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Causal information flow and information transfer delay from ENSO and IOD to precipitation variability in the Upper Indus Basin, Pakistan

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In 2022, La Niña and negative Indian Ocean Dipole (IOD) coincided, causing abnormally warm sea surface conditions in the eastern Indian Ocean (near Indonesia). This provided additional moisture to feed monsoon depressions, resulting in heavy rainfall in Pakistan. El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are two modes of sea surface temperature variability that can significantly impact precipitation in Pakistan's Upper Indus Basin. The current study used in situ observations and reanalysis ERA 5 precipitation data to determine the causal influence of ENSO and IOD on precipitation variability using an information-theoretic generalization of Granger causality. The predicted causal effect and causal delay obtained using conditional mutual information, a.k.a. transfer entropy, were further validated using conditional means ("composites") - precipitation means computed for different ENSO states; El Niño (positive), La Niña (negative), and neutral. Uncovering the causal and delayed effects of ENSO and IOD, as well as associated mechanisms, on subsequent precipitation in the UIB could provide a stronger foundation for improving seasonal climate predictions with a longer lead time, as well as understanding how regional and large-scale drivers affect regional precipitation.

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