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Ergodic theory of climate: variability, stability and response

Abstract : Climate studies deal with changes in the statistics rather than in the exact state of the Earth system. Ergodic theory is the art of relating the dynamics of a system to its statistical properties and is thus particularly suitable to a unifying theory of climate. The focus of this work is on the spectrum of transfer operators, governing the evolution of statistics by the dynamics. It is shown that crucial information about a system's variability and stability can be extracted from approximations of the transfer operators and their spectrum.

These results are first applied to stochastic nonlinear oscillators relevant to El Niño-Southern Oscillation (ENSO). Novel analytical formulas are found for the spectrum when the noise is weak, which are compared to numerical results from the reduction method. A key result is the direct relation between the shrinkage of this spectrum and the slowing down of a system undergoing a crisis. In addition, it is shown that the eigenvectors bear the signature of the nonlinearities and could allow to unravel the nature of dominant patterns of variability such as ENSO. It is a matter of great debate whether the Earth system can undergo such dramatic events and if state-of-the-art climate models are able to resolve them and to give early-warnings. The transition from a warm to a snow-covered Earth due to the icealbedo feedback found in a General Circulation Model (GCM) of intermediate complexity, is an example of such crisis. We explain how the slowing down occurring at the crisis is due to the shrinkage of the spectrum. The study of the spectrum thus allows to discuss the validity of concepts such as climate sensitivity or linear response as well as the applicability of early-warning indicators of crises to high-dimensional systems such as climate.
