Statistical physics offers a new way to look at climate

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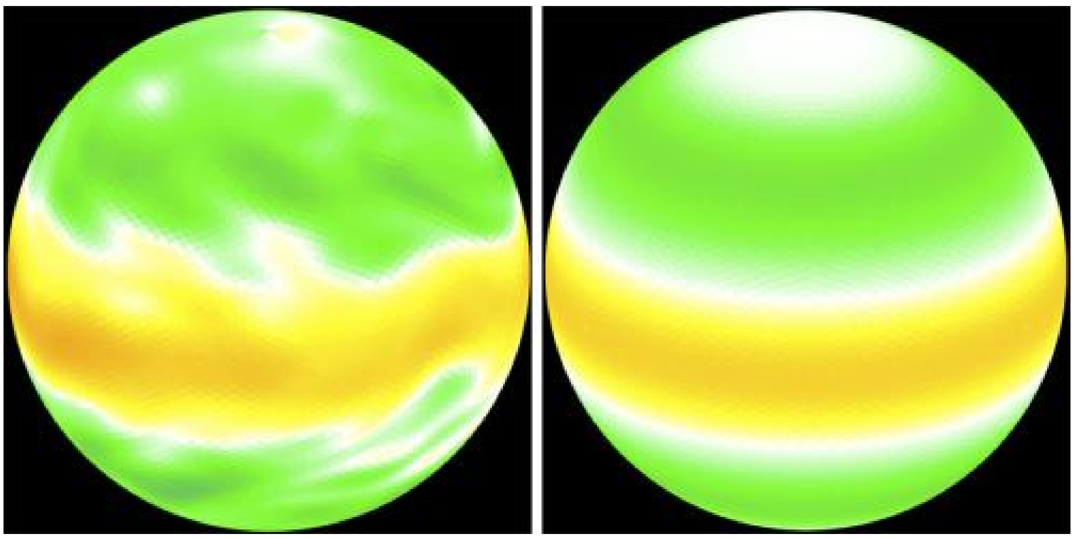

New research suggests that statistical simulations based in basic physics could make for new climate models that are more useful and require less brute-force computing power. The picture shows two models of fluid jets on a hypothetical planet. The statistical simulation (right) is able to arrive at the climate of the jet directly, whereas the tradition model (left) needs to follow every little swirl of air to arrive at the relevant statistics. Credit: Marston Lab/Brown University

Scientists are using ever more complex models running on ever more powerful computers to simulate the earth's climate. But new research suggests that basic physics could offer a simpler and more meaningful way to model key elements of climate.

The research, published in the journal *Physical Review Letters*, shows that a technique called direct statistical simulation does a good job of modeling fluid jets, fast-moving flows that form naturally in oceans and in the atmosphere. Brad Marston, professor of physics at Brown University and one of the authors of the paper, says the findings are a key step toward bringing powerful statistical models rooted in basic physics to bear on climate science.

In addition to the Physical Review Letters paper, Marston will report on the work at a meeting of the American Physical Society to be held in Baltimore this later month.

The method of simulation used in climate science now is useful but cumbersome, Marston said. The method, known as direct numerical simulation, amounts to taking a modified weather model and running it through long periods of time. Moment-to-moment weather—rainfall, temperatures, wind speeds at a given moment, and other variables—is averaged over time to arrive at the climate statistics of interest. Because the simulations need to account for every weather event along the way, they are mind-bogglingly complex, take a long time run, and require the world's most powerful computers.

Direct statistical simulation, on the other hand, is a new way of looking at climate. "The approach we're investigating," Marston said, "is the idea that one can directly find the statistics without having to do these lengthy time integrations."

It's a bit like the approach physicists use to describe the behavior of gases.

"Say you wanted to describe the air in a room," Marston said. "One way to do it would be to run a giant supercomputer simulation of all the positions of all of the molecules bouncing off of each other. But another way would be to develop statistical mechanics and find that the gas actually obeys simple laws you can write down on a piece of paper: PV=nRT, the gas equation. That's a much more useful description, and that's the approach we're trying to take with the climate."

Conceptually, the technique focuses attention on fundamental forces driving climate, instead of "following every little swirl," Marston said. A practical advantage would be the ability to model climate conditions from millions of years ago without having to reconstruct the world's entire weather history in the process.

The theoretical basis for direct statistical simulation has been around for nearly 50 years. The problem, however, is that the mathematical and computational tools to apply the idea to climate systems aren't fully developed. That is what Marston and his collaborators have been working on for the last few years, and the results in this new paper show their techniques have good potential.

The paper, which Marston wrote with University of Leeds mathematician Steve Tobias, investigates whether direct statistical simulation is useful in describing the formation and characteristics of fluid jets, narrow bands of fast-moving fluid that move in one direction. Jets form naturally in all kinds of moving fluids, including atmospheres and oceans. On Earth, atmospheric jet streams are major drivers of storm tracks.

For their study, Marston and Tobias simulated the jets that form as a fluid moves on a hypothetical spinning sphere. They modeled the fluid using both the traditional numerical technique and their statistical technique, and then compared the output of the two models. They found that the models generally arrived at similar values for the number of jets that would form and the strength of the airflow, demonstrating that statistical simulation can indeed be used to model jets.

There were limits, however, to what the statistical model could do. The study found that as pace of adding and removing energy to the fluid system increased, the statistical model started to break down. Marston and Tobias are currently working on an expansion of their technique to deal with that problem.

Despite the limitation, Marston is upbeat about the potential for the technique. "We're very pleased that it works as well as it did here," he said.

Since completing the study, Marston has integrated the method into a computer program called "GCM" that he has made easily available via Apple's Mac App Store for other researchers to download. The program allows users to build their own simulations, comparing numerical and statistical models. Marston expects that researchers who are interested in this field will download it and play with the technique on their own, providing new insights along the way. "I'm hoping that citizen-scientists will also explore climate modeling with it as well, and perhaps make a discovery or two," he said.

There's much more work to be done on this, Marston stresses, both in solving the energy problem and in scaling the technique to model more realistic climate systems. At this point, the simulations have only been applied to hypothetical atmospheres with one or two layers. The Earth's atmosphere is a bit more complex than that.

"The research is at a very early stage," Marston said, "but it's picking up steam."

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