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Indian Ocean Dipole, El Niño-Southern Oscillation, and large-amplitude internal waves recorded in Andaman Sea corals during the satellite era

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The Indian Ocean is surrounded by highly populated areas that are susceptible to climate extremes, such as floods, droughts, and heatwaves. Timing and severity of these climate extremes are influenced by ocean-atmosphere interactions of the Asian Monsoon, Indian Ocean Dipole (IOD), and El Niño-Southern Oscillation (ENSO), all of which are influenced by global warming. Continuous remote sensing by satellites of surface ocean temperature, one of the main drivers of basin-wide climate extremes, are limited to the upper few mm of the water column making assessments of broader scale understanding beneath the surface difficult. The carbonate skeletons of massive shallow-water corals provide continuous monthly-resolved proxy records of subsurface temperature that may complement available satellite-based sea surface temperature (SST) products, and may provide insights into the water column dynamics of the shallow ocean and its atmospheric forcing.

Here we present monthly-resolved records of the Sr/Ca-temperature proxy from shallow-water *Porites* corals collected in the southern Andaman Sea (Ko Racha Yai, Thailand, ~7.6°N), northeastern Indian Ocean. Coral Sr/Ca tracks the variability and annual cycle of high-resolution (~5 km x 5 km) monthly satellite SST during 1985-2010 fairly well, including a double-peak in spring and fall SST resulting from regular monsoon forcing. Interestingly, coral Sr/Ca indicates prominent events of exaggerated cooling in some winters that are not apparent in the satellite SST product. These prominent cooling events in coral Sr/Ca occur in winters coinciding either with years of positive IOD (pIOD), combined pIOD and El Niño, or La Niña. Consequently, we report for the first time a distinct IOD signal in a temperature (proxy) record from the northeastern Indian Ocean, a region normally considered too far north of the IOD core region off western Sumatra-Java, in the equatorial eastern Indian Ocean.

We suggest the difference between substantially lower coral Sr/Ca temperature relative to satellite SST in specific winters can be best explained by differences in temperature between coral depth (5-10 m) and sea surface (upper few mm) where satellite SST are monitored. Importantly, the Andaman Sea is characterized by large, eastward-travelling large-amplitude internal waves (LAIW), which carry cold subpycnocline water into shallower coral reef areas. These upslope intrusions of cold waters rarely extend to the sea surface, and are not visible in satellite SST. The effect of

cooling of subsurface waters by LAIW is strongest during periods with shallower pycnocline, such as during the Northeast Monsoon (winter) season. We investigate if changes in pycnocline depth, as suggested by coral Sr/Ca temperatures relative to satellite SST, are modulated by changes in the intensity of the Asian Monsoon on interannual to decadal timescales.

Our results may provide unique insights into the atmospheric modulation of northeastern Indian Ocean shallow subsurface temperatures by the interaction of the Asian Monsoon, IOD, and ENSO since the start of the satellite era, not available from any instrumental source of observation. Extending these coral records beyond the satellite era will further improve our understanding of the complex interaction between ocean and atmosphere variability in this region under past, present, and future climate change.