Indian Ocean warming regimes as hydro-climatic drivers of recent East African Rift Valley lake expansions

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ABSTRACT

Eastern Africa's water resources and river systems are highly sensitive to hydro-climatic variability, facing increasing pressures from changing climate baselines. Over the past fifteen years, the Central Kenya Rift Valley has experienced sustained and significant lake level rises, most notably in Lakes Baringo and Bogoria. Understanding the large-scale climatic drivers of these hydrological changes is essential for anticipating future shifts in regional water systems. Traditionally, scalar indices such as the Indian Ocean Dipole Mode Index (DMI) have been utilized to explain regional rainfall variability. However, these static indices often show limited skill in capturing the multi-season precipitation trends that drive long-term hydrological changes. This research aims to explore whether spatially distinct Indian Ocean warming regimes provide a more comprehensive explanation for the recent precipitation intensification observed in the region. The study utilizes forty years (1985–2024) of high-resolution, satellite-derived sea surface temperature trend fields from the Copernicus Climate Data Store. A spatial K-means clustering approach is applied to identify dominant multi-decadal warming regimes across the Indian Ocean basin. The capacity of these derived cluster indices to explain Central Kenya Rift Valley rainfall is systematically evaluated and compared against the standard DMI using regression models and structural breakpoint analyses. Furthermore, vertically integrated moisture transport and total column water vapour fields from the ERA5 reanalysis are investigated to diagnose the underlying physical mechanisms linking ocean warming to continental precipitation. The spatial clustering analysis reveals four coherent warming regimes, with the cluster situated in the western-central tropical Indian Ocean demonstrating a robust, multi-season teleconnection with Rift Valley precipitation. This spatial index explains substantially more rainfall variance than the DMI across both the primary rainy seasons. Breakpoint analysis identifies a distinct ocean-atmosphere regime shift around 2009, which closely aligns with the onset of the observed lake expansions and corresponds to a significant increase in seasonal rainfall totals. Diagnostic analyses of atmospheric moisture suggest that this precipitation intensification is primarily driven by a thermodynamic enrichment of the atmospheric moisture columns, which substantially increase precipitable water, rather than by an anomalous horizontal kinetic wind jet. These findings suggest that moving beyond spatially aggregated scalar indices toward localized, trend-based warming clusters can enhance our understanding of changing hydro-climatic baselines, offering valuable insights for anticipating long-term changes in East African hydrological systems.

Keywords: Indian Ocean warming, hydro-climatic variability, East African Rift Valley, atmospheric moisture, precipitation trends