NATIONAL RESEARCH COUNCIL
DIVISION ON EARTH AND LIFE STUDIES
BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE
500 5th Street, NW, Room Keck 607
Washington, DC 20001

Contract #: DE-SC0005113

Title: A National Strategy for Advancing Climate Modeling

Final Report

Period Covered: 9/1/2010 to 8/31/2012

Author: Edward Dunlea

Date: November 30, 2012

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A National Strategy for Advancing Climate Modeling

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Project Identification Information

Sponsor Award Number: DE-SC0005113
Project Name: A National Strategy for Advancing Climate Modeling
Responsible Staff Officer: Edward Dunlea, Senior Program Officer
Award Dates: 09/01/2010-08/31/2012

Project Goals and Accomplishments

Project Objectives

Climate models are the foundation for understanding and projecting climate and climate-related changes and are thus critical tools for supporting climate-related decision making. This study developed a holistic strategy for improving the nation's capability to accurately simulate climate and related Earth system changes on decadal to centennial timescales. The committee's report is a high level analysis, providing a strategic framework to guide progress in the nation's climate modeling enterprise over the next 10-20 years. This study was supported by DOE, NSF, NASA, NOAA, and the Intelligence Community.

Project Accomplishments

Report Process: The Committee organized 5 committee meetings throughout 2011 including a 50-person community workshop, held numerous teleconferences during the information gathering process and the report review process, and commissioned approximately a dozen interviews of key individuals in the climate modeling community and government agencies. The Committee's report was reviewed by a 13 independent experts and all reviewer comments were addressed.

Report Publication: The Committee released its report to the public in September, 2012. Along with the report, a four-page "Report in Brief" was prepared and a website called "Climate Modeling 101" was developed to explain to a lay audience what climate models are and why they are important. The report and all related materials can be found here: http://dels.nas.edu/Report/National-Strategy-Climate-Modeling/13430

Report Summary: A brief summary of the report is included below.

Dissemination: The report was briefed to all sponsoring agencies, OSTP, OMB, the Navy, GAO, and staffers on the House Science Committee. The report was presented at the September, 2012 Sackler Forum organized jointly by the UK Royal Society and the US National Academy of

Sciences, at a USGCRP IGIM workshop on CMIP5 (September, 2012), and at a NCAR Director's Committee meeting (September, 2012). A public webinar was held (September 28, 2012) at which 92 people participated. The Climate Modeling 101 website had more than 1,200 visitors as of November, 2012.

Continuing Activities beyond the Period of Performance

Dissemination: NRC staff and the Committee will continue to explore ways to enhance the visibility of the study; as of the writing of this report, one further briefing with leaders in the climate modeling community is planned.

Cost Status

	Actual Costs 8/31/2012	Costs for Period Apr 12 - Aug 12	Cost to Complete	TOTAL COST
Direct Labor	$88,972.67	$2,932.28	$0.00	$88,972.67
Overhead	$56,219.83	$1,845.86	$0.00	$56,219.83
Travel	$38,711.46	$496.06	$0.00	$38,711.46
Reports	$0.00	$0.00	$0.00	$0.00
Technology/Comm	$11,225.87	$301.82	$0.00	$11,225.87
Meeting Expense	$7,873.81	$0.00	$0.00	$7,873.81
Other Direct Costs	$3,903.76	$0.00	$0.00	$3,903.76
General and Admin	$43,109.67	$1,825.18	$0.00	$43,109.67
TOTAL	**$250,017.07**	**$7,401.20**	**$0.00**	**$250,017.07**

Funded amount: $250,000.00

Remaining to be funded: $0.00

A NATIONAL STRATEGY FOR ADVANCING CLIMATE MODELING

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For committee biographies and statement of task, please go to our website:

http://www8.nationalacademies.org/cp/projectview.aspx?key=49288

NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING
INSTITUTE OF MEDICINE
NATIONAL RESEARCH COUNCIL

REPORT IN BRIEF

A National Strategy for Advancing Climate Modeling

Information about future climate is central to decisions made in all sectors, from agriculture to insurance to emergency preparedness planning. As the effects of climate change unfold, the need for climate projections that enable scientists and decision-makers to understand and prepare for future conditions will increase. A more unified climate modeling enterprise in the United States could help meet increasing demands for climate data. Building a national strategy for climate modeling—including a community-led evolution to a common software infrastructure shared by all climate researchers, and holding an annual climate modeling forum to facilitate communication between climate modelers and the users of climate data—would help improve the United States' capabilities to simulate present and future climate, and provide useful climate information.

From farmers deciding which crops to plant to insurance companies assessing flood risks, people from all sectors of society use information about climate to make decisions every day. In the past, many of these groups have relied on records of historical weather patterns as predictors of future climate conditions.

However, as the effects of climate change become more apparent— with potential impacts including sea-level rise, an ice-free Arctic in some seasons, and large scale ecosystem changes— past conditions will no longer serve as reliable predictors of future climate events. Climate change could increase the likelihood and severity of extreme weather and climate conditions such as regional droughts and extreme flooding, events that have caused hundreds of billions of dollars of damage over the past few decades alone.

Figure 1. The users of climate data are diverse, including city planners, energy producers, and farmers.

Credits: iStockphoto.com; USDA; Wikimedia Commons/Florian.Arnd

To enable society to respond and adapt to these changes, it will become increasingly important to develop climate models that can accurately simulate past and present climate, and project future climate. Over the past several decades, enormous progress has been made in developing reliable climate models. However, further advances will be needed to deliver climate projections at the scale and level of detail desired by decision makers.

Box 1. What are Climate Models?

Climate models are computer codes that use mathematical representations of known processes of Earth's climate system—such as movements and cycles of energy and water in the atmosphere, ocean, and land surface, including sea ice and snow—to simulate past climate conditions and project future ones.

Challenges Facing Climate Modeling

The climate information that decision makers desire often requires climate model projections at higher spatial resolutions and on more specific time scales than are currently available. There are limits to how reliable these projections can be, but a proven strategy for gradually improving climate models has been to use finer grids—the

units of climate models that contain information physical and climate characteristics on a given location—and add in new processes of concern to users, such as interactions between climate change and polar icesheets, or land and ocean ecosystems. This requires more powerful computing hardware. Indications are that future increases in computing power will be achieved not through developing faster computer chips, but by connecting far more computer chips in parallel—a very different hardware infrastructure than the one currently in use. It will take significant effort to ensure that climate modeling software is compatible with this new hardware.

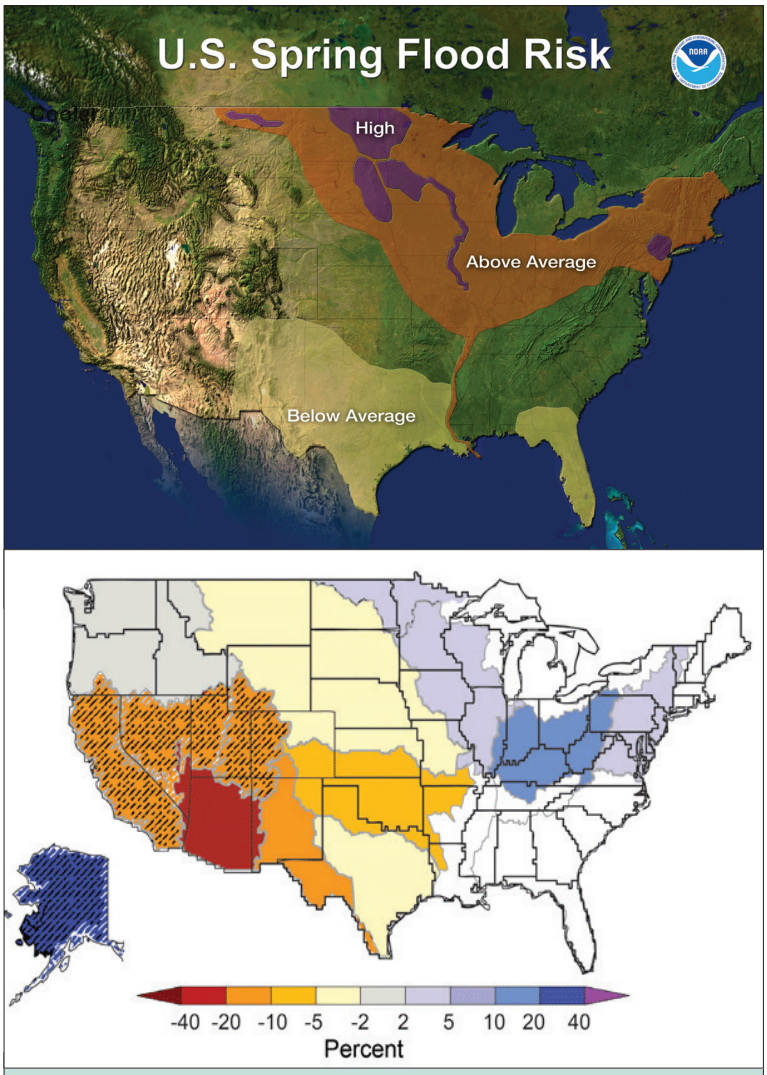

Figure 2. Weather and climate models provide information over short and long timescales. Upper image: The spring 2011 flood risk outlook (a short-term climate prediction) from NOAA's National Weather Service helped with preparations for extensive flooding of Mississippi and Missouri rivers that occurred in 2011. Lower image: Projected long-term changes in annual average runoff can help with water management planning. Here, climate models for the middle of the century show lower average runoff in the southwest, and greater runoff for the Northeast. Hatched areas indicate strong agreement among different models, giving greater confidence in those projections. Sources: http://www.noaa.gov/extreme2011/mississippi_flood.html; USGCRP, 2009.

Box 2. What's the Difference Between Climate and Weather?

Weather is the set of meteorological conditions (temperature, precipitation, etc) at a location at a given time. ***Climate*** is the expected average weather conditions over time.

The U.S. climate modeling community is diverse, consisting of several large global climate modeling efforts and many smaller groups running regional climate models. This diversity allows multiple research groups to tackle complex climate modeling problems in parallel, enabling more rapid progress. But it can also lead to duplication of effort, and make it more difficult to prioritize limited human and computational resources.

Promoting unification in some aspects of the U.S. climate modeling enterprise could enable more efficient, coordinated progress. This does not mean establishing only one U.S. center for climate modeling; instead, different climate modeling institutions could pursue their own methodologies but would work within a common modeling framework in which software, data standards and tools are shared by all major modeling groups nationwide.

Steps to a National Strategy

A national strategy for climate modeling could help the United States move toward the next generation of climate models. The committee suggested steps in several new directions to reach this goal:

- ***Evolve to a Common Software Infrastructure***

Gradually evolving to a shared software infrastructure for building, configuring, running, and analyzing climate models could help scientists navigate the transition to more complex computer hardware. The U.S. supports several climate models, each conceptually similar but with components assembled with slightly different software and data output standards. If all U.S. climate models employed a single software system, it could simplify testing and migration to new computing hardware. A common software infrastructure would help scientists compare and interchange climate model components, such as land surface or ocean models— an effective mechanism for probing uncertainties in abilities to simulate the climate system. It might also facilitate sharing of well-accepted model components across the

U.S. modeling community, freeing resources to address other critical topics.

The best pathway for achieving a common software infrastructure involves a community-based decision process, in which individuals, institutions, and managers all see advantages, which may be scientific, computational, or resource driven, to the new system. Efforts from above to dictate transformations to specific infrastructures are likely to meet with less success than those that have come from the bottom up.

- ***Convene a National Climate Modeling Forum***

An annual U.S. climate modeling forum would help bring the nation's diverse modeling communities together with the users of climate data. This would provide climate model data users with an opportunity to learn more about the strengths and limitations of models and provide input to modelers on their needs.

Currently, climate modelers and data users often learn about progress in their field through specialty conferences and scholarly journals, which can be slow, haphazard, and inefficient in communicating advances across different communities, such as global versus regional climate modelers versus users. An annual climate modeling forum could help inform the community of current and planned activities at core modeling centers, provide a venue for discussions of priorities for the national modeling enterprise, and bring disparate climate science communities together to design common modeling experiments.

- ***Nurture a Unified Weather-Climate Modeling Effort***

Many physical and chemical processes—from the formation of ice crystals in clouds to the circulation of ocean currents—can affect both climate and weather. For example, small cumulus clouds driven by daytime heat can trigger large thunderstorms, but can also affect the climate system over decades by changing the reflection of sunlight from Earth's surface. Because climate varies over such long time periods, it takes longer to collect observational data to test the models thoroughly. Using processes that vary on weather timescales—such as cloud cover—to test climate models can advance both weather and climate modeling. Efforts to unify the weather-climate modeling effort would be most successful if they involved collaboration among operational weather forecast centers, data assimilation centers, climate modeling centers, and the external research community.

- ***Develop a Program for Climate Model Interpreters***

The needs of climate data users are diverse and complex. Some users, such as farmers or town planners, require information about their local region; others, such as international development organizations, require climate data on a global scale. Meeting these varied needs involves ensuring that the ever-expanding volumes of climate data are easily and freely available, and that these data are useful and easily understandable to all users. This often entails communicating the uncertainty that is inherent to all climate models.

It is a challenge for the climate modeling community to work directly with the broad array of climate model users. Although there are already organizations using climate model outputs and translating them into products to meet user needs, there are no recognized mechanisms for verifying the quality of the information provided. Developing a national education and accreditation program to train climate model interpreters to use technical findings and output from climate model in a range of applications could help ensure the accuracy and appropriateness of climate information, as well as help communicate users needs back to climate model developers.

Supporting Areas

Work in each of the following areas is already underway; continuing these efforts will help support the success of the national climate modeling enterprise:

- ***Sustain State-of-the-Art Computing Systems for Climate Modeling***

To increase computing and data capacity, the report suggests a two-pronged approach that involves the continued use and upgrading of existing climate-dedicated computing resources at modeling centers, together with research to transition to the more complex computer hardware systems expected over the next 10 to 20 years.

Another option is building a national climate computing facility, but this would be expensive, could divert resources away from other critical climate modeling investments, and would only be beneficial if the current level of investment in computing capabilities at climate modeling centers were also maintained.

- ***Continue to Contribute to a Strong International Climate Observing System***

Sustained observational data on factors such as temperature, precipitation, clouds, snow and ice, and ecosystem change is critical for advancing understanding of the processes that drive the climate system. Maintaining a climate observing system is an international enterprise, but requires strong U.S. support that has come under threat due to funding cuts. For example, the number of current and planned

Earth-observing satellite missions will decline by more than a factor of three by 2020. Over the next several decades, it will be important to maintain existing long-term datasets of essential climate variables, and to launch innovative new climate measurements that help characterize Earth system processes.

- ***Develop a Training and Reward System for Climate Model Developers***

Model development is among the most challenging tasks in climate science because it requires knowledge of climate physics, numerical analysis, and computing, as well as the ability to work effectively in a large group. Graduate fellowships in modeling centers, extended postdoctoral traineeships of three to five years, and rewards for model advancement through well-paid career tracks could help entice high caliber computer and climate scientists to become climate model developers.

- ***Enhance the National Information Technology Infrastructure that Supports the Sharing and Distribution of Climate Modeling Data***

Ever larger amounts of climate model and observational data are being generated. Facilitating broad access to these data for researchers, data users, and decision makers is challenging but increasingly important. Beyond stabilizing support for current data infrastructure efforts, the United States should develop a national information technology infrastructure that builds on existing efforts to facilitate and accelerate data display, visualization, and analysis, for experts and the wider user community.

- ***Continue to Pursue Advances in Climate Science and Uncertainty Research***

To meet national needs for improved climate information over the next several decades, U.S. climate modelers will need to address an expanding breadth of scientific problems while striving to make predictions and projections more accurate. Progress toward this goal can be made through a combination of increasing model resolution, advances in observations, improved model physics, and more complete representations of the Earth system. As a general guideline, priority should be given to climate modeling activities that focus on addressing societal needs and where progress is likely, given adequate resources.

Research on understanding and quantifying uncertainty would help climate modeling efforts support decision making. Specifically, research should help determine how to use observational records to better understand and quantify model uncertainty in projections of future climate change, how to incorporate quantifications of uncertainty more fully into the climate modeling process, and how to communicate uncertainty more effectively to users of climate models and decision makers.

Read this report and locate related reports at http://dels.nas.edu/basc

Committee on a National Strategy for Climate Modeling: Chris Bretherton (*Chair*), University of Washington; **V. Balaji,** Princeton University; **Thomas Delworth,** Geophysical Fluid Dynamics Laboratory, Princeton; **Robert E. Dickinson,** University of Texas, Austin; **James A. Edmonds,** Pacific Northwest National Laboratory; **James S. Famiglietti,** University of California, Irvine; **Inez Fung,** University of California, Berkeley; **James J. Hack,** Oak Ridge National Laboratory; **James W. Hurrell,** National Atmospheric Research Center; **Daniel J. Jacob,** Harvard University; **James L. Kinter III,** Center for Ocean-Land-Atmosphere Studies; **Lai-Yung Ruby Leung,** Pacific Northwest National Laboratory; **Shawn Marshall,** University of Calgary, Canada; **Wieslaw Maslowski,** U.S. Naval Postgraduate School; **Linda O. Mearns,** National Center for Atmospheric Research; **Richard B. Rood,** University of Michigan; **Larry L. Smarr,** University of California, San Diego; **Edward Dunlea** *(Study Director)*, **Katie Thomas** (*Associate Program Officer*), **Rob Greenway** (*Program Associate*), **Rita Gaskins** (*Administrative Coordinator*), **April Melvin** (*Christine Mirzayan Science and Policy Fellow*), **Alexandra Jahn** (*Christine Mirzayan Science and Policy Fellow*), National Research Council.

The National Academies appointed the above committee of experts to address the specific task requested by the U.S. Department of Energy, National Oceanic and Atmospheric Administration, National Science Foundation, National Aeronautics and Astronautics Administration, U.S. Intelligence Community. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies.

This report brief was prepared by the National Research Council based on the committee's report.For more information, contact the Board on Atmospheric Sciences and Climate at (202) 334-3512 or visit http://dels.nas.edu/basc. Copies of *A National Strategy for Advancing Climate Modeling* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.