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Inference of directed climate networks: role of instability of causality estimation methods

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Climate data are increasingly analyzed by complex network analysis methods, including graph-theoretical approaches [1]. For such analysis, links between localized nodes of climate network are typically quantified by some statistical measures of dependence (connectivity) between measured variables of interest. To obtain information on the directionality of the interactions in the networks, a wide range of methods exists.

These can be broadly divided into linear and nonlinear methods, with some of the latter having the theoretical advantage of being model-free, and principally a generalization of the former [2].
However, as a trade-off, this generality comes together with lower accuracy – in particular if the system was close to linear. In an overall stationary system, this may potentially lead to higher variability in the nonlinear network estimates. Therefore, with the same control of false alarms, this may lead to lower sensitivity for detection of real changes in the network structure.

These problems are discussed on the example of daily SAT and SLP data from the NCEP/NCAR reanalysis dataset. We first reduce the dimensionality of data using PCA with VARIMAX rotation to detect several dozens of components that together explain most of the data variability. We further construct directed climate networks applying a selection of most widely used methods – variants of linear Granger causality and conditional mutual information.

Finally, we assess the stability of the detected directed climate networks by computing them in sliding time windows. To understand the origin of the observed instabilities and their range, we also apply the same procedure to two types of surrogate data: either with non-stationarity in network structure removed, or imposed in a controlled way.

In general, the linear methods show stable results in terms of overall similarity of directed climate networks inferred. For instance, for different decades of SAT data, the Spearman correlation of edge weights in the networks is ~ 0.6.

The networks constructed using nonlinear measures were in general less stable both in real data and stationarized surrogates. Interestingly, when the nonlinear method parameters are optimized with respect to temporal stability of the networks, the networks seem to converge close to those detected by linear Granger causality. This provides further evidence for the hypothesis of overall sparsity and weakness of nonlinear coupling in climate networks on this spatial and temporal scale [3] and sufficient support for the use of linear methods in this context, unless specific clearly detectable nonlinear phenomena are targeted.

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