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Detection of early warning signals in paleoclimate data using a genetic time series segmentation algorithm

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Abstract

We present a novel approach of analysing – visualising time series of a geophysical variable and we characterise its abrupt transitions in comparison to benchmark time series produced with model dynamical systems: a mathematical model (stochastic resonance) and a climate model of intermediate complexity (2D meridional ocean circulation with an atmospheric forcing) [1]. The method combines a genetic segmentation algorithm that uses ordinal regression and clusters the different segments of the time series around centroids located in a six-dimensional (6D) space of statistical metrics. After detecting statistical similarities it helps compare the type of transition observed in the time series to three separate studied types: a) noise transition, b) subcritical bifurcation crossing and c) transition to a limit cycle. The proposed method complements the causality analysis of a record of abrupt transitions in a geophysical system.

1. Introduction

The flexibility of the algorithms available in the machine learning range of methods should be combined with comprehensive physical systems in order to elucidate the exploration of a novel system. Here, we present a work [2] that uses the bio-inspired method of evolutionary algorithms in order to detect early warning signals (EWS) of an abrupt transition (tipping point) that is recorded in a geological time series. Statistical metrics have been used in the past [3] in order to detect EWS which we here extend to include: mean value, autocorrelation, standard deviation, kyrtosis, skewness and slope. An evolutionary algorithm is used to efficiently investigate this broad phase space. Prior knowledge of the Dansgaard-Oesger (DO) [4] transition points is not inserted into the algorithm.

2. Methods

Figure 1 shows an example "chromosome" for a sample data series. Six statistical metrics are calculated for each of the segments. The algorithm runs probabilistically, which means that it has random initialization of the segmentation and converges to a different segmentation pattern after each iteration until 5 clusters are formed in the 6D space. The results are given in percentage of encounter coherence over the total number of runs. If a segmentation pattern is encountered in all the runs, we assess that the detection of tipping point is 100% certain.

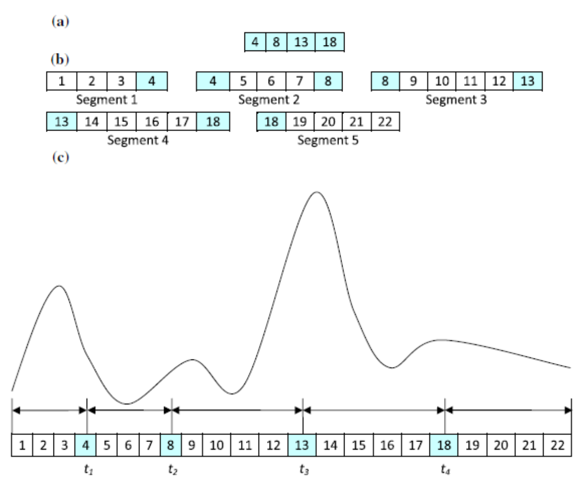

Figure 1: Chromosome representation of a sample time series composed of 22 data points. (a) Example chromosome. Each index corresponds to a position in the time series. (b) Segments that correspond to the chromosome. (c) The resulting segmentation of the time series. We obtain statistical characteristics for every segment. Image adopted with permission from [2].

3. Summary

The geophysical time series studied with this method are the ice cores NGRIP and GISP3 oxygen isotope data sets for the period spanning 50,000 yr before present (BP) until today. As a preliminary result, it is suggested that the DO events do not share the same classification and could be potentially attributed to different underlying dynamics. Further work has been conducted [5] in order to define a decision tree for the classification of the tipping points.

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