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The Complex Physics of Climate Change and Climate Sensitivity: A Grand Unification (Alfred Wegener Medal Lecture)

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Recent estimates of climate evolution over the coming century still differ by several degrees. This uncertainty motivates in part the work presented in this lecture.
The complex physics of climate change arises from the large number of components of the climate system, as well as from the wealth of processes occurring in each of the components and across them. This complexity has given rise to countless attempts to model each component and process, as well as to two overarching approaches to apprehend the complexity as a whole: deterministically nonlinear and stochastically linear. Call them the Ed Lorenz and the Klaus Hasselmann approach, respectively, for short.
We propose a “grand unification” of these two approaches that relies on the theory of random dynamical systems (RDS). In particular, we apply this theory to the problem of climate sensitivity, and study the random attractors of nonlinear, stochastically perturbed systems, as well as the time-dependent probability densities associated with these attractors. The random attractors so obtained are visually spectacular objects that generalize the strange attractors of the Lorenz approach.
Results are presented for several simple climate models, from the classical Lorenz convection model to El Nino-Southern Oscillation models. Their attractors carry probability densities with nice physical properties. Implications of these properties for climate predictability on interannual and decadal time scales are discussed.
The RDS setting allows one to examine the interaction of internal climate variability with the forcing, whether natural or anthropogenic, and to provide a definition of climate sensitivity that takes into account the climate system’s non-equilibrium behavior. Such a definition is of the essence in studying systematically the sensitivity of global climate models (GCMs) to the uncertainties in tens of semi-empirical parameters; it is given here in terms of the response of the appropriate probability densities to changes in the parameters and compared with numerical results for a somewhat simplified GCM.
This lecture is the result of recent collaborations with M. D. Chekroun, D. Kondrashov, J. C. McWilliams, J. D. Neelin, E. Simonnet, S. Wang, and I. Zaliapin; more broadly, it represents the fruition of all I learned from tens of Ph. D. students, post-docs and other colleagues over the years.