Non-parametric causal assessment in deep-time geological records

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The interplay between climate variables and the timing of their feedback mechanisms are typically investigated using fully coupled climate system models. However, as we delve deeper into the geological past, mechanistic process models become increasingly uncertain, making nonparametric approaches more attractive. Here we explore the use of two conceptually different methods for nonparametric causal assessment in palaeoenvironmental archives of the deep past: convergent cross mapping (CCM) and information transfer (IT). These methods have the potential to capture interactions in complex systems even when data are sparse and noisy, which typically characterises geological proxy records. We apply these methods to proxy time series that capture interlinked components of the Earth system at different temporal scales, and quantify both the interaction strengths and the feedback lags between the variables. Our examples include the linkage between the ecological prominence of common planktonic species to oceanographic changes over the last ~65 million years, and global interactions and teleconnections within the climate system during the last ~800,000 years.