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Sensitivity and predictability for weather and climate

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It is well known that the predictability of weather is dominated by sensitivity to initial data due to instabilities and nonlinearities. Sensitivity to model formulation seems to dominate the predictability of climate on decadal and longer time scales.

A brief review of the classical results on sensitivity to initial data will draw attention to issues of coarse graining of the phase space. The presence of multiple weather regimes requires us to refine the usual ideas of homogeneous divergence of trajectories associated with positive Lyapunov exponents.

The sensitivity of climate models to parameter values and parametrizations will be discussed next (Ghil et al., Physica D, 2008; Neelin et al., PNAS, 2010; Chekroun et al., Physica D, 2011). The theory of random dynamical systems provides a framework for this discussion that unifies the complementary approaches of nonlinear deterministic and linear stochastic systems.

It turns out that a climate model's parameter sensitivity can be smooth or it can be rough. A novel tool for examining the degree of roughness is the study of Ruelle-Pollicott (RP) resonances in the spectrum of the transport operator associated with the nonlinear dynamics. In particular, the size of the gap in this spectrum between the unit spectrum and the so-called subdominant resonance — i.e. the one closest to the unit circle but for the trivial one that lies on it — determines the rate of decay of correlations within the system, as well as the degree of roughness of its parameter dependence (Chekroun et al., PNAS, 2014).

These results will be illustrated using a hybrid coupled model of the El Niño–Southern Oscillation (Jin et al., Science, 1994). An important point for their application to full-scale general circulation models and the climate system itself is that partial observations are sufficient in order to determine the system's spectral gap. Small gaps are associated with pronounced low-frequency variability and slow decay of autocorrelations, while large gaps characterize the opposite situation.

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