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## Predicting climate change: Uncertainties and prospects for surmounting them

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General circulation models (GCMs) are among the most detailed and sophisticated models of natural phenomena in existence. Still, the lack of robust and efficient subgrid-scale parametrizations for GCMs, along with the inherent sensitivity to initial data and the complex nonlinearities involved, present a major and persistent obstacle to narrowing the range of estimates for end-of-century warming. Estimating future changes in the distribution of climatic extrema is even more difficult. Brute-force tuning the large number of GCM parameters does not appear to help reduce the uncertainties. Andronov and Pontryagin (1937) proposed *structural stability* as a way to evaluate model robustness. Unfortunately, many real-world systems proved to be structurally unstable. We illustrate these concepts with a very simple model for the El Niño–Southern Oscillation (ENSO). Our model is governed by a differential delay equation with a single delay and periodic (seasonal) forcing. Like many of its more or less detailed and realistic precursors, this model exhibits a Devil's staircase. We study the model's structural stability, describe the mechanisms of the observed instabilities, and connect our findings to ENSO phenomenology. In the model's phase-parameter space, regions of smooth dependence on parameters alternate with rough, fractal ones. We then apply the tools of random dynamical systems and *stochastic structural stability* to the circle map and a torus map. The effect of noise with compact support on these maps is fairly intuitive: it is the most robust structures in phase-parameter space that survive the smoothing introduced by the noise. The nature of the stochastic forcing matters, thus suggesting that certain types of stochastic parametrizations might be better than others in achieving GCM robustness. This talk represents joint work with M. Chekroun, E. Simonnet and I. Zaliapin.