Indian Ocean Climate and El Niño: A Two-Way Affair?

The cold upwelling that occasionally occurs off the eastern coast of Sumatra changes the climate of the region. Such unusual cooling, termed by some the "Indian Ocean Zonal Mode," may or may not be accompanied by a large contrast in sea surface temperature (SST) between the western and the eastern Indian Ocean, the "Indian Ocean Dipole" described on p. 5. Is the upwelling off Sumatra due to local winds, due to westerly wind bursts in the Pacific associated with El Niño events, or due to equatorial waves in the Indian Ocean? And do conditions in the Indian Ocean feedback to the Pacific?

H. Annamalai, who is with the Asian Australian Monsoon Research Team at the IPRC, has been conducting research to answer these questions. He spearheaded a project with **R. Murtugudde**, and IPRC researchers, **Jim Potemra**, **Shang-Ping Xie**, **Ping Liu**, and **Bin Wang** to search for the precursors of the unusual ocean cooling (1 standard deviation cooler than the mean temperature) off the Sumatra coast. Using atmosphere and ocean model-assimilated products together with rainfall data and model estimates of the Indonesian Throughflow transport, they looked at how the El Niño, the Throughflow, and the monsoon affect the upwelling.

The diagnostics conducted by the team showed that in the Indian Ocean there is a natural air-sea coupled mode with weak cooling off Sumatra. During a window from spring to early summer, this natural cooling can intensify, should El Niño-like conditions prevail in the central Pacific. This is because precipitation during spring over and near Sumatra is low in response to the SST anomalies occurring in the Pacific (Figure 5a).

The following sequence appears to happen: Warm SST anomalies in the central Pacific move the descending branch of the Walker circulation westward, inducing subsidence and suppressing rainfall over the equatorial Indian Ocean. This negative heating anomaly results in a Rossby wave that forces an anticyclone in the lower atmosphere of the southeastern Indian Ocean. This anticyclone is accompanied by alongshore winds causing upwelling off Java and Sumatra (Figure 5b). These stronger easterly winds force changes in the ocean currents and raise the thermocline, bringing cool water to the surface and reducing rainfall. These changes, in turn, strengthen the easterly winds, which then lead to the zonal mode.

Sensitivity experiments with an atmospheric general circulation model (GCM) support the hypothesis that the sea surface temperature in the equatorial western and central Pacific affects spring rainfall over the equatorial Indian Ocean. The cooling of the ocean surface off eastern Sumatra interacts with monsoon heating to the north, yielding increased rainfall along the monsoon trough in July and August (Figure 5c). The north-south heat gradient in the atmosphere favors a local north-south circulation that strengthens alongshore winds off Sumatra. The summer monsoon, therefore, may too have a role in the stronger upwelling.

Recently, Annamalai and a group of colleagues analyzed the circulation changes in the Indian and Pacific Oceans associated with the 1976–77 climate shift. From 1950 to 1976, El Niño events were accompanied by a basin-wide warm tropical Indian Ocean; from 1976 to 1999, El Niño events were usually accompanied by a strong Indian Ocean Zonal Mode. This shift was associated with a westward shift of a low-level anticyclone over the South China Sea and with considerably stronger westerly winds that occur during developing El Niño events.

Solutions obtained from both a simple atmospheric model and a comprehensive atmospheric GCM suggest that prior to the shift, the basin-wide warming of the Indian Ocean generates an atmospheric Kelvin wave associated with an easterly flow over the equatorial western and central Pacific. This easterly flow weakens the westerly winds associated with a developing El Niño. The strong east-west SST contrast that has occurred after the shift, however, does not generate a significant Kelvin wave, and the El Niño-induced westerlies are little affected and remain strong.

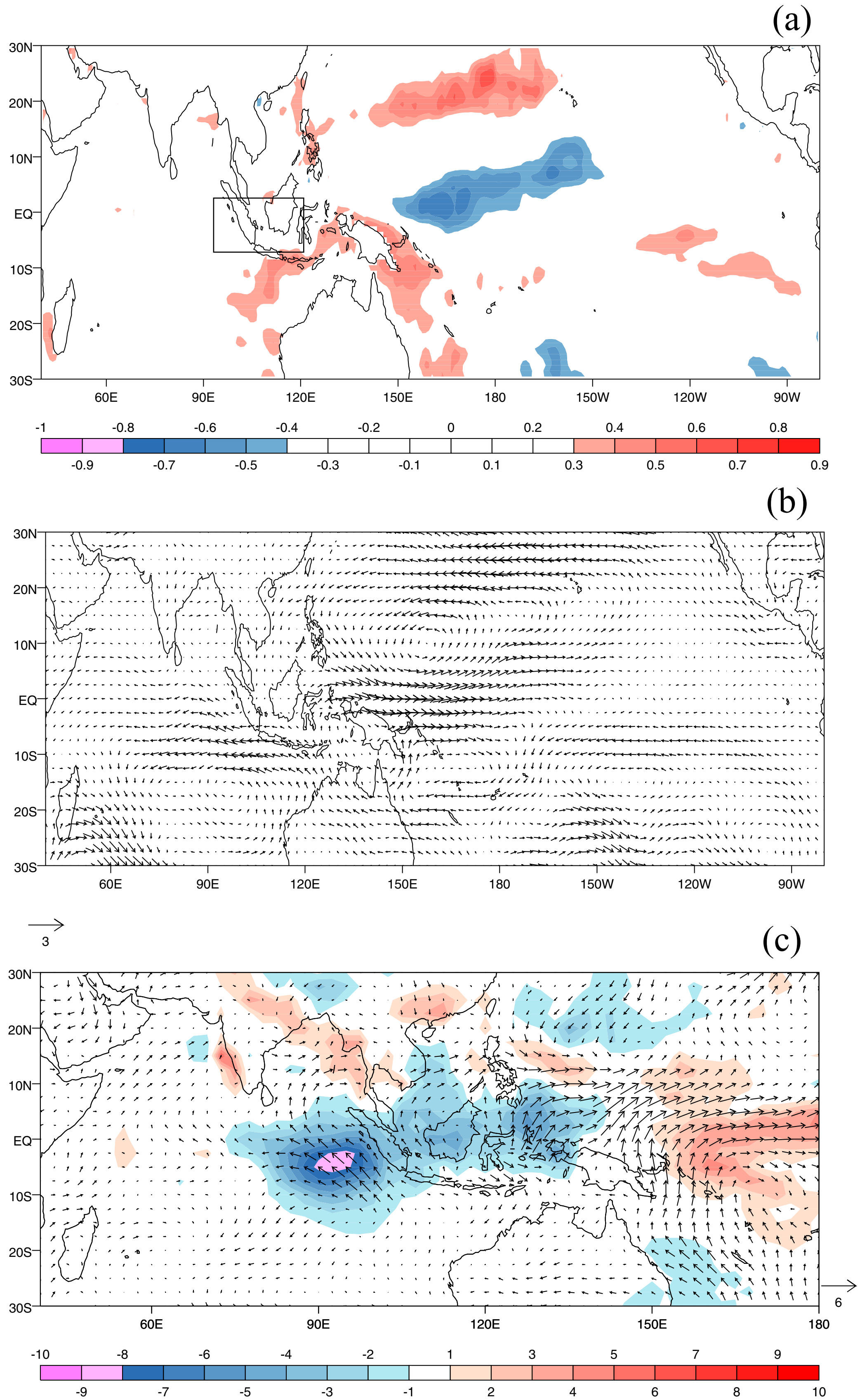

Figure 5. *Simultaneous correlation between spring anomalous precipitation over and near Sumatra (shown in box, 90ºE-120ºE, 10ºS to the equator) and (a) SST, (b) surface winds. (c) Composite anomalous precipitation and surface winds during July-August of years with a strong zonal mode.*