB and the northward direction along Sri Lanka. The result is an overall clockwise flow in the current anomalies in BoB during Phase 2.
- **Phase 6:** During Phase 6, the anomalies, in general, reverse signs from what they were during Phase 2, in agreement with the eastward shift of the MJO convective envelope from the Indian Ocean to the Western Pacific (**Fig. 2**). The result is an overall counter-clockwise flow in the current anomalies in BoB during Phase 6.

April and May:
As with October and November, the sub-seasonal OSCAR surface ocean current anomalies in the BoB during April and May are opposite between MJO phases 2 and 6 (**Fig. 4B**). Specifically:

- **Phase 2:** During phase 2, the current anomaly is ~ 10 cm s^{-1} in the $-u$ direction centered near 6°N extending from 80° to 100°E. The v component anomaly is most pronounced (~10 cm s^{-1}) moving south along the coast of Myanmar. The result is an overall clockwise flow in the current anomalies in BoB during Phase 2.
- **Phase 6:** During phase 6, there is a $+u$ anomaly, ~10 cm s^{-1}, at about 7°N extending from 87° to 97°E. In the v component a <10 cm s^{-1} anomaly begins at 5°N and moves up the coast of Myanmar to about 13°N. Overall the anomalies reverse (to counter-clockwise flow) which is expected due to the MJO propagation.

If MJO-driven variability causes deviations from the overall currents in the BoB (as this work suggests), there could be profound changes in the region. Intra-seasonal variability in wind forcing could alter upwelling or downwelling regimes in coastal areas, or impact mixing and advection in the surface ocean. These subtle anomalies could have an impact on SSTs and Chl-a, which is a proxy for surface ocean primary production.

Conclusions and Future Work

- The direction of the OSCAR surface ocean current anomalies seems most dependent on the phase of MJO, not the month. Some phases exhibit stronger anomalies than others.
  - In Phases 2 and 6, the anomaly pattern was coherent and suggested basinwide response to the MJO, and the anomalies act to strengthen or weaken the mean flow in the BoB.
- Phases 2 and 6 have the strongest opposite anomalies between all eight MJO phases.
- The strongest anomalies tend to occur near the equator closer to where the MJO propagates.
- Future research should focus on sub-seasonal variability of chlorophyll-a concentrations (**Fig. 5**) in the BoB for the months with strongest MJO-driven current anomalies.

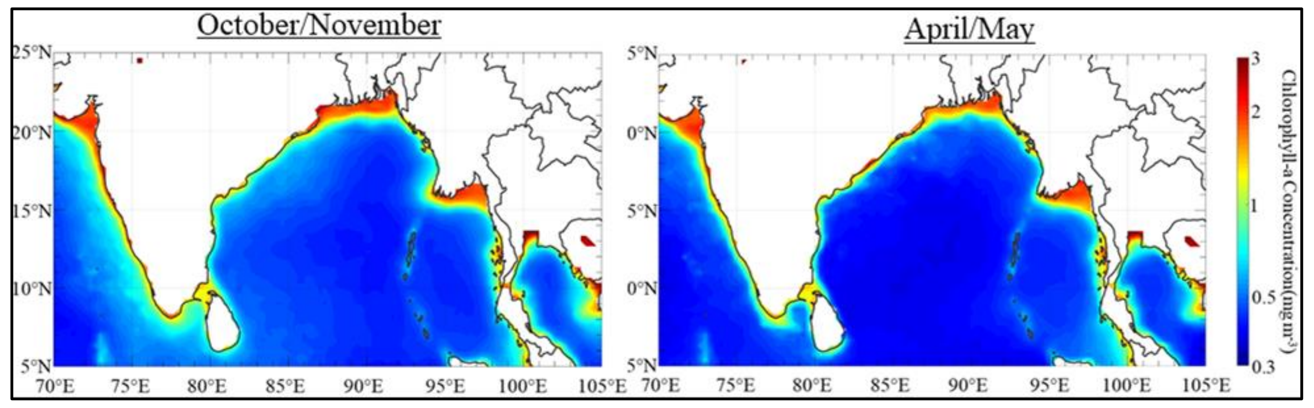


Figure 5: Composite mean chlorophyll-a concentration for the BoB in October and November (left), and April and May (right). Data source: MODIS/TERRA, OCx retrieval algorithms.