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Surrogate methods in geophysics

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When testing complicated null-hypotheses where closed analytic expressions are not available we often rely on Monte Carlo methods to produce artificial surrogate data. However, many geophysical time-series have internal structures ranging from the correlations of simple first order auto-regression processes to more complex structures such as pseudo-periodic behavior. Forcing wrong assumptions - in the extreme case, independence - on the artificial data may lead to serious errors such as overestimation of the number of degrees of freedom and therefore also overestimation of p-values and unwarranted acceptance of null-hypotheses.

Ideally, the artificial data should therefore fulfill the considered null-hypothesis but in all other aspects be statistically similar to the original data. Such aspects may include temporal correlations, power-spectra, distributions, pseudo-periodicity, and temporal asymmetry. Artificial surrogate data are also used for other purposes such as testing new algorithms on data with a specified structure.

The aim of the present paper is to review the different methods to generate artificial data. We include methods based on randomizing the phases of the Fourier spectrum, pseudo-periodic surrogates based on drawing analogs in reconstructed (embedded) phase-space, ARMA processes, methods based on wavelets, and two new approaches based on Empirical Mode Decomposition and Singular Spectrum analysis.

The different methods are applied to univariate time-series of different levels of complexity such as the El Nino-Southern Oscillation, the Quasi-biennial oscillation, and the Vostok ice core. The methods' abilities to faithfully reproduce the salient features of the original time-series are compared. We also investigate the possibilities of extending the methods to multivariate fields.