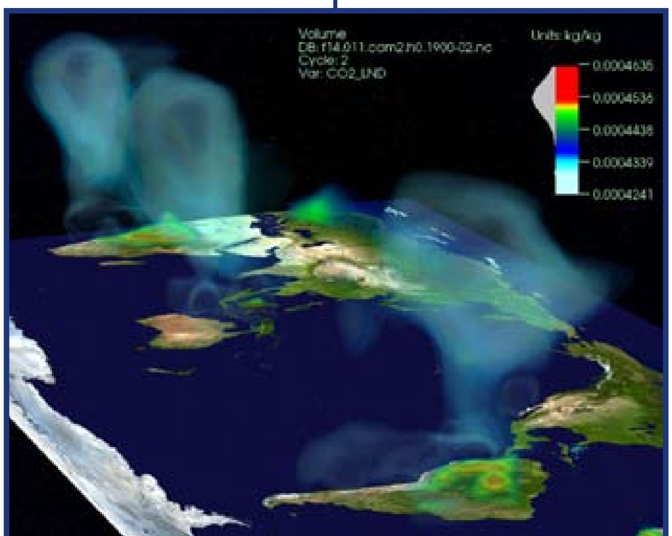
NATIONAL CENTER
FOR COMPUTATIONAL SCIENCES

Scientists Push Climate Simulation to a New Level

Project providing critical information for public and policy makers



A snapshot of the simulated time evolution of the atmospheric carbon dioxide concentration that originates from the land's surface.

Inez Fung, Jasmin John, and Forrest Hoffman
Visualization by Jamison Daniel, NCCS

The earth is getting warmer. Over the last century, the average temperature at the planet's surface has risen about 0.75°C (about 1.5°F), and without intervention there appears no reason to believe the trend is going to stop.

While the change may seem modest, the potential consequences could be dramatic. Melting glaciers and thermal expansion are contributing to a rise in the sea level. Typhoons and hurricanes are likely to become more severe. Some areas are getting wetter, while others can look forward to long-term droughts. Even growing seasons are lengthening.

The issue came to the forefront early this year with the release of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), sponsored by the United Nations. Scientists from more than 100 countries contributed to the report, which concluded that global warming is, in fact, beyond serious question, with 11 of the last 12 years ranking among the warmest in the last one and a half centuries.

The report, based on research published over the last several years, determined that there is more than a 90-percent chance that climate warming over the last 50 years has been the result of human activity. The primary culprits are chemicals known as greenhouse gases because they cause the atmosphere to trap more of the sun's heat than it would otherwise. The most important greenhouse gas is carbon dioxide, which is increased through the burning of fossil fuels by power plants, industry, and vehicles. Two other important greenhouse gases—methane and nitrous oxide—are linked mostly to agriculture.

A project headed by Warren Washington of the National Center for Atmospheric Research (NCAR) is using the formidable computing resources of the National Center for Computational Sciences (NCCS) to increase the confidence of global climate analysis. In doing so, the project will provide information needed by the public and policy makers alike to address their changing climate.

The project, known as the Climate-Science Computational End Station Development and Grand Challenge Team, is working to push climate simulation to a new level, both through the efforts of team members and by providing the scientific community as a whole with improved analytical tools.

"There will be intense research over the next decade or so to try to mitigate the effects of global warming through the possible use of increased renewable energy sources and possibly nuclear energy," Washington explained. "Advanced climate models can provide various scenarios of possible future climate change that will help guide policy makers in those decisions."

The challenge faced by climate scientists is no longer about whether the climate is getting warmer; that fact has been established by decades of measurement and research. Instead, scientists are working to determine exactly why the climate is changing, what the consequences are, and what, if anything, we can do about it.

"The warming discussed in the IPCC report, that's data," said Oak Ridge National Laboratory's (ORNL's) John Drake, chief computational scientist for the project. "That's observational data. There's very little that you'd even say is theory in that.

"So then, how do you characterize that? Here's where the theory starts to come in and where computing starts to play a role. Is it caused by human fossil-fuel burning, etc., or is this a natural variability within the climate system?"

Washington's team includes leading climate researchers from government and academia. Besides the scientists at NCAR, project members include the Department of Energy (DOE), the National Science Foundation, and the National Aeronautics and Space Administration (NASA). Researchers working on the project come from Oak Ridge, Lawrence Livermore, Lawrence Berkeley, Los Alamos, and Pacific Northwest national laboratories, as well as universities around the country.

The group has already made substantial contributions to the field. It is responsible for the Community Climate System Model (CCSM), which effectively simulates the effect of increasing greenhouse gases on temperature across the planet. The team also made the largest contribution of simulation data to the recent IPCC report.

At the time of those simulations, the project used the NCCS IBM pSeries Cheetah system, which has a peak performance of more than 4 teraflops, or 4 trillion calculations per second. Moving into 2007, the team is using the center's Cray XT4 Jaguar system, which has a peak performance of 65 teraflops, and its Cray X1E Phoenix system, which has a peak performance of more than 18 teraflops.

The project needs the increased computing power and more to improve the CCSM. While existing models allow researchers to accurately simulate the impact of increased greenhouse-gas concentrations on climate across the globe, the scientists are committed to simulating climate change on much smaller regions.

"By improving the scale and coming closer to the actual data, you can say what's the impact on a smaller area," Drake explained. "We'd like to be able to say, for example, what the different effects are between this side of the Appalachians and the other side of the Appalachians. That's a little fuzzy currently because we don't really resolve scales enough to tell what's the difference between Knoxville and Asheville. We'd like to be able to do that; clearly, that would be important information for people to have."

In addition, the researchers are committed to simulating the entire carbon cycle. The job is formidable. Instead of providing the increased levels of carbon dioxide in the global atmosphere, newer versions of the model will calculate emissions where they occur—at factories, power plants, and urban settings—and model the journey of carbon dioxide in the atmosphere. They will include the exchange of carbon dioxide between the atmosphere and the ocean. They will include the trees that take up carbon dioxide in the spring and summer and release it back in the fall and winter. And they will simulate the effect of deforestation in places such as the Amazon, where trees are increasingly unavailable to take carbon dioxide out of the atmosphere.

The job will be difficult. As the model becomes increasingly complex, each new element will introduce new errors that must be found and corrected.

"This is a hard problem," Drake explained. "It's not going to be solved in 5 years, or even probably in 10 years. There's still a lot of data that needs to be gathered in order to do this right. We will introduce errors that then need to be found and squeezed out of the theory. That's going to require new measurement data and novel techniques of applying the existing observations to find those places where our understanding is off."

The project is getting help in the form of not only more data, but also more complete data. NASA plans a 2008 launch of the Orbiting Carbon Observatory, a satellite that will collect precise carbon-dioxide measurements in the earth's atmosphere. DOE, too, will contribute to the quality of observation with the Atmospheric Radiation Measurement (ARM) program, which will focus on the role of clouds in absorbing or reflecting radiation. In fact, data from the ARM program is being stored at the NCCS.

The outcome will be of benefit not only to the dozens of leading scientists working on the project, but also to the scientific community in general.

"We think of the code that we're developing as an instrument," Drake explained. "We are all involved in supporting and providing access to this latest version of the code, of the model that's actually being developed. Each experiment builds on the next, so that's our instrument that we're constantly working on and improving and providing to people, because they can't do it on their own.

"No one can develop a climate model on their own anymore; it's just way too complicated. This community support for the instrument is the other value added of the end station."

— LEO WILLIAMS
williamsjl2@ornl.gov

For more information, contact:
John B. Drake
Computational Earth Sciences Group
Computer Science and Mathematics Division
Oak Ridge National Laboratory
865-574-8670
drakejb@ornl.gov