



The impact of North Indian Ocean sea surface temperatures on the Indian summer monsoon

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The relationship between sea surface temperature (SST) in the North Indian Ocean and Indian monsoon rainfall is investigated in both observational/re-analyses and climate model simulations. We focus on the partially land-enclosed Arabian Sea and Bay of Bengal, where SSTs are found to have significant correlations with All Indian Rainfall (AIR). This part of the Indian Ocean is therefore important for monsoon predictions, while this area tends to provide significant problems in coupled atmosphere-ocean model simulations. The observational variability of the SST-rainfall relationship is investigated on seasonal to decadal time-scales. This highlights a predominantly negative correlation over the monsoon trough area in North East India and a positive correlation over the rest of India, while these relationships are found to be weakened by the ENSO-monsoon teleconnection. Mechanisms are further investigated by performing a series of atmosphere-only model simulations using the Met Office Unified Model (MetUM). In these experiments we determine the response of the atmosphere to forced cold SST anomalies over isolated areas, which we also extend out into the equatorial Indian Ocean. The cold SSTs in the Arabian Sea and Bay of Bengal lead to a dramatic reduction in Indian rainfall, while cold biases in the equatorial Indian Ocean have the opposite effect, highlighting the competition between oceanic and continental Tropical Convergence Zones (TCZ). However, the impacts for the Arabian Sea and Bay of Bengal experiments are found to change between the pre-monsoon and post-monsoon onset periods. The impact on monsoon rainfall for cold SST biases in these regions is found to be the result of a balance between changes in regional low-level temperature gradients and the availability of moisture over the oceans, which determine the pathway of the monsoon jet and the moisture transport towards India. These experiments suggest that the intra-seasonal variability of the relationship between North Indian Ocean SSTs and monsoon rainfall in observations is further related to the competing impacts of changes in the North and equatorial Indian Ocean SSTs, which are strongly correlated. A further set of atmosphere-only experiments, forced by SSTs from coupled atmosphere-ocean MetUM simulations, highlights that the relatively poor monsoon rainfall in the coupled model simulations can be almost entirely attributed to relatively small-scale cold SST biases in the Arabian Sea and Bay of Bengal.