

Focus: The Tropical Indian Ocean

“The North Indian Ocean is a very special ocean: It is not connected to the poles, it is tropical, it has very strong seasonal forcing, with the total reversal of winds and dramatic current reversal. The time-dependence of flows from a week to months makes their monitoring a challenge.” With this description, IPRC distinguished guest **Satish Shetye**, director of the National Institute of Oceanography in Goa, India, and an expert on the physical oceanography of the Indian Ocean, introduced his talk, *Local and Remote Wind-forcing of the West India Coastal Current*, this past September at the University of Hawaii. The present theoretical framework for understanding the wind-driven circulation of the North Indian Ocean looks at surface currents as a consequence of wind-forced and free coastally- and equatorially-trapped Kelvin and Rossby waves. The framework has been successful in understanding the observed seasonal



cycle of currents. What about variations seen in currents from days to weeks? Recent observations of the West India Coastal Current off the coast of Goa, for example, show northward and southward movements with periods of a few days as well as with longer periods. Using an analysis of observed currents, local winds, and sea-level fluctuations in two nearby estuaries, Shetye concluded that over shorter time periods (less than about 10 days) this coastal current is driven by local winds, and over longer time periods, remote winds play dominant role.

Shetye’s talk on the complex Indian Ocean currents set the stage for the “Mini-Workshop on Indian Ocean Research at IPRC.” The workshop covered strategies for more accurate estimates of salinity, the challenge of modeling water exchange between the Arabian Sea and the Bay of Bengal, finding the source waters of the Leeuwin Current, and the impact of Indian Ocean sea surface temperature anomalies on the large-scale atmospheric circulation and climate.

The sharp contrast between the salty Arabian Sea, with its high evaporation rate, and the rather fresh Bay of Bengal, with its many river runoffs, has climate impacts. A challenge for models in simulating this salinity pattern is that direct rainfall measurements over the open ocean hardly exist and satellite-derived precipitation products have broad error ranges. IPRC researcher **Zuojun Yu** described the technique she and IPRC Director McCreary developed to evaluate precipitation products used in climate studies. They “convert” a precipitation product to sea-surface salinity (SSS) with an ocean model that parameterized runoff by nudging model surface salinity (S1) toward observed SSS at basin boundaries. The S1 fields obtained from the different products can then be evaluated against observations. **Max Yaremchuk** showed how SSS assimilation can produce accurate estimates of river discharge and rainfall over the Bay of Bengal.

During the Southwest Monsoon, Arabian Sea water flows along the western coast of India and into the Bay of Bengal. During the Northeast Monsoon, currents flow along the east coast of the bay and around

Sri Lanka and then westward and into the West. This current reversal, though, has been difficult to model. **Tommy Jensen** at IPRC has been using a 4½ layer model with tracers and floats. In the model, Arabian Sea water reaches the Bay of Bengal by flowing around Sri Lanka, but much of the Bay of Bengal water stays in the bay; if it does leave and reach the Arabian Sea, it is along the eastern boundary of the Indian Ocean across the equator, westward and then northward in the Somali Current. No floats move around Sri Lanka and then north along the western coast of India. Why can the model not simulate this? Is it because of the model's unrealistically thick surface layer that does not show shallow surface currents? Does the model not capture the response to the monsoon well enough for the wind driven circulation to act on the flow? Shetye, for instance, noted the present observations suggest that transfer of low-salinity water from the Bay of Bengal into the northern Arabia Sea occurs along the west coast of India after the Southwest Monsoon. **Jay McCreary** pointed out that Jensen's model offers an alternate route: low salinity water first moves south of the equator near the eastern boundary, then to the west, and northward into the Arabian Sea along the western boundary. Determining the relative importance of these two routes is a challenge.

Another puzzle tackled in the workshop was the source of the water in the Leeuwin Current off the western coast of Australia. This remarkable current flows into the face of winds and is the only permanent poleward flowing eastern boundary current. **Jim Potemra** described the complicated current system in the equatorial and southern Indian Ocean from which the Leeuwin Current might draw its water: the Indonesian Throughflow, the tropical Indian Ocean water in the Eastern Gyral Current, or as a spin off of the South Equatorial Current. Altimeter data suggest that during part of the year the supply may even come from Madagascar. Potemra wishes to explore this source with numerical models.

Beginning with research on the Indian Ocean Dipole, scientists have started to view the Indian Ocean as a shaper of climate, both regional and distant. At the workshop, **H. Annamalai** reviewed his research on the climate effects of the unusually high SST in the Southwest Indian Ocean during an El Nino and persisting into the following summer. By running model experiments in which he teased apart the effects of unusual SST patterns in the tropical Pacific and in the Indian Ocean, he showed that the unusually high SST in the IO increases local convection, altering the model's Walker Circulation over the Indian Ocean and causing subsidence in the tropical western Pacific, resulting in less than normal rainfall there. This suggests strongly that the Philippine anticyclone seen during and after an El Nino is partly induced by the SST anomalies in the southwestern Indian Ocean. His modeling solutions suggest moreover that the anomalously warm SST in this region also contributes to late onset of the monsoon rains over India. Finally, these anomalies in the southwest Indian Ocean may also oppose atmospheric disturbances over Pacific North America that are triggered by tropical Pacific SST anomalies.

It is well known that some part of Asia experiences large and robust anomalies in the summer following an El Nino. This is rather puzzling as it is the time when SST anomalies in the equatorial Pacific have disappeared. **Shang-Ping Xie** and his collaborators at the Ocean University of China show that this lingering influence of El Nino is a manifestation of the Indian Ocean warming that forms in response to the Pacific warming and persists through the summer. Xie calls this role of the Indian Ocean a "capacitor". He

hypothesizes that, once charged by El Niño, the capacitor explains summer circulation and precipitation anomaly patterns in the tropical Indo–western Pacific Ocean and East Asia.

Shetye, in a final session, presented newly detected relationships that might prove useful for rainfall forecasts during the Indian summer monsoon. He noted that analysis of recently available high-resolution precipitation and SST products suggest that a meridional SST gradient in the Bay of Bengal precedes a rainfall event. When SST is 0.75°C or higher in the northern than southern bay, the chance of rainfall and a low-pressure system developing in the northern part of the bay within 1 week is 78% during May–September. Shetye felt that here was a challenging problem for IPRC climate modelers: “Can this sequence of events be modeled to understand the processes that link these events?”