# Natural Time Analysis of Rainfall Event Series across Various Hydroclimatic Regimes

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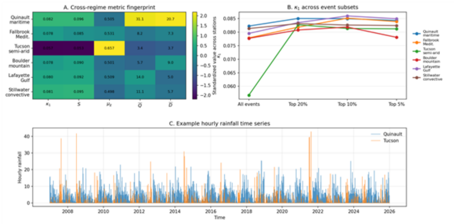


Figure: Natural-time fingerprints of rainfall organization across contrasting hydroclimatic regimes using a 6-hour inter-event dry period.
(A) Standardized cross-regime comparison of key natural-time and event-scale metrics for the full rainfall-event sequence, where $\kappa_1$ is the natural-time variance, $S$ is the forward entropy, $\mu_\chi$ is the energy-weighted mean natural-time position, $\overline{Q}$ is the mean event total rainfall, and $\overline{D}$ is the mean event duration.
(B) Comparison of $\kappa_1$ for the full event sequence and for the top 20%, top 10%, and top 5% strongest rainfall events. (C) Example hourly rainfall time series for two contrasting regimes (Quinault and Tucson).

Rainfall event sequences arise from nonlinear atmospheric dynamics acting across multiple temporal scales and under far-from-equilibrium conditions, making their organization difficult to characterize using conventional chronological-time statistics alone. Here, we investigate whether natural time analysis can serve as a data-driven statistical-physics framework for extracting temporal and multiscale structure from real hourly rainfall records. The motivation is to test whether such observables can distinguish contrasting hydroclimatic regimes, clarify the organization of extreme-event subsets, and reveal scale-dependent structure in environmental event series.

We use precipitation observations from the U.S. Climate Reference Network (USCRN) and define discrete rainfall events from hourly time series using inter-event dry periods. The ordered event sequence is then mapped into natural time, using event total rainfall as the main event weight $Q_k$. On this basis, we compute the natural time variance $\kappa_1$, the forward and backward dynamic entropies $S$ and $S^-$, their difference under time reversal, and $\mu_\chi$, the energy-weighted mean "position" of events in natural time. We further examine fluctuations of the entropy difference across multiple event scales, construct a scale-dependent complexity measure, and analyze rolling-window behavior of the natural-time observables to quantify temporal variability and clustering. In parallel, event duration, interarrival time, wet hours, and peak hourly intensity are treated as complementary event descriptors, and alternative natural-time weightings are tested to determine whether regime contrasts are controlled primarily by rainfall amount, persistence, intensity, or spacing. The analysis is performed using hourly rainfall data from stations representative of Pacific maritime, Mediterranean, semi-arid monsoonal, mountainous, Gulf Coast, and Great Plains convective rainfall regimes.

The natural-time observables show clear regime dependence. Specifically, the semi-arid monsoonal series exhibits markedly lower $\kappa_1$ and entropy, together with higher $\mu_\chi$, indicating a more intermittent and temporally uneven organization than wetter maritime and humid regimes. When the analysis is restricted to the strongest rainfall events, the natural-time metrics shift toward a narrower range across stations, suggesting that the extreme-event subset possesses a more coherent organization than the full event population. Multiscale analysis reveals additional regime-dependent structure, with the semi-arid series displaying a flatter scale profile than wetter regimes, while rolling-window calculations indicate differing temporal variability and clustering behavior among stations. Applying natural-time analysis with alternative event weights shows that the strongest regime contrasts emerge when rainfall amount, peak intensity, or inter-event spacing are emphasized, whereas duration-based weighting yields weaker contrasts. A robustness analysis using inter-event dry periods of 3, 6, and 12 hours shows that, although the number of identified events changes substantially, the principal natural-time signatures remain qualitatively stable. Overall, the results suggest that natural time can provide a multiscale and physically interpretable data-driven framework for characterizing rainfall organization and hydrometeorological extremes across contrasting climatic settings.

References:

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