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Areawise significance tests for recurrence network analysis

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Significance testing is arguably one of the most important concepts of time series analysis. Still, in many applications that include a windowed approach or a repeated analysis over a continuous range of parameters, results are often tested for every point separately. This gives rise to the requirement of multiple testing corrections and neglects possible intrinsic correlations within the analysis results that may make false positive significant points rather appear as continuous patches than as isolated points. To detect such false positive patches, we here introduce a general concept for an areawise significance test similar to the one presented by Maraun et al. [1] for the wavelet spectrum. There, the wavelet reproducing kernel is used to assess the scale of decay of intrinsic correlations which then determines the areawise test. Our test is more general and can in principle be applied to any analysis method but requires a numerical estimation of the scale of decay of the intrinsic correlations. This estimation can be achieved by choosing a null model and then calculating correlation functions of the analysis results of surrogate data following the null model for overlapping time windows or for the varying analysis parameters.

We here apply the areawise test to windowed and multiscale windowed recurrence network analysis in order to identify dynamical anomalies in palaeoclimate archives such as, for example, tree rings. In this context, recurrence based methods have already proven to be valuable tools but significance tests have so far only be restricted to pointwise tests. To apply the areawise test, we consider three null models, (i) Gaussian white noise, (ii) an AR(1) process and (iii) a data-adaptive model using iAAFT surrogates. For each null model, we create corresponding sets of surrogate data and then estimate the scale of decay of the intrinsic correlations of the measure of interest in the time and window width domains for windowed recurrence network analysis, and in the time and scale domains for multiscale windowed recurrence network analysis. To test our approach, we first study a non-stationary Rössler system and then apply the proposed analysis procedure to a paleoclimate time series of tree ring width indices from East Canada. We find dynamical anomalies in times following major explosive volcanic eruptions depending on the chosen embedding delay, possibly reflecting that different volcanic eruptions cause dynamical responses on different time scales. Still, to draw reliable conclusions about this effect, more proxy time series need to be analysed.

[1] D. Maraun, J. Kurths, and M. Holschneider. Nonstationary gaussian processes in wavelet domain: Synthesis, estimation, and significance testing. Phys. Rev. E, 75:016707, 2007.