

ADVANCED COMPUTING for and Adapting to



Dr. Warren Washington, a senior scientist at the National Center for Atmospheric Research, discusses with *SciDAC Review* the importance of computer models and simulations for understanding, mitigating, and adapting to climate change.

SciDAC Review: *As a former Chair of the National Science Board, how do you see climate science playing at the national and international levels in terms of awareness and priority?*

Dr. Washington: The recent report by the Intergovernmental Panel on Climate Change (IPCC; sidebar “Intergovernmental Panel on Climate Change,” *SciDAC Review*, Spring 2007, p49) for policy makers has highlighted that humankind is causing the Earth’s climate to significantly warm and change. Science agencies such as DOE have a special responsibility to help find solutions to this national and international problem. It is my expectation that climate science will sharply rise in priority as a science problem by both the Executive and Congressional branches of government.

Do you see any changes in the national research priorities in climate science and human or environmental impacts?

Not so much yet. But as the impacts of climate change become more apparent with increased severity of heat waves, droughts, water shortages, and more severe hurricanes, there will be more emphasis on understanding how we can better mitigate and adapt to the changes. For example, the DOE will need to study the carbon footprint and effect of various technology paths for energy production. There will be increased focus on what strategies to use to mitigate climate change, that is, to find a long-term stabilization for carbon dioxide and other greenhouse gases in the atmosphere.

What are some of the greatest long-term challenges to simulating and predicting climate?

We’ve done a pretty good job of understanding and modeling the heat balance of the Earth on a global scale. But, as we know from the experience of weather forecasting, capturing the

regional details is much harder. Yet it is necessary in order to provide decision makers with information about how to deal with the problem. Improving the predictive skill of the Earth system models will also depend on a sustained set of observations of the important climate components and processes. Climate changes involve decades to centuries and some of our observations are only a few years long. For example, the Atmospheric Radiation Measurement (ARM) program and the satellite record are only one or two decades in length. The complexities of biological and chemical processes that are also part of the Earth system give a long-term challenge for modeling and for measurement science.

What are some of the near-term opportunities in climate prediction and simulation and how can initiatives such as SciDAC address them?

Increased horizontal and vertical resolution for more regional detail is an area of immediate importance that SciDAC—with its ability to scale models for petaflops computers—can address. With increased computational resources we are building more comprehensive models and will be able to better account for climate variability and to quantify model statistics through ensemble forecasts. I am a strong proponent of higher resolu-

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tion in our runs when it can be shown to produce a better forecast. While we are increasing the resolution of our models, we are correcting biases in our model as well as increasing the complexity of our model as we move from climate models to Earth system models.

How did you decide in your research pathway to approach climate science through simulation and modeling?

We have seen a substantial improvement in our models over the last few decades. This improvement has come from increased resolution, understanding of the complex processes such as cloud radiation interactions, and observational studies of the climate system. The DOE Office of Science has been a leader in supporting these research improvements as well as providing the substantial computer resources required.

Understanding CLIMATE CHANGE

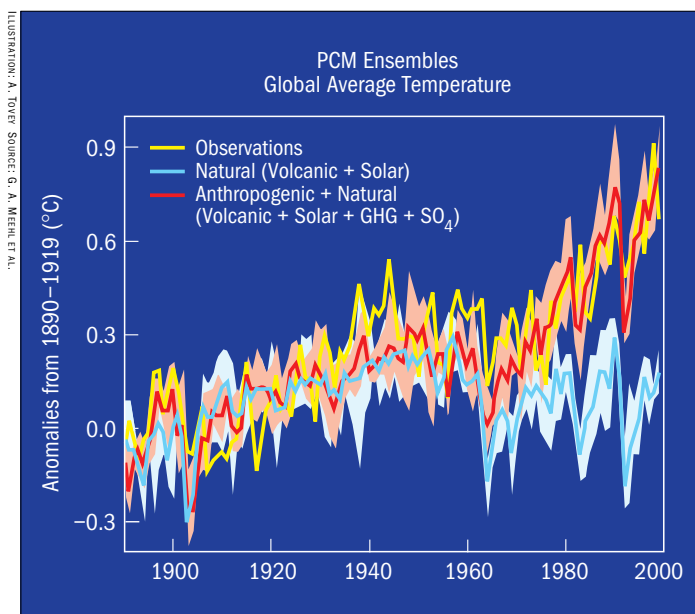


Figure 1. *Is climate change attributable to human activities? Simulation studies, such as those of Meehl et al. (see Further Reading, p9), provide evidence that climate change is indeed due to anthropogenic factors. In this graph, the yellow line depicts the upward trend in observed surface temperature anomalies. Twentieth-century forcing simulations run using the Parallel Climate Model (PCM), a global coupled climate model, indicate that natural forcing agents (blue line)—solar and volcanic factors—do not account for the sharp increase in observed global average temperature (yellow line). In fact, running the model with only the natural forcing agents shows that solar and volcanic activities would put the Earth in a slight cooling trend (blue line). Only with the inclusion of anthropogenic agents—human-generated factors, such as greenhouse gases (GHG) and sulfate (SO₄) aerosols—do simulation results (red line) approach the rapidly rising observed values (yellow line). Dr. Washington and his colleagues consider this strong evidence to be “the smoking gun for human-induced climate change.”*

How has high-performance computing influenced atmospheric science and climate change prediction?

For researchers in climate science, the question of whether or not climate change is attributable to human activity was put to rest several years ago with our DOE-supported simulations showing that the only way to duplicate the sharp increase of the global average temperature observed in the late 20th century was to include human generated greenhouse gases in the simulations (see Further Reading, p9). When the same simulation was run without the human-generated greenhouse gas increases, the model simulations show that the Earth

would be in a slight cooling trend with the natural forcings of volcanic and solar activities (figure 1). For us, that was the smoking gun for human-induced climate change.

The IPCC has been an important contributor to the world’s understanding of climate. How did SciDAC contribute to the IPCC Fourth Assessment Report (AR4)?

I consider the DOE/NSF collaboration on the IPCC project to be a huge success story. SciDAC brought immense software engineering talent, science tools, and raw computational power to the effort. It was a true collaboration; throughout the entire IPCC Community Climate System Model (CCSM; “Developing Models for Predictive Climate Science,” *SciDAC Review*, Spring 2007, p44) development, experiment design, and the simulation production process, SciDAC either took the lead or provided critically enabling technology. Some of the major contributions of the DOE to the model itself include the LANL Parallel Ocean Program (POP) ocean code, the LANL Community Sea Ice Model (CSIM), and parallel algorithm development and optimization at ORNL and ANL for the atmospheric and land models. The new flux coupler at the heart of the CCSM was developed as a collaborative SciDAC and CCSM project. The Leadership Computing Facility at ORNL (“The Experimental Apparatus of Computational Scientists,” *SciDAC Review*, Spring 2006, p38) and the facilities at NERSC (“Science-Driven Supercomputing,” *SciDAC Review*, Spring 2007, p36) provided a major portion of the computer time. The simulations using the CCSM3 were some of the most highly resolved and extensive of all the models contributing to the IPCC. Dr. Lawrence Buja, here at the National Center for Atmospheric Research (NCAR), managed all the runs across the centers and the combined simulation output produced in 2005 is somewhere in the neighborhood of 100 terabytes. Together with the Japanese Earth Simulator versions of our simulations, this was the largest data submission to the IPCC AR4 project of any modeling group in the world. This output is made freely available to the international community through another SciDAC project, the Earth System Grid.

It is wonderful to see the IPCC and assessment process using our data to come to such profound conclusions about the widespread, interlinked impacts of the future climate change. That some of these impacts are potentially catastrophic provides a sense of urgency to this work.

What impact on global environmental understandings and climate change science did the IPCC exercise and SciDAC-related activities have?

The certainty of the conclusions coming out of the IPCC AR4 report is effectively ending the public debate on the existence of

Biography in Brief: Dr. Warren Washington

Dr. Warren M. Washington is a senior scientist and head of the Climate Change Research Section in the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR). Dr. Washington earned a bachelor's degree in physics and a master's degree in meteorology from Oregon State University. After completing his doctorate in meteorology at Pennsylvania State University, he joined NCAR in 1963 as a research scientist. Dr. Washington's areas of expertise are atmospheric science and climate research, and he specializes in computer modeling of the Earth's climate.

Publications

In addition to publishing more than 100 papers in professional journals, Dr. Washington is also co-author of the book, *An Introduction to Three-Dimensional Climate Modeling*, an important reference on climate modeling.

Science Advisor

Dr. Washington has served as consultant and advisor to a number of government officials and committees on climate system modeling. From 1978 to 1984, he served on the President's National Advisory Committee on Oceans and Atmosphere. He participated in several panels of the National Research Council and chaired its Advisory Panel for *Climate Puzzle*, a film produced for the 1986 PBS television series *Planet Earth*. Dr. Washington was also a member of the Secretary of Energy's Advisory Board from

1990 to 1993 and has been on the Secretary of Energy's Biological and Environmental Research Advisory Committee (BERAC) since 1990. From 1996–2006 he served as the chair of the subcommittee on Global Change for BERAC.

In 1994 Dr. Washington held the office of President of the American Meteorological Society (AMS) and was Past President in 1995. He served on the Modernization Transition Committee and the National Centers for Environment Prediction Advisory Committee of the U.S. National Weather Service. In 1998, he was appointed to the National Oceanic and Atmospheric Agency Science Advisory Board. In May of 1995, he was appointed by President Clinton to a six-year term on the National Science Board, which helps oversee the NSF and advises the Executive Branch and Congress on science-related matters. In March 2000 he was nominated by President Clinton for a second six-year term and was confirmed by the Senate in September 2000.

Awards & Honors

The limits of this space make it impossible to fully list the many prestigious awards and honors bestowed upon Dr. Washington during his career, but some of these include: Le Verrier Medal of the Société Météorologique de France (1995); induction into the National Academy of Sciences Portrait Collection of African Americans in Science, Engineering, and Medicine (1997); the DOE Biological and Environmental Research Program Exceptional Service Award

for Atmospheric Sciences (1997) in the development and application of advanced coupled atmospheric-ocean general circulation models to study the impacts of anthropogenic activities on future climate; Sigma Xi Distinguished Lecturer (1998–1999); and the National Weather Service Modernization Award (1999).

Additionally, in 1999 Dr. Washington was awarded the Dr. Charles Anderson Award from the American Meteorological Society "for pioneering efforts as a mentor and passionate support of individuals, educational programs, and outreach initiatives designed to foster a diverse population of atmospheric scientists." In 2002, the National Academy of Engineering (NAE) elected Washington to its membership "for pioneering the development of coupled climate models, their use on parallel supercomputing architectures, and their interpretation."

Most recently, Dr. Washington was elected honorary member of the American Meteorological Society (AMS) in 2006, and he received the Charles Franklin Brooks Award from the AMS for outstanding services to the Society in January 2007. His current research involves the Parallel Climate Model (PCM; figure 1, p7) and the Community Climate System Model (CCSM; "Developing Models for Predictive Climate Science," *SciDAC Review*, Spring 2007, p44). He currently serves as a co-chair of the Climate Change Working Group within CCSM. The PCM is a DOE-supported effort and the CCSM is supported by both the NSF and the DOE.

anthropogenic climate change. The strength of the IPCC conclusions reflects the greatly increased confidence we have in the simulations coming out of our climate models and observations. This is a direct result of the improved science and numerical algorithms in the model, as well as the improvements in the model that come having access to the raw computational horsepower needed to run large ensembles at higher resolutions. All of these are elements supported by the SciDAC program.

The bottom line is that this is increasingly being viewed as a solved problem and that the most important problem facing mankind right now is climate change mitigation and adaptation. It is a huge relief to finally see the public climate change discussion moving forward to begin addressing how we should respond to it and attempting to determine the cost

and magnitude of the effort required to survive it. This frees us to move on as well. We are now changing the direction of our entire research effort in a similar manner, moving away from simply simulating whether or not climate change is occurring, to carrying out detailed simulations addressing critical adaptation/mitigation and energy strategy issues.

As an advisor to five U.S. Presidents your contributions are very distinguished and privileged within the U.S. Government. How can one take the state-of-the-art simulations of climate and bridge the gap between science and the political decision making process?

I believe the world now understands that climate change is a serious problem and that something has to be done about it. I expect there will be a need for addressing the various energy options. Climate models are really the tools available for

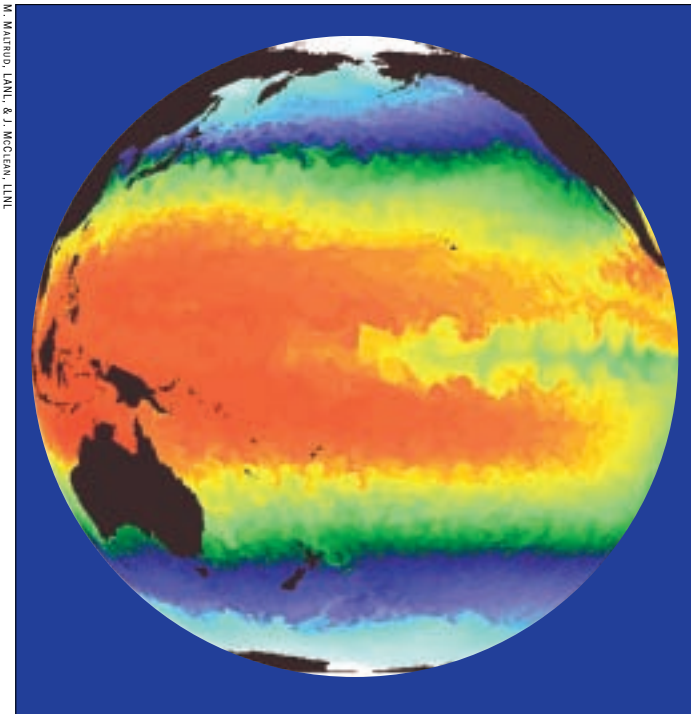


Figure 2. A visualization of sea surface temperature from a 0.1 degree global ocean simulation computer model, from the LANL Climate, Ocean, and Sea Ice Modeling (COSIM) project (“Science-Based Prediction at LANL,” p33).

examination of the options. SciDAC has a key role to play in helping test possible future climate and energy policy options.

Can nuclear energy solve the global warming problem? How warm can the Earth get before there are serious repercussions?

Both renewable and nuclear options are likely to be used in the solution of global warming. I do not subscribe completely to the idea that there is a critical threshold to global warming. However, many in the climate research community feel that we probably should not exceed a global warming of more than 2°C from the 1870s to 2100, which would cause substantial melting of glaciers over Greenland and resultant sea level rise. Also, because of the long lifetime of carbon dioxide in the atmosphere (average of about a century), we may not be able to lower the concentration in the future. Our modeling studies indicate it is much better to deal with this problem earlier than later.

Clearly a non-carbon energy revolution is needed. I think that everyone is still trying to come to terms with what it would take to build the 50 to 100 TW energy infrastructure required to support the world with a Western lifestyle. While nuclear energy won't solve the global warming problem itself, it will certainly be a big part of the solution. As with alternative energies, renewable energies, carbon sequestration, as well as increased efficiency of personal and public power generation, all will play a role.

Projected warming by the year 2100 for business-as-usual may be as large as 6°C or more globally, depending on the scenario chosen. There will be a greater warming over land and in the high latitudes, an Arctic Ocean free of summer ice,

a rise in sea level, widespread changes in rainfall, extreme weather events, and acidification of the world's oceans. Many scientists believe the IPCC projection for sea level rise is very conservative because it does not take into account the latest field data on dynamic ice sheet disintegration.

More recently, some scientists have argued that a warming of 2°C above pre-industrial temperatures—or, alternatively and more conservatively, a warming of 1°C above the year 2000 temperature—would lead to dangerous climate change based on effects of sea level rise and the extinction of species. The council of the European Union already in 2004 “reaffirms that, with a view to meeting the ultimate objective of the Convention to prevent dangerous anthropogenic interference with the climate system, overall global annual mean surface temperature increase should not exceed 2°C above pre-industrial levels.” It also “notes that scientific uncertainties exist in translating a temperature increase of 2°C into greenhouse gas concentrations and emission paths; however,

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recognises that recent scientific research and work under the IPCC indicates that it is unlikely that stabilisation of greenhouse gas concentrations above 550 ppmv CO₂ equivalent would be consistent with meeting the 2°C long-term objective and that in order to have a reasonable chance to limit global warming to no more than 2°C, stabilisation of concentrations well below 550 ppmv CO₂ equivalent may be needed.”

What is your vision of how humanity can address global warming and a sustainable path for the future?

This problem is clearly one that requires international cooperation. The DOE and SciDAC have the capacity to provide the climate science solutions.

Thank you for taking the time to answer our questions. ●

Further Reading

G. A. Meehl et al. 2004. Combinations of natural and anthropogenic forcings in twentieth-century climate. *J. Climate*, **17**: 3721–3727.