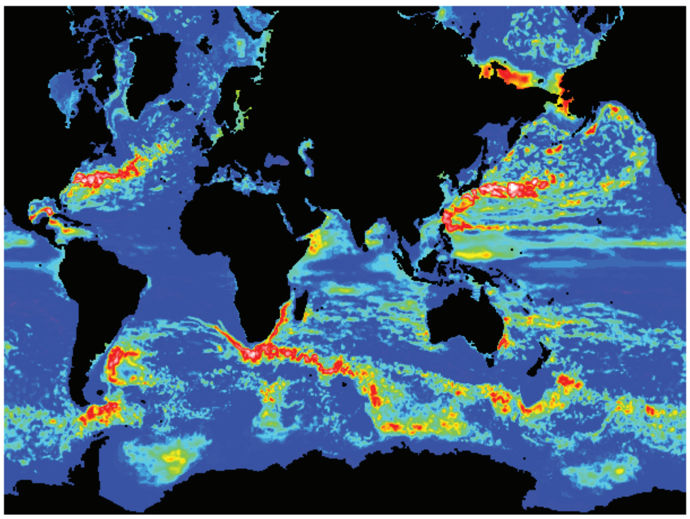
Simulation Helps Unlock the Ocean's Secrets

Project looks into the fate of trapped heat and greenhouse gases



Ocean surface height variability from ORNL Jaguar simulation.

The ocean is the 800-pound gorilla of climate studies.

A change in ocean currents could dramatically influence which regions on earth will be frigid and which will be temperate, which will be jungle and which will be desert. The ocean holds vast amounts of heat, as well as carbon dioxide and other greenhouse gases, and plays a pivotal role in regulating the earth's climate on timescales from years to millennia.

But while the ocean is undeniably important to climate, its role is not well understood. Scientists have a pretty good idea how much water is transported by currents such as the Gulf Stream, but they still don't understand the details of how materials and gases—including greenhouse gases—are carried from the surface of the ocean to its interior and back again.

More importantly, they are uncertain what role the ocean plays in climate change. This is important both now, when the scientific community agrees that the earth is warming and the repercussions may be catastrophic, and on timescales of tens and hundreds of thousands of years, as the earth moves from ice age to ice age.

"We don't yet really understand the role of the ocean in regulating climate," explained Synte Peacock of the University of Chicago. "For example, only about half of the carbon dioxide that has been emitted over the last 100 years or so currently resides in the atmosphere. The rest is in the ocean and the terrestrial biosphere. But the absolute amount stored in the ocean, and how it is distributed, is still being debated. What will future ocean uptake of gases such as CO_2 look like? Where will the CO_2 that enters the upper layers of the ocean in coming decades go, and on what timescales will it be transported through the ocean interior? These are questions for which we don't yet have firm answers."

A team led by Peacock is using the immense computing power of the National Center for Computational Sciences to run the most fine-grained, global-scale simulations ever of how the world's oceans work. In doing so, the team will not only provide new knowledge of the currents and processes at work in the oceans, it will also provide many more details about the possible long-term fate of gases and chemicals released into the ocean.

The team is using the center's Cray XT4 Jaguar supercomputer to perform the first-ever 100-year simulation of the ocean at a fine enough scale to include the relatively small, circular currents known as eddies. The task is daunting. The earth is enveloped by 319 million cubic miles of ocean, which covers nearly three-quarters of the planet to an average depth of more than 12,000 feet. By exposing the ocean to winds, heat, and freshwater fluxes that are the same for each simulated year, the team will be able to determine what changes in the ocean are due to its internal dynamics and what changes are imposed on it from interaction with the atmosphere.

“There is a lot we don’t understand,” Peacock said. “If you release carbon dioxide, what will happen to it? It will mix, get diluted, get transported into the interior ocean, and eventually make it back to the surface; but how long will it take, and what pathways will it take?”

The group will perform a series of virtual tracer studies, following both particles and dissolved material as the simulations push them around the ocean. These experiments will give scientists an idea of how something might be transported from the surface to the ocean depth and around the globe, and of how long the journey might take. The job will be complicated by the difference in timescales between the surface (with a turnover on the order of decades) and the deep ocean (where the same process may take centuries).

The inclusion of ocean eddies is a key element in the project. Eddies are the “weather” of the ocean. Ranging in diameter from about 100 kilometers near the equator to about 10 kilometers near the poles, they play a key role in the dynamics of the ocean. Until recently, researchers lacked the computing power to simulate eddies directly on a global scale, and simulations were forced to incorporate parameterizations to account for their influence. Although scientists agree that ocean models must include eddies to provide an accurate picture of the ocean’s circulation, it is still not clear how eddies will affect global heat transport and the stirring of chemicals in the ocean.

“There is evidence that eddies can actually change the average flow of the oceans,” Peacock noted. “Once you get to the resolutions you need to include the eddies, you get features that don’t exist otherwise in a coarser-mesh model. An example of this is a series of east-west jets which criss-cross the Pacific Ocean. These just don’t exist in the coarser-grid-size models.”

The team’s ocean model will eventually be incorporated into a fully eddy-resolving version of the Community Climate System Model, a global climate model being developed primarily by researchers at the National Center for Atmospheric Research. According to Peacock, this will be the first time that a coupled climate model includes an ocean able to resolve eddies.

“Lots of people run coupled models,” she explained, “but usually the ocean components in the models use a coarse grid size. It will be interesting to see what happens when one runs a coupled model which has eddies in both the ocean and the atmosphere.”

This information will be extremely valuable for climate scientists and policy makers alike, since a reliable ocean model is critical to a reliable climate model. By helping us understand how the ocean handles the massive amounts of heat and greenhouse gases it contains, Peacock’s team will help us become more knowledgeable and responsible guardians of the planet.

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