Response and Fluctuations in the Climate Systems

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The climate is a complex, chaotic, non-equilibrium system featuring a limited horizon of predictability, variability on a vast range of temporal and spatial scales, instabilities resulting into energy transformations, and mixing and dissipative processes resulting into entropy production. Despite great progresses, we still do not have a complete theory of climate dynamics able to encompass instabilities, equilibration processes, fluctuations, and response to changing parameters of the system. The lecture will be divided roughly in three parts.

- First, we will provide an overview of the large-scale dynamical processes inside the climate system taking the point of view of nonequilibrium thermodynamics. We will introduce concepts like efficiency, irreversibility, and entropy production and investigate their relevance for understanding the properties of the climate system. We will show, in particular, how they can be relevant for understanding critical transitions and for interpreting circulations in planetary circulations different from the Earth's [1].

- Second, we will introduce the statistical mechanical point of view on nonequilibrium systems. We will present some applications of the response theory developed by Ruelle for non-equilibrium systems, showing how it allows for setting on firm ground and on a coherent framework concepts like climate sensitivity and climate response. We will show results for simple, intermediate complexity, and comprehensive global climate models. The results are promising in terms of suggesting new ways for approaching the problem of climate change prediction and for using more efficiently the enormous amounts of data produced by modeling groups around the world [2].

- Third, we will delve into the problem of studying the response of the system when we have rough dependence of the system's properties on the parameters. We will discussion a paradigm for "climatic surprises", i.e. occurrence of radically new climate phenomena resulting from perturbations. The lack of correspondence between forced and free fluctuations shows a clear violation of the fluctuation-dissipation theorem [3]. Finally, we will provide a new point of view on critical transitions based on the concept of edge state, which is the gate for noise- induced transitions. We will introduce the Melancholia states, which are climate repellors separating the co-existing warm and snowball states of the climate system [4].

References

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