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Temporal variations in seismic parameter probability model: Insights into the seismic cycle

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Earthquake activity reflects the complexity and non-linear dynamics of the Earth's crust, involving a wide range of spatial and temporal scales. Fault ruptures span from microscopic cracks to large fault systems, while recurrence intervals between events range from seconds to several centuries. Despite this complexity, empirical observations consistently reveal scale-invariant patterns, such as power-law distributions governing earthquake magnitudes and aftershock decay rates, and multifractal spatial distribution of epicenters. These features, along with long-range interactions, are hallmarks of non-linear dynamic systems and suggest that classical Boltzmann-Gibbs statistical mechanics may not fully capture the behavior of seismicity.

In this study, we apply the q-exponential distribution, derived from the maximization of the Tsallis entropy in the frame of non-extensive statistical mechanics, across various seismotectonic contexts [1-4]. Bayesian inference is performed on data within sliding time windows, each containing a fixed number of events and shifting with each new. We find that the q-exponential distribution may provide a better fit to the magnitude data compared to the classical exponential model defined by the Gutenberg-Richter law. We observe that variations in the entropic parameter q are associated with different phases of the seismic cycle.

Alongside probability models commonly used in the literature, such as the tapered Pareto and the generalized gamma distributions, we also propose the q-exponential distribution to model the spatial distribution of epicenters, represented by the Voronoi cell areas generated from epicenter locations within each time window. The best-fitting model for the Voronoi cell areas in each time window is identified by comparing the posterior marginal likelihoods of all fitted models. Results indicate that the preferred statistical model varies across time in correspondence with shifts in seismic behavior, suggesting a link between the phases of the underlying geophysical process and the statistical features of the earthquake sequences.

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