Geophysical Research Abstracts
Vol. 14, EGU2012-8157, 2012
EGU General Assembly 2012

Empirical modeling of ENSO dynamics: Predicting critical transitions in spatially distributed systems

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We present an approach to predicting regime transitions in the climate system's behavior from observed time series. This approach is based on constructing reduced-order stochastic models of a discrete evolution operator from the observations. These models are given by the superposition of a deterministic and a stochastic component; the latter is sought as a state-dependent random function.

Artificial neural networks with certain priors are used for the parameterization of the models. Model learning takes place in a subspace of the system's phase space obtained by projection of the measured spatial field onto its leading empirical orthogonal functions.

The ability of our reduced-order stochastic models to predict regime transitions for times longer than the observation time interval is illustrated on time series of the sea surface temperature (SST) field. These time series are taken from simulations using the intermediate-complexity model of Jin and Neelin (J. Atmos. Sci., 1993; Science, 1994; JN hereafter) for the El-Niño/Southern Oscillation (ENSO). The JN model uses partial differential equations in time and longitude along the Equator and was derived as a simplification of the spatially multi-dimensional Cane-Zebiak coupled ocean-atmospheric model (Zebiak and Cane, Mon. Wea. Rev., 1987).

Slow changes in the model parameters were introduced into the JN model to simulate slowly changing external conditions of the Tropical Pacific's ocean-atmosphere system. Given only scalar time series from the JN simulations, we show that jumps in qualitative behavior can be predicted by our stochastic, data-based model many years (more than duration of time series) in advance. The predictable aspects include evolution of the probability density function and of the spectral density, including critical transitions from chaotic to regular (periodic or quasi-periodic) behavior and vice versa.

References:

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