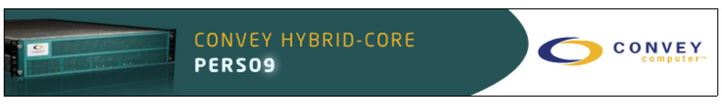

Climate Modeling Research at Argonne National Laboratory

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inside SC09 Argonne National Laboratory is one of the U.S. Department of Energy's oldest and largest national laboratories for science and engineering research. Managed by UChicago Argonne, LLC, for the U.S. Department of Energy's Office of Science, Argonne supports over 200 research projects in the areas of energy, biological and environmental systems, and national security and operates major experimental and computational facilities for the nation.

"Understanding climate change is an interdisciplinary effort that combines many Argonne research areas," observes Rick Stevens, associate laboratory director of Computing, Environment, and Life Sciences (CELS) at Argonne. "We are creating the scientific understanding and computational tools required first to understand and then to respond to global climate change at a regional level."

Climate modeling research at Argonne has three main thrusts. The first involves developing climate models capable of executing efficiently on ultra-high-speed supercomputers, with full integration of biosphere and atmospheric processes. For example, Argonne is part of a multi-laboratory project that is working to transform the Community Climate System Model (CCSM) into an Earth system model that fully simulates the coupling between the physical, chemical, and biogeochemical processes in the climate system. Argonne leads the integration of the various components through its development of the Model Coupling Toolkit and co-development with the National Center for Atmospheric Research of the CCSM coupler.

The second climate research thrust at Argonne involves improving climate model accuracy. For example, Argonne is working with the University of Chicago to transform unevenly distributed observational data into value-added data for climate models. Central to this work is the statistical analysis of quantities averaged from the observation grid to the model grid, and the study of correlations in errors across space and time. This work builds upon Argonne's extensive expertise in environmental sensing, as does another project that has produced a new procedure for estimating uncertainty in estimates of surface energy fluxes generated from a limited set of measurements.

The third research thrust involves developing models of the interactions between social and economic systems and the Earth system. "As we gain deeper understanding of climate change, increased attention must be focused on climate change impacts on natural and human systems and on the costs and benefits of potential human mitigation and adaptation responses," notes Ian Foster, director of Argonne's Computation Institute. "Argonne and its partners bring to this problem unique expertise in energy systems, environmental modeling, and the economic modeling and computational methods required to build integrated assessment models capable of resolving regional issues."

Argonne research is yielding new insights into such issues as how available arable land and agricultural productivity may change as a result of changes in income, population distribution, and climate and how uncertainty in economic model inputs translates into uncertainty in model outputs.

Providing Access to Accurate Climate Data

Advances in climate modeling depend heavily on availability of accurate data. Argonne plays a major role in generating and ensuring access to high-fidelity atmospheric measurements, via its leadership of DOE's Atmospheric Radiation Measurement Climate Research Facility (ACRF), a DOE national user facility.

"Argonne has the overall responsibility for ACRF operations, which operates 287 instruments at the five field sites and mobile facility," explains Doug Sisterson, a research meteorologist and ACRF operations manager. "These instruments represent 821 data streams, for a combined daily volume of 10 gigabytes."

Spending 6-18 months in each place, ACRF's mobile facility has been to Africa (2006), Germany (2007), China (2008), and currently it is deployed in the Azores. In 2011, Argonne atmospheric scientist Rao Kotamarthi will lead the science campaign in India. Argonne is also designing and building a new mobile facility for streamlined deployments worldwide, including measurements on ships and ocean platforms.

In addition, Argonne operates the ACRF Southern Great Plains climate research site in Oklahoma and Kansas, which has provided continuous, surfaced-based atmospheric observations at that fixed site since 1995. Argonne also has substantial remote sensing expertise for probing the atmospheric boundary layer and above with laser and microwave-based instrumentation.

Exploiting Supercomputers for Climate Research

The numerical methods used to solve the equations that describe climate behavior require enormous calculations, for example to resolve important ocean circulation features explicitly, without resorting to parameterization of their effects. Argonne operates a range of high-performance computer systems used in climate modeling research. At the forefront is the Argonne Leadership Computing Facility (ALCF), operated for the U.S. Department of Energy's Office of Science for the national and international scientific community. ALCF's flagship computer is Intrepid, a 557-teraflop IBM Blue Gene/P system with 163,840 processors.

Climate studies carried out on Intrepid include development of the next-generation Community Climate System Model; formulation of theories of the general circulation of the ocean with an emphasis on how the ocean and the atmosphere work together to make our planet livable; and research to improve the accuracy of climate models for regional use. Based on their potential for scientific breakthroughs, these high-impact studies have been awarded large allocations of computer time on Intrepid by the U.S. Department of Energy's INCITE (Innovative and Novel Computational Impact on Theory and Experiment) program.

In addition, Argonne's Laboratory Computing Resource Center (LCRC) provides mid-range supercomputer capabilities for applications and software development. LCRC's newest cluster, called Fusion, is based on IBM iDataPlex nodes, running Intel Nehalem series quad-core processors and Mellanox QDR InfiniBand communications fabric. Fusion's 320 dual socket nodes provide 26 teraflops of computing capability.

One climate model that has made great use of the LCRC facilities is the Fast Ocean Atmosphere Model (FOAM). FOAM, a fully coupled general circulation model, enables simulation throughput of over 100 years per day of computation. The model has been used extensively for both recent and deep-time paleoclimate research. It has also been used as a testbed for climate model techniques such as the hybrid parallel integration scheme that has been implemented in the CCSM.

"The LCRC provides an excellent development and production platform for FOAM," says Rob Jacob, a computational climate scientist at Argonne. "LCRC systems have enabled us to study processes that control climate on geologic time scales."

Climate Modeling Research: The Next Steps

Climate modeling research will continue to demand the most advanced computer systems available. "Formidable challenges remain as we work to incorporate the full carbon and hydrologic cycles and improve resolution to the level that clouds and land use can be incorporated realistically," observes Ray Bair, Chief Computational Scientist in CELS. "Access to a broad spectrum of high-performance systems, from teraflops to petaflops to exaflops, is critical for success."

According to Rao Kotamarthi, "The only way to study solutions to the complex interactions that govern the climate system is through climate modeling on advanced computer systems. Through such modeling, not only can we compare theoretical calculations with observations, we also can make predictions about future climate."

Economists and social scientists are also excited by the potential for transformative research offered by high-performance computing. Observes Argonne partner Ken Judd of the Hoover Institution and the University of Chicago: "Economists are used to running programs on laptops. But the world economy is every bit as complex as the atmosphere—and understanding it is just as important, given that any human response to climate change is likely to have profound economic implications."

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