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Causality and information transfer in systems with extreme events

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The mathematical formulation of causality in measurable terms of predictability was given by the father of cybernetics N. Wiener [1] and formulated for time series by C.W.J. Granger [2]. The Granger causality is based on the evaluation of predictability in bivariate autoregressive models. This concept has been generalized for nonlinear systems using methods rooted in information theory [3,4]. The information-theoretic approach, defining causality as information transfer, has been successful in many applications and generalized to multivariate data and causal networks [e.g., 5]. This approach, rooted in the information theory of Shannon, usually ignores two important properties of complex systems, such as the Earth climate: the systems evolve on multiple time scales and their variables have heavy-tailed probability distributions. While the multiscale character of complex dynamics, such as air temperature variability, can be studied within the Shannonian framework [6, 7], the entropy concepts of Rényi and Tsallis have been proposed to cope with variables with heavy-tailed probability distributions. We will discuss how such non-Shannonian entropy concepts can be applied in inference of causality in systems with heavy-tailed probability distributions and extreme events, using examples from the climate system.

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