Atmospheric drivers of extreme precipitation events in the Indian sub-continent

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INTRODUCTION

- Extreme precipitation events in the Indian sub-continent have profound socio-economic and environmental impacts, particularly due to their role in triggering flash floods.
- These events are driven by a combination of atmospheric conditions, moisture sources and pathways, geomorphology, and hydrometeorology.
- However, while the hydrometeorological and geomorphological factors have been extensively studied, the role of atmospheric drivers and moisture pathways remains underexplored, creating a significant research gap.

Objective

- To analyze the atmospheric processes and moisture sources contributing to widespread extreme hourly precipitation events across the Indian sub-continent during the period 1981–2020.

STUDY AREA

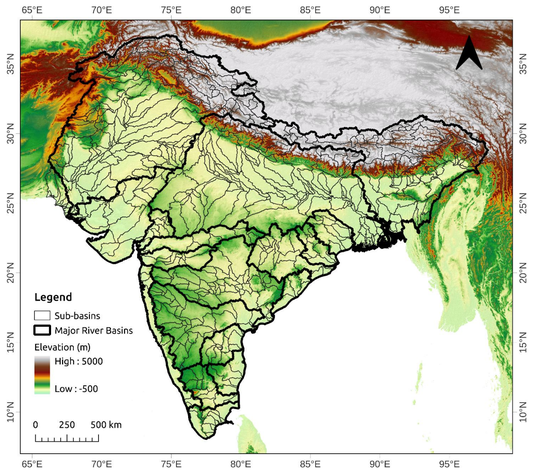

Figure 1. Map of the Indian subcontinent highlighting major river basins across India.

DATA

Type of data	Resolution	Source
Precipitation, Dew point temperature	0.1°/Hourly	ERA5-Land (Muñoz Sabater, J., 2019)
Wind velocity vectors, Relative humidity, Temperature, Geopotential height	0.25°/Hourly at different pressure levels	ERA5 (Hersbach et al., 2023)
Air temperature at 2m, Wind velocity vectors at 10m, Surface pressure, Sensible and latent heat flux, Solar radiation	0.25°/Hourly	ERA5 (Hersbach et al., 2023)

METHODOLOGY

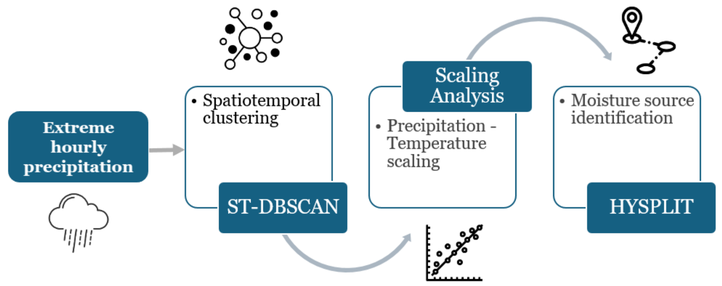

Figure 2. Methodology

- Applied ST-DBSCAN on 6-hourly 99.9th percentile precipitation with a 16 km spatial threshold.
- Performed scaling analysis of hourly precipitation and dew point temperature following Mishra et al. (2012).
- Identified moisture sources using the methodology of Nanditha et al. (2022).

RESULTS

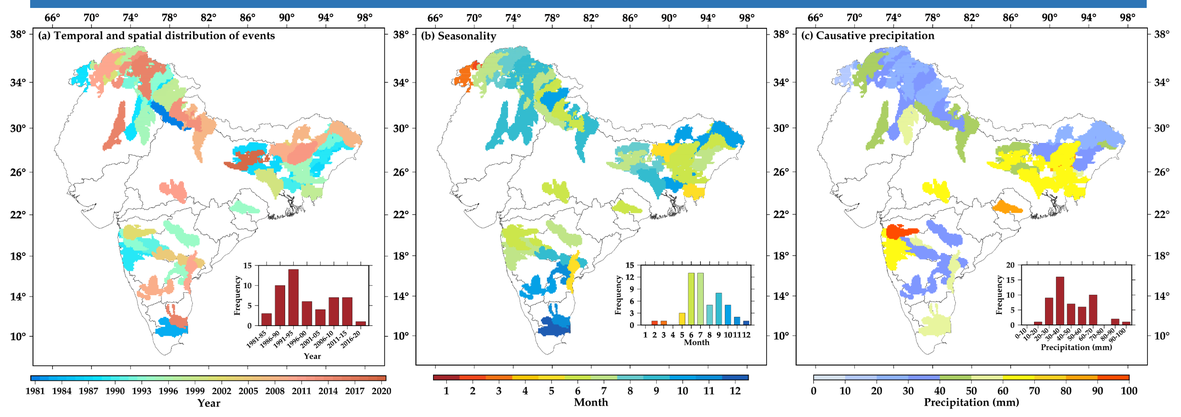

Figure 3. Spatiotemporal characteristics of widespread extreme precipitation events (>50,000 km²) over India (1981–2020).

Events peaked during 1985–1995 and are now becoming more localized. The Himalayas are most affected, with seasonal dominance in JJAS, OND in southern India, and bimodal occurrence in eastern India. All clusters exceed the 99.9th percentile in 6-hour precipitation, with lower intensities mainly in the western Himalayas.

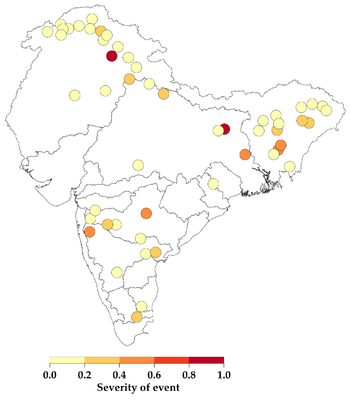

Figure 4. Severity of widespread extreme precipitation events, colored by normalized severity (0–1 scale).

Severity is defined as the product of event duration, precipitation depth, and cluster area. High-severity events are concentrated in the western Himalayas, lower Brahmaputra basin, and parts of peninsular India.

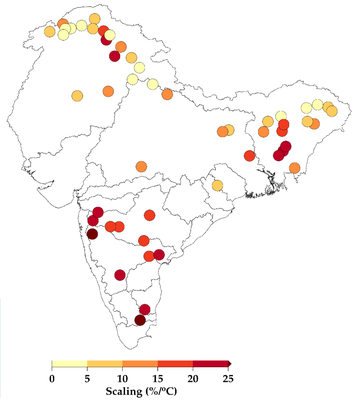

Figure 5. Scaling relationship between hourly precipitation and dew point temperature for event clusters (1981–2020).

Linear regression shows the percentage change in precipitation (>0 mm) per °C increase in dew point (>0°C). Super-scaling is evident in extreme event clusters over peninsular India and the lower Brahmaputra region.

RESULTS

Oceanic moisture dominates extreme precipitation in peninsular India, while recycled land moisture is the primary source over the Himalayas.

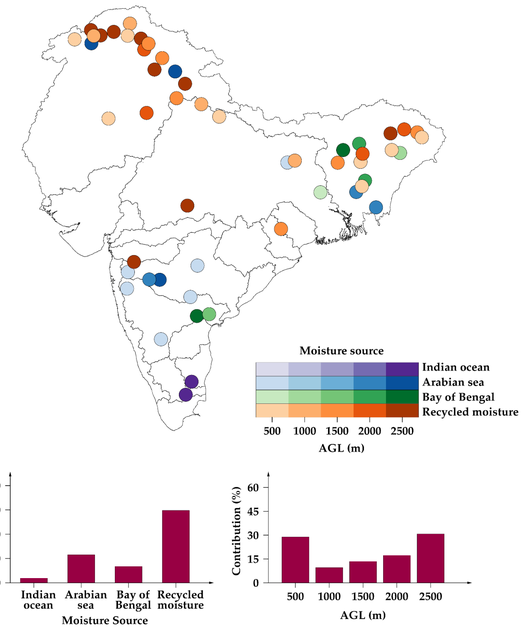

Figure 6. Significant moisture sources for cluster centroids and their respective trajectories above ground level (AGL) reveal distinct regional patterns.

CONCLUSIONS

- Our findings highlight the interconnected dynamics between the atmosphere, land, and ocean in driving extreme precipitation.
- We find the Himalayas as a major hotspot, with most extreme events occurring during the Indian summer monsoon season.
- We observe super-scaling in extreme precipitation event clusters of peninsular India and lower Brahmaputra.
- We find recycled moisture from land surfaces is the dominant source of moisture in the Himalayas, whereas moisture from the Arabian Sea and the Bay of Bengal primarily drives precipitation extremes in peninsular India.
- The study underscores the importance of incorporating atmospheric drivers into disaster management frameworks and early warning systems to enhance preparedness and mitigate impacts effectively.

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References

For references, please scan the QR code.

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