Much improved climate predictions from statistical mechanics

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A study from the European Horizon 2020 TiPES project confirms that the large uncertainties of climate models used in the IPCC reports might be reduced considerably by the use of statistical mechanics. The technique, which has been regarded with skepticism by some experts, leads to greatly improved climate predictions and might also help with assessing tipping points, the authors conclude in *Scientific Reports*.

A major challenge in climate prediction is the uncertainty on how we are going to deal with climate change. Computer simulations must be run again and again with different scenarios that vary in future economic development, amounts of climate-influencing gases, the change in use of land use practices, political decisions, etc.

But advanced climate models of the IPCC class are time consuming and run on supercomputers which are expensive to work with. Only a limited selection of scenarios are being considered with each new generation of climate model.

The consequence is large gaps in our understanding of the climate system because results from different scenarios and models cannot easily be compared. There are many unanswered questions such as when and how will tipping points set in? Exactly how much will a given amount of CO_2 added to the atmosphere affect the global mean temperature in present days as well as over the coming centuries?

Now, Valerio Lucarini, University of Reading, UK and Valerio Lembo, Universität Hamburg, Germany and Francesco Ragone, Ecole Normale Superieure, Lyon, France document in *Scientific Reports* that these uncertainties might be reduced considerably. They find that the quality of information extracted from advanced climate models improve significantly when subjected to the theory of statistical mechanics.

"What we have done is show that the approach is feasible even in a climate model of the class used for IPCC projections," explains Valerio Lucarini.

The group constructed so called mathematical response operators that translate inputs in the form of forcing scenarios to outputs in the form of climate change signals. The method was then applied to the newest generation of advanced climate models, called CMIP6.

The calculations accurately predicted variations in global mean temperature as well as large scale oceanic currents like the Atlantic meridional overturning circulation and the Antarctic circumpolar current, demonstrating that the method works.

It is the first time this approach, which is extremely theoretical and uses very basic mathematical and physical properties, has been applied to a full scale complex climate model with a fully interactive ocean.

"In principle, the tools we use here allow you to bridge the gap between different scenarios and to—let's say—decompose the effect of different forcings. So then it is like a black box. You give me a time period and an amount of forcing and I give you the answer. In real time. It is a very efficient way to use the data and you can basically construct a complete scenario of forcing for a given model," explains Lucarini.

"Many people believed that this would not be feasible for a model of the IPCC class. Instead, we have shown that it works. And just like it is easier to predict the statistical motion of billions of molecules than the exact motion of one, this approach actually works better the more complex the climate model is," says Lucarini.

Theoretically, the approach is expected to also facilitate the assessment of tipping points. Testing the response of the system under a variety of scenarios is now more accessible, meaning such experiments can uncover where the system is most sensitive in certain directions for certain forcing. That is exactly the situation when we near a tipping point.

More information: Valerio Lembo et al, Beyond Forcing Scenarios: Predicting Climate Change through Response Operators in a Coupled General Circulation Model, *Scientific Reports* (2020). DOI: 10.1038/s41598-020-65297-2

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