Investigating Spatiotemporal Patterns of Soil Moisture - Precipitation Dependence over India

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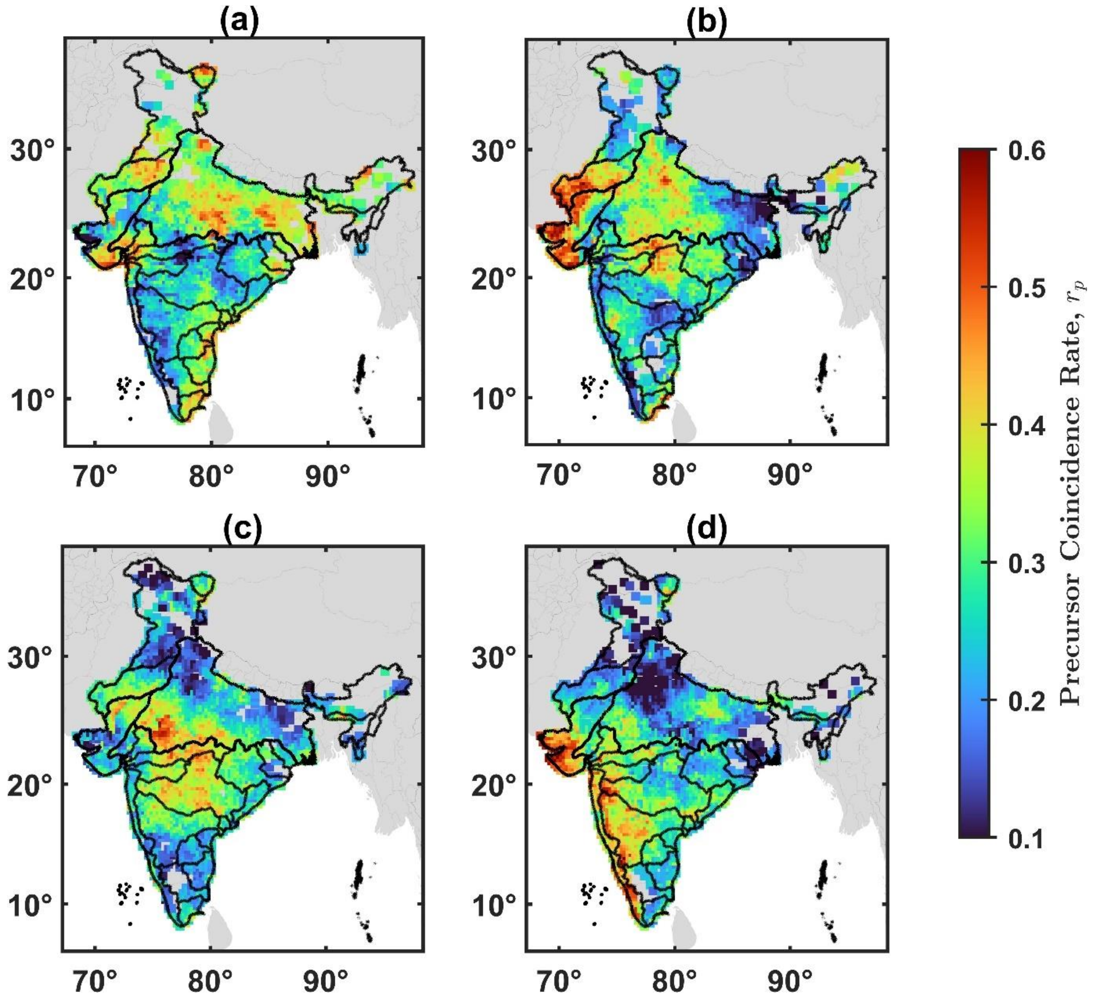
In Hydrocomplexity: Addressing Challenges in Hydrology from a Holistic Perspective III Online Discussion Session (319)

22 June'22



Learning from IPCC AR6

- **Climate Change** - impacted almost all phases of the global water cycle[1]
- Extreme Precipitation events have **increased – past few decades**[1,2]
- Observed increases in precipitation extremes – not directly translated to observed increases in **flooding**[3,4]
- Decrease in **antecedent soil moisture –** decline in observed flood discharge[4]
- Preconditioned Compound Event[5]

IPCC AR6 – ***"Low confidence in regional changes on flood frequency as it is strongly dependent on antecedent conditions!!!"***

1) IPCC AR6 – 2021
2) Roxy et al., 2017
3) Sharma et al., 2018
4) Wasko et al., 2020
5) Zscheischler *et al.* 2020

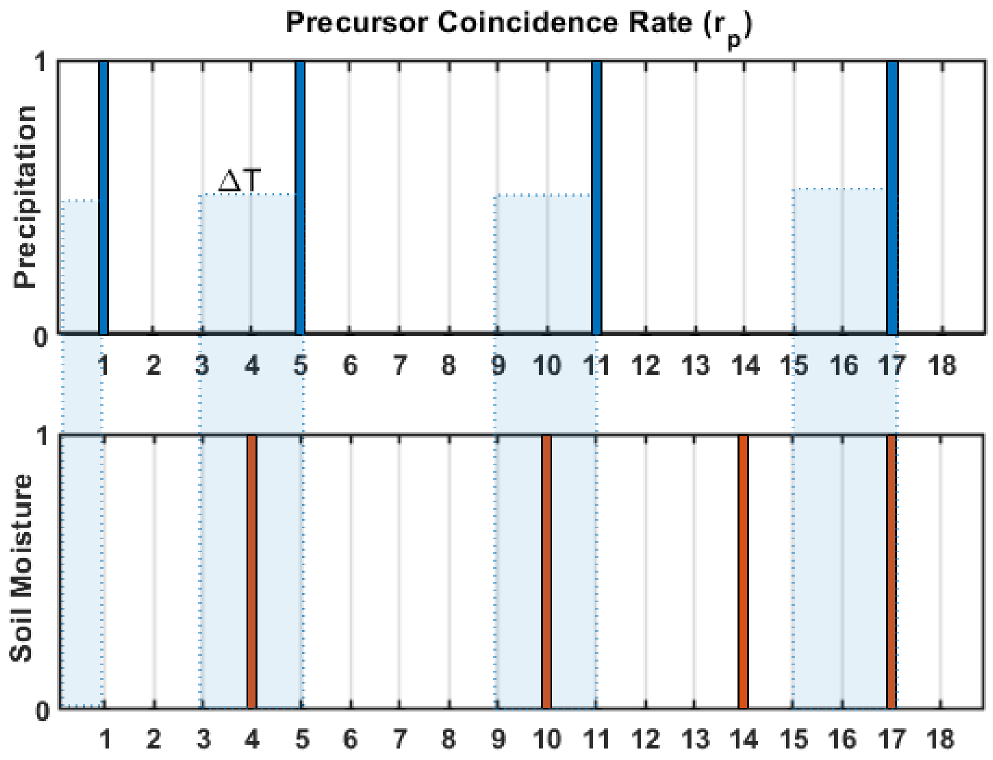
Research Objectives

RO1 How to quantify and characterize the **spatiotemporal patterns** of SM –P dependence?

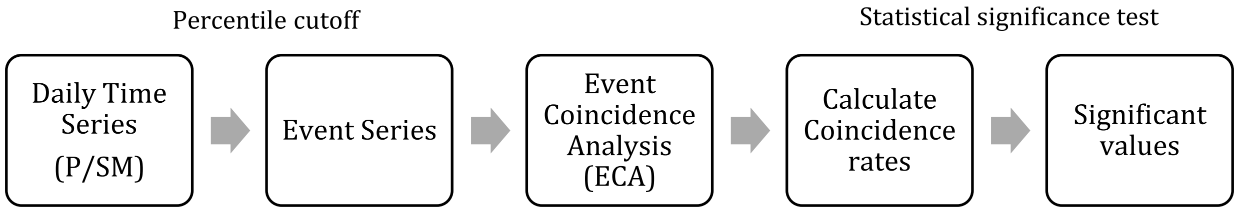
RO2 Does the SM-P patterns undergo **spatial/temporal shifts** over time?

Do the **temporal evolution** correspond to **changing flood** patterns?

Event Coincidence Analysis



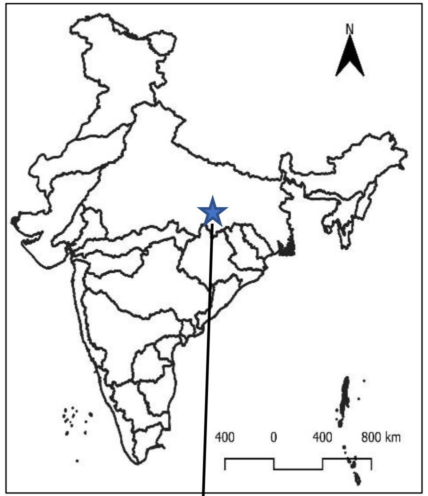
- Event Coincidence Analysis[1,2,3] (ECA) – quantifies and characterize - coincidences between event series
- Helps to consider the timings of well-defined events
- Two parameters - temporal tolerance interval ΔT and joint time delay of τ
- Statistical significance test[3] to ensure that observed coincidences are not random
- Recent studies[4] – disentangled SM-P Covariation patterns using ECA

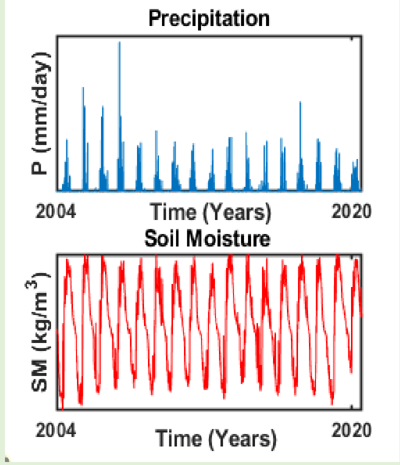


1) Donges et al., 2011, 2016
2) Siegmund et al., 2016
3) Siegmund et al., 2017
4) Sun et al. 2018

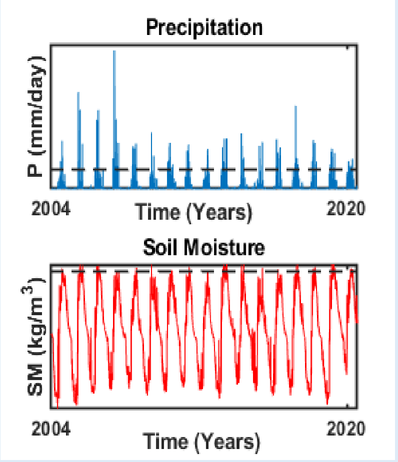
Methodology & Data

Step 1 – Data Preparation

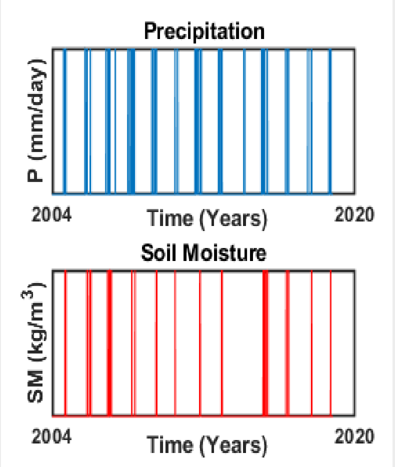




Step 2 – Percentile Cut-off



Step 3 – Event Series



Step 4 – Tail Dependence

Limit of Tail Dependence:

$$\chi = \lim_{u \to 1} P\left(F_Y(y) > u \mid F_X(x) > u\right)$$

Tail Dependence Measures:

$$\chi(u) = 2 - \frac{\log P\left(F_X(x) < u, F_Y(y) < u\right)}{\log P\left(F_X(x) < u\right)}$$

$$\bar{\chi}(u) = \sum_{0.90 < u \leq 0.95} \chi(u)$$

Step 5 – ECA

Precursor coincidence rate

$$r_p = \frac{1}{N_P} \sum_{i=1}^{N_P} H\left(\sum_{j=1}^{SM} I_{[0,\Delta T]}\left((t_i^P - \tau) - t_j^{SM} \right) \right)$$

Trigger coincidence rate

$$r_t = \frac{1}{N_{SM}} \sum_{j=1}^{N_{SM}} H\left(\sum_{i=1}^{N_P} I_{[0,\Delta T]}\left((t_i^P - \tau) - t_j^{SM} \right) \right)$$

Significance test at $\alpha = 0.05$

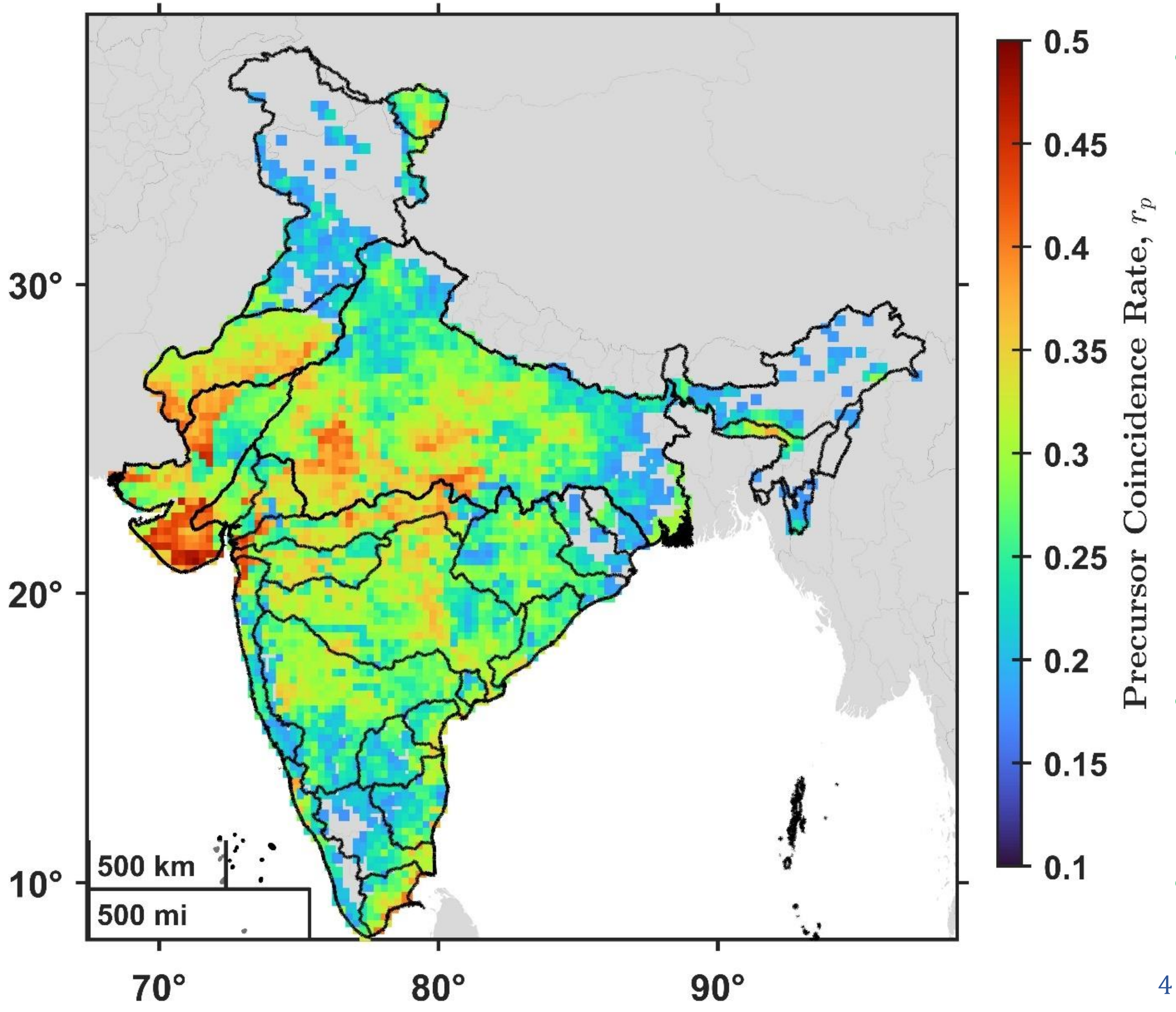
Precipitation

- GPM – Global Precipitation Measurement
- $0.1° \times 0.1°$
- IMERG - Integrated Multi-satellitE Retrievals for GPM
- IMERG – Version 06

Soil Moisture

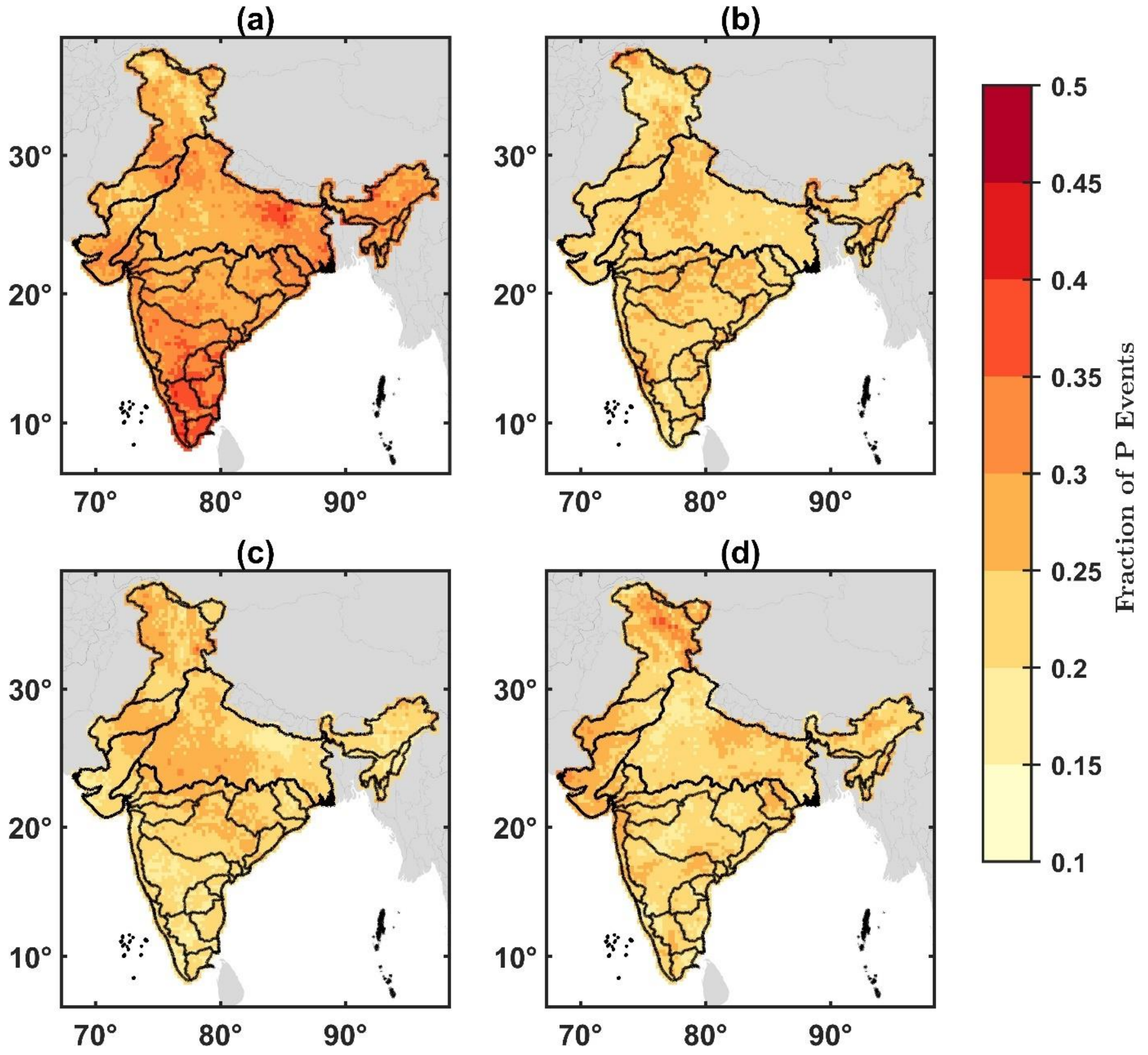
- NASA's Global Land Data Assimilation System
- $0.25° \times 0.25°$
- GLDAS – CLSM 2.2
- With GRACE-Data Assimilation

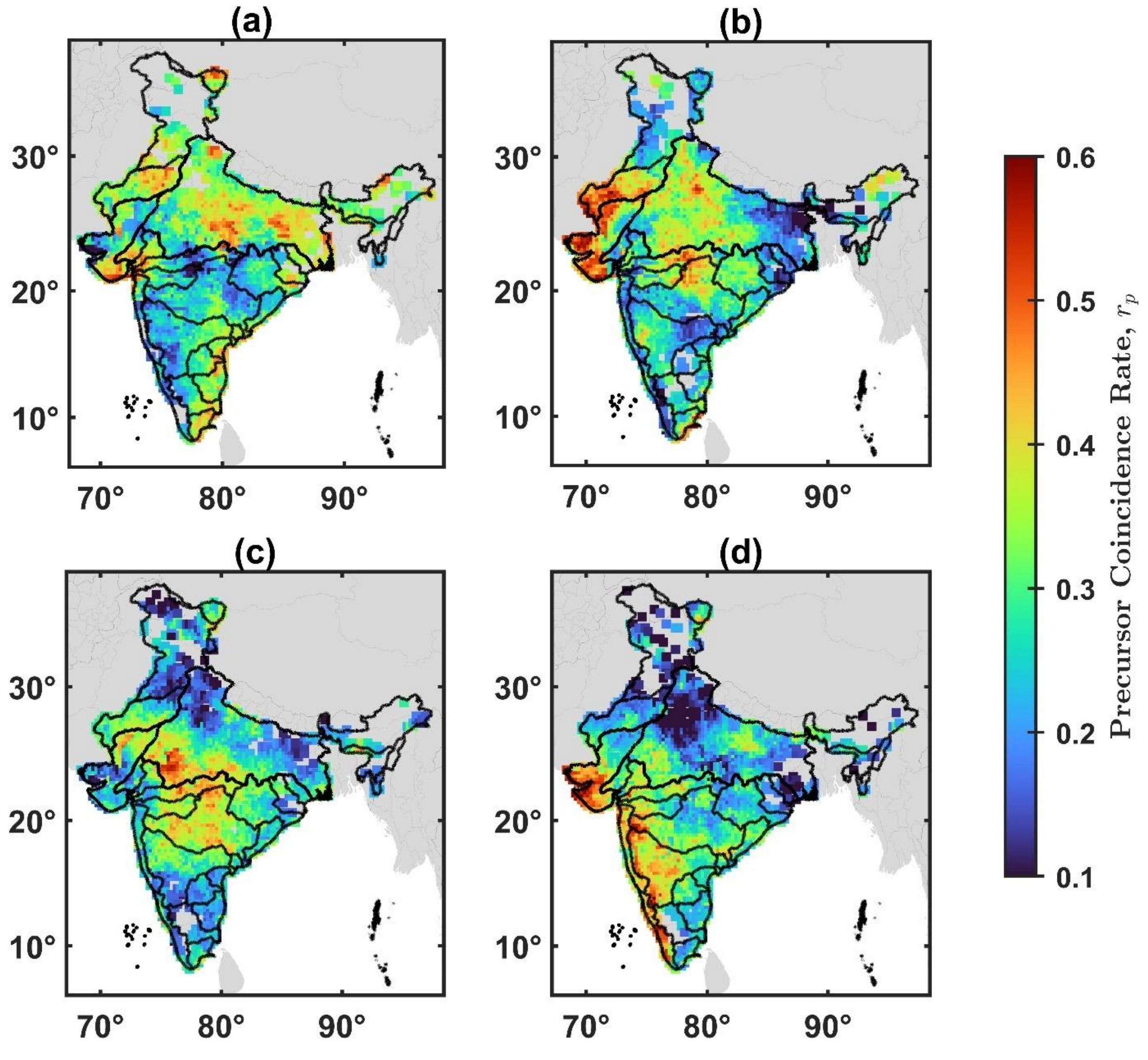
Spatiotemporal evolution of SM-P



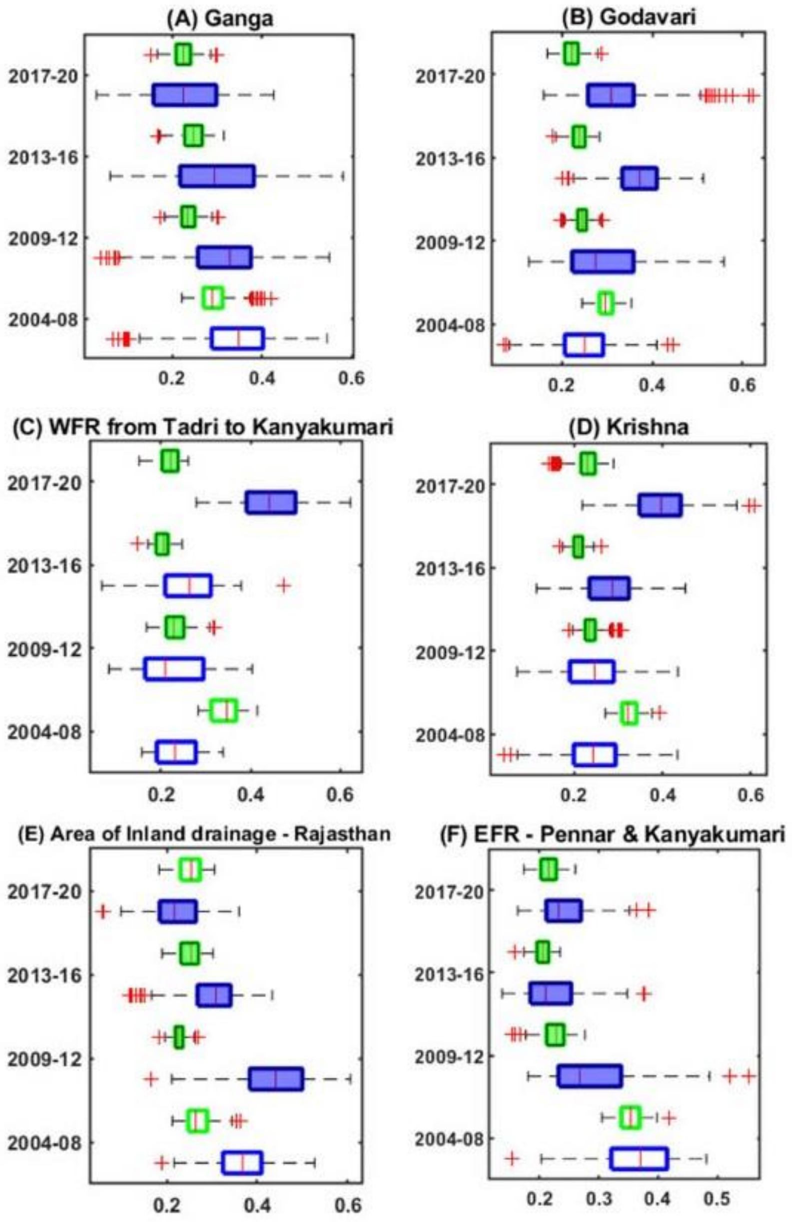
- Temporal Tolerance – 2 days
- Grid points with r_p>0.40 (40% of P events were preceded by SM event) - Ganga river basin (2A), West flowing rivers of Kutch and Saurashtra including Luni (18), inland drainage of Rajasthan (19), and Narmada river basin (12)
- SM-P preconditioning - weaken - towards the corners of the country
- Impact of **temporal evolution**?

Spatiotemporal evolution of SM-P



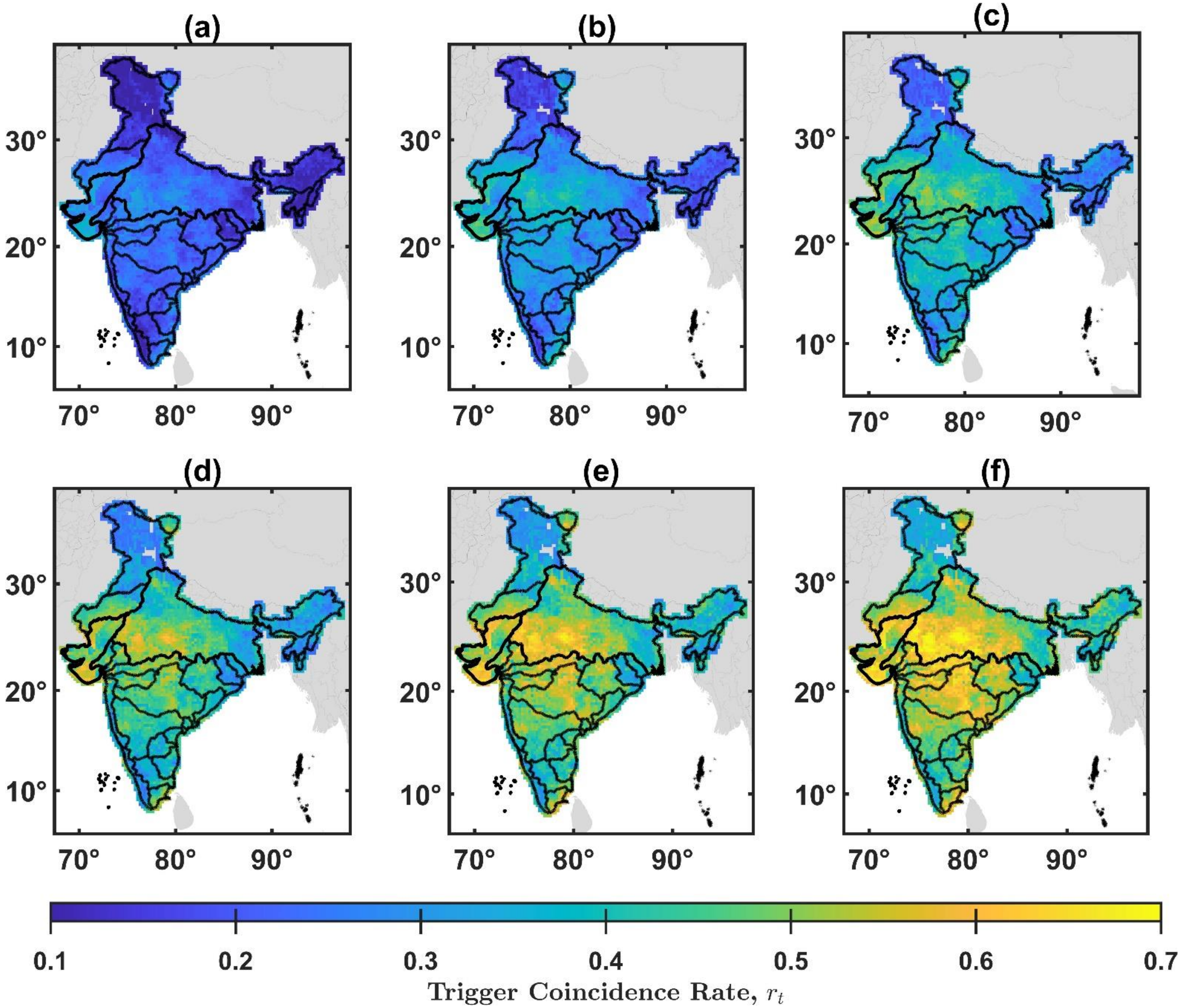


Basin-scale Analysis



- SM-P preconditioning has undergone significant changes over the years
- Visualize the change in the hydrological regime and compare it with the influence of possible meteorological forcings
- Temporal evolution of precursor coincidence is seen to be insensitive to the changes in the proportion of P extreme events
- Intensification of precipitation
- Role of catchment conditions and other land-use factors

Trigger Relationship between SM&P



- Possible SM-P coupled relationship
- Our regions matches - increased soil moisture - precipitation coupling in transitional regions between wet and dry climates
- Preliminary analysis only
- Difficulties in establishing causal relation from observational data

Take Home Message

- ECA can be used as an additional tool in hydro-metrological studies
- Temporal Evolutions – disconnect between P events and precursor coincidence
- Possibly due to intensification of extreme precipitation, changing LULC
- Clustering of trigger hotspots - dominant atmospheric coupling mechanisms between P and SM.
- These locations can be regarded as proxies and provide additional information in forecasting extreme precipitation events

Thank you!!

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https://doi.org/10.1016/j.jhydrol.2022.127898

Journal of Hydrology 610 (2022) 127898

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

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Research papers

Spatiotemporal dependence of soil moisture and precipitation over India

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ARTICLE INFO

Keywords:
Event coincidence analysis
Precipitation
Soil moisture

ABSTRACT

Anthropogenic climate change has impacted almost all phases of the global water cycle. Growing consensus asserts that extreme precipitation events will only rise in the years to come. However, an increase in extreme precipitation events does not necessarily correspond to higher flood risk. Much onus lies on the antecedent