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Predicting climate change using response theory: Global averages and spatial patterns

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The provision of accurate methods for predicting the climate response to anthropogenic and natural forcings is a key contemporary scientific challenge. Using a simplified and efficient open-source general circulation model of the atmosphere featuring $O(10^5)$ degrees of freedom, we show how it is possible to approach such a problem using nonequilibrium statistical mechanics. Response theory allows one to practically compute the time-dependent measure supported on the pullback attractor of the climate system, whose dynamics is non-autonomous as a result of time-dependent forcings. We propose a simple yet efficient method for predicting—at any lead time and in an ensemble sense—the change in climate properties resulting from increase in the concentration of CO_2 using test perturbation model runs. We assess strengths and limitations of the response theory in predicting the changes in the globally averaged values of surface temperature and of the yearly total precipitation, as well as in their spatial patterns. The quality of the predictions obtained for the surface temperature fields is rather good, while in the case of precipitation a good skill is observed only for the global average. We also show how it is possible to define accurately concepts like the inertia of the climate system or to predict when climate change is detectable given a scenario of forcing. Our analysis can be extended for dealing with more complex portfolios of forcings and can be adapted to treat, in principle, any climate observable. Our conclusion is that climate change is indeed a problem that can be effectively seen through a statistical mechanical lens, and that there is great potential for optimizing the current coordinated modelling exercises run for the preparation of the subsequent reports of the Intergovernmental Panel for Climate Change.

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