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Nonlinear approaches to detecting tipping points in Earth's climate history

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In the last years the existence of tipping elements in the Earth's climate system has gained increased attention. Here, tipping behavior refers to dynamical transitions of some subsystem leading to a qualitatively different state. In the light of the recent debate on possible regime shifts due to global climate change it is necessary to understand if, when and where such transitions have occurred in the past in order to assess possible future risks.

As tipping of climate elements should be accompanied by changes in the nonlinear dynamics (e.g., due to bifurcations or noise-induced transitions), methods from nonlinear time series analysis can lead to additional insights regarding the existence of past transitions. In this work, we study the capabilities of several recently developed methods like recurrence network analysis or visibility graphs as well as spatio-temporal methods to reveal complex signatures of past nonlinear regime shifts. The potentials and limitations of these novel approaches are systematically compared with those of classical early warning indicators like increasing autocorrelation, variance, etc. We illustrate the performance of the different methods for synthetic time series exhibiting tipping point behavior as well as different paleoclimate time series.