The physics of climate sensitivity: a tale of deterministic and stochastic dynamical systems

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The climate system is a nonlinear, heterogeneous and complex physical system that exhibits variability on many scales of time and space. Its dynamical behavior results from a plethora of physical, chemical and biological processes. Hence, it is typically studied across a hierarchy of models, from low-dimensional systems of ordinary differential equations to infinite-dimensional systems of partial and functional differential equations. The theory of differentiable dynamical systems (DDS) has provided a road map for climbing this hierarchy and for comparing theoretical results with observations.

The climate system is also subject to time-dependent forcing, both natural and anthropogenic, e.g. solar luminosity variations, volcanic eruptions and changing greenhouse gas concentrations. Hence increased attention has been paid recently to applications of the theory of non-autonomous and random dynamical systems in order to describe the way that this complex system changes on time scales comparable to a human lifetime and longer. This talk will review the road from the classical applications of DDS theory to low-dimensional climate models with no explicit time dependence to current efforts at applying non-autonomous and random dynamical systems theory to high-end climate models governed by partial and functional differential equations, deterministic as well as stochastic.

We discuss the pullback and random attractors associated with such high-end models and the non-uniqueness of the invariant measures supported on these attractors. The presentation moves from observations of the geophysical phenomena to modeling them and on to a proper physical and mathematical understanding of the models thus obtained.

This mathematical approach complements the statistical physics approach, via fluctuation-dissipation theory, to climate sensitivity, by permitting the treatment of a system that is very far from equilibrium. Issues of distinguishing between forced climate change and intrinsic climate variability will be discussed and connections between the two approaches will be made as time permits.

[l] Ghil, Chekroun, Physica D **237**, 2111 (2008).

[2] Chekroun, Simonnet, Physica D **240**, 1685 (2011).

[3] Ghil, Discr. Cont. Dyn. Sy **37**, 189 (2017).