

Multivariate Approach Reveals a Higher Likelihood of Compound Warm-wet Spells in Urban India



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Sucheta Pradhan,
Dr. Poulomi Ganguli



Indian Institute of Technology
Kharagpur, India

This presentation participates in OSPP



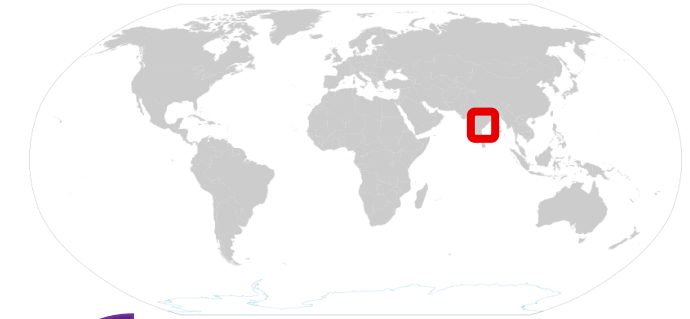
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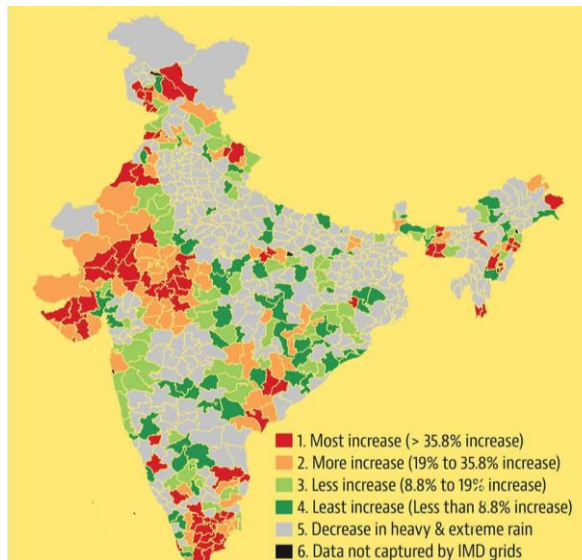
BY

Compound Heat-stress - Pluvial Flood

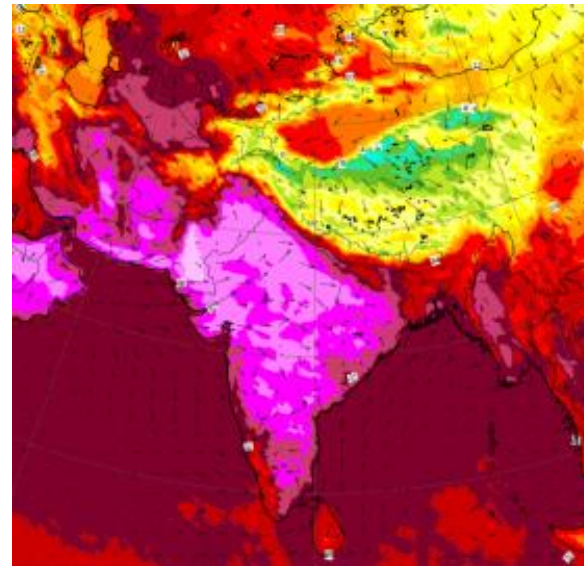
- Indian subcontinent is one of the hotspots of *deadly heat stress* ([IPCC AR6: Physical Sciences basis, 2021](#)).
- Increasing trend in *heavy precipitation* and *floods* over several locations of South Asia during past few decades ([Roxy et al. 2017](#); [Masson-Delmotte et al., 2021](#))
- Coincidence of heatwaves-extreme rain driven pluvial floods in a short time window would have a devastating consequences on *agro-ecosystem, natural, & built environment systems* ([Porter et al., 2014](#); [FAO 2015](#), [Wang et al., 2021](#)).



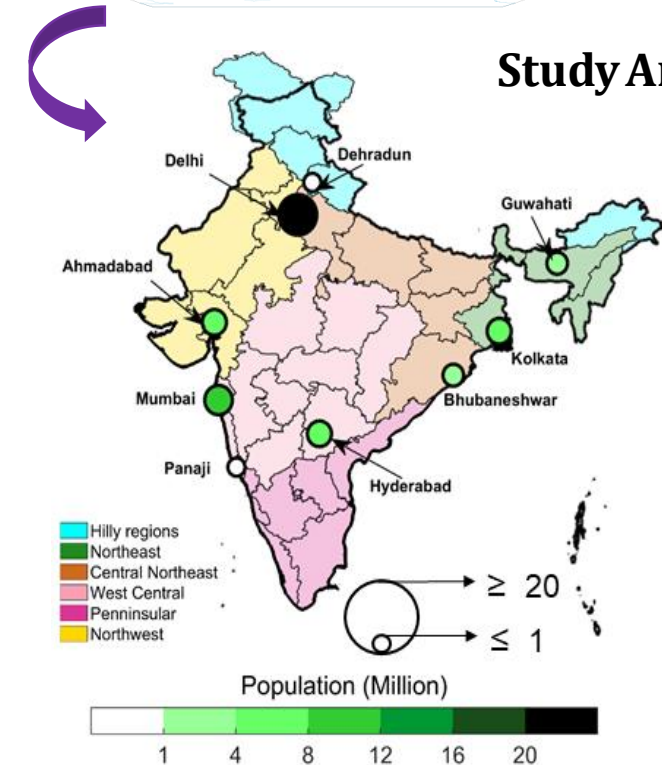
Study Area



Changes in rainfall wrt 30-yr LPA



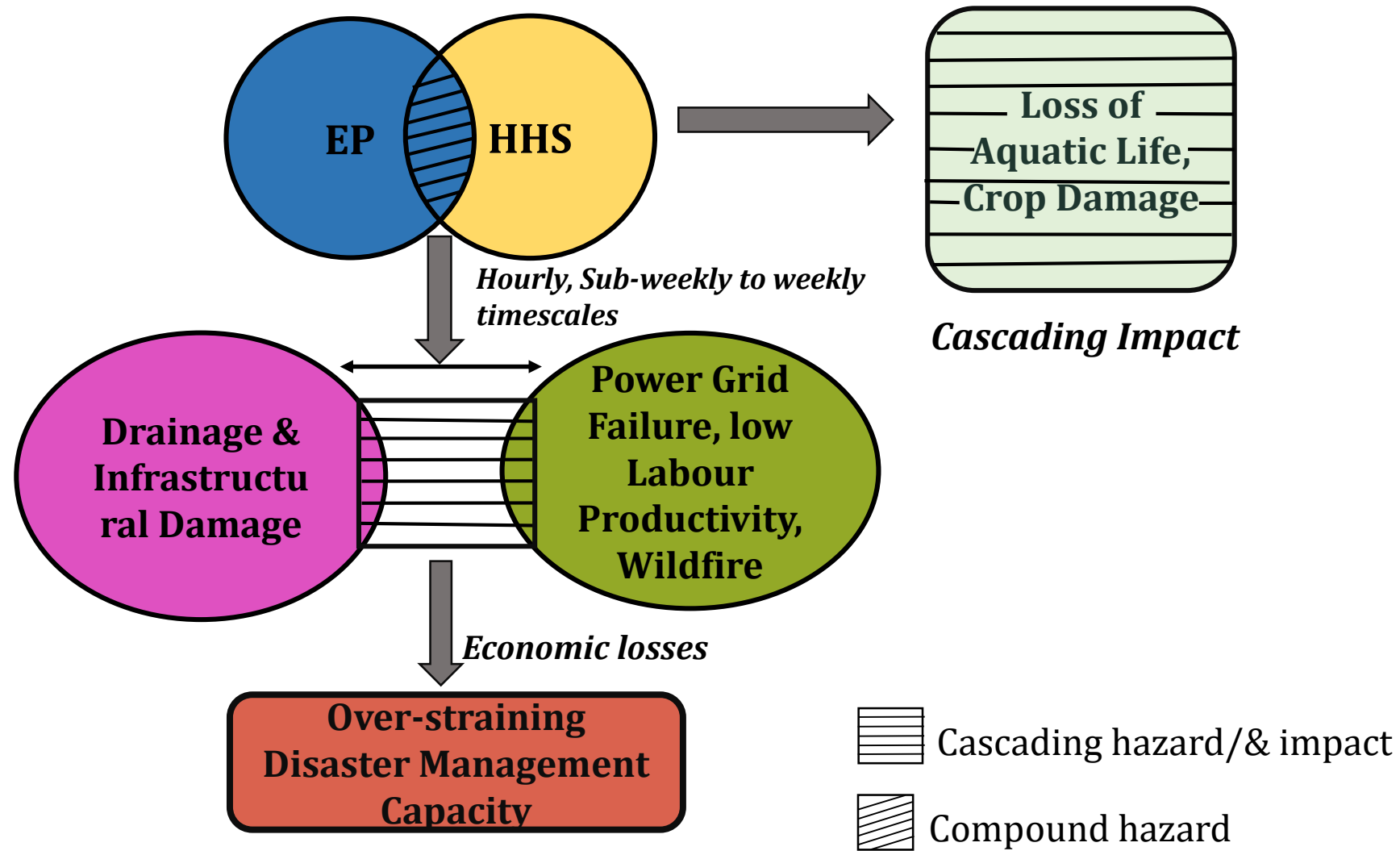
Heatwave spells in ([WMO, April 2022](#)).



Research Gaps

- Most of the studies have assessed trends in heatwaves, droughts and dry spells considering the **dry bulb** temperature only ([Saeed & Schleussner, 2021](#)).
- Very few studies have investigated concurrent or successive (lagged d -day) occurrence of extremes, i.e., **HHS-EP** (Humid Heat Stress-Extreme Precipitation) over **tropics**.
- No unified assessments → over **homogeneous monsoon regimes** of India.
- Most studies focused on univariate assessments and underestimate the risk of interdependency between triggering drivers ([Zscheischler & Seneviratne, 2017](#)).

Interactions of Compound Hazards vs Cascading Impact



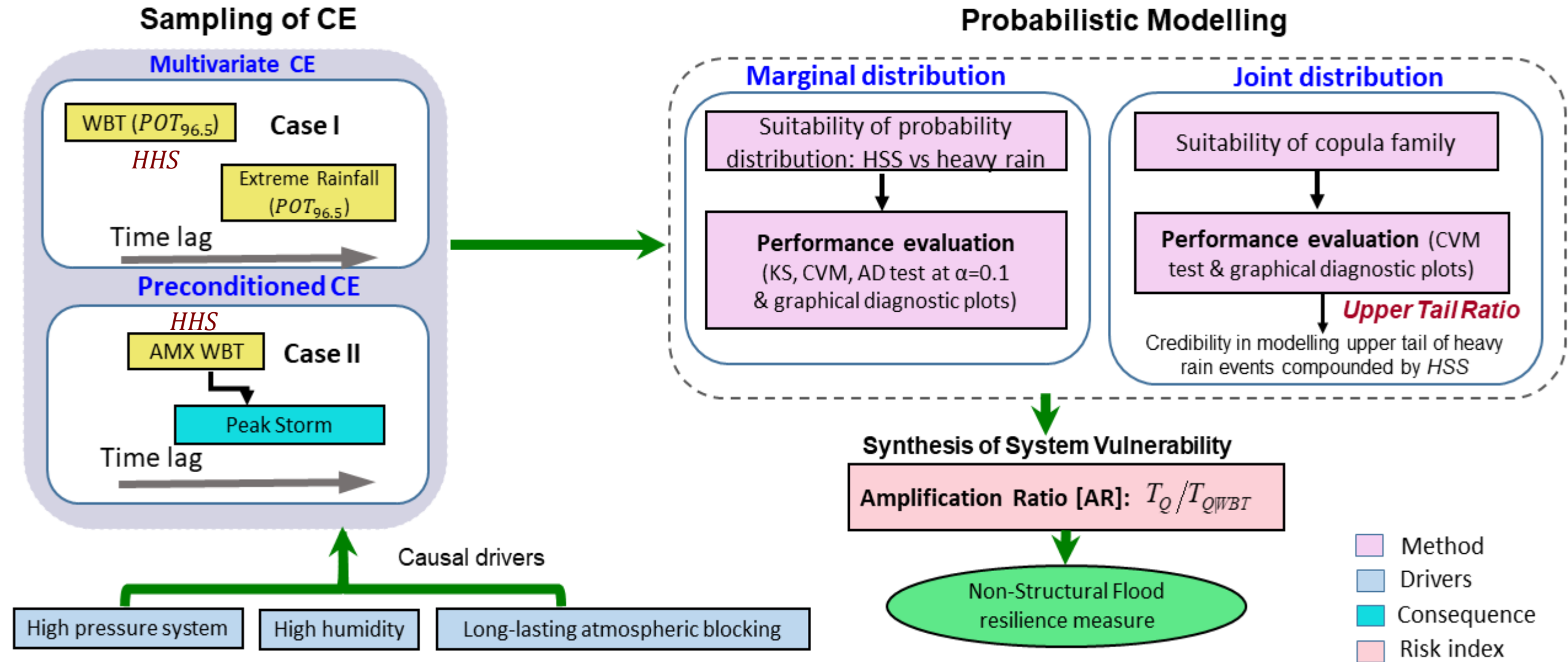
Heat wave



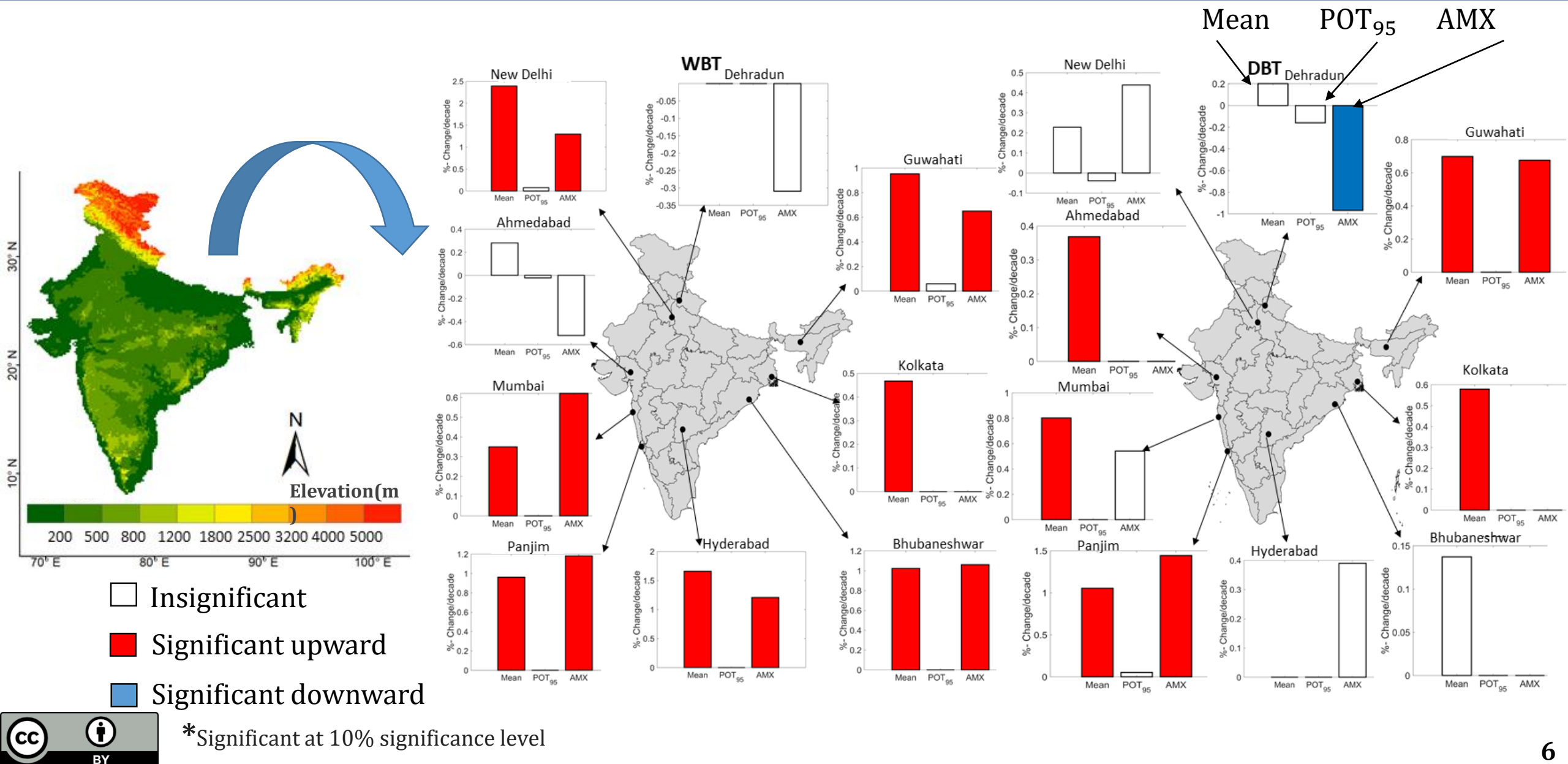
HHS-induced Flooding



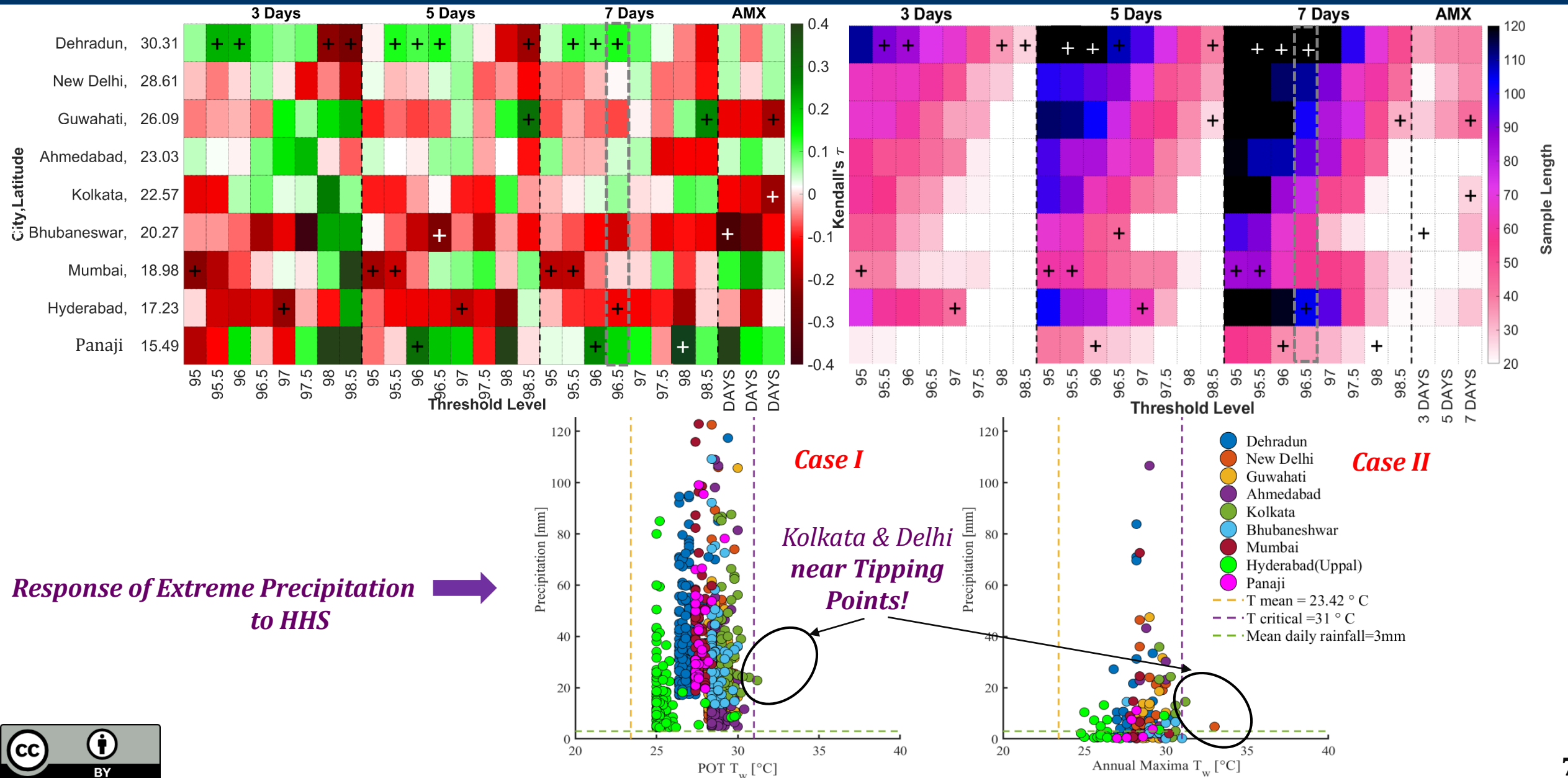
Methodology: CCP – Framework for Assessing Compound Hazards



Trends in Mean vs Extreme Dry/Wet-bulb Temperatures

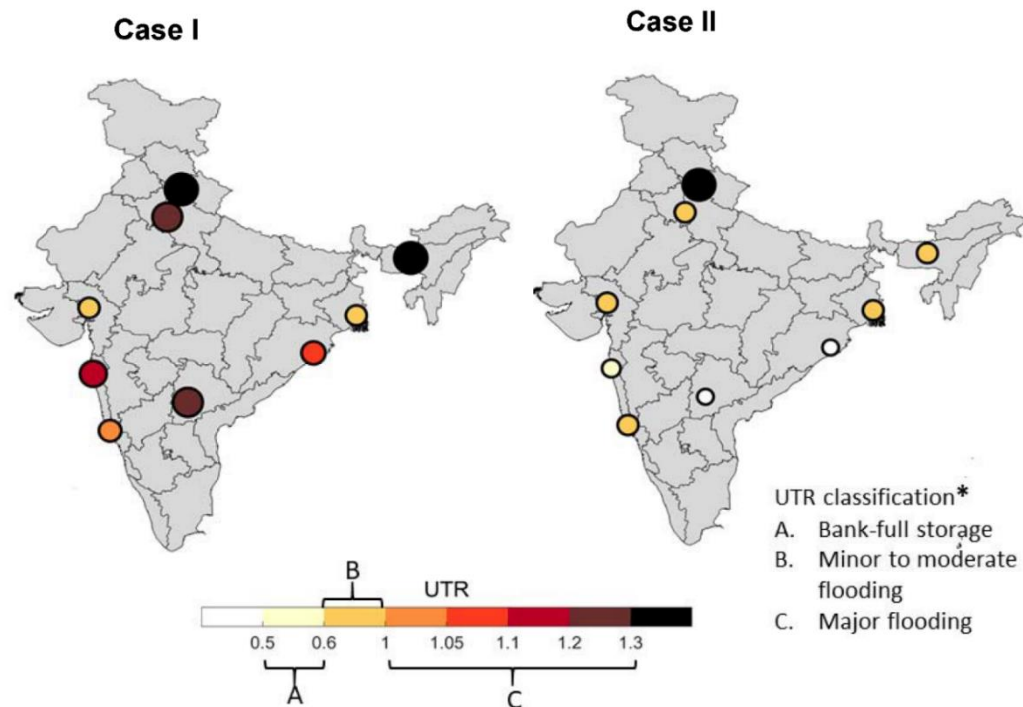


Variability in Dependence pattern of HHS-EP Compound Events



Upper Tail Distributions of Extreme Rain in Response to Warming

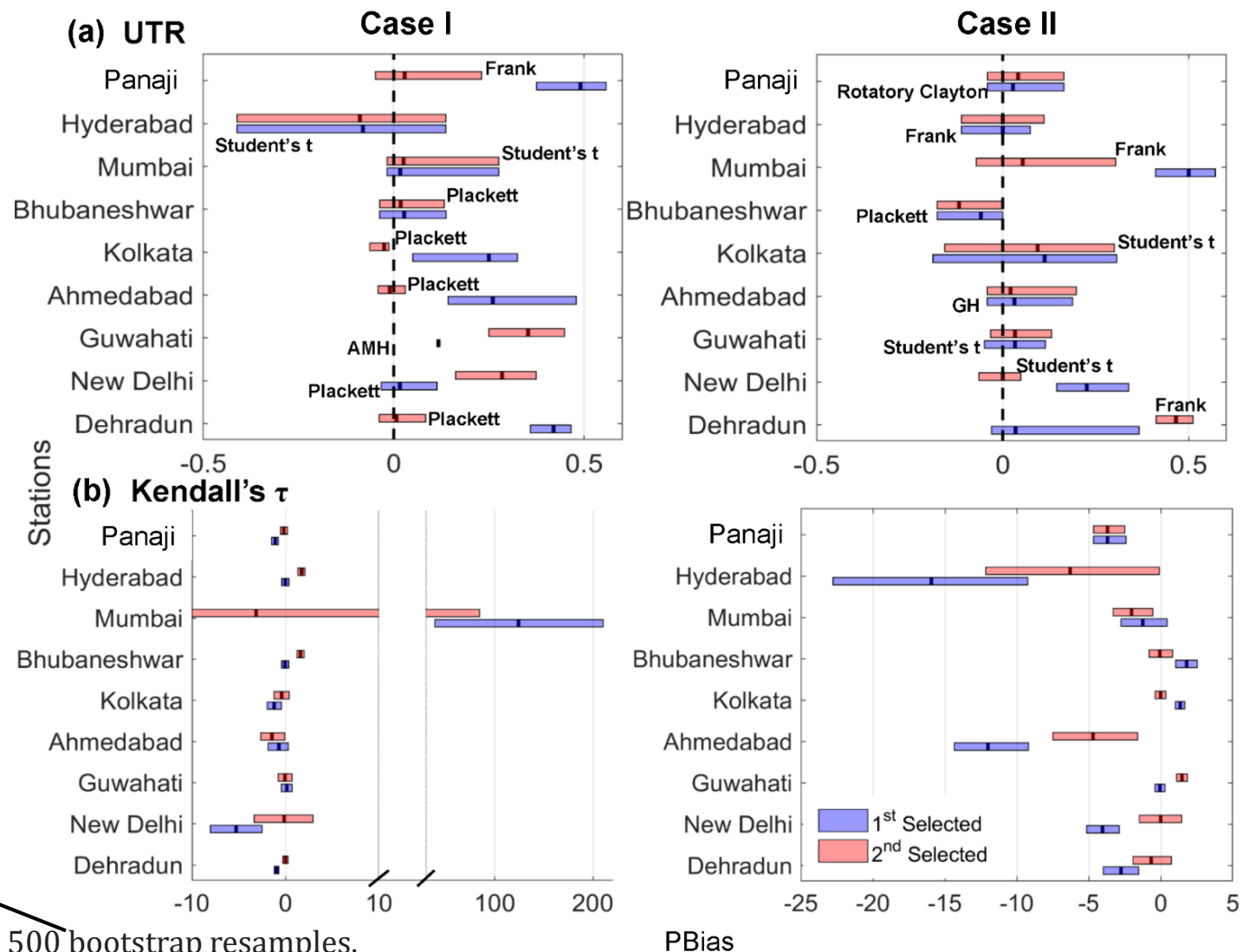
$$UTR = \frac{\text{Maximum precipitation depth within a week of occurrence of HSS}}{\text{Atsite 10-year return level of JJAS maxima precipitation}}$$



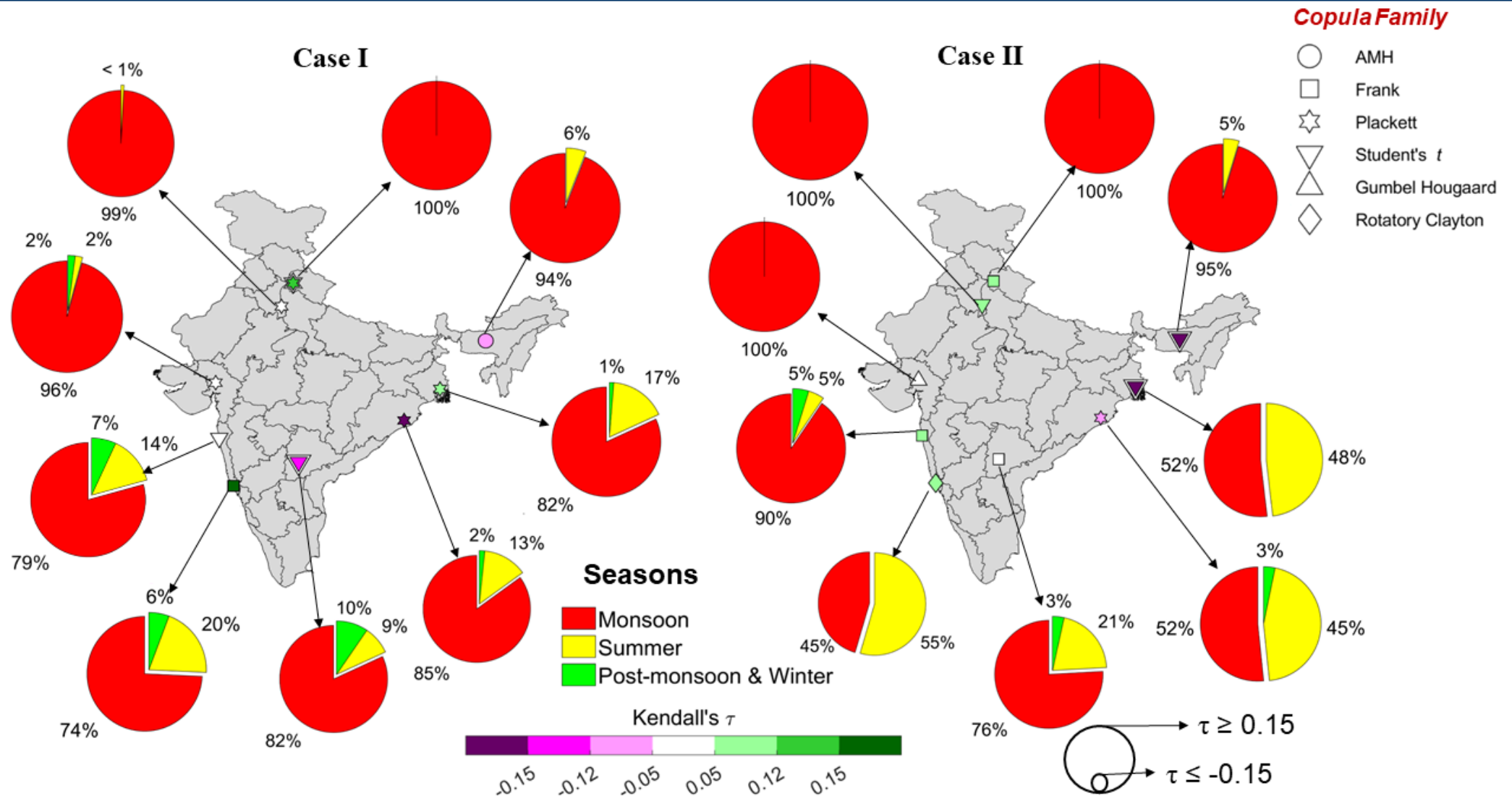
$$PBias = \frac{UTR_{observed} - UTR_{simulated}}{UTR_{observed}}$$

Obtained from 500 bootstrap resamples.

Uncertainty Assessment in Copula-Fit: Upper Tail & Total Dependence

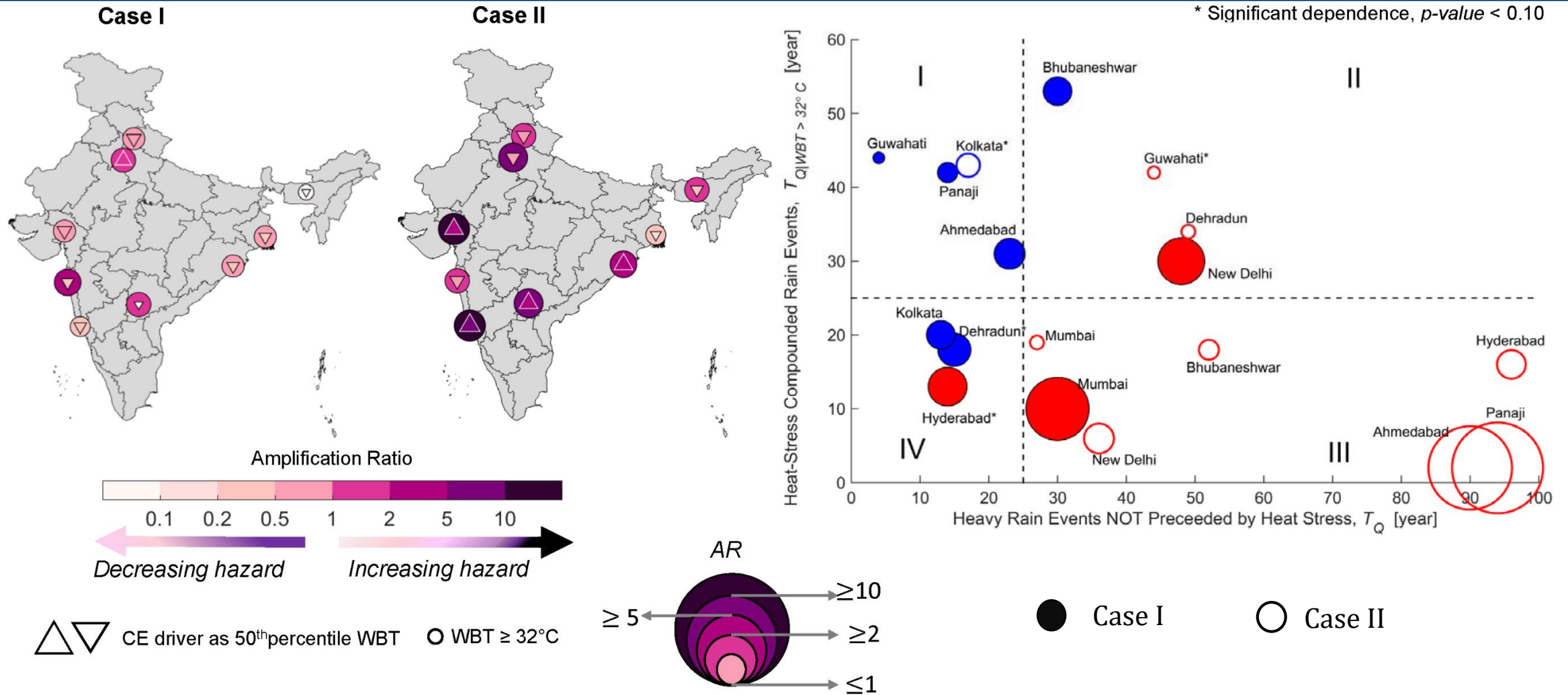


Time of Emergence of HHS-EP Compound Events



Total dependence through Kendall's τ

Spatial Variations in HHS-driven Extreme Rainfall Risk

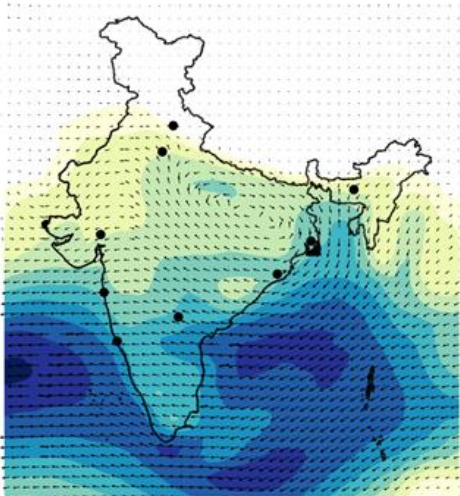


$$AR = \frac{\text{Return period of at-site peak rain event}}{\text{Conditional return period of extreme precipitation compounded by the HHS event}}$$

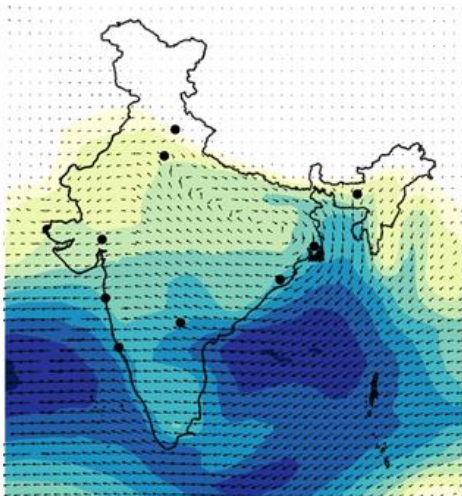
Causal Attribution in *HHS-EP* Compound Events: Evidence of More Moisture Convergence

Case I

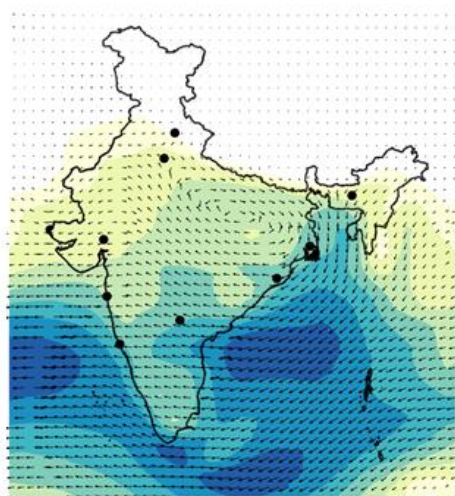
Moisture Transport on the Day of HS



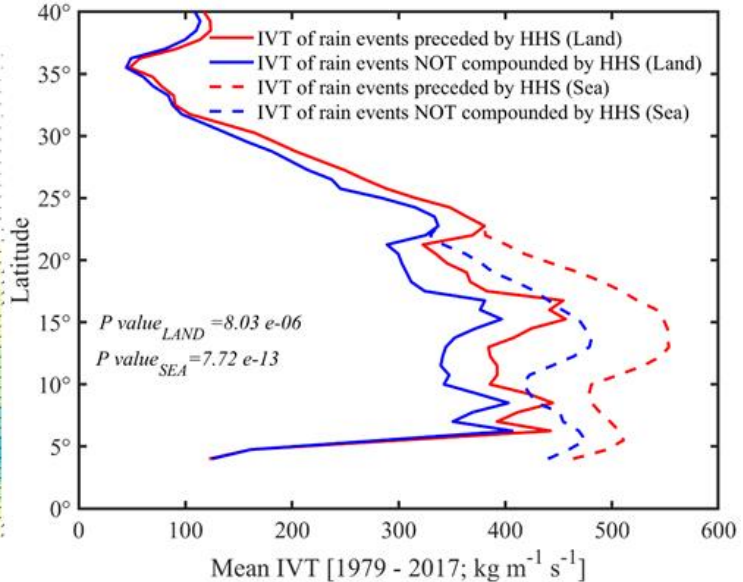
Moisture Transport on Precipitation Days Preceded by HS



Moisture Transport on Precipitation Days NOT Preceded by HS

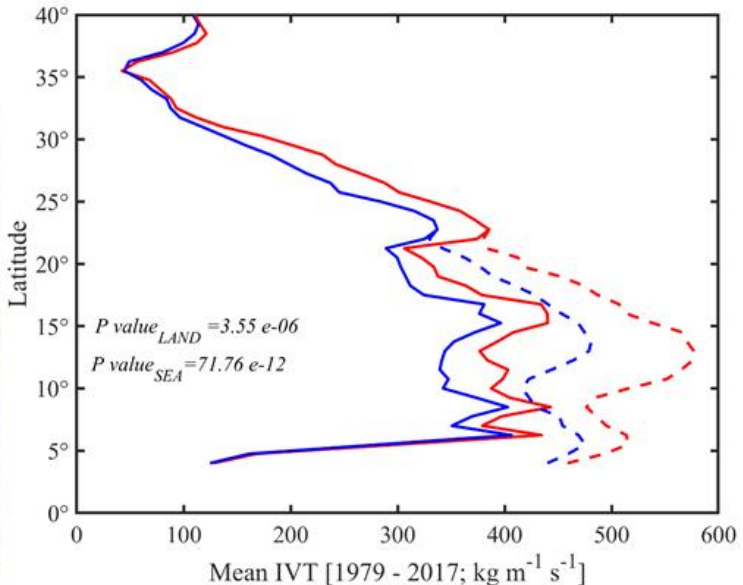
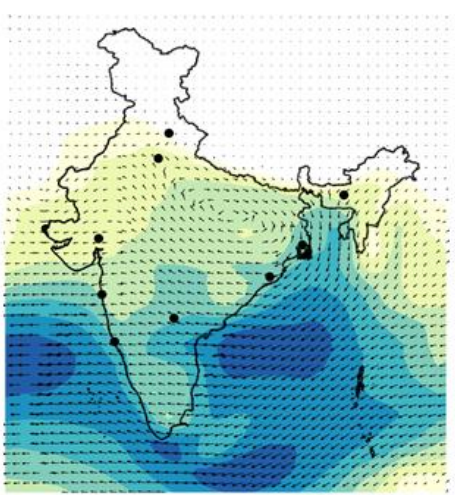
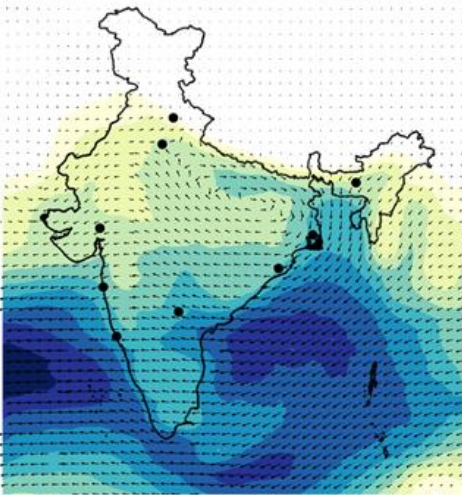
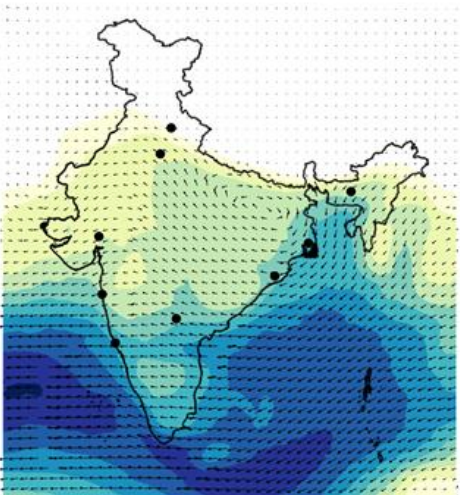
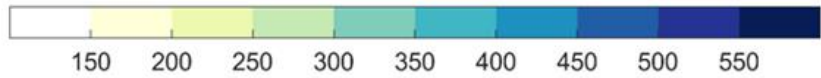


Zonal maxima of Mean IVT



Case II

Mean IVT [1979-2018; kg m⁻¹ s⁻¹]



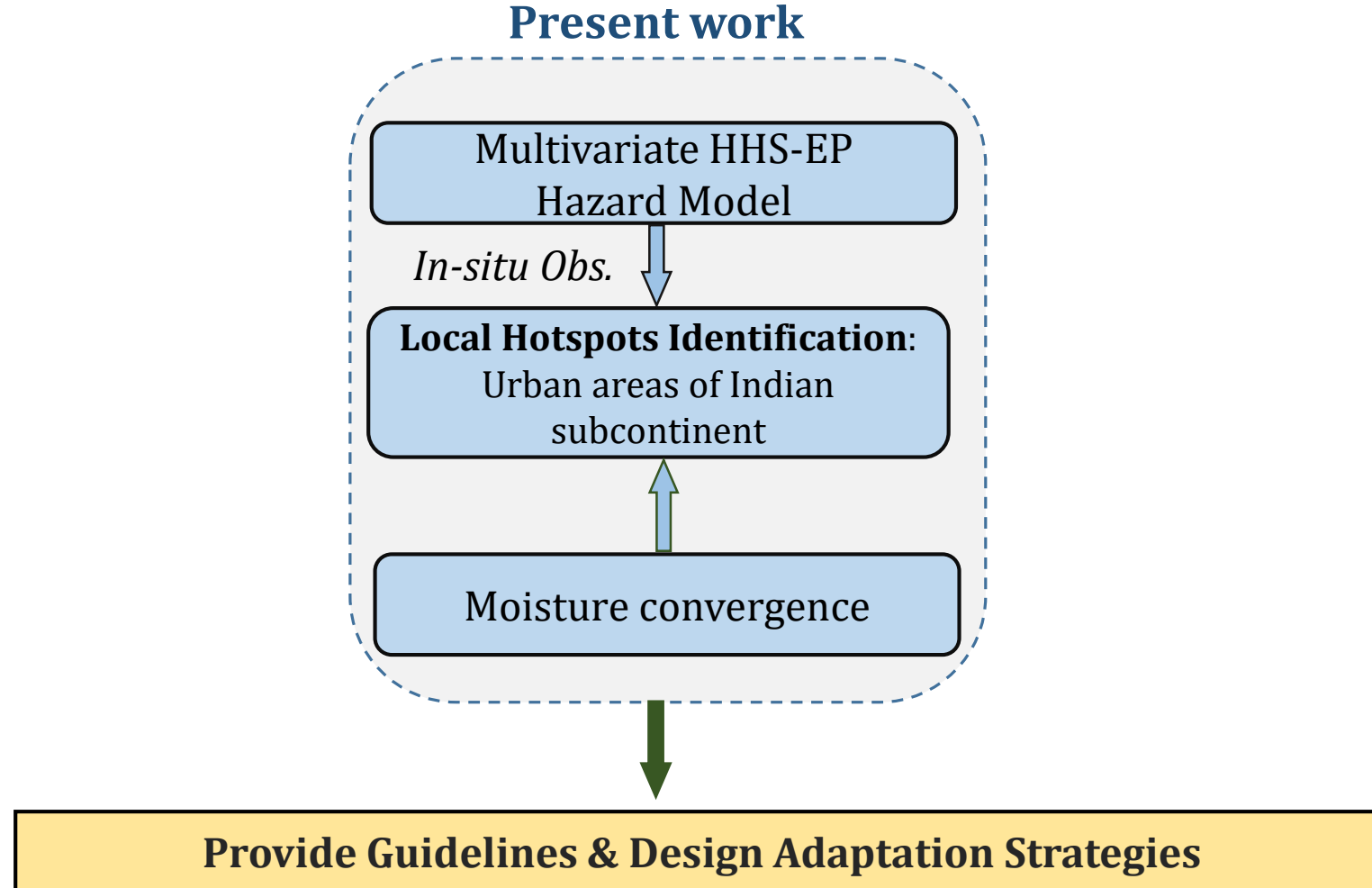
Concluding Remarks

❑ Spatial Heterogeneity in Dependence Pattern of HHS-EP Events

- Assessed compound event potential of HHS-EP events across urban agglomerates of India via two cases:
 - ❑ **Case I:** 96.5th percentiles of drivers → HHS & EP
 - ❑ **Case II:** Annual maxima HHS & rainfall peak
- **UTR** suggests susceptibility to moderate to severe rain-induced flooding compounded by the HHS events

❑ Precipitation Frequency Amplification and its link to Moisture Convergence

- **Moisture convergence** is more pronounced during precipitation days preceded by the HHS.
- CCP-framework identifies “**hotspot**” cities
 - ❑ Case I: Mumbai, New Delhi & Hyderabad
 - ❑ Case II: Ahmedabad, Panaji, Hyderabad, New Delhi & Bhubaneshwar



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4. Saeed, F., Schleussner, C.-F. & Ashfaq, M. Deadly Heat Stress to Become Commonplace Across South Asia Already at 1.5°C of Global Warming. *Geophys. Res. Lett.* 48, e2020GL091191 (2021).
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6. Tandon, N. F., Zhang, X. & Sobel, A. H. Understanding the Dynamics of Future Changes in Extreme Precipitation Intensity. *Geophys. Res. Lett.* 45, 2870–2878 (2018).
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Thank You
Any Questions



Contact:

Sucheta Pradhan(sucheta98@kgpian.iitkgp.ac.in)

Dr. Poulomi Ganguli (pganguli@agfe.iitkgp.ac.in)

