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Towards a new paradigm for analysing nonlinear geoscientific time series

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Complex networks are an emerging new concept for data analysis and modelling in various geoscientific disciplines, which primarily makes use of the spatial structure of statistical interdependences in spatially extended systems. It has been found that the backbone of this spatial structure can often be described by a discrete graph, the topology of which encodes fundamental properties of the overall system. For many problems of contemporary interest in Earth sciences, such as geomorphological structures (river networks) or spatio-temporal patterns of seismic activity, complex networks provide a generic description. In addition, networks constructed from climatological observations or model data allow novel insights into important physical processes determining the dynamics of the climate system. I give an overview about the corresponding basic methodology for constructing and analysing climate networks as well as possible variants thereof, and discuss some new findings reg arding recent climate variability on both global and regional scales.
Another prospective idea is applying complex network methods in the context of (univariate) time series analysis. For this purpose, the recurrence property of states in phase space is utilised. Specifically, complex networks are defined according to the mutual proximity of individual state vectors (observations) in the phase space of the underlying system. I show several examples illustrating how the local as well as global properties of the resulting recurrence networks correspond to the geometric attractor properties of some low-dimensional toy models, and provide some theoretical background. Moreover, I demonstrate that applying recurrence network analysis to real-world time series provides a new exploratory tool for identifying hidden dynamical transitions. As a specific example, some palaeoclimate time series are studied, where distinct time periods with substantial changes in the dynamics of the recorded proxy variable are identified. The presented results trigger so me new hypotheses about potential climatological mechanisms of the underlying large-scale climate shifts.
From a conceptual point of view, climate networks and recurrence networks can be understood as two representatives of a new and widely applicable class of methods, which are based on discrete spatial structures containing only the most significant associations between specific entities (geographical positions, state vectors, different interacting variables, etc.). Both specific approaches have in common that the resulting networks encode key properties related with the dynamics of the underlying complex system. This suggests that complex network methods provide a new paradigm for analysing and modelling geoscientific systems, the future potentials and possible limitations of which still have to be explored in great detail in future research.