

Community Comments: Nima Zafarmomen

The manuscript presents a regime-based analysis of Indian Summer Monsoon (ISM) rainfall for JJAS 1961–2018, using: IMD 0.25° daily rainfall, k-means clustering to identify 11 spatial rainfall regimes, NCEP–NCAR Reanalysis-1 to characterize circulation, pressure, and moisture anomalies for each cluster, Markov-chain style transition probabilities between regimes, A decomposition of rainfall change (1961–1989 vs 1990–2018) into frequency vs intensity contributions by regime and region. The study aims to link objectively derived rainfall regimes to synoptic drivers (depressions, trough position, breaks, etc.), examine their transition dynamics, and use these regimes to interpret long-term regional rainfall changes (particularly over Thar & Kutch, Indo-Gangetic Plains, and Northeast India).

We thank reviewer for the suggestions.

The manuscript would benefit from a clearer articulation of what is genuinely new compared to prior regime-based studies of the ISM (e.g., Straus 2022, Catto et al. 2012–style decompositions, previous clustering of rainfall vs winds). Please more explicitly contrast your k-means rainfall regimes with wind-based regimes and IMD active/break diagnostics, and state what new physical insight emerges.

We thank the reviewer for this important point. This has been flagged by another reviewer, and we have highlighted the unique points of our study in the reply and made changes to the manuscript to highlight the same (See Reviewer 1, Comment 1).

The Elbow method and five initializations provide only limited evidence that 11 clusters are "optimal," especially for high-dimensional rainfall fields. Please show more formal robustness tests (e.g., silhouette scores, explained variance, random subsampling, or clustering on sub-periods), and ideally a sensitivity example for $k = 9$ or 12.

Thank you for pointing this out. When k-means with independent random seeds (that's N_M_k random numbers) converges to the same cluster solution in two initializations, that alone is sufficient to demonstrate that the clusters are stable and did not arise by chance because the probability of two independent random initializations being the same is infinitesimally small. In that sense, running five initializations was already an over extension. We have therefore changed the description in the text to avoid giving the false impression to the future readers that more iterations is a better test.

We show within cluster and between cluster distances with the elbow method in this work. This is the most widely used method that shows compactness and separability. We are also familiar with the above mentioned tests to decide the optimal number of clusters and have used them in our other studies. We do not agree with the reviewer that these are somehow more formal tests than within

cluster and between cluster elbow tests. In our experience, multiple statistical tests do not even agree on the precise number of clusters but help in finding the range of optimum number of clusters as a guidance. We agree with Anderberg's view in Cluster analysis for applications (1973), that the data from real systems may not have a fixed set of clusters, however the good clusters are more compact, separable and stable, which is demonstrated in this paper. However, the major test of any clustering methodology is their physical interpretability, which in this case is evident from the synoptic systems associated with the rainfall clusters and their transition dynamics. Hence, 11 clusters worked nicely for this dataset and problem at hand.

The transition matrix is interpreted as a Markov chain, but daily rainfall regimes are highly autocorrelated and embedded in multi-day synoptic systems. Please discuss the validity and limitations of the Markov assumption, and consider including multi-day transitions (e.g., 2-day lag).

Autocorrelation and Markov structure are not mutually exclusive. In fact, a first-order Markov chain naturally produces autocorrelated sequences. If a cluster has a high self-transition probability, like Cluster 3 with $P_{33} = 0.75$, the resulting time series will be strongly autocorrelated, with long runs of the same state. In addition, we are not using the Markov chain to forecast the next rainfall regime, and we make no claim that the ISM state sequence is literally generated by a first-order Markov process. Rather, the transition matrix is compact summary of the sequential behavior of rainfall regimes.

Several regimes are qualitatively associated with monsoon depressions, mid-tropospheric cyclones, and trough positions, but the linkage remains somewhat descriptive. Can you provide more objective metrics (e.g., depression track climatology, MTC detection, trough latitude index) to verify that specific clusters indeed correspond to those synoptic features?

We respectfully disagree that the synoptic associations are merely descriptive. Depressions, mid-tropospheric cyclones, and monsoon troughs are not subtle features, they are the most prominent synoptic systems in the Indian summer monsoon, with unambiguous signatures in pressure, wind, and moisture fields. Moreover, the composite anomaly maps in Figures 5 and 6 are computed over 58 years of data. Conducting full depression track climatology, MTC detection, and trough latitude index analyses as per the reviewer suggestion, is beyond the scope of this paper.

I strongly recommend to consider "Analysis of historical global warming impacts on climatological trends for the partially gauged Hirmand river basin based on multiple data products and bias correction methods" in your paper.

This work is not relevant in our study.