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Tipping point analysis of geophysical time series and data fields

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Tipping point analysis techniques help anticipate, detect and forecast tipping points in a dynamical system. The methodology combines monitoring short- and long-term memory in a time series with potential analysis that analyses and extrapolates the system states.

For anticipating tipping points, early warning signal (EWS) indicators include dynamically derived lag-1 autocorrelation (ACF, [1]), power-law scaling exponent of Detrended Fluctuation Analysis (DFA, [2]), and recently developed power-spectrum-based EWS indicator, which similarly monitors dynamical changes in memory along the record [3]. When indicators rise monotonically, this denotes an upcoming transition or bifurcation and can be used as EWS for tipping. By combining several EWS indicators, it is possible to identify and distinguish different types of tipping, such as forced transitions and genuine bifurcations (when the structure of the system potential changes [5]).

Potential analysis detects a bifurcation in a series at the time when it happens, which is illustrated in a colour plot mapping the potential dynamics of the system [4-8]. It provides a “portrait” of a time series with multiscale representation of the number of detected system states. Potential analysis is also used in forecasting time series by extrapolation of Chebyshev approximation coefficients of the kernel distribution, with reconstruction of temporal correlations in the data, taking into account seasonality in geophysical and environmental series [8]. Tipping point analysis techniques have been extensively tested on artificial data and on various observed geophysical and environmental datasets [2-11], and proved to be applicable to trajectories of dynamical systems of arbitrary origin [12-14].

The recent generalization of the EWS to data fields [15] reviews multidimensional methods based on principal component analysis [16] and linear approximation of system dynamics using generalized autocorrelations [17]. It provides applications to an analytical system (Van der Pol oscillator) and observed hurricane data from multiple stations over the Atlantics, where it is possible to obtain a spatial EWS from a pressure data field. We estimated the direction of hurricane propagation based on 2D EWS and observed good agreement with the actual hurricane propagation, which is also confirmed in data generated from a stochastic model of air pressure.

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