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Spatial and temporal variability of extreme rainfall events over Peninsular Malaysia

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ABSTRACT

We present the first analysis of spatial and temporal variability of extreme rainfall events (ERE) using daily Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) from 1981–2021 over Peninsular Malaysia. Regional variability of rainfall extremes was analysed using the coupled Empirical Orthogonal Function method and K-means clustering algorithm, revealing five regions: South (R1S), West (R2W), Northwest (R3NW), East (R4E), and Southwest (R5SW). During the Southwest monsoon, western regions' ERE fluctuates, peaking in July (R2W) and August (R5SW). In May and October, EREs are predominant over R3NW. EREs are widespread across Peninsular Malaysia during the Northeast monsoon, especially over R4E. El Niño years vary across ERE metrics (annual count, sum, and mean maximum), whereas La Niña events show more pronounced peaks in these metrics, particularly in November and March. Combined El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) generally result in decreased ERE metrics. This study provides recent insights into ERE variability, enhancing flood management.

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1 Introduction

Under the warming climate, the hydrologic cycle is projected to intensify, causing shifts in weather patterns and more frequent occurrences of extremes such as droughts and heavy rainstorms, including extreme precipitation in the future (IPCC 2013, 2022). Understanding the changes and mechanisms leading to extreme rainfall events is crucial in effective water management for decision making and policy planning (Ali and Fowler 2022). The increased intensity and frequency of extreme precipitation events attributed to climate change are associated with socioeconomic losses and impacts on agriculture, and, consequently, food security (FAO 2021, WMO 2021). Over the past few decades, Malaysia has experienced significant weather events, including severe droughts in the El Niño year of 1997, widespread floods during the La Niña phase in 2011 and 2012, and various impactful incidents such as thunderstorms causing wind damage, flash floods, and landslides (Chan 2015). Annual monsoonal floods occur across different periods and regions, with varying severity, exemplified by the heavy floods during the Northeast monsoon (NEM) of 2014 (Ooi *et al.* 2017). Floods, the most prevalent natural disasters, lead to numerous casualties, disease outbreaks, crop damage, substantial losses in economic, financial, and public assets, and intangible losses (Ooi *et al.* 2017, Yusoff *et al.* 2018). Factors such as inadequate urban drainage systems and local topographic features can exacerbate the impact of heavy precipitation events, increasing the likelihood of flood occurrences. Extreme rainfall events (EREs), influenced by the cyclical monsoons during the local tropical wet season, precede most water-related hazards (Maqtan *et al.* 2022).

In studies examining rainfall trends across Peninsular Malaysia, several key findings emerge. Abdul Halim *et al.* (2014), using hourly rainfall data from 1975 to 2010, and Ng *et al.* (2022), analysing daily rainfall records from 1989 to 2018, observed significant increases in extreme precipitation indices, indicating a rise in both frequency and intensity of rainfall events, particularly during monsoon seasons. Both studies noted the influence of regional climate patterns like NEM and El Niño Southern Oscillation (ENSO) on precipitation extremes. Similarly, Sa'adi *et al.* (2023), examined hourly and daily rainfall records from 1970 to 2015, and reported increasing trends in heavy rainfall days during NEM. Moreover, Cheng and Aghakouchak (2014), utilizing historical rainfall data from 1949 to 2000, noted significant increases in maximum rainfall amounts, particularly in Kelantan, signifying a notable intensification of extreme climatic events in specific areas. However, Wan Zin *et al.* (2010), based on daily rainfall data from 1971 to 2005, found localized variability, with some stations showing increases in extreme rainfall while others exhibited no significant changes post-1980s, including negative trends on the northwest coast and in Kota Bharu, Kelantan. These studies underscore the persistent risks associated with EREs, spanning multiple decades from the late 20th century into the early 21st century. Given the dynamic nature of weather patterns and the variability in study findings, conducting a contemporary analysis is essential to validate recent trends in extreme precipitation over Peninsular Malaysia.

Additionally, these studies rely on station data, which are prone to issues such as sparse spatial coverage, short record

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