Distinct Characteristics of Active and Break Spells in Flood and Drought Years of the Indian Summer Monsoon

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1. Background and Research Objective

- The intra-seasonal variation of the Indian summer monsoon is marked by alternating "active" periods of high rainfall and "break" periods of deficient or no rainfall **(Gadgil, 2003; Rajeevan et al., 2010).**
- While previous studies have extensively documented the characteristics of active and break spells, there is limited understanding of how these spells manifest differently across flood and drought years.
- We show that active spells on average occur more frequently in flood years (4.6 per year) than in drought years (2.3 per year), although their typical durations remain similar. Break spells are more frequent (3.9 per year) and longer during drought years compared to flood years (1.2 per year).

Research Objective:

- This study examines the significant differences in the frequency and duration as well as propagation associated with active and break monsoon spells between flood and drought years.
- What are the systematic differences in the incidence of ISO modes between flood and drought years?
- How do these differences translate to manifestations of active and break spells across flood and drought years?
- What role do various seasonally persisting conditions play and which factors impart systematic differences across years?

2. Data and Methods

a. Datasets:

- *Rainfall Data*: Active and break spells were identified using daily rainfall data from the India Meteorological Department (IMD) at a spatial resolution of 0.25° × 0.25°, covering Central India (21°–26°N, 72°–85°E) for the period 1979–2020.
- *Reanalysis Data*: Daily atmospheric variables such as specific humidity, horizontal and vertical winds, relative vorticity, total column water (TCW), and mean sea level pressure (MSLP) were obtained from the ERA5 reanalysis dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF), with a spatial resolution of 0.25° × 0.25°.

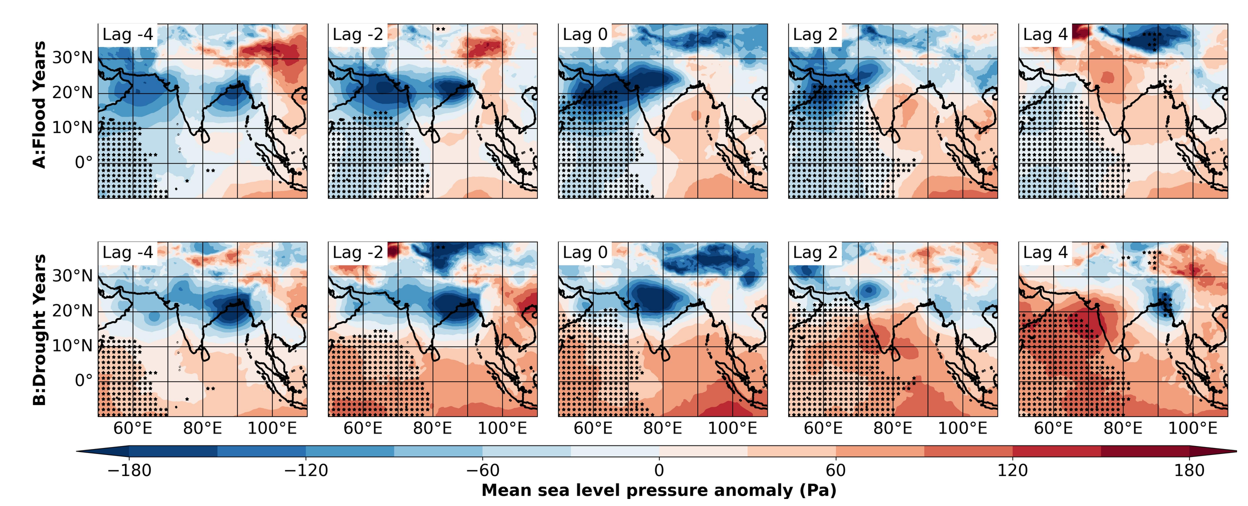
b. Identification of Years and Spells:

- Based on the India Meteorological Department (IMD) criteria and methodology from **Rajeevan et al. (2010)**, we identified 7 drought and 5 flood years during 1979–2020, along with active and break spells over Central India.
- Drought years recorded 27 break spells and 16 active spells, whereas flood years had only 6 break spells but 23 active spells, indicating a strong contrast in intraseasonal variability.

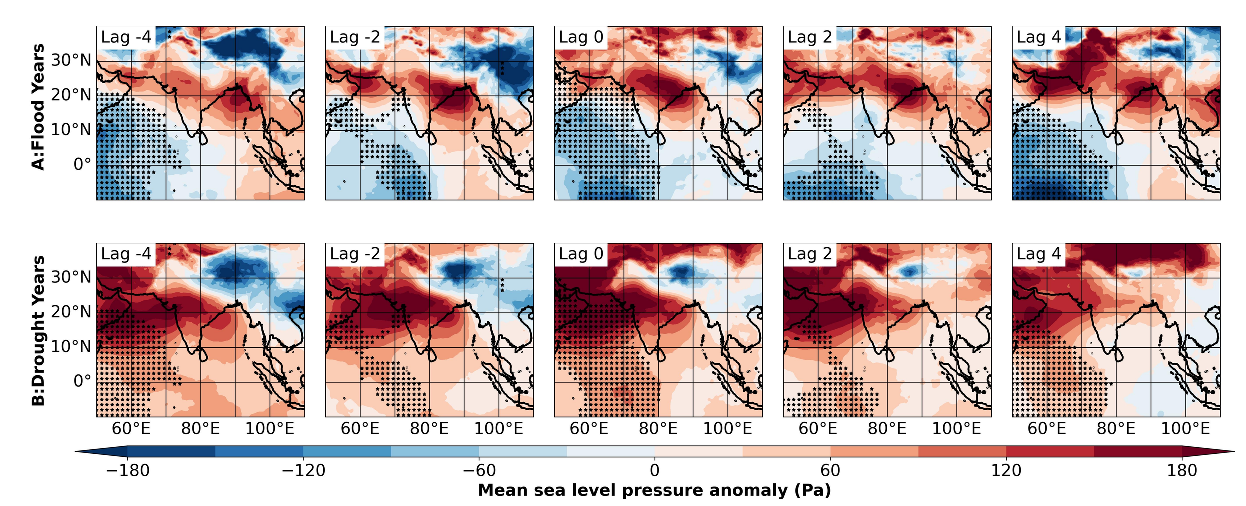
c. Multichannel singular spectrum analysis (MSSA):

- To extract intraseasonal (ISO) modes for each year separately we used MSSA algorithm.

3. Mean sea level pressure (MSLP)



Active Spell: The significant difference is that flood years have negative MSLP anomaly over the Western Indian Ocean and Arabian Sea, compared to positive anomaly for drought years.



Break Spell: The westward movement of positive MSLP anomalies during flood years shortens break spells, while their stationary northward propagation in drought years prolongs them.

4. Intraseasonal oscillation (ISO) modes

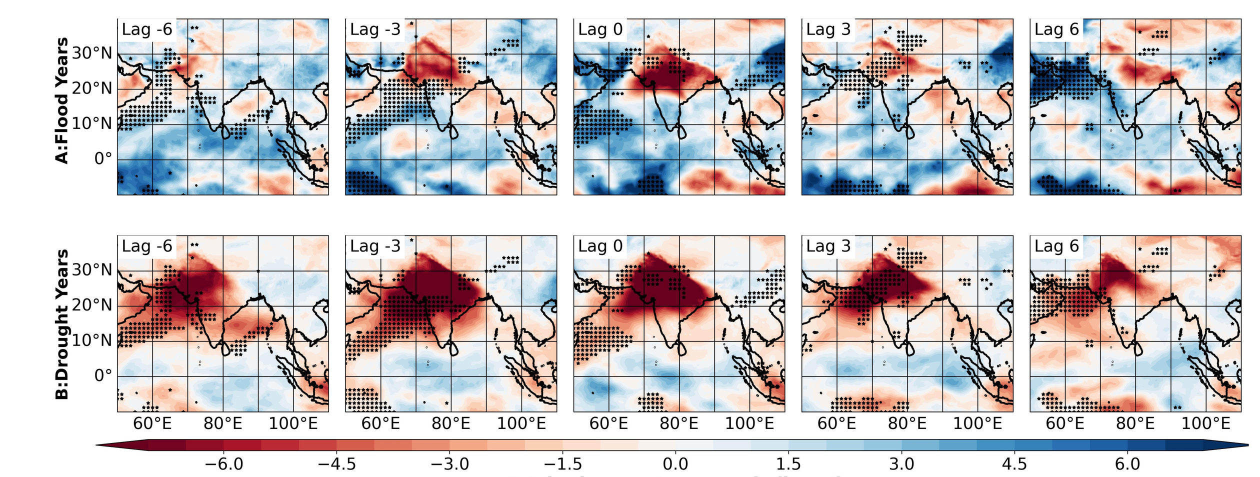
•**Low Frequency (LF) ISO Dominance in Drought Years**: LF-ISO (20–60 days) **(Karmakar et al., 2017)** explains **36.1% of rainfall variance** in drought years, compared to **16.7% in flood years**, indicating stronger poleward propagation in drought years.

•**High Frequency (HF) ISO Dominance in Flood Years**: HF-ISO (10–20 days) **(Krishnamurti and Bhalme, 1976)** contributes **16.7% of rainfall variance** in flood years, compared to **8.3% in drought years**, highlighting stronger westward propagation from the Bay of Bengal in flood years.

•**Over 90% of active days** align with the positive phase of HF-ISO, while **85–90% of break days** coincide with its negative phase in flood years.

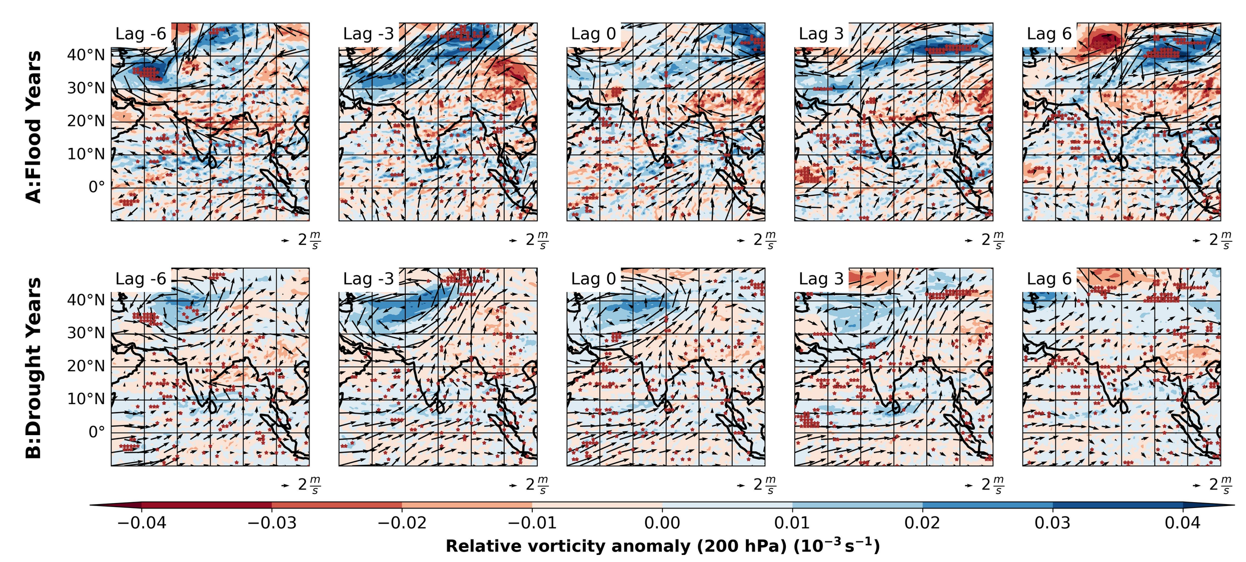
•In drought years, **active days** align with the positive phase of LF-ISO, while **break days** occur during its negative phase.

5. Total column water (TCW)

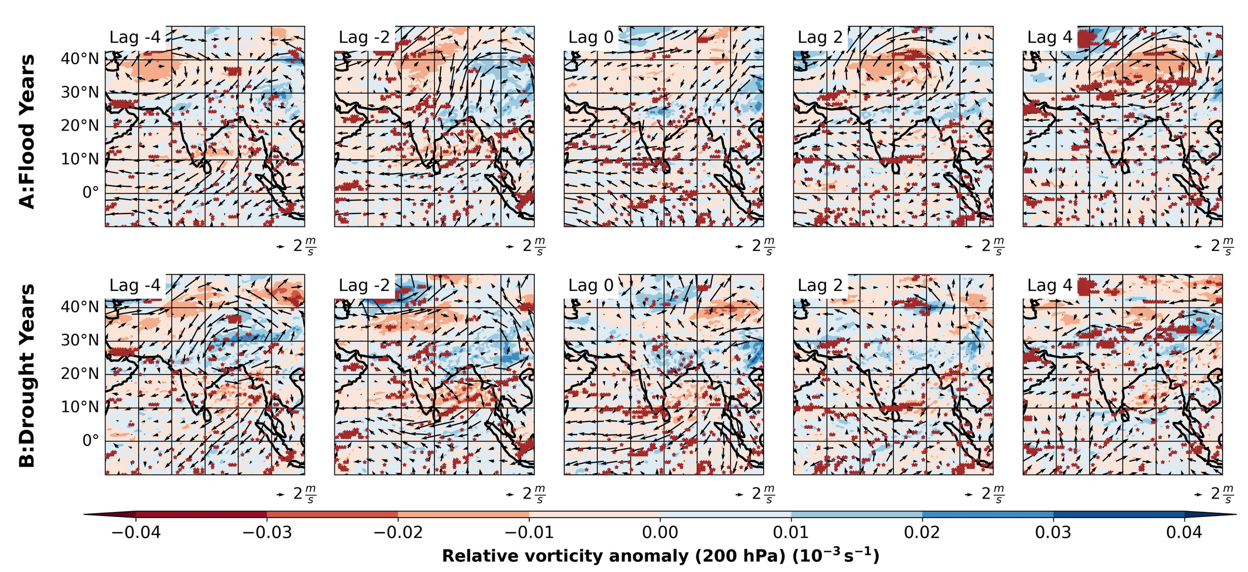


Break Spell: The negative anomaly is more intense and extensive during drought years, , pointing to potential midlatitude dry air intrusions during drought.

6. Background Wind at 200 hPa

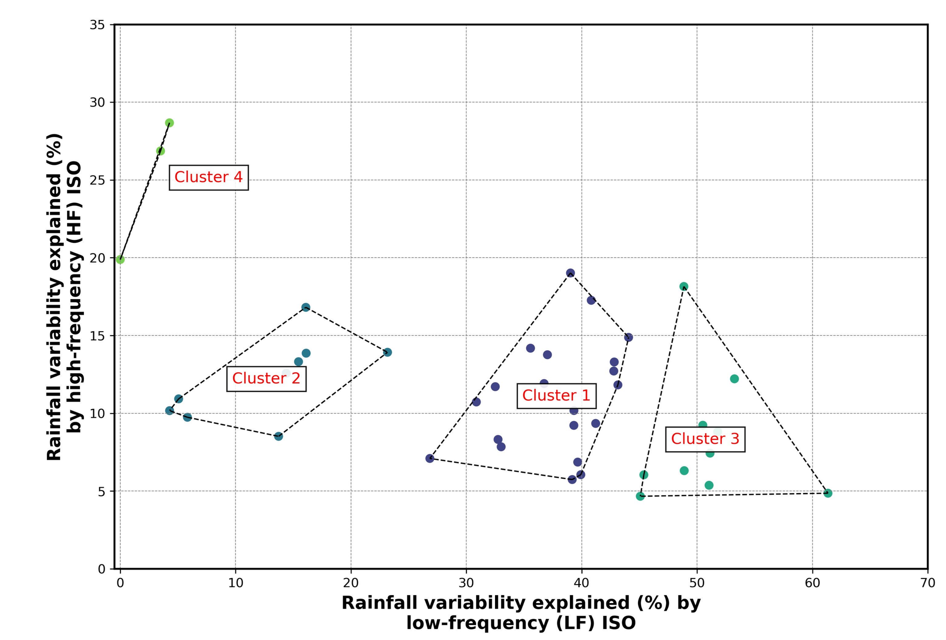


Break Spell: The upper-tropospheric low is more intense and stationary during droughts, while in flood years it extends northwestward, leading to weaker westerlies over CI.



Active Spell: The Tibetan High is more intense and stationary during flood years, while in drought years it shifts northwestward, resulting in weaker easterlies over Central India.

7.Cluster based on LF and HF ISO intensity



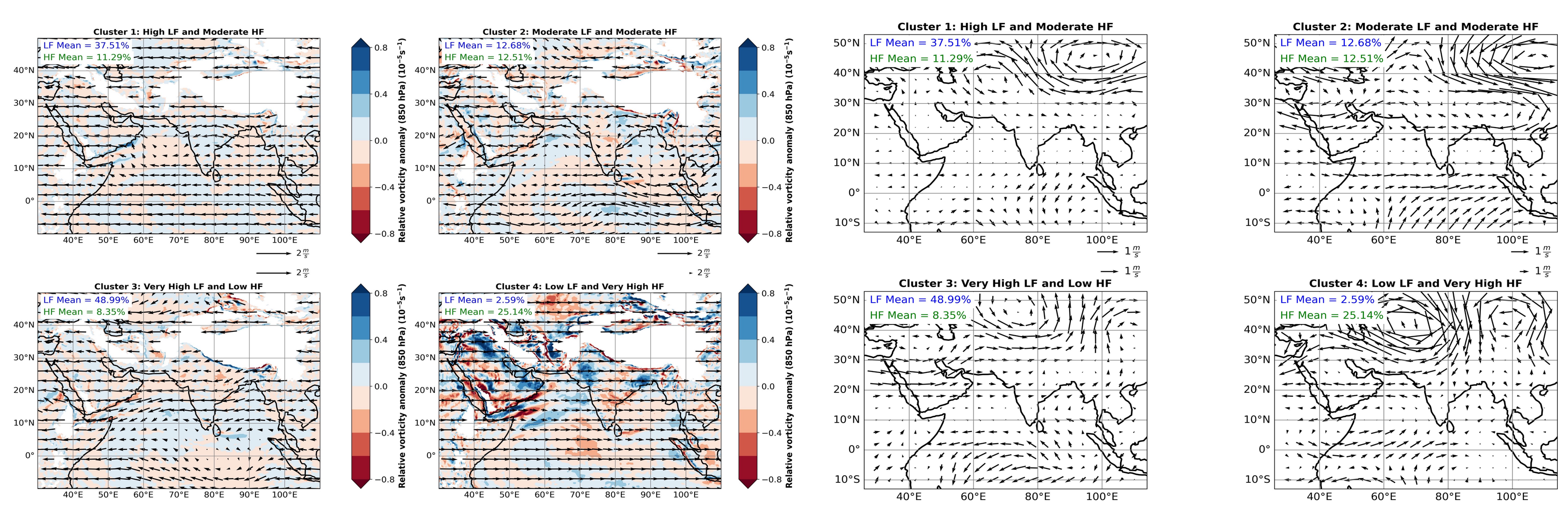
Cluster	Description	LF Variability (%)	HF Variability (%)	Rainfall over CI (% of Mean)
1	High LF and Moderate HF	37.51	11.29	100.1
2	Moderate LF and Moderate HF	12.68	12.51	104.2
3	Very High LF and Low HF	48.99	8.35	92.0
4	Low LF and Very High HF	2.59	25.14	112.1

•The cluster with the strongest LF-ISO and weakest HF-ISO records the lowest rainfall (92% of the long-term mean), while the opposite cluster experiences the highest rainfall (112% of the long-term mean).

•These findings align with observed HF and LF ISO intensities during flood and drought years.

• Strong HF-ISO activity is associated with enhanced formation and north-westward propagation of low-pressure systems from the Bay of Bengal to Central India, contributing to above-normal rainfall.

8.Seasonally averaged composites of Wind at 850 hPa and 200 hPa



Wind at 850 hPa : Stronger LF-ISO intensity weakens moisture transport to Central India by inducing anomalous easterlies, leading to a moisture deficit.

Wind at 200 hPa : A robust Tibetan High north of CI for Cluster 4 and a strong upper-tropospheric low for Cluster 3.

9. Conclusions

•We found a notable difference in the frequency and duration of active and break spells between flood and drought years.

•MSLP composites show a transition from negative anomalies in flood years to positive anomalies in drought years, while TCW composites indicate potential dry air intrusions during droughts.

•Background winds at 200 hPa show that conditions favourable for active spells are more prominent during flood years, whereas conditions supporting break spells prevail during drought years.

•Seasonal rainfall shows a decreasing relationship with low-frequency ISO (LF-ISO) strength and an increasing relationship with high-frequency ISO (HF-ISO) strength.

•Seasonally averaged winds exhibit strong vertical shear during strong HF-ISO years, while weaker shear during strong LF-ISO years favours dry air intrusions from the mid-latitudes.

Acknowledgements

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