Oak Ridge Leadership Computing Facility

WORLD IN THE BALANCE

How the Jaguar supercomputer improves knowledge of climate change

U.S. DEPARTMENT OF ENERGY | Office of Science

Oak Ridge National Laboratory

OLCF Oak Ridge Leadership Computing Facility

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“What’s the use of a fine house if you haven’t got a tolerable planet to put it on?”

—Henry David Thoreau

Earth’s climate is changing as a consequence of our energy use. Burning fossil fuels quickly releases carbon that had been trapped over time. Greenhouse gases, such as carbon dioxide from fossil fuels, methane from melting permafrost, and nitrous oxide from farming, will raise Earth’s average temperature by 2 to 12 degrees Fahrenheit this century, according to the United Nations’ Intergovernmental Panel on Climate Change (IPCC), which shared a 2007 Nobel Prize with Al Gore.

Supercomputers can help us explore our options as we try to adapt to climate change and lessen its risks. Models and simulations of complex, dynamic situations provide insight that aids U.S. governmental bodies tasked with assessing climate change—including the Department of Energy (DOE), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA). With four of the 25 swiftest supercomputers at DOE’s Oak Ridge National Laboratory (ORNL), the lab has become an interagency crossroads for climate research. Case in point: NOAA has launched a computational climate center and research collaboration at ORNL’s Oak Ridge Leadership Computing Facility (OLCF). Such partnerships leverage the public investment in science.

The OLCF hosts the world’s most powerful high-performance computing system for open science. Called Jaguar, the Cray XT system has a peak calculating speed of more than 2 petaflops, or quadrillion calculations per second. Its almost a quarter million AMD Opteron processing cores working concertedly can do in a day what it would take every person on Earth working together several hundred years to do—assuming each could complete one calculation per second.

As a “time machine” of sorts providing a window into our climate past, present, and future, Jaguar can provide science-based answers to inform policy, guide strategy, and accelerate action. Below are goals of select climate experiments on DOE supercomputers.

Probing the past. Scientists incorporate what is known about climate into models that simulations set in motion. The simulations reflect the past and present and probe the future. The Community Climate System Model (CCSM) couples independent models describing Earth’s atmosphere, oceans, lands, and sea ice. Validating that models correctly depict the past improves confidence that simulations can accurately forecast responses to forcing agents, such as atmospheric carbon.

In 2009 Science magazine published a simulation of “abrupt” climate change that caught events missed by other simulations. Most climate simulations are discontinuous, amounting to snapshots of century-sized time slices taken every 1,000 years or so. Such simulations can miss transitions occurring over centuries or millennia. Oak Ridge supercomputers had the power to run the CCSM in continuous simulations that stitched together an uninterrupted stream of climate snapshots and recovered Earth’s history as a motion picture. The results showed ice sheets melting in North America and Eurasia 19,000 years ago. By 17,000 years ago, melting glaciers had dumped so much freshwater into the North Atlantic that the overturning ocean circulation stopped and Greenland cooled. Freshwater flux continued until about 14,500 years ago, then virtually stopped. Over ensuing centuries, Greenland’s temperature rose by 27 degrees Fahrenheit and sea level rose about 16 feet. Based on the simulations, researchers proposed a new mechanism to explain events during Earth’s most recent period of natural global warming. Led by Zhengyu Liu of the University of Wisconsin and Bette Otto-Bliesner of the National Center for Atmospheric Research (NCAR), the work may illuminate the effect of today’s glacial melting in Greenland and Antarctica on tomorrow’s oceans.

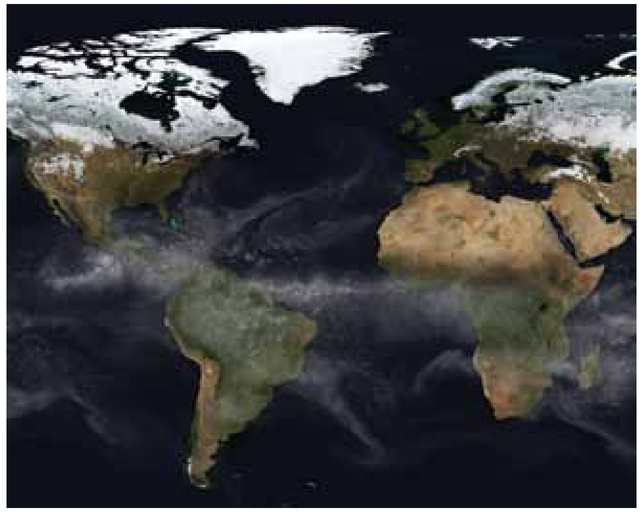
Another project on Jaguar simulates past extreme weather, such as hurricanes and heat waves, to improve climate models predicting future extremes. Led by Gilbert Compo of the University of Colorado, the project reconstructs global weather conditions in six-hour intervals from 1850 to present. Analysis of events such as the Children’s Blizzard of 1888 and the 1930s Dust Bowl ensures models accurately reflect data and builds confidence that models can forecast accurately.

Picturing the present. DOE supercomputers at ORNL and Lawrence Berkeley National Laboratory provided more than half of the joint DOE/NSF data contribution to AR4, IPCC’s fourth assessment report, which concluded global warming is definitely happening and humans caused most of it since the mid-20th century. As a group the IPCC neither conducts research nor monitors climate. Instead it evaluates climate change by assessing peer-reviewed, published scientific literature. The DOE/NSF data was contributed to a repository that scientists worldwide accessed to write approximately 300 journal articles cited in AR4. Recently, DOE and NSF’s NCAR selected ORNL, DOE’s largest science and energy laboratory, as a computational end station for climate science. That means Jaguar will run crucial simulations using the CCSM and generate the largest set of publicly available climate data anywhere. The data will be placed in a repository for analysis, publication, and inclusion in AR5, expected in 2014. The comprehensive and detailed studies enabled by Jaguar will improve the level of certainty for IPCC conclusions.

In another study, led by ORNL’s Kate Evans, a team of scientists at ORNL and NCAR uses Jaguar to simulate how climate responds to aerosols from volcanic eruptions. Sulfur dioxide gas can circulate for weeks, interacting with oxygen to form a sulfate aerosol that stays in the atmosphere for years. Solar radiation bounces off aerosol particles to cause short-term cooling. In contrast, human-produced gases trap solar radiation to cause long-term warming. The cooling can mask the warming. The simulation harnesses Jaguar’s processing power to calculate temperature, pressure, and other variables for millions of points on the globe every 150 seconds from 1978 to present. When observational and simulation data match, confidence rises in a model’s ability to predict a response.

Forecasting the future. A project led by NOAA’s Venkatramani Balaji models natural and forced climate variability at a resolution high enough to depict physical processes realistically. The model explores the limits of climate prediction, the ability of the ocean’s “memory” to modulate climate change, and the behavior of hurricanes in a warmer world. The work will provide insight into climate variability over decades and improve prediction of regional events.

Whereas simulations cited in AR4 looked at weather features in about 87-mile resolution, a NASA simulation on Jaguar led by Max Suarez examines features 2 miles across—a resolution so fine it shows clouds. Cloud processes regulate the flow of radiation in the upper atmosphere, control precipitation, and exert other effects. Among the atmospheric processes playing roles in climate, cloud processes are among the most important but least understood. Jaguar may improve understanding of how clouds affect climate and capabilities for predicting weather and simulating climate change.



This summer the Oak Ridge Climate Change Science Institute was established to develop, coordinate, and execute the programs of ORNL’s multi-agency, multidisciplinary climate change research partnerships. The institute brings together some of the best minds of a generation and leadership-class computing to accelerate solutions so we can adapt to present change and lessen future risks.

Petascale Jaguar:

Balancing speed and power to solve complex problems