

The Role of Atmospheric Dynamics in Controlling Record Humid Heatwave Characteristics in Disparate Climate Regimes of India

Saptashree Deb, Dr. Poulomi Ganguli

Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, Kharagpur, India

Introduction

- The 21st century has recorded the warmest decade ever, and 2024 was hottest year on record (NASA Earth Observatory 2019).

When Heat Meets Humidity?

High Temperature + High Humidity

South Asian (SAS) is among the Deadliest hotspot (>25000 across SAS: 1992-2020 (WMO, 2022))



- ~ 489 000 heat-related deaths occur each year, with 45% of these in Asia (WHO, 2024).
- India reports 219+ deaths and up to 40,000 heatstroke cases over 2024 summer (TOI 2024; Reuters, 2024).

- Recent heatwaves have also stressed critical infrastructure, exacerbating persistent power outages across South Asia (Climate Analytics 2026)
- in Delhi, peak electricity demand reached a record high of 8,439 MW during the extreme heatwave episode of May 2026 (TOI 2026)

Methods

Determination of daily heatwave magnitude, M_{dly} (●), using the following equation (Lo et al. 2021):

$$M_{dly}(T_{dly}) = \left\{ \frac{T_{dly} - T_{25p}}{T_{75p} - T_{25p}} \right\}$$

accumulated daily heatwave magnitude index (HWMId) ($n \geq 3$):

$$HWMId = \sum_{d=1}^n M_{dly}(T_{dly})$$

The Metastatistical Extreme Value Distribution (MEV)

At first, the ordinary event series, ET_x^w , is fitted with the lognormal, GEV, kernel. The parent distribution $F(x; \theta)$ is selected based on the minimum AIC (Kang et al. 2016), while the goodness-of-fit using the Kolmogorov-Smirnov (KS).

Operationally, the MEV distribution is defined by:

$$\zeta_{MEV}(x) = \frac{1}{M} \sum_{j=1}^M [F(x; \theta_j)]^{n_j}$$

the number of events/year (n)

the parameters (θ) of the "ordinary" distribution ($F(x, \theta)$)

where M is the number of years on record, $F(x; \theta_j)$ is the selected parent distribution of the ordinary values in the j^{th} year, and n_j is the number of events in the j^{th} year.

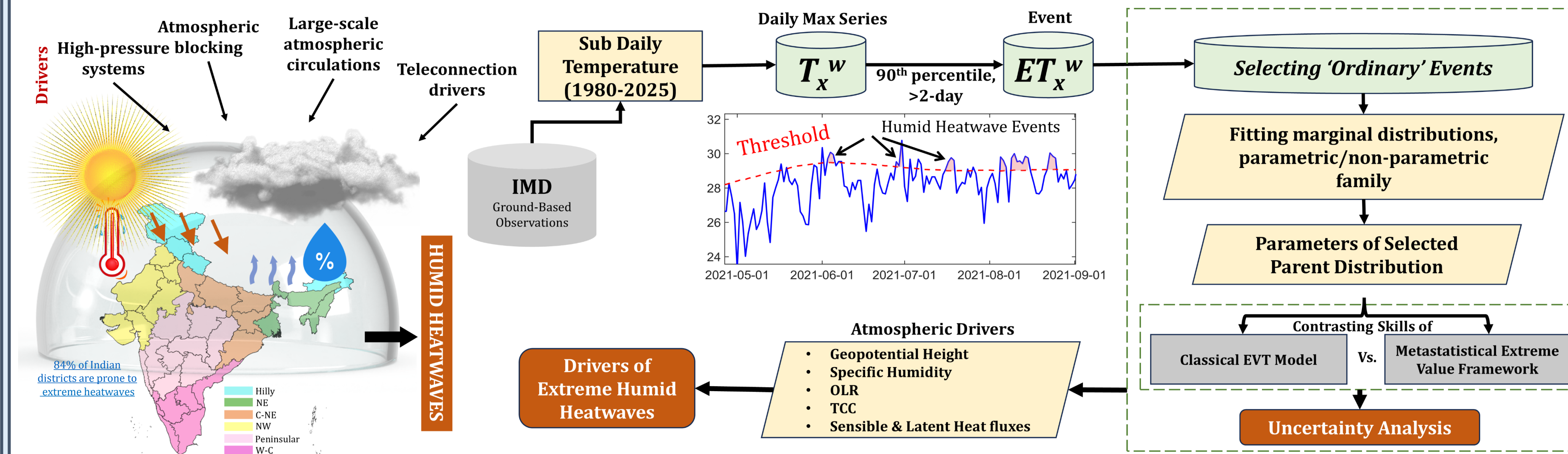


Fig. Workflow of overall analysis

Results

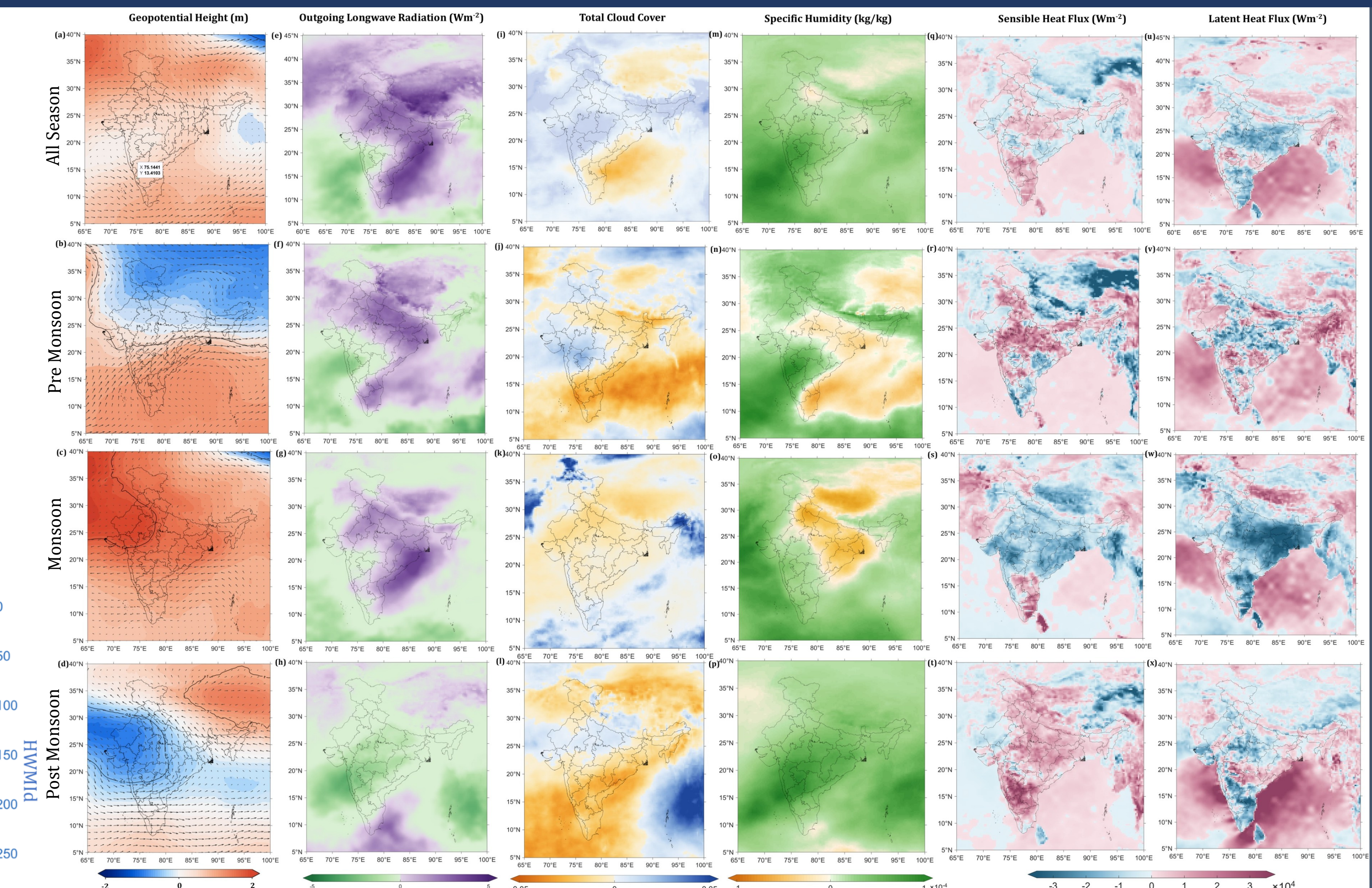
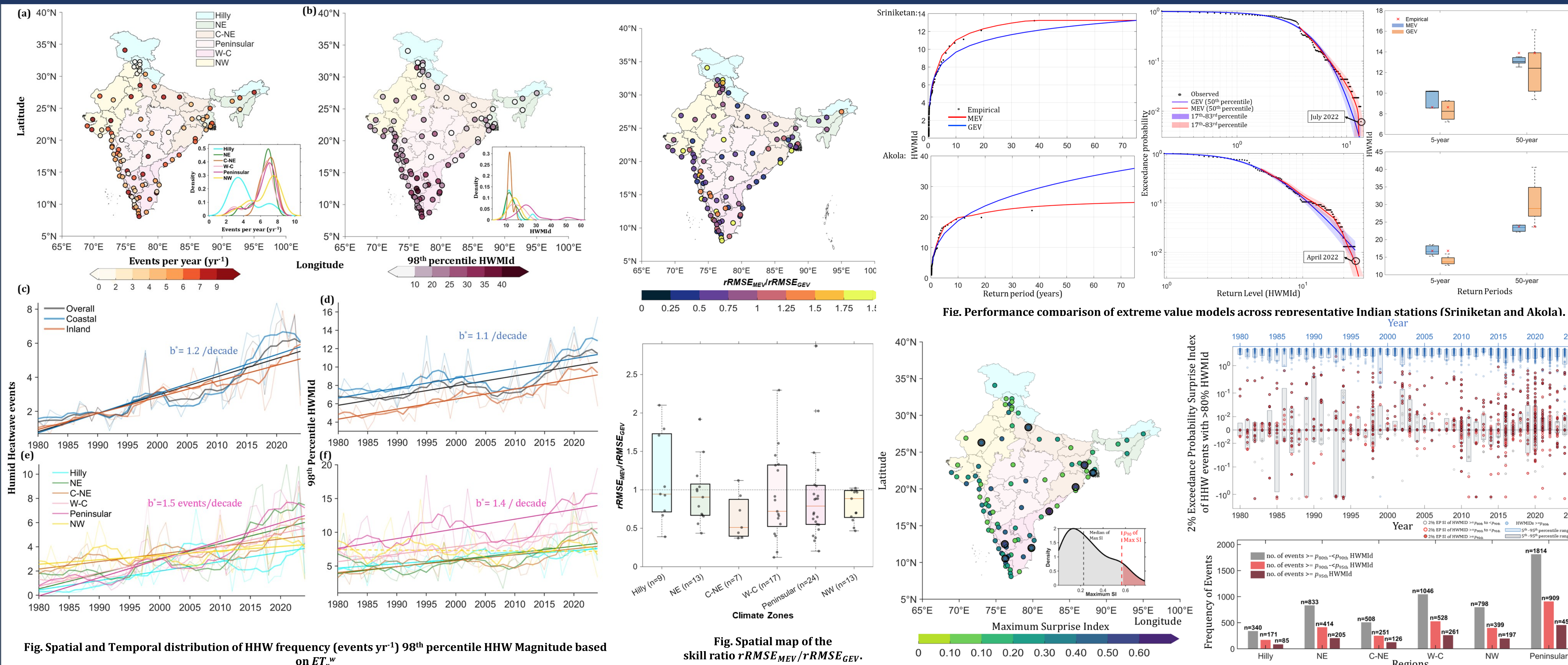


Fig. Composite anomalies of large-scale atmospheric controls during extreme humid heatwaves, including the record-breaking events across India.

Discussion

- 70% of the cities show RMSE ratio <1, indicating MEV outperforms GEV across most sites. Peninsular, Northeast, and West-Central zones show more stable performance ratios.
- The heavier upper tail behaviour indicated by large variations in the SI in post-2010s, show record HHW events tend to become more frequent in recent years.
- HHW composites reveal spatially disparate anomalies in atmospheric circulation, moisture, cloud cover, radiation, and surface heat fluxes during extreme HHWs across Indian subcontinent for all seasons combined, pre-monsoon, monsoon, and post-monsoon periods.

Related Publication

- S. Deb, A. Raut, P. Ganguli, in *Climate Change Impact on Water Resources*, J. Das, N. V. Umamahesh, J. H. Pu, M. Pandey, Eds. (Springer Nature, Singapore, 2025), pp. 357–371. DOI: 10.1007/978-981-97-9180-4_23
- Deb, S., Sherke, S. R., Ganguli, P.: Shifting Patterns of Summer Humid Heatwaves Highlight Growing Threat over South Asia and Middle East–North Africa. *Climate Dynamics*. Manuscript ID: CLDY-D-25-00841(R1).