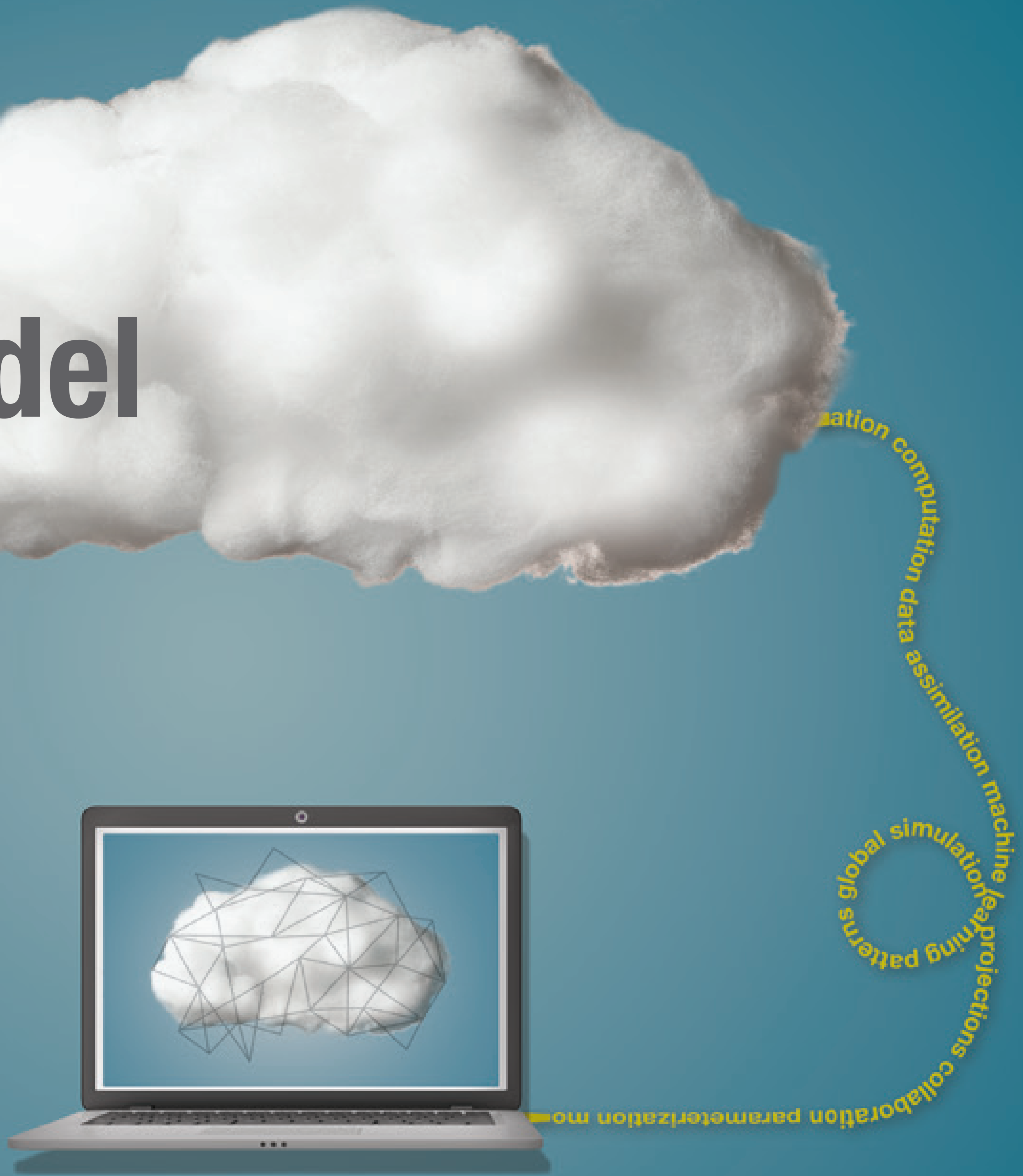
# A Model Climate

Computer models hold the key to understanding our climate and predicting its future. Researchers from across the country are on a quest to improve those models.

by Robert Perkins




When it comes to climate change, one thing is certain, says Caltech climate scientist Tapio Schneider: "Global warming is upon us. Earth has warmed 1.8 degrees Fahrenheit over the past century. This warming is consistent with what basic physics tells us we should expect, given the accumulation of human greenhouse gas emissions in the atmosphere."

The question, then, is not whether but *how much* the earth will be warming and how fast. For these projections, researchers rely on computer models to generate how-and-when scenarios.

"Projections with current climate models, such as how features like rainfall extremes will change, still have large uncertainties, and the uncertainties are poorly quantified," says Schneider. "For cities planning their stormwater management infrastructure to withstand the next 100 years of floods, this is a serious issue; concrete answers about the likely range of climate outcomes are key for planning."

Making predictions more accurate is important for reasons ranging from economic to environmental. As cities contemplate building seawalls to protect against rising ocean waters and farmers attempt to determine what to plant to cope with shifting precipitation patterns, everyone needs improved climate predictions.

"Caltech's effort in climate modeling comes at a critical time in the history of climate science," says John Grotzinger, chair of Caltech's Division of Geological and Planetary Sciences. "Current models diverge significantly in their predictions of future warming. The question is how we can achieve greater accuracy in predictions."

Where does all the uncertainty in the models come from? Scientists say it is the result of lack of computing power both to resolve fine details of the climate system, such as the turbulent dynamics of clouds, and to systematically integrate observations of, for example, clouds and ecosystems into models.

## Building a better model

Facing the certainty of a changing climate coupled with the uncertainty that remains in predictions of *how* it will change, scientists and engineers from across the country are teaming up to build a new type of climate model that is designed to provide more precise and actionable predictions.

The comprehensive effort capitalizes on the vast amounts of data that are now available and on increasingly powerful computing capabilities both for processing data and for simulating Earth's system.

The new model will be built by a consortium of researchers led by Caltech in partnership with MIT; the Naval

Postgraduate School (NPS); and JPL, which Caltech manages for NASA. The consortium, dubbed the Climate Modeling Alliance (CliMA), plans to fuse Earth observations and high-resolution simulations into a model that represents important small-scale features, such as clouds and turbulence, more reliably than existing climate models. The goal is a climate model that projects future changes in critical variables such as cloud cover, rainfall, and sea-ice extent with uncertainties at least two times smaller than existing models.

## Cloudy data

Current climate modeling relies on dividing up the globe into a grid and then computing what is happening in each sector of the grid as well as how the sectors interact with one another. The accuracy of any given model depends in part on the resolution at which the model can view the earth; that is, the size of the grid's sectors. Limitations in available computer processing power currently mean that those sectors generally cannot be any smaller than tens of kilometers per side.

Those might seem small on a global scale but, for climate modeling, the devil is in the details: details that get missed in a too-large grid.

For example, low-lying clouds, like those you might find over the Pacific off the coast of California, are especially important for regulating Earth's temperature (in part, by reflecting sunlight), as anyone who has experienced a cool overcast day in spring knows. They do this in part by reflecting sunlight, but they are so small that they fall through the cracks of existing models.

Similarly, changes in Arctic sea ice have been linked to wide-ranging effects on everything from polar climate to drought in California. But it is difficult to predict how that ice will change in the future because it is sensitive to the density of cloud cover above and the temperature of ocean currents below, neither of which can be resolved by current models.

With the temperature rising and the clock ticking down, a new strategy is needed, one that involves new thinking about how to fuse climate models with the massive amounts of data being generated today.

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—Andrew Stuart

## Zooming in

To capture the large-scale impact of these small-scale features, the team will use high-resolution simulations that model the features in detail in selected regions of the globe. Those simulations will be nested within the larger climate model. The effect will be a model capable of "zooming in" on selected regions, providing detailed local climate information about those areas and informing the modeling of small-scale processes everywhere else.

"The ocean soaks up much of the heat and carbon accumulating in the climate system. However, just how much it takes up depends on turbulent eddies in the upper ocean, which are too small to be resolved in climate models," says Raffaele Ferrari, Cecil and Ida Green Professor of Oceanography at MIT. "Fusing nested high-resolution simulations with newly available measurements from, for example, a fleet of thousands of autonomous floats could enable a leap in the accuracy of ocean predictions."

Existing models are often tested by checking predictions against observations. "But that system only works to the degree that a human then goes in and fixes the model based on their best understanding of the system," Schneider says.

To accelerate and expand the cycle of fusing data with models, Schneider is working with Caltech computational scientist Andrew Stuart. The new model will use data-assimilation and machine-learning tools to train the model to improve itself in real time, harnessing both Earth observations and the nested high-resolution simulations.

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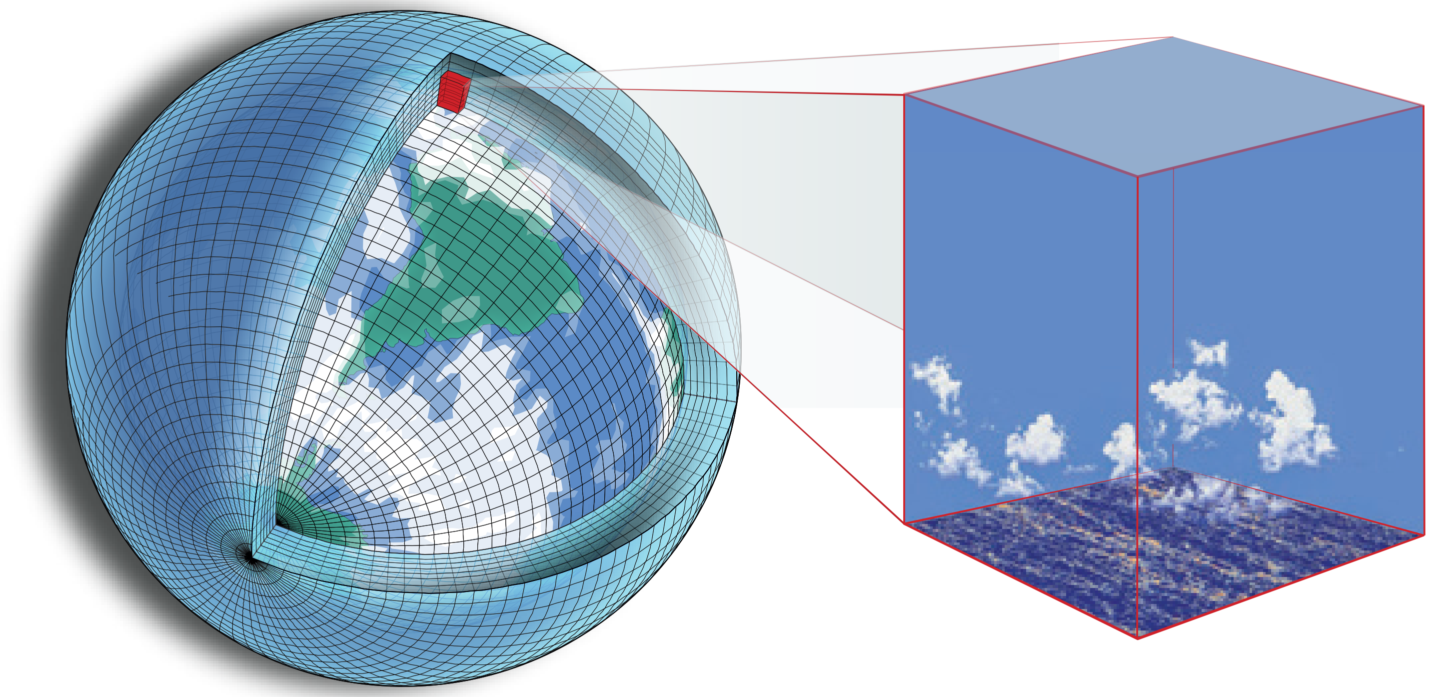
"The topic requires collaboration across traditionally disparate disciplines," Schneider adds, "and what we are doing with Andrew is a good example of how this works well at Caltech."

Each of the partner institutions brings a different strength and research expertise to the project. At Caltech, Schneider and Stuart will focus on creating the data-assimilation and machine-learning algorithms as well as models for clouds, turbulence, and other atmospheric features. At MIT, Ferrari and John Marshall, also a Cecil and Ida Green Professor of Oceanography, will lead a team that will model the ocean, including its large-scale circulation and turbulent mixing. At NPS, Frank Giraldo, professor of applied mathematics, will lead the development of the computational core of the new atmosphere model in collaboration with fellow researchers Jeremy Kozdon and Lucas Wilcox. At JPL, a group of scientists will collaborate with the team on campus to develop process models for the atmosphere, biosphere, and cryosphere.

The consortium will operate in a fast-paced, start-up-like atmosphere and hopes to have the new model up and running within the next five years, an aggressive timeline for building a climate model essentially from scratch.

"A fresh start gives us an opportunity to design the model from the outset to run effectively on modern and rapidly evolving computing hardware, and for the atmospheric and ocean models to be close cousins of each other, sharing the same numerical algorithms," says Giraldo.

"The goal for us is to get ahead of the unnatural experiment we are currently conducting with the climate system," adds Schneider, "to provide accurate and actionable climate predictions before the climate system has revealed the answer to the question of how it will change, and before it is too late to mitigate that change and adapt to it efficiently."



Climate models divide Earth's surface and atmosphere into grid boxes within which temperatures, winds, and ocean currents are computed. Like pixels in an image, the smaller these individual boxes, the clearer and more accurate the model they ultimately create. Clouds are too small to be resolvable in global models, but they can be resolved in high-resolution simulations in limited areas.

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**Tapio Schneider** is Caltech's Theodore Y. Wu Professor of Environmental Science and Engineering and senior research scientist at JPL.

**Andrew Stuart** is the Bren Professor of Computing and Mathematical Sciences.

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