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Extracting the signal of driving force from hierarchical system by Slow Feature Analysis

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Extracting the signals from non-stationary time series has been a challenge in many fields such as climate sciences. Hierarchical theory suggests that varying driving force leads to the non-stationary behavior. Extracting and analyzing the slowly varying features are in favor of understanding non-stationary dynamical systems. Slow feature analysis (SFA) is an effective technique for extracting slowly varying driving forces from fast varying non-stationary time series. The basic idea of SFA is to nonlinearly extend the reconstructed signal onto a combination form with one or higher order polynomials and apply the principal component analysis to this extended signal and related time derivatives. The algorithm can seek an optimal solution from a group of functions directly and extract the uncorrelated features ordered by slowness. A series of studies have shown its superiority in extracting the driving force of non-stationary time series. The extracted signal was found to be highly correlated with the real driving force. Results based on ideal models showed that either the slow driving force itself or a slower subcomponent can be well detected by SFA. Despite all this, further investigation of SFA is still needed to reduce its uncertainty.

In this study, we establish two types of non-stationary models by the logistic map with time-varying parameters: one includes two varying driving forces with different time periods constraining the evolution of time series in a non-stationary way; and another involves three-layer structure encompassing two superimposed signals in which the slower signal of driving force is modulated by the slowest one. Based on the ideal models and SFA, we conduct numerical experiments to develop corresponding analysis method and discuss its application prospect in extracting driving force signals. We find that for the first kind of system, either the slowest signal or the combination of two driving forces constructed by SFA contains uncertain information. However, we can detect the two independent driving forces from the constructed signal by wavelet analysis. For the system of three-hierarchies including two superimposed signals of driving force, successive applications through SFA on the original time series and the constructed SFA signal can in turn detect the slowest and the second-slowest varying driving forces signals. The successful application of SFA shows its promising prospect in analyzing the external driving forces in non-stationary system and its related dynamic mechanisms.