EGU24-268, updated on 20 May 2024
https://doi.org/10.5194/egusphere-egu24-268
EGU General Assembly 2024

Heavy-Precipitating Mid-Tropospheric Cyclonic Systems of the Indian Summer Monsoon in a Warming Climate

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Since the last couple of decades, western India has been experiencing persistent, intense rain episodes frequently during the summer monsoon season. Most of the pluvial episodes are accompanied by diverse convective systems modulated by the background monsoon circulation. As the climate warms, the changing environmental conditions affect the nature and intensity of the weather systems. This study discusses the evolving large-scale conditions under global warming, along with the recent changes in the occurrence of a special class of heavy-precipitating synoptic systems, the mid-tropospheric cyclones (MTCs). Observed particularly over the Northeast Arabian Sea, MTCs exhibit pronounced mid-level vorticity with minimal signature at the surface. Observational results suggest significant increasing trends in deep convection and heavy precipitation over western India during the summer monsoon season. The background conditions are dominated by warming in the Arabian Sea and the Indian Ocean, accompanied by strengthening of cyclonic circulation and ascending motion at mid-level over western India. An objective vortex identification using reanalysis dataset indicates a rise in the seasonal frequency and duration of heavy precipitating mid-tropospheric cyclonic systems over western India, resulting in a significant amplification of precipitation from these systems. Furthermore, outputs from seven global climate models of the Coupled Model Intercomparison Project Phase 6 (CMIP6) are used to assess the potential changes in the large-scale patterns conducive to the development and sustenance of mid-tropospheric cyclonic systems over western India with continued global warming following the Shared Socioeconomic Pathway 5-8.5 (SSP5-8.5) scenario. The models project stronger moisture transport over western India that triggers greater moisture convergence along the Indian west coast, aided by elevated water vapor content due to local sea surface warming. We also notice an increase in seasonal mean ascent and relative vorticity, particularly, at the middle troposphere, thereby creating a favorable setting for the occurrence of MTCs and the deep convective clouds in the late 21st century. This interplay between circulation–convection–precipitation on different spatiotemporal scales over the South Asian monsoon domain carries significant implications for assessment of regional hydrological extremes in a warming climate.