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Non-Shannonian information theory connects inference of causality and understanding of extreme events

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Inference of causality and understanding of extreme events are two intensively developing multidisciplinary areas highly relevant for the Earth sciences. Surprisingly, there is only a limited interaction of the two research areas.

Quantification of causality in terms of improved predictability was proposed by the father of cybernetics N. Wiener [1] and formulated for time series by C.W.J. Granger [2]. The Granger causality evaluates predictability in bivariate autoregressive models. This concept has been generalized for nonlinear systems using methods rooted in information theory [3]. The information theory of Shannon, however, usually ignores two important properties of Earth system dynamics: the evolution on multiple time scales and heavy-tailed probability distributions. While the multiscale character of complex dynamics, such as the air temperature variability, can be studied within the Shannonian framework in combination with the wavelet transform [4], 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, we will focus on causal effects of the North Atlantic Oscillation, blocking events and the Siberian high on winter and spring cold waves in Europe, including the April 2021 frosts endangering French vineyards. Using the non-Shannonian information-theoretic concepts we bridge the inference of causality and understanding of the occurrence of extreme events.

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