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# Dynamical systems analysis of the "El Niño Southern Oscillation" phenomenon

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Since the 1980s, when the World Meteorological Organization launched the TOGA (Tropical Ocean-Global Atmosphere Program) program, great advances have been made in understanding ENSO by studying a hierarchy of models (Dijkstra, 2005). At the most complex end of this hierarchy are the Global Climate Models (GCMs), with which simulations of the entire climate system are performed, while at the most elementary end are the simple dynamical models that involve the minimum number of modes necessary to generate the phenomenon and therefore represent the dominant physical processes. Conceptually, two different ways of understanding the irregular oscillations of ENSO are still valid: it could be either a self-sustained oscillator of a chaotic nature or a stable mode excited by atmospheric noise.

In this work, we use methods from complex systems to revisit the ideas regarding two plausible dynamics of ENSO. We ask if the dynamics can be better represented as a self-sustained oscillator of a chaotic nature or a stable mode excited by noise. For this, we analyzed the sea surface temperatures (SSTs), one of the output variables of the simulations generated with GCMs, the most complex simulations available from the extended system. This temperature field averaged in a particular region of the eastern equatorial Pacific (Niño 3.4) gives rise to a temporal signal widely used for ENSO monitoring and as a proxy for the study of the oscillation. In order to analyze the dynamics of the system, we reconstruct the phase space from an embedding of the temporal signal. We find that three modes are enough to recover the ENSO dynamics of the extended system, in principle of infinite dimension. Our conceptual model is based on the existence of a self-sustaining oscillation with a critical slowing down in phase space; that is, the system traverses a region of phase oscillation with a critical slowing down in phase space; that is, the system

traverses a region of phase space more slowly, and includes a periodic forcing that gives rise to chaotic behavior for certain values of the parameters. We validate the model with a topological and statistical analysis of the periodic orbits in the system and, in addition, we show that the complexity of the signal is better represented as a self-sustained oscillator of a chaotic nature than as a stable mode excited by noise (Wang, 2018).

Dijkstra, HA, Nonlinear Physical Oceanography, volume 28. Springer, 2nd revised edition, 2005.

Wang C., A review of ENSO theories, *National Science Review*, Volume 5, Issue 6, November 2018, Pages 813–825