



I am going to talk about something that is of great interest to National Oceanic and Atmospheric Administration (NOAA)—namely, the task of translating emerging climate science into a form that is useful to decision makers. Toward that end, NOAA has proposed a major reorganization of the agency that would result in the creation of a climate service on the management scale of the existing weather service. In addition, NOAA has asked Congress for permission to revise its overall research program to include the satellite service.

Before delving into that, I want to talk first about the need for a broader multiagency approach to the overall climate change problem that has come up over the last few years. It is increasingly apparent that no one agency can tackle this on its own. It is going to take the capacity of a number of agencies, especially in cases where the challenge is extremely large like in the Defense Department.

In January 2009, just at the end of the Bush Administration, the Office of Science and Technology Policy (OSTP) invited

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representatives from some 23 federal agencies to discuss the future of climate research and begin development of next-generation strategy for the U.S. Global Change Research Program. The proposed FY2011 budget provides a total of \$2.6 billion across 13 agencies to support that effort. As it turns out, each of those 23 agencies has an interest in climate information. It is not just the four major research organizations—the National Science Foundation (NSF), the Department of Energy (DOE), NASA, and NOAA. The full suite of mission-driven agencies are finding that they need to respond to mandates imposed specifically by Congress or that they need to react to impending changes in natural resources or protected habitat areas. At the end of the day we found that there was a general need to understand the future at local or regional scales and at a wide variety of time scales ranging from weeks out to decades. This need imposes a tremendous challenge on the modeling community as well as on the research and observational communities.

That challenge continues today, although I am pleased to report that we have seen some major breakthroughs. As you may know, the Department of Energy recently decided to open up their major computational facilities to earth science researchers, especially at NASA, NOAA, and the NSF. Earth scientists are now competing for awards to use the DOE's petaflop (10<sup>15</sup> floating point operations per second)-scale computational machines to test their coupled forecast models at different resolutions.

NOAA was lucky enough to gain support, through the FY2009 Economic Stimulus Package, to buy two of that class of computational facilities. We have installed one at the Oak Ridge National Laboratory in Tennessee and are using it to run our long-term climate models. We are building a second one in West Virginia that will look at shorter time scales and support development of ensemble and probabilistic forecast information that we can use to test the resolution envelope and see how far our existing tools can be pushed with current technology. At the present, we are running one of our atmospheric models at the Oak Ridge machine in test mode. We are using 1-kilometer resolution globally and have seen some stunning results. If I had more time I could play a video clip that NASA has produced. So far, however, none of us really understand

how well those models actually simulate reality; how they would play out over time; how they need to be initialized, tested, and verified; or how we should manipulate the huge amounts of data that our major satellite systems are able to provide. In the meantime, however, we are busy running models to support the next generation of the Intergovernmental Panel on Climate Change Assessment, which is due to come out in the 2013–2014 period.

I know that our laboratory at Princeton, for example, has just completed runs on a sequence of models using our tremendous computational capability at Oak Ridge. Other researchers are looking at long-term scenarios of 100 years or more with complex system models that include carbon and nitrogen cycles. Yet others are looking at decadal predictability using a range of initialization levels based on the last several decades and then running forward 30 to 40 to 50 years. Still others are looking at the impact of initializing their runs at higher spatial resolution—say 25-kilometer resolution rather than 200-kilometer resolution—to see how that affects results over a decade or so. While we are not certain yet what these higher-resolution models will show, we are beginning to test the resolution envelope to see if we can enhance predictability.

One of the major challenges ahead will be to collect the data necessary to support or verify our predictions. How do we build observing systems that will be useful for initializing these higher-resolution models? How do we produce information out of these models that some 23 different agencies will be able to use? If we are interested, for example, in storm extremes, coastal surge extremes, or wave extremes, how do we get that information out of the model? How do we levy requirements to the civilian modeling community so that they can work with us and gain access to the information that they need? Finally, how do we establish the uncertainty bounds on our predictions and forecasts?

So what I want to do is talk a little bit about how NOAA is approaching that problem and how it is working with different communities of decision makers. I will provide a couple of examples so that you can see how we are developing our service concept and how we propose to tackle the grand challenge that I have just described. Our proposal includes organizational,

budget, and mission structures that will enable us to monitor the climate using appropriate observing systems, build our data sets, and then use the data collected to produce products and services that describe the current state of the climate and typical climatologies. We also want to define appropriate climatological norms and applicable climatologies that decision-making communities can use. Today's products, which typically provide variables like temperature and precipitation, are not well suited for climatic issues. We need to know flood frequencies, hundred-year flood plains, and wave climatologies along the coast. While we need to continue to conduct research, we need to target that research on the grand challenge problems of predictability, understanding drought, and understanding how climate impacts marine ecosystems and coastal environments.

We also need to develop the next-generation models and test predictability measures, improve our understanding of longer-term climate change, test the resolution envelope, and test our ability to replicate historical changes over time. Once we have done that, we can begin to produce authoritative and timely information that is appropriate for government entities. We also need to work with the private sector to understand their role and interest and help define the proposed climate service from a private-sector-provider point of view as well as a federal-entity point of view. Finally, we need to continue to work with the decision-making communities as we have for the past 20 years to collaboratively define and tailor information that government leaders can use as they try to understand how climatological norms are changing over time.

So let me give you two examples. One is more applicable to today's decision makers, while the other is research oriented and looks to the future. The first has to do with drought-related information. It is clear from looking at both current and long-term trends that the water cycle across the country is going to change. We expect more water to be available at higher latitudes and less at lower latitudes. This is a huge concern in the Western states where water is gold. In anticipation of this problem, the Governors' Association in that area has been working with the scientific community to try and define how you build preparedness information.

Typically, state governments are responsible for allocating and managing the large water systems within their borders. They were primarily interested in how you deal with preparedness information for the people who use water in their states rather than developing response mechanisms for existing droughts. So, in the early 2000s, government decision makers met with the scientific community and designed a program to improve observations and consolidate data information with other participating agencies. They wanted to see if they could improve predictability and better understand the impacts of drought. They also want to educate their communities and to build an early warning system that would provide preparedness information to their state governments so that they could better manage the situation in the future.

In 2006, President Bush signed a new law that assigned NOAA the lead for the integrated Drought Information System and directed the cooperation of a number of other federal agencies in cooperation with state and tribal communities. I am pleased to report that it is well underway. An implementation plan was quickly developed on the basis of the strategy laid out in the public law. On the order of 8–10 other agencies have joined us in this; the implementation team is made up of over 50 people. We have begun to build out the capabilities to improve observations and tackle the predictability problem. We have also secured resources from Congress to support the effort. We have set up a project office and have developed a basic understanding for how to approach the problem. We realize that we need to work these issues regionally because drought in the Colorado basin is different from drought in the Flint-Apalachicola-Chattahoochee system in the Southeast, the Chesapeake Bay, the Hudson River, the Missouri River, or the Columbia River. So, we are planning to build a national system through a set of regional entities.

Two of our first systems are currently underway and almost wrapping up their prototypes—the Colorado basin and the Flint-Apalachicola-Chattahoochee. What is fascinating is that it is not just scientists sitting around the table. At the regional level, these sessions include not only the scientific community that is developing the information, the drought monitoring, and the outlook

capability, but also the state, local, and tribal decision makers, as well as representatives from such private industries as ski resorts, ranches, and corporate agriculture.

As you may know, there has been some controversy over the last few years in the Flint-Chattahoochee-Apalachicola system about water allocation rights. It turns out that Atlanta wants to draw more water from Lake Lanier than it has in the past. This naturally led to a lawsuit because legally they were not allowed to have that water. Fortunately, it has also resulted in a more open dialogue among the states that use that water as they have tried to resolve such issues. Although the court issue has yet to be resolved, it has helped to socialize the scientific information.

We also held a workshop with the Western governors and various members of their policy-making staffs. It was great to see them employing some of the decision tools that we had made available. So that is another example of a very active effort. The outcome provided vision and direction to the scientific community. The involvement of decision and policy makers in such interactions is, I think, an interesting model that is likely to prove useful.

A very different approach that we are taking is our work with NOAA's National Marine Fisheries. Given that their job is to regulate and try to sustain fisheries, they are very interested in how marine ecosystems might change over time and how this might lead to future changes in regulations. This is very much a research problem; it has not yet reached the decision-making context at all. So, we have begun to look at how we would build observing systems, how we would monitor sentinel sites, and how we would begin to factor in ecosystem effort changes in two of our long-term climate models. We have sent scientists to the Geophysical Fluid Dynamics Laboratory at Princeton where we run our big models. They are trying to put advanced marine chemistry and nutrient models into some of the lab's ecosystem models. They are seeing indications that there will be change due to factors such as ocean acidification, nutrient loading, and current cycles. As a result, over the next few years, we may be able to build hypotheses and begin to evaluate. In particular, we want to look at how we could use the protected habitat areas that NOAA manages, both the estuarine

reserves and the marine sanctuaries, as sentinel sites at different scales and how we would begin to monitor and survey a large marine ecosystem like the California current system. We want to see if we can detect these changes and, if so, set up a program to begin to monitor whether or not change is occurring on a longer time frame.

So those are two very different examples; I hope they give you a sense of the complexity of taking on this challenge. We do need direct engagement between the user community and the civilian science community to ensure that we get the best out of both worlds. The civilian science community needs to understand the requirements of the decision-making community. It provides some directed vision for the scientific community to work with and provides goals that the two communities can work together on. Still, each has to have its own capacity to develop and work toward this issue.