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A data-driven prediction method for fast-slow systems

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In this work, we present a prediction method for processes that exhibit a mixture of variability on low and fast scales. The method relies on combining empirical model reduction (EMR) with singular spectrum analysis (SSA). EMR is a data-driven methodology for constructing stochastic low-dimensional models that account for nonlinearity and serial correlation in the estimated noise, while SSA provides a decomposition of the complex dynamics into low-order components that capture spatio-temporal behavior on different time scales.

Our study focuses on the data-driven modeling of partial observations from dynamical systems that exhibit power spectra with broad peaks. The main result in this talk is that the combination of SSA pre-filtering with EMR modeling improves, under certain circumstances, the modeling and prediction skill of such a system, as compared to a standard EMR prediction based on raw data. Specifically, it is the separation into “fast” and “slow” temporal scales by the SSA pre-filtering that achieves the improvement.

We show, in particular that the resulting EMR-SSA emulators help predict intermittent behavior such as rapid transitions between specific regions of the system’s phase space. This capability of the EMR-SSA prediction will be demonstrated on two low-dimensional models: the Rössler system and a Lotka-Volterra model for interspecies competition. In either case, the chaotic dynamics is produced through a Shilnikov-type mechanism and we argue that the latter seems to be an important ingredient for the good prediction skills of EMR-SSA emulators. Shilnikov-type behavior has been shown to arise in various complex geophysical fluid models, such as baroclinic quasi-geostrophic flows in the mid-latitude atmosphere and wind-driven double-gyre ocean circulation models. This pervasiveness of the Shilnikow mechanism of fast-slow transition opens interesting perspectives for the extension of the proposed EMR-SSA approach to more realistic situations.