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Spatiotemporal distribution and variation characteristics of extreme precipitation of Hunan Province

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Under global climate change, extreme precipitation events are becoming more frequent and intense, posing increasing risks to hydrological and drought-related disasters. Hunan Province in southern China is particularly vulnerable, yet the long-term spatiotemporal evolution of extreme precipitation remains insufficiently understood. This study investigates the characteristics and driving features of extreme precipitation in Hunan Province to support disaster prevention and water resource management. Daily precipitation records from 97 national meteorological stations spanning 1961–2024 were analyzed using a suite of extreme precipitation indices defined by the WMO Expert Team on Climate Change Detection and Indices (ETCCDI). Heavy rainfall was characterized using the R50 threshold based on regional precipitation classification standards. Empirical Orthogonal Function (EOF) analysis, the Mann–Kendall trend and abrupt change tests, and Morlet wavelet analysis were applied to examine spatial patterns, temporal variability, abrupt shifts, and periodic signals. The results indicate an overall drying tendency in extreme precipitation across Hunan Province. Consecutive dry days (CDD) show a significant increasing trend, while consecutive wet days (CWD) decrease significantly. Although 75.3% of stations exhibit declining annual total precipitation (PRCPTOT), 66% show increasing extreme heavy precipitation (R99P), suggesting reduced mean precipitation but intensified extremes. Spatially, extreme precipitation exhibits a hierarchical structure consisting of large-scale regional coherence, topography-modulated counter-phase patterns, and localized fragmented distributions. Abrupt changes are concentrated mainly before the 1980s, particularly during the 1960s, with fewer change points detected after 1990, primarily in central Hunan. Significant periodicities are identified at 2.07–2.25 years, ~31 years, and ~60.3 years, corresponding to ENSO-related short-term variability, medium-to-long-term oscillations, and AMO-related ultra-long-term signals, respectively. Overall, extreme precipitation in Hunan Province is characterized by increasing aridity, heightened local extreme rainfall risks, and multi-scale climate modulation. These findings advance scientific understanding of extreme precipitation evolution in complex terrain and provide critical insights for improving regional forecasting and early warning systems. The contrasting trends—increasing drought risk alongside intensified extreme rainfall—highlight the urgent need for integrated adaptation strategies that enhance water resource management resilience and infrastructure preparedness under climate change.