Cray Supercomputers in Climate, Weather and Ocean Modeling

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The practical impact of weather, climate and ocean prediction on the world’s population and economy drives the usage of high performance computing (HPC) for earth system modeling. The socioeconomic impacts of improved predictive capabilities are well-recognized by scientists as well as government leaders. The earth’s environment plays an important role in shaping economies and infrastructures, and touches upon nearly every aspect of our daily lives, including recreational activities, food supplies and energy resources.

Cray supercomputers are synonymous with the solution of mission-critical scientific problems and have been systems of choice for many years in the earth system research and operational communities where production capability computing is of strategic importance. Earth system modeling is a key application area that spans nearly the entire spectrum of Cray’s customer base, ranging from those whose core business is earth system modeling to multi-disciplinary HPC centers.

From performance to system and data management, climate, ocean and weather modeling present unique HPC challenges. The computational requirements for simulations of appropriate spatial and temporal scales are immense and require maximum scalability to execute in practical time frames. Cray builds innovative HPC systems that deliver exceptional performance to scientists around the world – from entry-level systems up to the largest and most powerful systems in the world. Cray’s goal is to maximize sustained application performance by combining cost-effective commercial technologies with custom-designed innovations that significantly increase performance, reliability and usability.

This balanced system design approach delivers high-efficiency computing and maintains this efficiency at scale, whether jobs require tens or thousands of processors. The focus on high-efficiency computing allows scientists and forecasters to produce results in the shortest amount of time possible while investigating increasingly complex phenomena. It also allows scientists to solve problems considered difficult to handle on commodity clusters or systems designed for commercial applications. As an example, the Weather Research and Forecasting (WRF) model was used to examine the scalability of a next-generation high-resolution scientific problem on a petascale Cray XT5™ architecture. A record-breaking result of 50 sustained teraflops (trillion floating point operations per second) using 148,480 processing cores was achieved demonstrating that this capability is realizable when combining a scalable system architecture and application design.

Leading Science Enabled by Cray Systems

Cray solutions have been chosen by scientists worldwide to solve their challenging problems. Today the fastest supercomputer available to the weather and climate research community is the petaflops Cray XT5 supercomputer at the U.S. Department of Energy’s (DoE) Oak Ridge National Laboratory (ORNL) with a current peak performance of over 2.3 petaflops (quadrillion floating point operations per second). The Cray XT5 supercomputer is achieving unprecedented results and is a key resource in the Intergovernmental Panel on Climate Change (IPCC) assessments by the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL), ORNL, the
National Center for Atmospheric Research (NCAR) and the National Aeronautics and Space Administration (NASA).\textsuperscript{1}

Cray XT™ systems are also installed at several operational meteorological and hydrological services and leading climate research centers worldwide. Examples include NOAA, NCAR, Korea Meteorological Administration (KMA), Brazilian National Institute for Space Research (INPE) and Center for Weather Forecasts and Climate Studies (CPTEC), Danish Meteorological Institute (DMI), the U.S. Naval Oceanographic Office (NAVO), MeteoSwiss and the Finnish Meteorological Institute (FMI). The KMA system is one of the largest operational numerical weather prediction centers worldwide and the largest in the Asia Pacific. In addition, the NOAA Climate Modeling and Research System is the largest supercomputer in the world dedicated to climate research.

Of particular importance to operational centers, Cray is also able to deliver custom-designed and fully integrated solutions to meet operational and site specific requirements. A key component of both the DMI and KMA systems is a fully redundant system architecture featuring operational and research/backup systems with a globally shared file system.

Nearly every large scientific HPC site in government and academia uses some of its computing resources for earth system modeling. Centers such as the National Energy Research Scientific Computing Center (NERSC), ORNL, the HECToR system at the Edinburgh Parallel Computing Centre (EPCC), the Arctic Region Supercomputing Center (ARSC), the Bergen Centre for Computational Science (BCCS) in Norway and the Centre for Scientific Computing (CSC) in Finland, devote a significant portion of their computing power to leading climate, weather and ocean research.

Some examples of leading science performed on Cray XT systems are Project Athena, the DoE-UCAR Climate Science Computational End Station, the NOAA GFDL CHIMES Project and IPCC AR5 assessments, and the NOAA Hazardous Weather Testbed Spring Experiment.

**Project Athena**

Following the World Modelling Summit for Climate Prediction in 2008, Project Athena was formed with a goal to determine the feasibility of using dedicated high-end computing resources to rapidly accelerate progress in climate variability and climate change simulation. Researchers ran two state-of-the-art atmospheric global circulation models at the highest possible spatial resolution and longest possible timescales. One was the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and University of Tokyo's Nonhydrostatic Icosahedral Atmospheric Model (NICAM). The other was the European Centre for Medium-Range Weather Forecasting (ECMWF) Integrated Forecast System (IFS).

Using the entire 18,048-core Athena Cray XT4™ and a portion of the 99,072-core Kraken Cray XT5 supercomputers at the National Institute Computational Sciences, the group ran multiple IFS simulations at multiple resolutions (from 128-km grid to 10-km grid) for multiple decades and NICAM simulations down to 7km grid spacing to test the impact on climate simulations of explicitly resolving cloud processes.
DoE-UCAR Climate Science Computational End Station

In preparation for the fifth IPCC assessment, the DoE, National Science Foundation (NSF), NASA and university researchers have partnered in a Climate Science Computational End Station Development and Grand Challenge Team. Their aim is to achieve unprecedented simulations and coordinated model development of the next-generation climate model. The primary computational resources are the Cray systems at ORNL and NERSC. With millions of hours of access to the Cray petaflops systems at ORNL and NERSC, IPCC researchers will be able to apply greater computational resources to climate problems than ever before and develop the next generation of climate system simulations.

NOAA GFDL CHIMES Project

Through an agreement between the DoE Office of Science and NOAA, the CHIMES (Coupled High-Resolution Modeling of the Earth System) Project is exploring advanced high-resolution climate models from GFDL on the ORNL Cray XT5 petaflops system.1

NOAA Hazardous Weather Testbed Spring Experiment

The NOAA Hazardous Weather Testbed Spring Experiment program was designed by National Severe Storms Laboratory (NSSL), the Storm Prediction Center and the National Weather Service to improve severe weather forecasts and warnings. Since the 2007 spring season, the University of Oklahoma's Center for Analysis and Prediction Storms (CAPS) in cooperation with NOAA used Cray XT systems as the computational platforms for the experiment. In 2008 observational data from more than 120 weather radars were used for the first time to enable the most realistic storm predictions. In 2009 both the University of Tennessee National Institute of Computational Science’s 608 teraflops Cray XT5 system and Pittsburgh Supercomputing Center’s Cray XT3™ system were used to produce the highest resolution thunderstorm forecasts to date.2

Worldwide Applications Expertise

Cray’s worldwide Environmental Applications team is engaged in a number of activities concerned with porting and tuning weather and climate models. In many of these efforts, particularly with the community models, Cray works with the application developers so that optimizations will be incorporated into the released code. Efforts include, but are not limited to: work on WRF, UM, HadGEM, NEMO, CCSM, MOM4, IFS, HIRLAM, ALADIN, AROME, HARMONIE, COSMO, COSMOS.

In addition, Cray established a Center of Excellence for Earth System Modeling (CoE-ESM) in early 2009. Based in Seoul, South Korea, the CoE-ESM builds on the expertise developed through the Earth System Research Center (ESRC), a cooperative venture between Cray and KMA. ESRC was established in 2005 to advance the science of earth system modeling over the East-Asia Pacific region and to foster collaborative research and development that maintains KMA as a leading-edge facility for its users. Now entering its sixth year, ESRC has proven to be a highly successful collaboration with the completion of 16 individual projects with university researchers and a number of workshops in conjunction with the Korean Meteorological Society.
Cray Leadership in Climate, Weather and Ocean Modeling

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2 Coupled High-Resolution Modeling of the Earth System (CHiMES) http://www.gfdl.noaa.gov/~vb/chimes/index.html