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High-resolution global coupled ocean/sea ice modeling

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requires 4.5 wall-clock hours on 144 1.5-Gflops CPUs of the NERSC IBM SP to complete one simulated year. NERSC gave CCSM2 special queue priority to complete this project in a timely fashion. Preliminary results of 800 model years were presented to 250 participants at the Seventh Annual CCSM Workshop held in Breckenridge, Colorado, on June 25–27, 2002.

INVESTIGATORS W. Washington, P. Gent, J. Hack, J. Kiehl, G. Meehl, and P. Rasch, National Center for Atmospheric Research; B. Semtner, Naval Postgraduate School; J. Weatherly, U.S. Army Cold Regions Research and Engineering Lab Laboratory.

PUBLICATION J. T. Kiehl and P. Gent, "The Control Climate Simulation from the Community Climate System Model (CCSM2)" (in preparation).

URL http://www.ccsm.ucar.edu/index.html

High-Resolution Global Coupled Ocean/Sea Ice Modeling

The objective of this project is to couple a high-resolution ocean general circulation model with a high-resolution dynamic-thermodynamic sea ice model in a global context. Currently, such simulations are typically performed with a horizontal grid resolution of about 1 degree. At this resolution (about 30 to 50 km in the polar regions), the ocean model cannot resolve very narrow current systems (including fronts and turbulent eddies) that play a crucial role in the transport of heat and salt in the global ocean. Similarly, lower-resolution sea ice models cannot resolve important dynamics that occur in regions of complicated topography (such as the Canadian Archipelago).

This project is running a global ocean circulation model with horizontal resolution of approximately 1/10th degree—between 11 km and 2.5 km (Figure 2). This is the highest-resolution simulation even attempted with a such a realistic model. This configuration has dimensions of 3600 × 2400 × 40, resulting in 177 million active ocean grid points (some grid points are on land). The code being used is the Parallel Ocean Program (POP), developed at LANL under the Department of Energy's CHAMMP program. At NERSC, 448 processors are used to run the model. One year can be simulated in about eight wall-clock days (86,000 processor hours), generating over 500 GB of output. Eight model years have been run to date, with a goal of 30–50 years. After the ocean simulation has run for 10–15 model years, it will be coupled with a sea ice model to more accurately simulate the polar circulation.

The interaction of the ocean and overlying sea ice in global coupled numerical models is poorly understood, though very important. When ocean water freezes into sea ice, salt is released into the upper ocean, making it more dense. Conversely, when the ice melts, it creates a layer of fresh water that is less dense than the underlying ocean. This delicate balance between melting and freezing is very difficult to simulate with coarse grids. In particular, high vertical resolution is needed near the surface to simulate this salinity balance correctly. High horizontal resolution is required to properly simulate the current systems that advect these salinity anomalies into the open ocean. Inaccuracies in the surface ocean properties due to poor representation of ocean-ice interaction can have wide-ranging global consequences. Most notable is the possibility that too much fresh surface water can inhibit vertical convection in the northern seas (since it is less dense than the salty water beneath it), which then disrupts the entire global heat budget. Coarse-resolution simulations have found that the circulation and heat budget are extremely sensitive to the way sea ice is prescribed in ocean-only runs. The best tool for simulating the global circulation accurately is a high-resolution, fully coupled ocean-sea ice model.

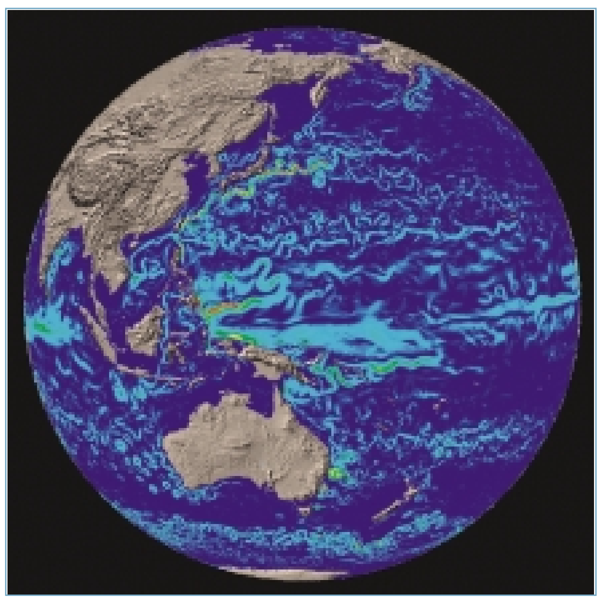

FIGURE 2 High-resolution (1/10 degree) POP ocean model currents at 50m depth. Blue = 0; red > 150 cm/s.

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URL http://www.lanl.gov/orgs/t/t3/codes/pop.shtml

Supernova Explosions and Cosmology

This collaboration brings together the SciDAC Supernova Science Center and the members of the PHOENIX/SYNPOL collaboration. The goal is a better understanding of supernovae of all types through simulation and model validation. Specific objectives are to clarify the physics of supernova explosions, to improve the reliability of such explosions as calibrated standard candles, and to measure fundamental cosmological parameters. Despite decades of research and modeling, no one understands in detail how supernovae work. The problem persists largely because, until recently, computer resources have been inadequate to carry out credible multi-dimensional calculations.

On June 4, 2002, at the American Astronomical Society meeting in Albuquerque, N.M., Michael Warren and Chris Fryer from Los Alamos National Laboratory presented the results of one of several projects in this collaboration, the first 3D supernova explosion simulation, based on computation at NERSC (Figure 3). This research eliminates some of the doubts about earlier 2D modeling and paves the way for rapid advances on other questions about supernovae.

Earlier one-dimensional simulations of core-collapse supernovae almost always failed to explode. Two-dimensional simulations were qualitatively different from 1D, leading to a robust explosion without fine-tuning of the star's physical properties. They showed that the explosion process is critically dependent on convection, the mixing of the matter surrounding the iron core of the collapsing star. It was believed that the results could again be changed radically by adding a third dimension, but the 3D simulations turned out to be similar to the 2D results. The explosion energy, explosion time scale, and remnant neutron star mass do not differ by more than 10 percent between the 2D and 3D models. With these 3D results, researchers are ready to attack more exotic problems that involve rotation and non-symmetric accretion.

The 3D simulation used a parallel smooth particle hydrodynamics (SPH) code coupled with a flux-limited diffusion radiation transport. Supernova calculations are computationally demanding because many processes, involving all four fundamental forces of physics, must be modeled and followed for more than 100,000 time steps. Typical simulations (1 million particles) took about three months on the IBM SP at NERSC.

In the next five years, the Supernova Cosmology Project and the Nearby Supernova Factory experiments will increase both the quality and quantity of observational supernova data at low and high redshift by several orders of magnitude. The purpose of these experiments is to improve the use of supernovae as tools for cosmology by determining the underlying physics behind these catastrophic events and to utilize these tools to help us understand the dark energy that drives the acceleration of the universe. The only way to fully exploit the power of this amazing data set is to make a similar order-of-magnitude improvement in computational studies of supernovae, via spectrum synthesis and radiation hydrodynamics. The focus of the PHOENIX/SYNPOL collaboration's portion of this project is to start the process of creating 3D spectrum synthesis models of supernovae (Figure 4) in order to constrain the observations and place limits on the explosion models and progenitors of supernovae using the full-physics 1D models as a guide.

Currently two sets of spectrum synthesis codes, PHOENIX and SYNPOL, are used at NERSC to study the model atmospheres of supernovae. PHOENIX models astrophysical plasmas in one dimension under a variety of conditions, including differential expansion at relativistic velocities found in supernovae. The current version solves the fully relativistic radiative transport equation for a variety of spatial boundary conditions in both spherical and plane-parallel geometries for both continuum and line radiation simultaneously and self-consistently using an operator splitting technique. PHOENIX also solves the

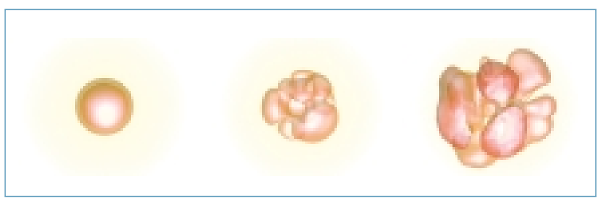

FIGURE 3 Computer visualization shows (left to right) three stages of a simulated supernova explosion over a period of 50 milliseconds, starting about 400 milliseconds after the core begins to collapse. The surfaces show the material which is flowing outward at a speed of 1,000 kilometers/second. Left is the initial spherical implosion. Center, as in-falling gas approaches the core, it is exposed to a higher and higher influx of neutrinos that heat the gas and make it buoyant. Right, as more cold gas sinks in, it is heated and rises, resulting in enough convective energy transfer to create an explosion.