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Robust estimates of climate change and the generalization of structural stability

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Climate models are among the most detailed and sophisticated models of natural phenomena in existence. At the same time, given the socio-economic importance of future estimates of climate change, the reliability of these estimates is becoming more and more critical. The lack of robust and efficient 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. Continuing efforts at brute-force tuning the large number of model parameters present in GCMs do not appear to achieve the desired reduction of uncertainties.

Andronov and Pontryagin proposed 70 years ago an interesting way to consider the question of model robustness, namely *structural stability*, in which the qualitative, topological behavior of solutions was used as a criterion. Unfortunately, many “real-world" systems — physical, chemical and biological — proved to be structurally *unstable*.

We propose here to revisit the notion of “robustness" of physical models in general, and climate models in particular, using the concepts and tools of *stochastic stability*. This approach seems particularly appropriate, given recent interest in stochastic parametrizations for GCMs. The Lorenz (1963) model and associated simple models constitute our theoretical laboratory. We will review some recent results in the mathematical literature and apply them to this laboratory. This application will help us pinpoint the difficulties still ahead in our approach, as well as the most promising ways to proceed for more detailed and realistic climate models.