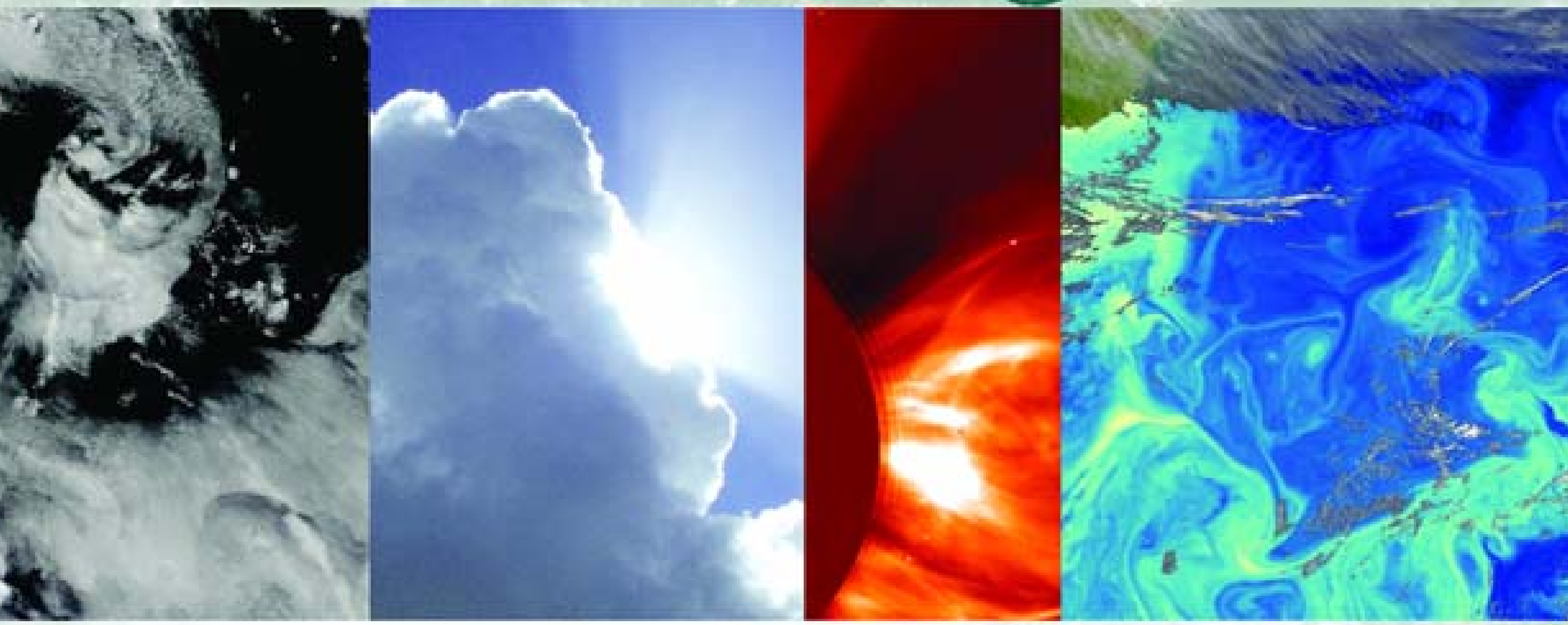
Forecasting Environmental Changes



A Report of the Fifth National Conference on Science, Policy and the Environment

February 3-4, 2005 • Washington, DC

Craig M. Schiffries, Editor

National Council for Science and the Environment
Improving the scientific basis for environmental decisionmaking

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The National Council for Science and the Environment (NCSE) has been working since 1990 to improve the scientific basis of environmental decisionmaking and has earned an impressive reputation for objectivity, responsibility, and achievement.

The Council envisions a society where environmental decisions are based on an accurate understanding of the underlying environmental science, its meaning, and its limitations. In such a society, citizens and decisionmakers receive accurate, understandable, and integrated science-based information. They understand the risks, uncertainties, and potential consequences of their action or inaction.

Endorsed by more than 500 academic, scientific, environmental, and business organizations, and federal, state, and local government, NCSE works closely with the many communities that create and use environmental knowledge to shape environmental decisions.

The Council conducts a range of innovative activities in the following areas:

Promoting Science for the Environment
The Council played an instrumental role in stimulating the National Science Foundation initiative to triple its annual budget for environmental research, education, and scientific assessment. The Council presents expert testimony to Congressional committees, consults regularly with key decisionmakers in government, and works to promote funding for environmental research and education at numerous federal agencies.

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NCSE brings members of the academic community together to help them improve their environmental programs and increase their value to society. The University Affiliate Program, the Council of Environmental Deans and Directors, and the Minority Programs Office are three NCSE programs designed to serve this purpose.

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The Council advances science to inform environmental decisionmaking through conferences, workshops, and partnerships, including the annual National Conference on Science, Policy and the Environment, and the annual John H. Chafee Memorial Lecture on Science and the Environment.

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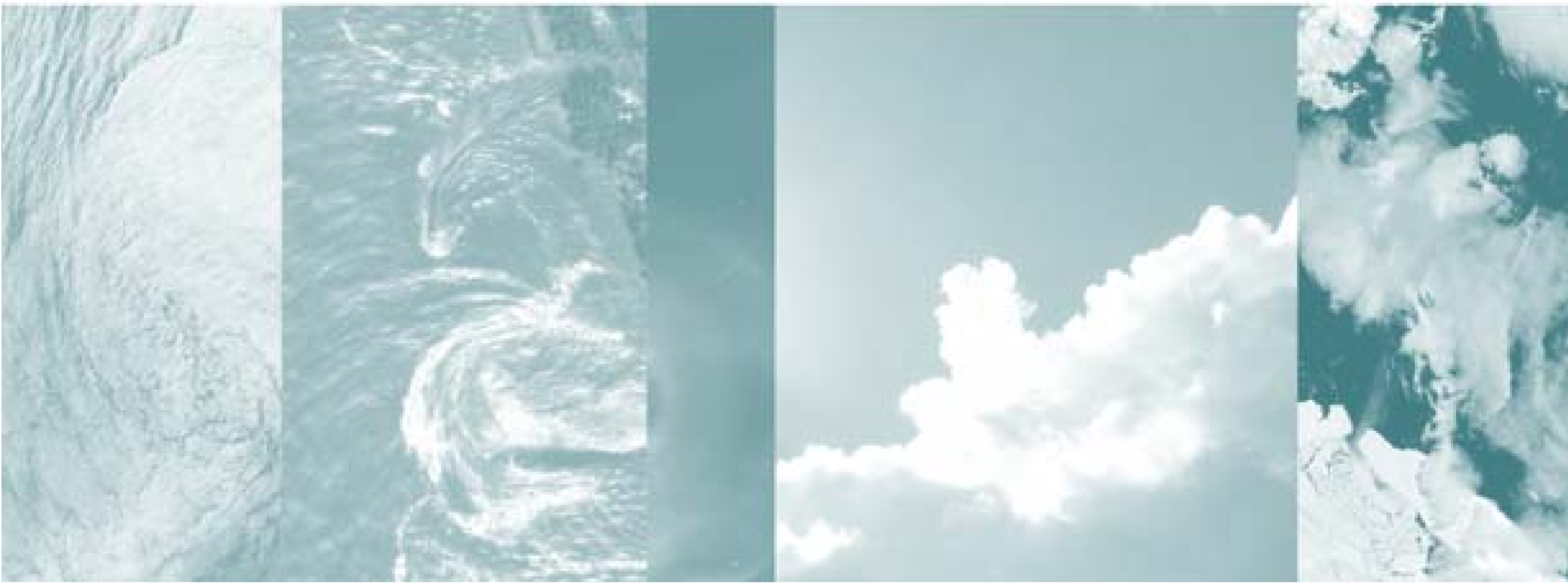
The Council brings stakeholders together through its Center for Science Solutions to develop and implement science-based solutions to specific environmental problems. The first program under the Center, the National Commission on Science for Sustainable Forestry, supports research to develop a better scientific foundation for assessing and improving forest management practices.

Forecasting Environmental Changes



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“We live in a country where the scientific content of public policy issues is increasing sharply. It follows that scientific literacy is essential to sustaining our democracy. We must therefore work to ensure that NCSE and others that share its goals grow in strength and influence.”

JAMES GUSTAVE SPETH

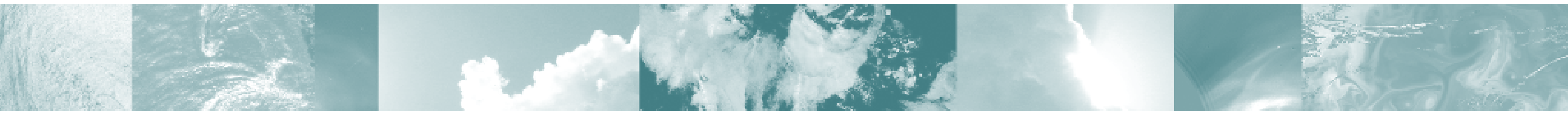
Dean, Yale School of Forestry & Environmental Studies
Former Administrator, United Nations Development Programme
Founder and Former President, World Resources Institute

“Our topic—forecasting environmental changes—ranks as one of the grand challenges facing scientists, engineers, policymakers and concerned citizens in our time. Fundamental research on the environment has great promise to contribute in myriad ways to our nation and our world.”

ARDEN L. BEMENT, JR.

Director, National Science Foundation

Contents



Executive Summary

The devastating tsunami in the Indian Ocean on December 26, 2004, focused global attention on the need to improve environmental forecasting and decisionmaking. The 5th National Conference on Science, Policy and the Environment: *Forecasting Environmental Changes* served as a forum to connect researchers who study environmental conditions and trends with decisionmakers who need that information.

More than 850 leading researchers, policymakers, government officials, business executives, educators, and students from 46 states participated in this multi-stakeholder conference. They assessed our ability to understand and forecast environmental changes, identified opportunities for improving these capabilities, and articulated user needs for achieving specific societal benefits of environmental forecasting systems.

The conference was designed to provide input into major environmental forecasting systems under development, such as the Global Earth Observation System of Systems (GEOSS) and the National Ecological Observatory Network (NEON). It also explored opportunities for building capacity and improving coordination among the many institutions, programs, activities, and individuals engaged in environmental forecasting.

Participants applied lessons learned from successful environmental forecasting approaches—including examples from meteorology, oceanography, and geology—to help design new systems for forecasting ecological changes. They also addressed how improvements in environmental forecasting will foster improvements in environmental decisionmaking and promote a broad range of societal benefits.

For example, former NSF Director Rita Colwell highlighted opportunities for improving human health. Gen. John Kelly, Deputy Undersecretary of Commerce for Oceans and Atmosphere, described economic benefits of weather forecasts. Ann Bartuska, Deputy Chief for Research and Development of the U.S. Forest Service, discussed opportunities for improving land management decisions. Many speakers focused on opportunities for reducing loss of life and property from natural disasters.

"All the technology in the world doesn't do a lot of good if you can't get the word out," said Charles Groat, Director of the U.S. Geological Survey. In the case of the Indian Ocean tsunami, the entire warning chain was weak. The monitoring system in the Indian Ocean was inadequate; communication channels to local authorities were insufficient; and public education was lacking. Establishing a network of sensors in the Indian Ocean is easy in comparison with establishing lines of communica-

James Gustave Speth, Dean of the Yale School of Forestry and Environmental Studies, delivers the opening keynote address at NCSE's 5th National Conference on Science, Policy and the Environment: Forecasting Environmental Changes.

Participants attend a luncheon during the conference.

tion to local authorities and educating local populations how to respond. D. James Baker, President of the Academy of Natural Sciences, emphasized that better policy choices are also a key part of reducing loss of life and property.

National Science Foundation Director Arden Bement said that forecasting environmental changes ranks as one of the grand challenges facing scientists, engineers, policymakers, and concerned citizens in our time. Fundamental research on the environment has great promise to contribute in myriad ways to our nation and our world. He emphasized that the National Science Foundation embraces three aspects of environment: the natural, social, and constructed environments. Insights into all three comprise our ability to perceive, and to provide for, our future.

Charles Kennel, Director of the Scripps Institution of Oceanography, expressed a vision of the future in which the advent of "nanonets" (systems of networked nanosensors) will herald a state of continuous awareness of the operation of the Earth's systems. That continuous awareness will lead to new scientific insights as information and understanding from disparate areas will be brought together. Society will use continuous awareness to adaptively manage its environment and to promote a more unified global view of the problems that confront us in this century.

Jack Dangermond, Founder and Chairman of ESRI, said geography provides a framework for understanding patterns, relationships, and processes at all scales, not just the whole globe but also neighborhoods, watersheds, cities, states, and nations. Geography provides a framework for modeling the future and for visualizing, integrating, and referencing what we know. Geographic Information Systems, the language of geography, can be used for forecasting environmental changes, improving environmental decisionmaking, and making the world a better place.

Walter Reid, Director of the Millennium Ecosystem Assessment, demonstrated how scenarios and science assessments can be applied to environmental forecasting and decisionmaking. He described the Millennium Ecosystem Assessment as an international program designed to meet the needs of decisionmakers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes.

James Gustave Speth, Dean of the Yale School of Forestry and Environmental Studies, focused on climate disruption, which he believes is the single biggest threat facing society today. Speth offered a 10-point plan of action that builds on the many positive, encouraging initiatives already under way. He addressed opportunities for the United States to assert a leadership role in global environmental issues and change the way we understand the future of our planet.

William D. Ruckelshaus, First and Fifth

Administrator of the U.S. Environmental Protection Agency, addressed collaborative approaches to environmental decisionmaking that have risen spontaneously and in increasing numbers throughout the country since the early 1980s. His lecture, *Choosing Our Common Future: Democracy's True Test*, harkened back to his role as the U.S. representative to the Brundtland Commission, which drafted the landmark report *Our Common Future* (1987) and led to one of the largest gatherings of world leaders in history at the Earth Summit in Rio de Janeiro in 1992.

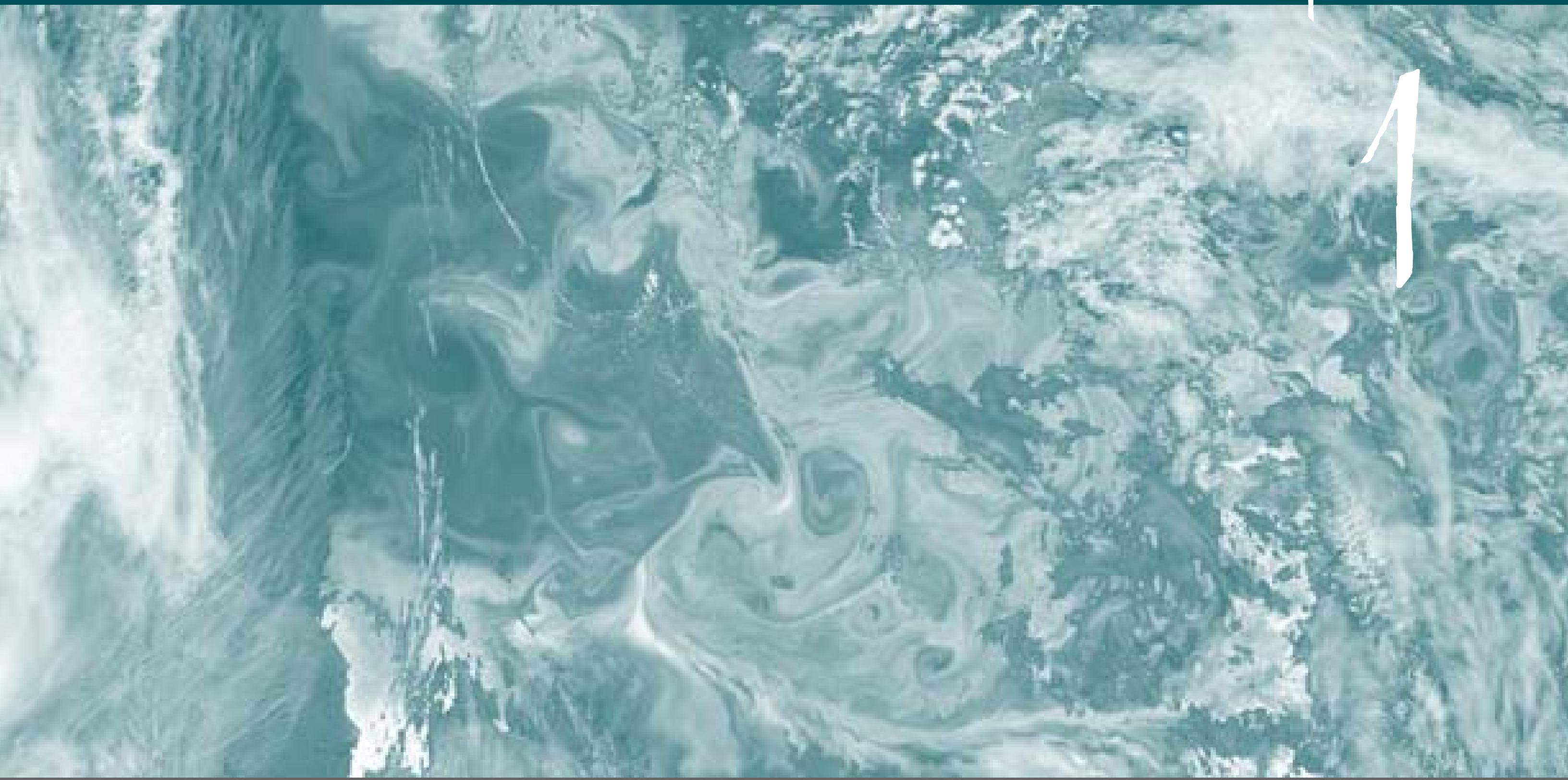
This report contains the recommendations of the conference participants—researchers, government officials, educators, business executives, civil society representatives, and decisionmakers from international, national, state, and local organizations—who provided diverse perspectives on forecasting environmental changes.

Conference attendees participated in one of 19 simultaneous breakout sessions organized along three themes: linking systems and users; connecting institutions; and scientific and technological connections. Participants in each session developed targeted recommendations addressing a particular aspect of environmental forecasting. A set of seven primary recommendations was drawn from a synthesis of the targeted recommendations. The primary recommendations are as follows:

1. Engage users in the design, development, and operation of environmental forecasting systems.
2. Build strong partnerships to facilitate environmental forecasting.
3. Improve data and information management systems for environmental forecasting.
4. Advance interdisciplinary research on environmental forecasting.
5. Develop and deploy innovative technologies for environmental forecasting.
6. Improve education, outreach, and communications to increase the societal benefits of environmental forecasts.
7. Implement an integrated environmental forecasting system.

A coherent vision for environmental forecasting has been articulated by leading scientists and policy makers. Specific societal benefits and user requirements have been identified. While national and international bodies have endorsed strategic plans and implementation plans, it is now essential to move from planning to action. The final recommendation of the 5th National Conference on Science, Policy and the Environment: *Forecasting Environmental Changes* is a call for action. Now is the time to fully implement an integrated environmental forecasting system that will take the pulse of the planet, revolutionize our understanding of the Earth and its biosphere, and provide a broad range of societal and environmental benefits.

Chapter 1



Introduction

The National Conference on Science, Policy and the Environment is built on the idea that stakeholder-informed science is a powerful tool for building consensus necessary to solve the serious environmental problems we face. The 1st National Conference, held in December 2000, introduced the concept of sustainability science, which is a synthetic, interdisciplinary approach used to understand the complex interactions between society and nature. The 2nd National Conference focused on the role of science in achieving sustainable communities. The 3rd National Conference addressed education for a sustainable and secure future. The 4th National Conference explored the role of science in achieving sustainable relationships among water, people, and the environment.

The devastating tsunami in the Indian Ocean on December 26, 2004, focused global attention on the need to improve environmental forecasting and decisionmaking. The 5th National Conference on Science, Policy and the Environment: *Forecasting Environmental Changes* served as a forum to connect researchers who study environmental conditions and trends with decisionmakers who need that information.

The 5th National Conference engaged more than 850 participants from 46 states. This multi-stakeholder meeting brought together leaders from academic institutions, business, government, and non-profit organizations. It included elected and appointed officials at local, state, and national levels of government, as well as leaders of international organizations and civil society.

The conference included plenary sessions, symposia, and breakout sessions (see agenda, Appendix A). The plenary sessions set the context of the major topics and provided an opportunity to learn from leading scientists and policymakers, including Yale Dean James Gustave Speth, ESRI Founder and CEO Jack Dangermond, and National Science Foundation Director Arden Bement. The symposia addressed four crosscutting themes and included presentations and discussions from balanced panels of experts. The breakout sessions generated recommendations on specific topics. Speakers provided diverse perspectives on environmental forecasting, and their remarks establish a solid body of background information.

The conference was designed to provide input into major environmental forecasting systems under development, such as the Global Earth Observation System of Systems (GEOSS) and the National Ecological Observatory Network (NEON). It also explored opportunities for building capacity and improving coordination among the many institutions, programs, activities, and individuals engaged in environmental forecasting. Building connections among these forecasting elements was the focus of 19 concurrent interactive breakout sessions organized along three themes:

Linking Systems and Users

1. Connecting forecasts with policymakers
2. Improving the usefulness of environmental information for personal decisionmaking
3. Sharing forecasting information with users
4. Improving academic programs to prepare the next generation of forecasters
5. Providing real-time forecasts—How to assess and meet user needs

Connecting Institutions

6. Integrating U.S. efforts with international initiatives
7. Linking levels of government: Federal-state-local
8. Cross-sectoral connections: Engaging the private sector as a partner

Scientific and Technological Connections

9. Linking ocean, atmospheric and terrestrial observation and forecasting systems
10. Integrating economic, social, and environmental forecasting
11. Working across spatial scales: From molecular to global
12. Forecasting environmental change of the landscape at a regional scale
13. Working across temporal scales—Short-term and long-term approaches
14. Facilitating the development of environmental sensors and sensor networks
15. Fusion and integration of satellite remote-sensing and ground-based observations and presentation for environmental policy
16. Examining the role of eco-informatics in environmental decisionmaking
17. Cyberinfrastructure for all: Connectivity, content, and collaboration
18. Linking environmental indicators with forecasting
19. Moving from observation to forecasting systems: Linking characterization, process research, modeling, prediction, and delivery

Four concurrent symposia examined major projects and issues that cut across the themes:

1. Creating a Global Earth Observation System of Systems

(GEOSS): Benefits for Environmental Forecasting
2. Creating a National Ecological Observatory Network (NEON): Developing the Capacity for Ecological Forecasting
3. Environmental Change: An Interactive Discussion About the Future
4. Engaging Users in Environmental Forecasting

William D. Ruckelshaus, First and Fifth Administrator of the U.S. Environmental Protection Agency, delivered the Fifth Annual John H. Chafee Memorial Lecture at NCSE's 2005 National Conference. His lecture, *Choosing Our Common Future: Democracy's True Test*, harkened back to his role as the U.S. representative on the Brundtland Commission that drafted the landmark report *Our Common Future* (1987), which led to one of the largest gatherings of world leaders in history at the Earth Summit in Rio de Janeiro in 1992. NCSE has published the text of Ruckelshaus' lecture in a separate report, which is the fifth in a series of books documenting the annual John H. Chafee Memorial Lecture on Science and the Environment.

Chapter 2 of this report contains the text of selected plenary lectures. Chapters 3 and 4 contain summaries of plenary roundtable sessions and the four simultaneous symposia. Chapter 5 contains recommendations generated by participants in the 19 breakout sessions. Several overarching recommendations emerged from these diverse sessions; these have been synthesized into a set of general conference recommendations in Chapter 6.

The need to improve environmental forecasting and decisionmaking will present serious challenges for researchers and policymakers in the future. The stakeholders gathered at this conference made it clear that many individuals and institutions are striving to meet these challenges. We hope that connections made and information shared at the 5th National Conference on Science, Policy and the Environment will catalyze new ideas and partnerships needed to forecast environmental changes—for the people and ecosystems of today, and for generations to come.

Chapter 2

Plenary Addresses and Awards

Plenary Addresses

James Gustave Speth, *Some Say by Fire: Forecasting, Climate Change, and What We Can Do as Americans*

Arden L. Bement, Jr., *From New Sight to Foresight: The Long View on the Environment*

Jack Dangermond, *Building a Digital Abstraction of the Earth*

Lifetime Achievement Award

William D. Ruckelshaus, *Choosing Our Common Future: Democracy's True Test*

Some Say by Fire: Forecasting, Climate Change, and What We Can Do as Americans

James Gustave Speth
Dean, Yale School of Forestry & Environmental Studies
Former Administrator, United Nations Development Programme
Founder and Former President, World Resources Institute

I must begin by saying how genuinely impressed I am by the rapid emergence of our host, NCSE, to a position of true leadership in environmental research, in environmental education, and in linking good science to environmental decision-making. We live in a country where the scientific content of public policy issues is increasing sharply. It follows that scientific literacy is essential to sustaining our democracy. We must therefore work to ensure that NCSE and others that share its goals grow in strength and influence.

I also commend the work you will be doing here to design an integrated, science-based capacity for environmental forecasting. I hope that work goes well. My talk will focus on the morning after the forecast—what happens to forecasts after they are offered. This is where my bit of expertise lies, and I also believe that is where much of the problem lies in our country today. And I want to focus on climate change because I believe that climate change—or better, climate disruption—is the single biggest threat societies face today.

My story begins when I was chair of the president's Council on Environmental Quality (CEQ). I was approached by Gordon MacDonald, a top environmental scientist, and Rafe Pomerance, then president of Friends of the Earth. They were seeking my help in calling wide attention to the climate change threat. I promised to take the matter to the president if they would prepare a scientifically credible memorandum on the problem. It was not long before the report was on my desk, signed by four distinguished American scientists—David Keeling, Roger Revelle, and George Woodwell, in addition to MacDonald. Its contents were alarming. The report predicted "a warming that will probably be conspicuous within the next twenty years," and it called for early action: "Enlightened policies in the management of fossil fuels and forests can delay or avoid these changes, but the time for implementing the policies is fast passing." The year was 1979—a quarter of a century ago.

I presented the report to President Carter and others in his administration. The administration responded by asking the National Academy of Sciences (NAS) to assess the scientific basis for concern about man-made climate change. Massachusetts Institute of Technology scientist Jule Charney led the NAS review, and the "Charney Report" was published in late 1979. Its findings supported those in the report I had received at CEQ. The chair of the NAS's Climate Research Board summarized them: "The conclusions of this brief but intense investigation may be ... disturbing to policymakers. If carbon dioxide continues to increase, the study group finds no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible... A wait-and-see policy may mean waiting until it is too late."

Of course, since these early beginnings, forecasting climate change, as well as efforts to influence policy with the results, have grown into a huge international enterprise, probably the largest ever such effort in the environmental field. The Intergovernmental Panel on Climate Change has been at the center of the activity, and many of our federal agencies, our National Academy of Sciences, and innumerable U.S. academic institutions and research centers have been deeply involved.

All this effort is at last yielding some significant, if seriously belated, responses. The Kyoto Protocol goes into effect this month thanks to the Russian ratification. Most significant are the actions being taken by European governments, both through the European Union and individually.

A remarkable plan has been developed by the government of Prime Minister Tony Blair in the United Kingdom, for example. The Blair government is committed to a 60 percent reduction in U.K. greenhouse gas (GHG) emissions by around 2050, has developed a plan of action to back it up, and estimates that the costs would be "very small—equivalent in 2050 to just a small fraction (0.5 to 2 percent) of the nation's wealth, as measured by GDP, which by then will have tripled as compared to now."

One can only be encouraged by these developments in Europe. Significant steps are also being taken by a number of major corporations and a fair portion of U.S. states. I will discuss these positive developments shortly. They are contributing to a momentum that is building and that offers hope. But if we are honest, I believe the only conclusion we can draw is that scientific efforts to influence policy action and public opinion on climate change have not had anything like the impact they should have had.

I say this for several reasons. First, despite the fact that there have been credible forecasts and serious warnings from the scientific community for the better part of three decades, the buildup of GHG in the atmosphere has proceeded apace, climate change has begun in earnest, and even optimistic projections forecast a lot more and a lot worse.

One of the most comprehensive studies ever of the impact of climate change on a particular region is the 2005 Arctic Climate Impact Assessment (ACIA), sponsored by the eight countries bordering the Arctic region and carried out by an international team of three hundred scientists. The report makes disturbing reading. Here are some of the findings:

- The Arctic is warming much more rapidly than previously known, at nearly twice the rate as the rest of the globe, and increasing greenhouse gases from human activities are projected to make it warmer still.
- In Alaska, western Canada, and eastern Russia, average winter temperatures have increased as much as 3°C to 4°C in the past 50 years and are projected to rise 4°C to 7°C over the next 100 years.
- Arctic summer sea ice is projected to decline by at least 50 percent by the end of this century with some models showing near-complete disappearance of summer sea ice. This is very likely to have devastating consequences for some Arctic animal species such as ice-living seals and for local people for whom these animals are a primary food source.
- Warming over Greenland is projected to lead to substantial melting of the Greenland Ice Sheet, contributing to global sea-level rise at increasing rates. Over the long term, Greenland contains enough melt water to eventually raise sea level by about 7 meters (about 23 feet).

The report points out that Arctic developments could affect societies far away from the region by contributing to sea level rise, adding to positive feedbacks that accelerate warming, and disrupting ocean currents.

Looking ahead, among the most widely accepted projections of future fossil fuel use are those provided by the International Energy Agency (IEA). Its 2004 "reference scenario," a business-as-usual projection, has total world carbon dioxide emissions climbing by 62 percent by 2030. This is about three times what we should tolerate if we want to protect climate.

The U.S. Energy Information Administration has developed a similar business-as-usual scenario for the United States, looking ahead to 2025. It has both coal use and CO_2 emissions increasing in the United States by about 42 percent between 2002 and 2025. Of course, we should be reducing our emissions during this period, not increasing them.

It would be one thing if, despite our failure to curb emissions, we had in fact put in place adequate measures to reduce GHG emissions rapidly, starting soon. But alas, we have not done that either. The many inadequacies of the Kyoto Protocol are well known, and at the recent climate negotiations, efforts to move the discussion beyond Kyoto got nowhere.

Finally, there is the situation here in the United States.

The current administration has opposed the Kyoto Protocol and refused to work with the international community within the framework of the U.N. climate treaty. It had opposed the McCain-Lieberman climate bill as well as efforts to treat carbon dioxide as a pollutant under the Clean Air Act and to strengthen vehicle mileage standards, and it has pursued an anti-climate energy strategy while resisting international efforts to frame renewable energy goals. And this is also true: the Clinton Administration did surprisingly little on the climate issue in its eight years in office.

Almost as distressing is the state of U.S. public opinion on climate change. In 2003, Gallup reported that global warming was "a bit of a yawn" to most Americans. Last year it reported that the public is "practically dozing." The percentage of Americans who worry "a great deal" or a "fair amount" about the "greenhouse effect" or global warming slipped seven points between 2003 and 2004, from 58 percent to 51 percent. Nearly as many Americans (47 percent) now say they worry "only a little" or "not at all" about the issue. As a result, global warming ranks near the bottom of the list of specific environmental issues for which Gallup measured public opinion.

In short, it would seem that some of the best scientific and policy analysis ever done on any subject has failed to generate sufficient response both internationally and in the United States I think we must acknowledge that for decades we have thrown outstanding science, attractive policy analysis and prescriptions, innumerable warnings, and abundant data at a set of extremely serious global-scale environmental problems, with limited response. I think it is time to assess why this "rationalist," forever hopeful approach is not working better. I think we need to peel back the onion for deeper and deeper understanding of the causes of this non-benign neglect. I suspect we will not like what we find.

Something is terribly, tragically wrong with the way the system works—doesn't work—today. Let me take a crack at some of what I think is wrong. It is an inadequate and incomplete analysis, but it is a start.

- First, the climate issue, like most global-scale environmental concerns, is very hard to communicate—it is technical, longterm, and chronic rather than acute.
- Second, the results of scientific research and forecasts on climate generally reach an exceedingly small audience. I read *Science* and *Nature* every week, and for years now there has been an outpouring of newsworthy results regarding climate. But these results—often startling in their significance—rarely if ever make it beyond *Science* and *Nature*. We simply lack the arrangements needed to ensure that good climate science gets to the public. Related to this problem is the well-known reluctance of scientists to speak out and get engaged in policy and public debates. I know that many scientists believe they have spoken up and even spoken out, but I would argue that the scientific voice has been exceedingly modest compared to both the potential and the need. And then there is the disturbingly low environmental and energy literacy of the public, as measured, for example, by the repeated surveys of the National Environmental Education and Testing Foundation.
- Next, the natural carriers of science's messages to the public and into the policy process—the NGOs and the media—have not given the climate issue the urgent priority that it deserves. For many environmental groups it is one priority on a long list; for some it is not a priority at all. Meanwhile the media, when it gets around to the climate story at all, is afflicted with bal-

ance-itis—striving to give equal treatment to the other side of the story when in fact it may deserve little or no attention. International comparisons of the media have shown that U.S. news reports on climate tend to treat the issue as more uncertain, controversial, and theoretical than coverage in other countries.

- Fourth, even when the first three hurtles are crossed, there is the skilled opposition from various economic and ideological interests. This ranges all the way from charlatans claiming that climate change is a hoax to traditional energy industry lobbying—which is going on at least three climate fronts in the Congress today. Along the way, the energy industry and others have orchestrated skillful media advertising campaigns such as the one against the Kyoto Protocol and the more recent one promoting coal.

These factors might be thought of as the conventional reasons why good science is not heard and heeded. But beyond these barriers to action lie some newer and less conventional ones. For example, the environmental community is being charged with not treating the climate issue in the right way. The authors of *The Death of Environmentalism* put it this way:

> Over the last 15 years environmental foundations and organizations have invested hundreds of million of dollars into combating global warming. We have strikingly little to show for it...
>
> [Environmental leaders are not] articulating a vision of the future commensurate with the magnitude of the crisis. Instead they are promoting technical policy fixes like pollution controls and higher vehicle mileage standards—proposals that provide neither the popular inspiration nor the political alliances the community needs to deal with the problem.

I worry that these criticisms get close to blaming the victim. The part of this argument to which I subscribe is that sound science and rational analysis are not enough to carry the day, and that all of us concerned about environment must recognize that we are in a struggle over our core values as Americans and over our vision for the future. We've got to communicate in ways that appeal to the heart as well as the head and speak to peoples' values and aspirations as well as their intellects. In other words, if we want people to listen to the science, we've got to approach them in a very different way.

Another issue gaining prominence—actually it is a very old issue—is religion trumping science. The ways religion impacts receptivity to science-based forecasts is complex and cannot be quickly described, certainly not by me. Religious organizations have been at the forefront of environmental causes in America for a long time.

One of the most powerful statements supporting action on climate, "Earth's Climate Embraces Us All," was organized by the National Religious Partnership for the Environment and signed by leaders of most religions and Christian denominations, including the National Association of Evangelicals. Evangelicals for the Environment is an important source of leadership on climate and other issues. So we must be cautious about generalizations and oversimplifying complex phenomena. But there is another side. Many among the one-third of Americans that are evangelical Christians perceive liberals and scientists as contemptuous of their beliefs. Some see science as a threat or at least as a challenge. *The New York Times* reported in 2003 that "Americans are three times as likely to believe in the Virgin Birth of Jesus (83 percent) as in evolution (28 percent)." Some Christian fundamentalists believe—as did former Interior Secretary James Watt—that we are living in the End Time, so that the long-term environmental future of the planet as we know it is not a concern. Politically active groups associated with the Christian Right support a good many Washington political figures who have very low ratings from the League of Conservation Voters.

All of this suggests that good environmental science and forecasting are absolutely necessary but far, far from sufficient. If we want forecasting to affect real-world events, we need strategies to address the issues I have just catalogued, and probably others. I think such strategies can be identified, and we should get busy with this task soon. Perhaps that can be the next

NCSE project. There is much to be done: A serious effort at environmental education in America. A major media-based public education effort like those on smoking, AIDS, drugs, and drunk driving. A science-led organization devoted exclusively to using all tools available to get climate science before the public. The creation of a bipartisan national commission to make recommendations for U.S. policy on global-scale environmental challenges. Let's build this agenda and move it forward.

In the meanwhile, we Americans have a job to do. We are tragically late in addressing climate change; irreparable damage will unfold in the decades ahead due to our past negligence. Our responsibility now is to prevent the situation from deteriorating further. That, at least, we owe our children and grandchildren.

Fortunately, the outlines of a climate strategy are visible, in part because of the good efforts already being made to move our country in the right directions. What follows is a ten-point plan of action that builds on the many positive, encouraging initiatives already under way.

1. State and local action.

With the path forward blocked in Washington, states and localities across the country have moved to fill the breach. Twenty-eight states have developed or are developing action plans to reduce greenhouse gas (GHG) emissions. Many of these, such as the programs in Massachusetts and Oregon, focus on reducing GHG emissions from power plants. Other states, such as Connecticut and New Jersey, have more ambitious legislation that seeks to reduce overall emissions in the state. New York aims to have 25 percent of its power from renewables by 2013. California has taken the lead in regulating GHGs from vehicles.

Our goal in the years immediately ahead should be to strengthen and deepen state and local commitments and actions. We should work to get every state to adopt an overall GHG reduction plan, a renewable energy portfolio standard, the California plan for vehicles, and an energy efficiency program that covers everything from much tighter building codes to transportation and land-use planning.

2. Carrots and sticks with business.

The good news here is that many corporations are not waiting on federal action on climate and are taking significant, voluntary initiatives to reduce their GHG emissions. They are doing it because the anticipate they will be regulated one day, because of shareholder pressure, because of public image campaigns and consumer pressure, because of lawsuits or the threat of liability for damages, because of pressure from insurers and lenders, and in many cases because they know it is the responsible thing to do.

These factors have combined to bring forth some impressive action by leading companies. Our strategy regarding business should be to escalate on all those fronts that recognize and reward positive performance by business as well as those that put serious pressure on business to reduce emissions.

3. Greening the financial sector.

The financial and insurance sectors are waking up to climate risks. It is estimated that socially responsible investment portfolios in the United States now exceed $2 trillion. Institutional investors, large lenders, and insurers are becoming increasingly sensitized to financial risks (and opportunities) presented by climate change.

Investors large and small should use shareholder resolutions and negotiations to pressure companies to improve climate-risk disclosure and to take risk-reducing actions. The Securities and Exchange Commission should require companies to disclose fully the financial risks of global warming. Mutual fund managers and other investment managers should be pressed to develop climate-risk competence and to support climate-risk disclosure and action at companies in which they are investing.

4. A sensible national energy strategy.

National energy legislation will be on the congressional agenda in the period immediately ahead. It is essential that the results move us strongly into a low-carbon future.

It is now customary for pro-business publications like the *Economist* and *Business Week* to urge adoption of sensible energy policies for the United States. In August

2004, they were joined by *Fortune*, which suggested four U.S. initiatives: (1) improve fuel economy through subsidizing hybrids, cutting oil and gas subsidies, and applying the gas-guzzler tax to SUVs; (2) ramp up spending on alternative fuels, including hydrogen and biofuels, (3) redouble our commitment to energy efficiency, taking advantage of our position as the Saudi Arabia of energy waste to wring more and more production out of each unit of energy; and (4) get serious about solar and wind power. We must hope the U.S. business community is listening to its own best thinkers.

Our goal in this area must be national energy legislation that moves strongly forward along these lines, putting the United States squarely on the road to a low-carbon economy.

5. Enact McCain-Lieberman.

The McCain-Lieberman bill is modest by international standards, seeking only to cut U.S. greenhouse gas emissions to 2000 levels by 2010, but it is the best hope of getting the United States on the path to emissions reduction. The bill garnered 43 votes in the Senate in 2003, and Senators McCain and Lieberman are determined to keep pushing.

Our goal here must be to build broader public support—from business, universities, religious organizations, the conservation community, and elsewhere—to get McCain-Lieberman passed into law, and the sooner the better.

6. Hands across the seas.

The signers of the Kyoto Protocol, now including Russia, represent an international coalition that can press the United States to start a credible program of GHG emissions reduction and join the climate treaty process with other nations. European advocates of trade sanctions and other measures aimed at the United States are not going away. The European Union could also invite U.S. states to participate in its cap-and-trade GHG market. If it is too late for the United States to comply strictly with the Kyoto Protocol, it is certainly not too late for us to begin rapidly down that path and catch up during the more ambitious post-2012 phase of GHG reductions.

7. Climate-friendly cooperation with developing countries.

With China's emissions now already half of the United States' and Asian emissions almost equal to ours, future agreements under the climate treaty should provide for developing country commitments on climate and GHGs. Such agreements need not seek (yet) actual reduction in GHG emissions from the developing world as a whole. They should, however, vigorously promote measures to achieve rapid decreases in developing-country GHG releases per unit of GDP or, as it is sometimes put, reductions in the carbon intensity of production.

To support these efforts, the international community, including the World Bank and others, should launch major new programs. Such programs should include large-scale capacity building assistance, urgent transfer of green technology, programs to link access to low-cost capital to climate-friendly investments, expanded incentives to encourage international investment in climate-supporting projects, country-specific North-South compacts to reverse tropical deforestation, and lighter tariffs and improved economic access to countries complying with climate agreements, as the European Union has proposed.

8. Climate-friendly consumers and institutions.

Mahatma Gandhi told us to "Be the change you want to see in the world." We can each do our part to reduce our own carbon emissions. Individually, it is satisfying; collectively, if a lot of us get moving, it's significant.

We can each do our part every day as climate-conscious consumers, and we can urge the adoption of tougher building codes, appliance efficiency standards, and mileage standards; better mass transit; and much else. Also, we need a clear, accurate system of "climate-friendly" labeling. Some have proposed the idea of a certification program for "climate-neutral products."

What if all American colleges and universities joined in a commitment to reduce their GHG emissions impressively below 1990 levels by 2015 or 2020? What if all U.S. religious organizations made a similar commitment? And all fraternal organizations? And all environmental, consumer, civil rights, and other organizations with commitments to the public interest such as private foundations? All hospitals?

We can make a big difference by getting the institutions with which we are associated to take climate action, starting locally, then expanding regionally and nationally.

9. Limits on coal.

In November 2004 *The New York Times* reported that plans were being laid to construct 118 coal-fired power plants in 36 U.S. states. American coal use is projected to go up by more than 40 percent over the next twenty years.

A measure of the wastefulness of U.S. electricity consumption is that, while the United States consumes about 45 percent more energy and electricity than the European Union, our GDP is only about 5 percent higher than the European Union's, measured by purchasing power. The capacity for the United States to grow by using existing energy inputs more efficiently is huge. Yet, instead of moving in that direction, plans are being laid to do the worst possible thing we could do climate-wise—launch a new generation of more than a hundred coal-fired power plants without plans for capturing and storing the carbon.

We will need a combination of national, state, and local efforts to ensure that climate and other environmental risks are taken into account in decisions regarding new coal plants. National, state, and local environmental and public health groups can collaborate in such a strategy. In Congress, the prospect of all these coal plants should spur (with enough local backing) the so-called four-pollutants bill, which would regulate not only sulfur, nitrogen, and mercury from power plants but also carbon dioxide.

10. A movement of concerned citizens.

More than anything else we need a new movement bringing together a wide array of civic, scientific, environmental, religious, student, and other organizations with enlightened business leaders, concerned families, and engaged communities, networked together, protesting, demanding action and accountability from governments and corporations, and taking steps as consumers and communities to realize sustainability in everyday life. There is much to be done to increase public awareness and build such a movement. I hope some of the grassroots networks that grew in the election campaign of 2004 will turn their attention to building awareness and action on climate. Religious organizations have a big role here, too, as the National Religious Partnership for the Environment is already proving. The entertainment industry and the media need to do far more.

Scientists can no longer content themselves with publishing and lecturing. Only the scientific community has the credibility to take the climate issue to the public and to the politicians, but with some notable exceptions, it has not been as outspoken as it should be. That must change. Otherwise, I do not see how we can convince enough people. The various intellectual and policy communities—such as the foreign policy, consumer, and social policy communities—should come out of their silos (we're all in silos) and take up this cause.

Climate disruption is too important to be left only to the environmentalists. If the environmental community could have won this fight without you, it would have done so already. And someone should build an initiative among those who voted for President Bush to communicate to the president that they did not vote for his energy or climate policies.

We need to build the movement. If we do, we will not fail. Changing U.S. energy and climate policies has proven extremely difficult in the face of powerful industry opposition. That is why a powerful popular movement for change is so essential. I am reminded in this context of Teddy Roosevelt's words:

"Here is your country—
Do not let anyone take it or its glory away from you
Do not let selfish men or greedy interests skim
Your country of its beauty, its riches or its romance.
The world and the future and your very children shall
Judge you according as you deal with this sacred trust."

I thank you.

From New Sight to Foresight: The Long View on the Environment

Arden L. Bement, Jr.
Director, National Science Foundation

I would like to thank James Renick, Chancellor of North Carolina A&T State University, for introducing me today. I know Dr. Renick as a visionary leader who has worked to enhance his university in multiple ways, whether through electronic infrastructure, new facilities, or the interdisciplinary curriculum. He has also been a visionary in providing leadership among a cluster of research HBCUs—Historically Black Colleges and Universities—to build capacity in graduate research.

It is my privilege to address the National Council for Science and the Environment and all participants here today. Our topic—forecasting environmental changes—ranks as one of the grand challenges facing scientists, engineers, policymakers and concerned citizens in our time. Fundamental research on the environment has great promise to contribute in myriad ways to our nation and our world.

The title of my talk is *From New Sight to Foresight: The Long View on the Environment*. This sums up our evolving vision of environmental research and engineering at the National Science Foundation.

Foresight means the "perception of the significance and nature of events before they have occurred." Another definition is "care in providing for the future; prudence." Both definitions inform the National Science Foundation's role in environmental research and education.

At NSF we embrace three aspects of environment: the natural, social, and constructed environments. Insights into all three comprise our ability to perceive, and to provide for, our future.

I have also mentioned "new sight"—by which I mean the expanded vision bestowed by vast observational networks and breakthroughs in sensors. Development of these tools is part and parcel of our ability to foresee.

Then there is the "long view." Some of you will be familiar with NSF's Long-Term Ecological Research Program (LTER), now celebrating its 25th anniversary. But how many have heard of the Long-Term Ecological *Reflection* Program? A participant in this Oregon State University venture, essayist Robert Michael Pyle, contemplated beauty and decomposition at an LTER site deep in a forest of the Pacific Northwest. Musing over the unhurried pace of decay and regeneration in the forest, he observed that "Most of us take the short-term view, most of the time."

The long view, Pyle noted, "requires faith in the future—even if you won't be there to see it for yourself." In NSF's approach to the environment, we are constantly stretching that view, across disciplines, across time and across space.

For almost two decades, NSF has supported major, cross-disciplinary efforts on the environment, ranging from global change—initially focused on physical science—to biocomplexity in the environment, grounded in biological science but involving all disciplines.

Today we look at the grand challenges in environmental sciences posed by the National Research Council, and we all involve people. This is a bellwether, a recognition that the environment has a human dimension, and it is critical. Today the biggest challenge in taking the long view is to integrate the social sciences into environmental investigations.

In the early days of Earth observation from the air, a camera aboard a balloon captured images of San Francisco, devastated by the 1906 earthquake. New estimates of lives lost there have expanded from the traditional toll of a few hundred to at least 3,000, because many single women and immigrants who died were not counted. The official count was kept low so as not to slow the pace of rebuilding.

It is chilling how much old images of the 1906 San Francisco earthquake resemble recent images of the destruction wrought by the Sumatra earthquake and tsunami of December 26, 2004. Turning to this recent event, one of the most lethal environmental disasters in human history, of almost Biblical proportions, I would like to outline how NSF views its environmental portfolio.

The earthquake and tsunami have heightened awareness in the engineering and science research communities of their responsibility to create new knowledge about our human and organizational institutions, ecological systems, the constructed environment, and about our vulnerability in the face of natural catastrophes. Much attention is being paid by the media and elsewhere—and rightfully so—to the need for improved warning-buoy systems in the oceans.

The undersea earthquake that set off the tsunami has gotten less attention. Yet this rare magnitude 9 earthquake was the largest since the Alaskan earthquake of 1964. The Sumatran earthquake released approximately as much energy as all global earthquakes in the period from 1976 to 2004 combined. The earthquake set the Earth ringing like a bell—an oscillation that will continue for a month, at least.

NSF's vision of environmental research is a troika of investigations into the natural, constructed, and social environments. In the first realm, the Global Seismographic Network (GSN) is the primary international source of data for locating earthquakes and warning of tsunamis. The GSN is funded by the National Science Foundation and the U.S. Geological Survey. Within eight minutes of the earthquake, data flashed via satellite and the Internet to the GSN Data Center and beyond.

The Incorporated Research Institutions for Seismology (IRIS)—the GSN's parent body—has promoted a policy of international openness about seismological data. NSF has supported the GSN for 20 years—and this singular earthquake was the "canonical event" it was set up to record.

Geophysicists will be making discoveries based on these recordings for some time. At the same time, the GSN could serve as part of the foundation to expand our capability for tsunami warning in many areas of the world. Such systems also vitally need social and organizational components, linking geophysics with social science to benefit society.

What about the "constructed" dimension of environment? The Network for Earthquake Engineering Simulation (NEES) is dedicated to the grand challenge of preventing earthquake disasters. NEES facilities will simulate earthquakes and study how infrastructure and materials perform during seismic events.

Cyber-tools, such as the Web and grid computing, will enable unprecedented real-time, virtual and telepresence collaboration. One network node, Oregon State University's tsunami research facility, is the largest such facility in the world.

Natural hazards researchers traveled to Sumatra within weeks of the disaster before cleanup and reconstruction could obliterate vital data. Information on physical damage, and on how people responded, helps us to improve not just the stability of buildings and infrastructure, but also the capabilities of communities to protect themselves. Engineers are working alongside social scientists to assess physical damage as well as the social and economic impacts.

In fact, NSF has over 30 years of experience in providing research support for quick-response studies following disasters.

The devastation in Sumatra and Sri Lanka only reinforces the need to take the long view on environmental research. The transformation in scientific tools is helping us to do this—to obtain observations across the disciplines that are unprecedented in quality, detail, and scope.

Evolving in concert with the new tools are different ways of doing science, such as collaboration across large, multidisciplinary, often multinational teams. These new modes of working are the only way to meet the scientific challenges of our era.

The "collaboratories" employ embedded sensors in large grids, synthesis of massive datasets, and computational models of complex behavior. We see these patterns whether the topic of investigation is earthquakes, ecological systems, oceans, or even gravitational waves.

Although observational capability for human activity has been more limited, we are looking to identify new ways to integrate such variables as population distributions, utilities, transportation flows, and risk perception.

Planning is under way for ocean observatories. They will take targeted samples and measure multiple factors over space and time. For example, it will be possible to have instruments take samples automatically when triggered by actual events.

A number of institutions are banding together to create a prototype grid of wireless and optical networks to link oceanographers to ocean observatories off the coasts of Mexico, the United States, and Canada.

Another example from the geosciences is a component of the EarthScope program. An observatory, newly installed three kilometers down in California's San Andreas Fault, is now probing one of the world's most active faults. A drill has burrowed down through the granite beneath Parkfield, California—puncturing the fault like a soda straw. Sensors lining the tunnel will be able to search—for the first time—for signals that could alert us to a major earthquake.

Ecology is another discipline developing a blueprint for a network that will span the continent and beyond. We know that biodiversity is changing across the United States. We know that human activities are changing the geographic distribution of some basic elements of life, such as nitrogen and phosphorous. We've seen an infectious disease like West Nile Virus emerge locally and then spread across the entire country.

The National Ecological Observatory Network (NEON) will support fundamental biological research into such questions on a continent-wide scale.

Modeling is the flipside of observation—also essential for environmental forecasting. One model of the carbon cycle for North America predicts that a warming climate will enhance photosynthesis and production of carbon dioxide. The "carbon-only dynamics" indicates that the ecosystem will store less carbon in that scenario. That is the prevailing wisdom, anyway.

However, preliminary results indicate that once the nitrogen-cycle model is integrated along with the carbon model, North America shifts from adding carbon to absorbing it.

In any case, we do not currently have the computing capability to run this model. Forecasting calls for having observations, models, and the right processes plugged into in the model.

In the polar regions, a major global investigation will take place during the International Polar Year (IPY) of 2007-2008. A U.S. facility already in place at the North Pole exemplifies how we are seeking to characterize the environment at the extremes of the planet. This facility is exploring the little-known Arctic Ocean.

A research camp on the sea ice at the North Pole has an oceanographic mooring beneath. The mooring stretches more than 2.5 miles down and is anchored to the sea floor beneath the ice. It is hung with instruments tracking ocean parameters to create a benchmark to track fast-moving Arctic change. Unlike in Antarctica, which has no native peoples, human populations in the Arctic are already grappling with this rapid change.

The polar regions comprise about a third of the Earth's surface—and they influence what happens everywhere else. Some potential focus areas for NSF during the IPY are:

- Arctic climate change research, including building an Arctic Observation System that involves the Arctic peoples;
- Ice sheet dynamics; and
- Studies of life in the cold and dark.

We are looking for ways to link U.S. scientists with counterparts in other nations for collaborative IPY efforts, and planning is underway around the world.

We have seen examples of observatories now being planned or under construction. Longstanding sites in our

Long-Term Ecological Research program provide case examples of how environmental research has evolved at NSF. This program supports scientists and students studying processes over long periods and across broad scales. It now extends to marine sites, the Antarctic, urban areas, and even to agricultural ecosystems.

It wasn't always that way. The LTER network was first conceived as a research program at isolated, pristine sites. Now we recognize that all ecosystems lie on a gradient from "near-pristine" to "highly engineered," or even "constructed."

Today, an LTER site in the City of Baltimore investigates an urban ecosystem, and studies include social and economic factors. "For ecologists this is really a new thing," says Grace Brush, one of the participating ecologists. "Humans were something to be avoided. For me, at least, it has changed my thinking—to look at humans as part of the natural system."

LTER scientists are now working on creating a true network. They are beginning to probe overarching questions that draw upon a number of sites. Eventually the LTER network will be connected to the other networks I have mentioned.

The sites are evolving from a local focus to an orientation toward national research priorities and shared resources. One prime aim has become to enable ecological forecasting. LTER scientists are recognizing that they can pursue very fundamental environmental and ecological research—and make valuable contributions to society by doing so.

The LTER program has also cultivated a strong synergy between research and education. Scientists, teachers and students at the Niwot Ridge site in Colorado produced a book entitled *My Water Comes From the Mountains*. This book explores the water source for the city of Boulder and features brilliant watercolors by third-graders.

Our tools and methodologies often change our perception of what we are studying. A revolution in environmental sensors is already underway. Researchers at one LTER site—a Wisconsin lake—have teamed up with counterparts at a lake in Taiwan. Both lakes are fitted with sensors. The metabolism of the Taiwanese lake during a typhoon—a quick, episodic event— would have been missed without the autonomous sensors in place.

Before the typhoon, the lake waters were well-stratified by temperature. When the typhoon hit, the waters, nutrients and plankton communities essentially "mixed" or turned over. A day-and-a-half later, the waters were stratified again. If sensors had not been in place to capture this turnover, its occurrence would never have been known. Even though physical access to remote sites is limited, sensors can still record key events.

Being able to observe at different scales—because environmental processes operate differently at various levels—is also critical for forecasting. The grid scale needed to answer regional to continental questions is not currently possible with today's cyberinfrastructure.

As we develop observation systems, environmental and cyber-scientists must closely integrate efforts. As LTER scientist Tim Kratz of the University of Wisconsin comments, "We need to develop scalable infrastructure that allows easy inclusion of additional sites—and ways of handling data on that scale as well."

On Panama's Barro Colorado Island, advanced animal sensing is being used to explore the ecosystem. An antenna tower picks up signals from wild animals wearing radio collars. The networked towers send data directly to the Internet. A motion-sensitive camera in the forest recorded an ocelot preying upon a rodent, called an agouti. As the camera captured the culprit, the radio-signal from the agouti's collar showed the time of death. Biotelemetry, in fact, is now letting us track animals down to the size of large insects on scales of hundreds of miles.

Nature offers plenty of cues to improving how—and what—we sense. Wasps, for example, are extremely sensitive and can detect a wide variety of odors. Wasps have been trained to be attracted to a compound produced by a fungus that infects plants. The wasps are under study as models to detect environmental stress. One potential application might be in agriculture. A farmer might release them in a field to detect a fungal infection in crops.

As we consider how to make a compelling case for how fundamental research on the environment meets critical national needs, incorporating the human scale is the latest challenge. NSF programs like Coupled Human and Natural Systems, and Human and Social Dynamics, are ways to explore and expand that different sort of "long view." NSF's advisory committee for the environment has created a blueprint, *Complex Environmental Systems*, providing the outlines of our environmental directions. The committee also continues to define new, unifying areas of focus for research and education, such as water.

Social science provides insights on how people perceive problems as they interact with the natural environment. Researchers at Carnegie Mellon University observed that concerns about storm damage are far more important to coastal dwellers than are long-term sea-level rises associated with climate change. Substantial early damage from large, infrequent storms generally discouraged rebuilding in vulnerable areas. However, more frequent storms causing minor damage tended not to discourage homeowners from repairing property—even though damage over the long run often exceeded the value of the property.

Speaking of water and human settlement, satellite images of the most ancient area of human civilization, the Nile Valley, show a thin ribbon of inhabitable green running through the desert below the Aswan Dam and Lake Nasser, exemplifying how the natural, the constructed, and the social systems truly encompass "environment" in this part of the world. We see the stark truth: Where there is water, there is life.

I spoke at the beginning about taking the long view on the environment, exploring from the nano- to the global-scale. The ultimate goal for all of the observation systems—stemming from different disciplines, crossing a breadth of scales, based on the revolution in sensing—is to link up these systems with cyberinfrastructure.

Our nation is strongly committed to developing an integrated and sustainable Global Earth Observation System of Systems—an important U.S. administration priority, and an effort including 55 nations thus far. The United States has developed a strategic plan for our nation's contribution.

A saying, purportedly from a Swedish army manual, comes to mind: "If the terrain and the map do not agree, follow the terrain." With global observation capability, with cyberinfrastructure, with contributions from across the disciplines, and with our national needs as a framework, we are indeed poised to follow the terrain. Fundamental research to chart the environment of this planet shared by all nations contributes to the security of us all.

Thank you.

Building a Digital Abstraction of the Earth

Jack Dangermond
Founder and President, ESRI

The vision of building a digital abstraction of the Earth involves the creation of an evolving system for measuring, monitoring, modeling, planning, and managing the planet. Such an abstraction would support science and improve our ability to forecast environmental changes. More importantly—by linking science with planning and action—it would affect the planet's evolution.

In building a digital Earth, it is useful to consider Geographic Information Systems (GIS) as an emerging language for abstracting and communicating geography—the content and processes of the Earth. Perhaps this language could be thought about as creating a conversation about our future.

We use many languages to describe our world. They reflect our experiences. They include written, visual, and software languages; mathematics; statistics; music; art; and others. These formal languages also help us organize how we see the world. We use them to record and describe what we know. They support our thinking and conceptualization. They help us communicate ideas, and in so doing, they also help us collaborate. Languages are also living—evolving and expanding in response to a changing world.

Geography is the science of our world. GIS introduces new concepts and methods to geography—concepts of complex data modeling, interactive mapping, and integrating data and spatial analysis; visualization; modeling; and geoprocessing. These are all making advances, not just in geography but in all sciences.

GIS is also being used as a framework and process to apply geospatial information to a host of applications. This framework allows us to observe, measure, and analyze, then plan and take action. As a result, GIS is helping us create the future by integrating information from many sources.

Geography is increasingly being seen as a framework for understanding patterns, relationships, and processes at all scales, not just the whole globe but also our neighborhoods, watersheds, cities, states, and nations. It is a framework for thinking about things, modeling the future, visualizing, and integrating and referencing what we know.

Geography is very broadly defined to include social, cultural, economic, political, physical, and biological subjects. Over the years, geographers have developed many formal concepts and principles that build on the concept of place and are used to create geographic knowledge. These include a number of formal concepts, theories, and methods. GIS has embodied many of these principles and concepts into its fundamental technology, and as a result, GIS has become an instrument for extending and applying geographic knowledge.

GIS as a language integrates information. It also integrates our work, organizations, and disciplines and is a crosscutting tool to help us make decisions. The GIS language is helping us build geographic knowledge. It is a system for connecting things, communicating, and collaborating—the very things I believe the world needs.

Over the years, there has been a steady advancement in GIS technology (e.g., data modeling, spatial analysis, data management, cartography, and visualization). This evolution has been associated with advances in computing technology, improvements in spatial measurement (e.g., remote sensing and GPS), growth in geographic information science, and the invention and enhancements of GIS software technology.

GIS builds on the two fundamental parts of geography: the descriptive content and process. We use GIS to describe geography with data sets, data models, and maps. Process geography is described with models of how geography changes (e.g., models of erosion, flooding, vegetation growth and change, and urbanization).

In the early years, GIS focused primarily on content automation with simple geographic methods of area measurement, numeric and statistical processing of data, and mapping. As technology advanced, GIS incorporated many concepts of spatial analysis and modeling that have enabled new science, thinking, and applications to emerge—creating new knowledge. Today, it is safe to say, the science of geography and GIS technology are coevolving and synergistic.

It is also important to note that GIS technology has spread geographic principles far beyond geography. GIS is now used in virtually all sciences that use spatial location as a factor in their discipline. GIS has also provided a framework for applying geographic thinking into many fields, including almost every aspect of government, business, and education.

Also, GIS technology has led to much sharing of geographic data and related knowledge between and among disciplines and application areas. In geographic problem solving, GIS is providing a common language for collaboration. Examples of applications include weather forecasting, hydrological modeling and flood analysis, coastal mapping, marine ecosystem monitoring, web publishing of the National Map, ground water modeling, water security plans, disaster modeling and response, emergency environmental response, forest management, land use change, urban systems modeling, habitat modeling and restoration, analyzing human health and the environment, global food forecasting, improving agricultural productivity, social analysis and poverty, and nature conservation.

Initially, GIS has allowed sharing of basic data sets among and between GIS professionals and applications. As GIS has become more intelligent, we introduced the concept of model encapsulation. This allows users the ability to easily abstract and share process models, work flows, and related scripts. These abstractions are comparable to weeks, months, and even years of valuable personal knowledge about GIS and geography.

Sharing models not only saves time but also allows us to share knowledge across disciplines and among different organizations. GIS professionals are increasingly able to leverage one another's knowledge in a crosscutting and collaborative environment. Yet, organizing this geographic knowledge is only in its beginning stages. Technological advances in Web services, GIS portals, and mobile computing are providing a platform for disseminating geographic knowledge to a much wider audience. GIS technology will ultimately expand to be a fundamental way of exchanging our geographic experiences and knowledge among all levels of society and in all fields.

Recent advances in GIS are providing a systematic framework for organizing, sharing, and combining many different types of geographic knowledge. Just as words can make sentences that can be organized into paragraphs that tell stories, the basic GIS building blocks of data, data models, process and work flow models, maps and globes, and metadata are being assembled and used to describe our past and the present, as well as to help us create the future condition of our planet.

As important as it is to describe the actual world using GIS and geography, I think it's far more important to use GIS to imagine a better world. Languages help us define what's possible.

GIS is a new language. It encompasses many opportunities for us to advance science, design with nature in mind, make communities livable, increase efficiency, support economic development, improve human health, and mitigate conflicts.

GIS is especially well designed and suited for imagining our future. Actually, I think it's essential. Empowering geography with a language—GIS—will help us create a better future. GIS is becoming intelligent and collaborative. Connecting GIS into the societal infrastructure of the Web will lead to widespread collaboration, will bring about a better understanding, and will allow us to create a better future. The vision of creating a digital abstraction of the Earth must be supported if we are to survive as a society.

NCSE **Lifetime Achievement Award presented to:**

William D. Ruckelshaus

First and Fifth Administrator
U.S. Environmental Protection Agency

From introduction by H. Jeffrey Leonard, President and CEO, Global Environment Fund

With diplomatic skill, strong commitment to democratic process, and more than a little wit and charm, Bill has over many decades been at the forefront of efforts, at home and abroad, to bring rational, science-based thinking to the task of addressing difficult environmental challenges.

Ladies and gentlemen, it is a great honor for me to present to Bill Ruckelshaus the 2005 NCSE Lifetime Achievement Award for his distinguished career, in both the public and private sectors, as a tireless advocate for balanced, pragmatic, broadly supported, and sustainable solutions to vital environmental and conservation issues facing this country and, indeed, this planet.

The following remarks are excerpts from the Fifth Annual John H. Chafee Memorial Lecture on Science and the Environment delivered by William D. Ruckelshaus on February 3, 2005. NCSE has published the complete text of Ruckelshaus' lecture in a separate report, which is the fifth in a series of books documenting the annual John H. Chafee Memorial Lecture on Science and the Environment.

Choosing Our Common Future: Democracy's True Test

When the first wave of environmental concern swept America in the late 1960s and early 1970s under a Republican President and Democratic Congress, we passed massive laws controlling air pollution, water pollution, pesticides, radiation, toxic substances, and even solid waste—some 10 laws during the 1970s. We put in place a national system of restraints controlling the unwanted actions and substances. Yes, I said a system of restraints—laws, rules, regulations, even cultural restraints. Proper restraints voted on by freely elected officials are the essence of freedom. Let me quote from a speech delivered forty years ago by Chief Judge Barett Prettyman of the U.S. Court of Appeals at the Pentagon in honor of Law Day:

> In an ordered society of mankind there is no such thing as unlicensed liberty, either of nations or individuals. Liberty itself is inherently a composite of restraints. It dies when restraints are withdrawn. Restraints are the substance without which liberty does not exist. They are the essence of liberty...

In one sense, freedom is the *absence* of governmental restraint—unwarranted governmental restraints such as inhibitions of free speech, or the right to worship or to a jury trial for the accused. Those individual freedoms and many more are granted to us under the Bill of Rights.

The freedom our environmental laws are addressing is reflected in our collective obligation to order our activities so that our society will flourish—so that it will work. We collectively, through our Congress, placed restraints on individual, corporate, and government action so it didn't threaten our health or our environment.

This is the system of restraints to which Judge Prettyman referred. Without this ordering of our conduct, things begin to break down and our society and ultimately freedom itself are threatened. The system of restraints is simply the "rule of law" so often cited as necessary for an ordered and free society.

What we fashioned by our environmental laws was a top-down, command-and-control system of restraints.

In spite of some skeptics, this system worked pretty well. Our air and water are appreciably cleaner than when we started over thirty years ago. This is particularly apparent if we imagine where we would be today had we done nothing. Large point sources of pollution such as power plants or industrial emitters are permitted by government agencies and largely under social control. In addition, automobiles emit far less carbon monoxide, ozone, or nitrogen oxides than before controls were put in place. We have identified and eliminated, or greatly mitigated, the effects of many pesticides and toxic substances that were largely uncontrolled prior to the 1970s.

Of course our work is not complete. Protecting the environment is not like building a highway or painting a building. You can't do it and walk away from further work. You must stay everlastingly at it, or things begin to slide. By any measure, we have made enormous progress, and that should give us hope as we tackle the next set of issues. However, having responded to the first set of environmental concerns—the smell, touch, and feel kinds of problems—that gave rise to the first wave of public outcry, we have been facing a second set of issues where our "system of restraints" and our "essence of freedom" have not been nearly as successful....

Increasingly for many of our environment and natural resource problems, we are seeking to resolve them by the use of collaborative processes.

Since the early 1980s, collaborative decisionmaking processes have risen spontaneously and in increasing numbers throughout the country. In some cases, the goal was to bypass longstanding deadlocks. People, it seems, want their environmental problems solved and not merely massaged by government officials, and perpetual litigation seems to have limited appeal as a spectator sport. The American West seems to have specialized in this sort of process, probably because it is in the small timber, ranching, and mining communities of the West that the conflicts between livelihood and environmental protection seem particularly sharp.

Thomas Jefferson once pointed out that if the people appeared not enlightened enough to exercise their control of government, the solution was not to take away the control but to "inform their discretion by education." The collaborative processes that are springing up around the country are doing just that, giving to large numbers of citizens a new comprehension of the complexity involved in government decisions, out of which has got to come a heightened appreciation of, and tolerance for, the necessary work of government. If these processes work, if they spread, if they become an indispensable part of government at all levels, it will hold out hope that, once again, America will be ready for self-government and we will continue to show the way for a world desperately in need of democracy's blessings.

William D. Ruckelshaus served as Administrator of the U.S. Environmental Protection Agency (EPA) from its inception in December 1970 until April 1973. A decade later he was asked by President Ronald Reagan to return to the agency's helm, where he served as the fifth Administrator until 1985. While the challenges of administering the EPA evolved as the agency matured, Ruckelshaus consistently sought balanced, durable, and widely-supported approaches to environmental and conservation issues.

Ruckelshaus was the U.S. representative to the United Nations World Commission on Environment and Development (commonly known as the Brundtland Commission) from 1983 to 1987. The Commission's 1987 report on sustainable development, "Our Common Future," led to the 1992 Earth Summit in Rio de Janeiro, which was one of the largest gatherings of world leaders in history.

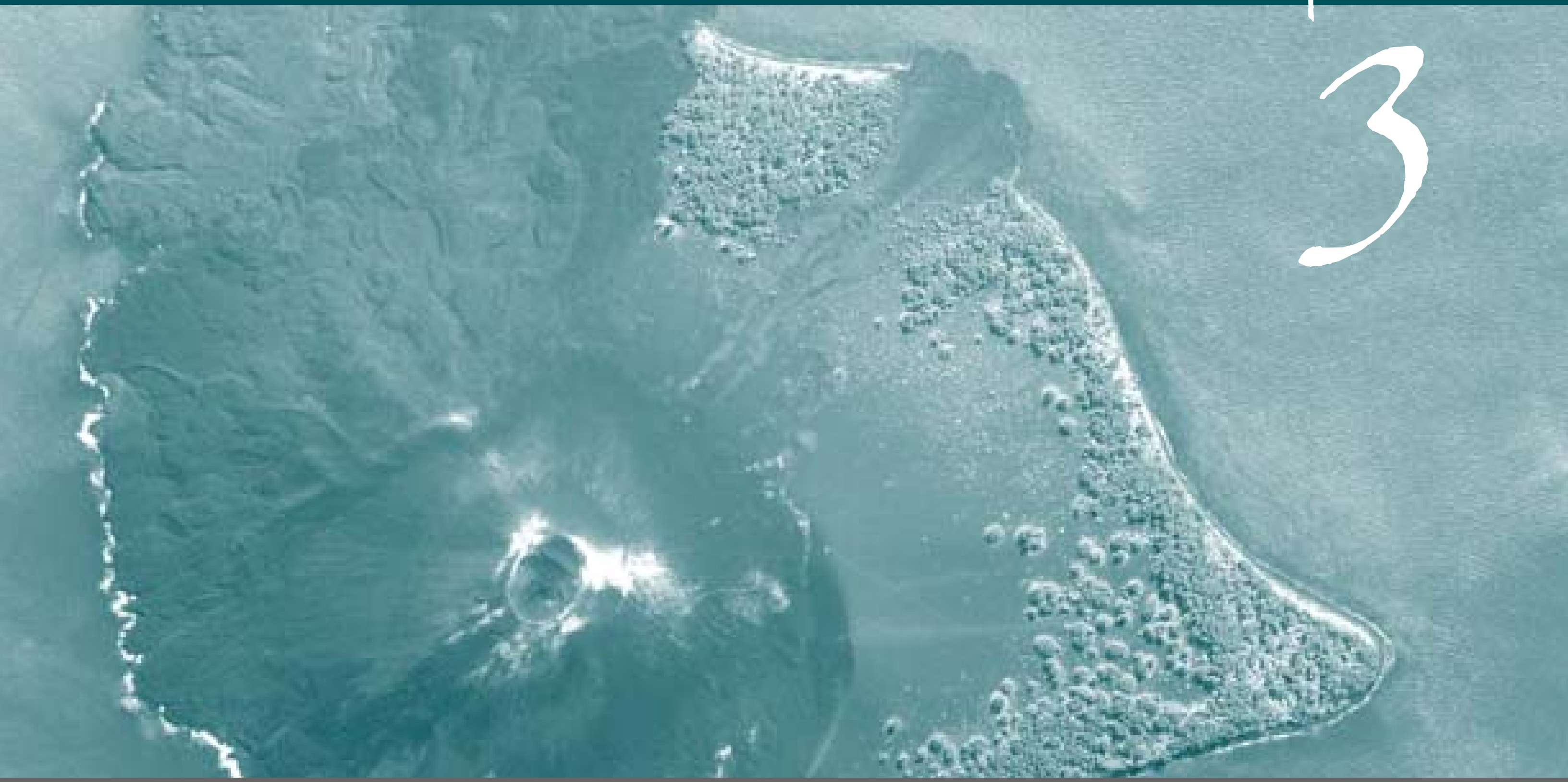
Ruckelshaus was appointed by President George W. Bush to serve on the U.S. Commission on Ocean Policy. The Commission issued its final report in September 2004, making recommendations to the President and Congress for a coordinated and comprehensive national ocean policy. Previously, Ruckelshaus was appointed by President Bill Clinton in 1997 to serve as the U.S. envoy addressing issues relating to the Pacific Salmon Treaty. He has served as Chairman of the Washington State Salmon Recovery Funding Board since 1999 and has been instrumental in efforts to recover endangered salmon species in the region.

Ruckelshaus is the immediate past Chairman of the World Resources Institute Board of Directors. He is also Chairman Emeritus of the University of Wyoming Ruckelshaus Institute for Environment and Natural Resources, Chairman of the Meridian Institute, and he serves on the board of several other nonprofit organizations.

Currently, Ruckelshaus is a Strategic Director in the Madrona Venture Fund and a principal in the Madrona Investment Group, L.L.C., a Seattle based investment company. He is the director of several corporations, including Cummins Engine Company, Pharmacia Corporation, Solutia, Inc., Coinstar, Inc., Nordstrom, Inc., and Weyerhaeuser Company.

Born in Indianapolis on July 24, 1932, Ruckelshaus graduated cum laude from Princeton University in 1957 with a Bachelor of Arts degree and obtained his law degree from Harvard University in 1960. He was a member of the Indiana House of Representatives and its majority leader from 1967 to 1969. In addition to his service as Administrator of the EPA, Ruckelshaus has held other leadership positions in the federal government including Acting Director of the Federal Bureau of Investigation and Deputy Attorney General of the United States.

Chapter 3



Roundtable Discussions

Roundtables

Lessons Learned from Successful Environmental Forecasting Approaches

Designing Ecological Forecasting Systems

Applying Environmental Forecasting to Environmental Decisionmaking

Plenary Roundtable

Lessons Learned from Successful Environmental Forecasting Approaches

Panel Discussion

D. James Baker, *President and CEO, Academy of Natural Sciences; Former Administrator, NOAA*
Charles Groat, *Director, U.S. Geological Survey*
Charles Kennel, *Director, Scripps Institution of Oceanography; Former Associate Administrator, Mission to Planet Earth, NASA*
Margaret Leinen, *Assistant Director, Geosciences, National Science Foundation*

Moderated by

Mohamed El-Ashry, *Former President and CEO, Global Environment Facility*

Panel members (from left) Mohamed El-Ashry, James Baker, Charles Groat, Charles Kennel, and Margaret Leinen.

The devastating earthquake and tsunami in the Indian Ocean on December 26, 2004, demonstrated the vital importance of improving and integrating our environmental forecasting systems and decisionmaking capabilities. In order to achieve that goal, Mohamed El-Ashry said it is important to draw upon many lessons that can be gleaned from successful environmental forecasting systems that are already in existence.

El-Ashry said the tsunami is a reminder of the vulnerability of developing countries to natural disasters. Experts from around the world agree that thousands of lives could have been saved if an effective tsunami forecasting and warning system had been in place in the Indian Ocean. Shortly after the tsunami, an international agreement was reached to create such a system. Recent natural disasters demonstrate that we are really dealing with global issues and global challenges that will require global cooperation. El-Ashry said that U.S. leadership, knowledge, and experience can come into play in addressing these global challenges.

The tsunami disaster highlighted the need for better communication and education. "All the technology in the world doesn't do a lot of good if you can't get the word out," said Charles Groat. In the case of the Indian Ocean tsunami, the entire warning chain was weak. The monitoring system in the Indian Ocean was weak; the communications infrastructure to local authorities was weak; and public education was weak. Establishing a tsunami warning system is easy in comparison to establishing lines of communication to local authorities and educating local populations how to respond.

D. James Baker provided a historical perspective on natural disasters. In September 1900, the Galveston Hurricane killed at least 8,000 people. In October 1998, almost 100 years later, Hurricane Mitch killed about 11,000 people in Central America. In 1883, the Krakatoa tsunami killed more than 36,000 people in Indonesia alone. At the end of 2004, the Indian Ocean tsunamis killed more than 150,000 people.

Baker said our ability to issue warning has improved, but we only do well for certain types of hazards in certain parts of the world. In most of the developed world, forecasting and communications systems enable us to broadcast warnings of severe weather that save thousands of lives every year. But even with a warning, it is still not possible to get an adequate response in many developing countries. The communication system is inadequate and most of the public does not know what to do. For the ocean, we can only issue warnings in certain parts of the world because our measurement and communication systems are not adequate. Even the developed world is at risk for tsunamis, which require underwater sensors. All parts of the system, including public education, are inadequate. Baker said we need more instruments on land and on satellites, a better communications network, and an educated public.

Baker said better policy choices are also needed. For example, the sustained scientific management of forested watersheds can reduce flooding and pollution, even in coastal zones that are far away from inland watersheds. Paved surfaces in urbanizing watersheds exacerbate flooding. Unfortunate government policies provide insurance for people to build in flood-prone areas. Baker emphasized that education and better policy choices are a key part of reducing loss of life and property, and for making life on Earth more sustainable. It is important for us to understand how our planet works in order to do this. A key lesson is that technology is essential, but it is not enough.

Major environmental forecasting initiatives such as the Global Earth Observation System of Systems (GEOSS) and the National Ecological Observatory Network (NEON) are being designed to achieve specific societal benefits and address the needs of both scientists and non-scientists, including policy makers, natural resource managers, and natural hazards planners.

Charles Kennel said that GEOSS is science serving society. As described in Chapter 4, GEOSS is a transformative initiative that would "take the pulse of the planet," revolutionize our understanding of the Earth, and achieve societal benefits in nine areas. The environmental-forecasting community should make its data as compelling and well publicized as the Mars Rover photographs, Kennel implored. "How come the Earth doesn't get any respect?" he asked.

Human architecture should precede system architecture in designing an observing system, Kennel emphasized. The most important part of the human architecture is the network of understanding that develops among the data providers, the scientists and the technologists, and the users of the information. A clear vision for what must be done results from a dialogue between capability and need.

Kennel said the building blocks of GEOSS will include satellites, aircraft, unpiloted automated vehicles, distributed sensor nets on land, in ice, in the ocean, and on the ocean bottom, moorings, robotic ocean floats, ships, and so on. The sensors will be both active and passive. The essential new element that makes it all possible is that this entire observing infrastructure will be coupled to a comprehensive cyber infrastructure using optical, wireless, and satellite communications with real time data assimilation into diagnostic and predictive models, all connected. “This is the vision. This system will self-assemble from such building blocks,” Kennel said.

The evolution of GEOSS has intriguing possibilities. Today’s sensors and platforms are large and expensive and many will stay that way, Kennel said. And the major backbone for the global Earth observing enterprise will continue to be sustained by government. But sensor nets will evolve rapidly, Kennel suggested. Eventually there may be hundreds of billions of sensors distributed around the surface of the Earth. Nanosensors could communicate via cell phone and emerging technologies. He suggested the term “nanonet” to describe a system of networked nanosensors.

Drawing an analogy with the development of the internet, Kennel noted that billions of unsophisticated users created products that none of the designers of the internet or any of the funders or any of the initial users could ever imagine. This occurred shortly after the first peer-to-peer use of the internet in which the network itself was supported by the government, but the uses of it were determined by the users. If we imagine that the Global Earth Observation System of Systems will follow a similar path, Kennel thinks that we have gone beyond the first phase of a government directed program and into the second phase of initial peer-to-peer interactions.

The third phase of this system will occur when there is broad access by unsophisticated users who can develop their own useful products. Kennel thinks it is time to at least enable the beginnings of this development by creating internet portals for high-level products, media adopted imagery, algorithms for submitting volunteer observations, simple decision support tools, and basic analytic tools and programs.

The science of the Earth will evolve to a new phase when this occurs. We have gone beyond identifying and understanding the basic processes that govern the Earth’s systems, and we are moving to a state of continuous awareness of their operation. That continuous awareness will lead to new scientific insights as information and understanding from disparate areas are brought together. But society will use continuous awareness to adaptively manage its environment and to promote a more unified global view of the problems that confront us in this century, Kennel concluded.

Drawing upon examples from meteorology, oceanography, geology, and biology, Margaret Leinen identified several lessons that can be applied to new environmental forecasting systems. In the aftermath of the tsunami disaster, many people have focused on the need to expand networks of ocean buoys that can sense the waves associated with a tsunami and on the need to improve transmission mechanisms for informing people about a tsunami forecast or warning. Observations and transmission mechanisms are necessary components of environmental forecasting systems, but they are not sufficient. Leinen said additional research on environmental processes and models is also essential for improving environmental forecasting systems. We need to improve our fundamental understanding of processes that drive environmental changes and to improve mathematical models that have the capacity to forecast future environmental changes. For example, fundamental research on meteorological processes and models can lead to more accurate forecasts and earlier warnings of major storms, even in the absence of additional data or improved observation systems.

Leinen stressed the importance of working at multiple spatial and temporal scales in order to improve our ability to forecast environmental changes. To illustrate this point, she discussed research on wildfires that was supported through NSF's Long Term Ecological Research (LTER) program. One of the important lessons is that the processes taking place in a wildfire depend on the scale of the system. In the initial stage of development, a wildfire is controlled by the amount and availability of combustible material. As the fire spreads and reaches a larger size, the connectivity of the combustible material controls the spread and intensity of the fire. Once the fire assumed a certain size, it generates its own weather. The processes controlling the predictability of the fire are largely dependent on the scale of the system. As we attempt to forecast more environmental phenomenon—such as wildfires, desertification, and precipitation associated with climate change—it is becoming increasingly clear that scientists need to understand processes operating at multiple scales.

Margaret Lenin and Charles Groat demonstrated the utility of improving our ability to forecast *what* will happen even if it remains difficult to forecast *when* an event will occur. For example, an active area of research concerns what will happen in Los Angeles as a result of a major earthquake in that area. An important component of this research is the development of quantitative models that are based on a deep understanding of processes that operate at different scales. The models show how an earthquake on different parts of the San Andreas Fault system will propagate, what kind of shaking will take place, and even more importantly, how the shaking will affect different kinds of buildings and the geospatial distribution of the effects. We can maximize the societal benefits of forecasts and minimize the cost of mitigation by retrofitting highly vulnerable structures in areas that have a high likelihood of strong shaking. The Federal Emergency Management Agency has joined with the National Science Foundation, the U.S. Geological Survey, and other agencies interested in mitigating the potential effects of earthquakes and preventing natural hazards from becoming natural disasters. An important lesson is that our ability to develop a deep understanding of processes and comprehensive models of *what* will happen is of great value because this enables us to prepare in advance for a catastrophic natural hazard even if we do not know *when* it will occur.

Changing directions, Groat said that we can use our understanding of environmental processes and our ability to forecast environmental changes to manage certain variables and achieve desired outcomes. Adaptive management approaches can be used for this purpose. Drawing on an experiment with adaptive management in the Grand Canyon below the Glen Canyon Dam, Groat described a collaborative process for manipulating environmental variables that affected precious resources—including critical ecosystems, habitats, and populations—to the satisfaction of stakeholders with different interests. A key lesson is that the development of rigorous and comprehensive environmental management systems based on environmental observations, understanding, models, and forecasts is a complex process that involves a long-term commitment and multi-stakeholder engagement. This is usually an expensive process. A daunting challenge is to apply this approach to managing natural hazards, such as wildfires, where key variables are controlled by both humans and nature.

Plenary Roundtable

Designing Ecological Forecasting Systems

Panel Discussion

Ann Bartuska, *Deputy Chief for Research and Development, U.S. Forest Service; Former President, Ecological Society of America*
Gary Foley, *Director, National Exposure Laboratory, U.S. Environmental Protection Agency*
Bruce Hayden, *Professor, University of Virginia; Co-Director, National Ecological Observatory Network (NEON) Project Office*
Thomas Lovejoy, *President, The H. John Heinz III Center for Science, Economics, and the Environment; Former President, American Institute of Biological Sciences*
Steven Stanley, *Professor of Paleobiology, Johns Hopkins University; Former President, American Geological Institute*

Moderated by

Ronald Pulliam, *Regents Professor, University of Georgia; Former Director, National Biological Service; Former President, Ecological Society of America*

Panel members (from left) Ann Bartuska, Gary Foley, Bruce Hayden, Thomas Lovejoy, and Steven Stanley.

Building on the first plenary roundtable discussion, Ronald Pulliam said the design of new ecological forecasting systems will benefit from lessons learned from other environmental forecasting systems. He highlighted two major challenges that should be addressed when designing new ecological forecasting systems, such as the National Ecological Observatory Network (NEON). One is to design systems that are relevant to decisionmaking. The other is to link local ecological studies with those at regional, national, and global scales. However, Pulliam said the technical challenges of designing ecological forecasting systems may not be as difficult as challenges of communicating the science and building bridges to decisionmakers.

As the U.S. Forest Service celebrates its 100th anniversary, the agency is focusing on how the past is informing the future and how it can make better decisions. Toward that end, the agency's Ann Bartuska addressed desirable attributes of an ecological forecasting system from the perspective of a land management agency:

- First, it is important to match the scale of the information with the scale of the decision. For example, the information needed to address forest fires at a site-specific scale is different from the information needed to address forest fires at an ecosystem scale or for the entire western United States.
- Second, forecasting systems should be practical and practicable. Forecasting systems will be supported in the long run if people can put them into practice and use them. They need to go beyond theory and grandiose science in order to provide added value to land managers.
- Third, ecological forecasting systems should be flexible and dynamic so that they can meet future needs that are not anticipated at the time they are designed. A system should have an intrinsic ability to be adaptable as new needs emerge. In many cases, it is possible to use the basic framework and adjust it to do something different in the future.
- Fourth, land managers should be able to make decisions and take actions based on ecological forecasting systems. In some cases, forest supervisors are given information about the effect of climate change on fire behavior over the next fifty years. They may not know what to do with this information if they have a one-year budget cycle and a five-year planning cycle. They need guidance in order to make decisions based on this information.

Bartuska emphasized that progress can be achieved through partnerships among federal, state, private, and academic institutions, as well as citizen scientists and volunteer monitors.

Gary Foley said the international Group on Earth Observations and the U.S Interagency Working Group on Earth Observations have produced plans and background documents that provide valuable guidance for ecological forecasting. A goal of these initiatives is to provide better data for decisionmaking and better decision support tools in order to achieve societal benefits from improved ecological forecasting. To achieve this goal, it is important to understand the needs of the user community. It is also useful to ask users what data and decision support tools that are using now, Foley added. Many environmental decisionmakers are not aware of existing data and decision support tools.

Foley outlined the large constituency of decisionmakers that would benefit from ecological forecasting. For example, the U.S. Environmental Protection Agency has four regulatory offices and 10 regional offices as well as contacts with 100 state environmental agencies and councils, 600 tribal organizations, and numerous local organizations. Existing channels of communication, including television and newspapers, can be used to improve outreach and education for the large community of environmental decisionmakers. It would be useful, for example, if ecological indicators and forecasts were included in weather reports, news broadcasts, and newspapers. This would enable decisionmakers and other users to become familiar with this information and use it in both institutional and personal decisionmaking. Beyond the technical challenges of improving environmental observations, science, and models, it is important to improve our ability to engage the user community, including people who may not recognize that they are members of the user community.

Bruce Hayden said nearly 200 people are actively engaged in planning and designing the National Ecological Observatory Network (NEON). As described in Chapter 4, NEON is envisioned as an unprecedented platform that will transform ecological research, address grand challenges in ecology and the environmental sciences, and achieve credible ecological forecasting and prediction. NEON will be designed to provide ecological forecasts that will benefit society over a period of decades. Before focusing on the science, it is important to identify what types of forecasts will help achieve the intended societal benefits.

Providing an historical perspective, Hayden discussed an environmental observing system proposed by Thomas Jefferson. It took more than 100 years before Jefferson's vision of a system for measuring meteorological variables in each county was established. It is now more than 200 years since Thomas Jefferson conducted his own biodiversity survey of Virginia, and we still do not have the ability to measure biodiversity in all counties across the nation. NEON may not be able to achieve that goal, but it can provide information on the status of ecological systems on a national scale.

Communications and education are important components of NEON. Drawing on examples from weather forecasting, Hayden said that map displays and nowcasting could be applied to ecological forecasting. People are interested in ecological conditions in their community. They could be encouraged to work with scientists to set up local networks in their community.

Hayden emphasized that NEON cannot be all things to all people. We have to control the expectations of our colleagues, he said. In planning NEON, researchers should look beyond their personal research interests. They need to adopt a 50-year perspective, including the needs of several generations of students. What critical forecasts do we need to make 10, 20, 30, and 40 years out? What science do we need to accomplish that particular end? Once we answer those questions, we will have a more focused scientific agenda, Hayden said. He encouraged people to read and vet the NEON planning documents. This participation is critical to the success of NEON.

Thomas Lovejoy discussed the relationship of the Heinz Center's study on *The State of the Nation's Ecosystems* to the question of ecological forecasting. *The State of the Nation's Ecosystems* lays out a blueprint for periodic reporting on the condition and use of ecosystems in the United States. Developed by experts from businesses, environmental organizations, universities, and federal, state, and local government agencies, it is designed to provide policymakers and the general public with a succinct and comprehensive—yet scientifically sound and nonpartisan—view of "how we are doing." The study identifies the major characteristics of ecosystems that should be tracked through time to provide this view, and, where possible, provides information on both current conditions and historic trends. It also highlights key gaps—situations where data do not exist or have not been assembled to support national reporting.

One of the most surprising results, Lovejoy said, is that for half of the indicators there are not adequate data for a national report. The candor of saying that we do not know is making a big impact on how people might pursue similar exercises in other countries. *The State of the Nation's Ecosystems* only provides data up to the present day. Nevertheless, the study is important for forecasting ecological changes. For example, the data can be used to populate forecasting models, to determine if past predictions were accurate, and to model how various decisions might affect the trends.

Lovejoy emphasized the relationship between climate change and the state of the nation's ecosystems. He recommends turning the debate around so that we can avoid problems. Rather than asking what levels of greenhouse gases are unsafe and what levels of interference with the climate system are unsafe, he recommends asking what levels of greenhouse gases are safe and what levels of interference with the climate system are safe. In addition to addressing the science of climate change we need to consider the context in which it is used.

Steven Stanley said that we need to understand the deep geological past in order to understand the future. The geological record of past ecological changes is contained in rocks, fossils, soft sediments, deep sea cores, ice cores from glaciers, and other sources. Stanley identified two classes of phenomena in the geological record. First, the record reveals major changes in global ecosystems, some of which have happened on shockingly rapid scales of decades or even a few years. Second, the record reveals whole states of the global ecosystem that are not at all like the present ecosystem. If scientists want to model the present ecosystem, we need to model these past states or else something in the model is deficient.

One example is from the Eocene (40 million years ago), which is not very long ago from a geological perspective. At that time, alligators were living in the Arctic Circle and palm trees were living in Wyoming. The climate of southeast England was like that of modern Malaysia. Atmospheric scientists have not successfully modeled these climatic states. Another example is based on evidence from a Greenland ice core. As the Earth was emerging from the last period of glacial expansion a few thousand years ago, there was a change in mean annual temperature in Greenland of approximately 10^{o}F in just a few years.

Based on his ideas about why the modern ice age began, Stanley thinks we can come out of it very quickly, even on a human time scale. Before the Earth moved into the ice age, there were forests in the Arctic, and there was an absence of tundra. We have to be concerned about future shifts from tundra to evergreen forests, which could encroach on the Arctic Ocean. Once the tundra begins to melt, there is a feedback loop in which more heat is trapped as a result of the decrease in albedo, or surface reflectivity. There may also be a loss of methane from tundra as it melts, and the methane could contribute to greenhouse warming. Likewise, the melting of sea ice and the warming of ocean water can cause further changes in climate systems and ecosystems.

Stanley said it is important to recognize key indicators, feedback loops, thresholds, and chain reactions in climate systems and ecosystems. It is possible to move to a different ecological state from which it is difficult to move quickly back to the previous ecological state. Based on his knowledge of the geological past, Stanley said, future climate change may be worse than envisioned.

Plenary Roundtable

Applying Environmental Forecasting to Environmental Decisionmaking

Panel Discussion

Ray Anderson, *Founder and Chairman, Interface, Inc.; Former Co-chair, President's Council on Sustainable Development*
Rita Colwell, *Distinguished University Professor, University of Maryland and the Johns Hopkins University Bloomberg School of Public Health; Chairman; Canon U.S. Life Sciences, Inc.; Director Emeritus, National Science Foundation*
Brigadier General John J. Kelly, Jr., *Deputy Undersecretary of Commerce for Oceans and Atmosphere*
Walter Reid, *Director, Millennium Ecosystem Assessment*

Moderated by

Dave Jones, *President and CEO, StormCenter Communications, Inc.*

Panel members (from left) Dave Jones, Ray Anderson, Rita Colwell, Gen. John Kelly, and Walter Reid.

Water Reid discussed the role of scenarios and international science assessments in applying environmental forecasting to environmental decisionmaking. He said that scenarios are important and underutilized tools for communicating long-range forecasting information to decisionmakers. Scenarios provide a valuable means of engaging decisionmakers, but there are still major hurdles in building ecology into global scenarios.

Scenarios are structured accounts of possible futures that often combine quantitative modeling with qualitative analysis. They are not forecasts or predictions but make use of many forecasting methods and models. Scenarios can be used in decisionmaking to allow exploration of the consequences of decisions made today on future outcomes, to widen perspectives, for public education, to allow testing of strategies and plans under different "futures," and to provide an unmatched opportunity to directly engage decisionmakers in discussion and consideration of scientific findings.

Reid described the Millennium Ecosystem Assessment as an international program designed to meet the needs of decisionmakers and the public for scientific information concerning the *consequences of ecosystem change for human well-being* and options for responding to those changes. It focuses on ecosystem services (the benefits people obtain from ecosystems), how changes in ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and response options that might be adopted at local, national, or global scales to improve ecosystem management and thereby contribute to human well-being and poverty alleviation.

Over the past 50 years, humans have changed ecosystems more rapidly and extensively than at any time in human history, Reid said. The changes made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains are being achieved at growing costs in the form of:

- Degradation and unsustainable use of ecosystem services.
- Increased likelihood of large magnitude, non-linear and potentially abrupt changes in ecosystems.
- Exacerbation of poverty for some groups of people and contributions to growing inequities and disparities.

The harmful consequences of ecosystem changes could grow significantly worse during the first half of the century. However, three of the four Millennium Ecosystem Assessment scenarios show that significant changes in policy can mitigate many of the negative consequences of growing pressures on ecosystems, although the changes required are large and not currently underway.

Major barriers still exist in developing global ecosystem service scenarios, including the paucity of global ecological forecasting models, the difficulty of linking models, and the difficulty of incorporating surprise events that result from thresholds and discontinuities.

Global scientific assessments can be powerful mechanisms for bringing forecasting information to bear on decision needs, Reid said. Such assessments are most effective when the process allows dialogue between scientists and users. They are intended to establish areas of scientific consensus, but they present all credible points of view or scientific results and identify areas of scientific disagreement. They also identify where insufficient knowledge exists to answer a policy-relevant question. Scientific assessments apply the judgment of scientists but explicitly state the level of certainty concerning conclusions. They are policy relevant but not policy prescriptive.

Jack Kelly provided an international, national, and NOAA outlook on Earth observations. Less than one month after the Indian Ocean earthquake and tsunami of December 2004, the United States announced an initiative to provide the nation with a nearly 100 percent detection capability for a U.S. coastal tsunami and a response time within minutes. The initiative will also expand monitoring capabilities in the Pacific and Caribbean basins, providing tsunami warnings for regions bordering half of the world's oceans. This initiative is part of a global tsunami warning system and a future global observation system.

Kelly said the Global Earth Observation System of Systems (GEOSS) will enable the collection and distribution of accurate, reliable Earth observation data, information, products, and services in an end-to-end process. It will be a distributed system of systems built on current international cooperation among existing Earth observing and data management systems.

Kelly noted the nine societal benefit areas of GEOSS (see Chapter 4) and focused on the ocean as an example. Better observations—from tide gauges, buoys, and sensors—will allow us to forecast with more accuracy and provide our coastal communities more effective warnings. This is important because more than half the world's population lives within 60 km of the shoreline, and this could rise to three-fourths by the year 2020. Approximately 25 percent of Earth's biological productivity and an estimated 80 to 90 percent of global commercial fish catch is concentrated in coastal zones. Worldwide agricultural benefits of better El Niño forecasts are conservatively estimated at $450 to $550 million per year. More than 90 percent of natural disaster-related deaths occur in developing countries, especially in coastal areas.

Kelly described the rapid progress of the international Group on Earth Observations. At the first Earth Observation Summit in Washington, D.C., on July 31, 2003, 33 nations and the European Commission adopted a declaration that signifies the political commitment to move toward development of a comprehensive, coordinated, and sustained Earth observation system. At the Second Earth Observation Summit in Tokyo on April 25, 2004, 43 nations and the European Commission adopted a Framework that defines the intent and scope of the Global Earth Observation System of Systems. At the third Earth Observation Summit in Brussels on February 16, 2005, 55 nations and the European Commission were expected to endorse a 10-year implementation plan for GEOSS.

In addition to the international GEOSS plan of implementation, Kelly discussed the *Strategic Plan for the U.S. Integrated Earth Observation System* (2005), which outlines the U.S. contribution to GEOSS. The vision of the U.S. plan is to "enable a healthy public, economy, and planet through an integrated, comprehensive, and sustained Earth observation system." The U.S. strategic plan contains several near-term opportunities, including a comprehensive and integrated data management and communications strategy, improved observations for disaster warnings, and a comprehensive and sustained land observation system.

Rita Colwell provided an integrated synthesis of multidisciplinary scientific advances related to global infectious diseases, water, and human health. With the rapid increase in international air travel, she said that bacteria and viruses travel almost as fast as money. Colwell emphasized that infectious disease is a moving target. She presented examples involving the mosquito *W. smithii*; hantavirus incidence in the southwestern United States; campylobacter incidence in Britain and Wales; tularemia incidence in Jamtland, Central Sweden; and cholera on the coast of Peru. Drawing on these and other examples, Colwell concluded that in a world of ever-more-rapid-change, patterns of disease expand across scales, and explanations must draw from biological, physical, and social science.

Understanding environmental factors affecting human health and well-being is one of the nine societal benefit areas of the Global Earth Observation System of Systems. Colwell demonstrated that there is tremendous potential for advances in this area. By examining relationships among such factors as weather, biology, and human interactions with the environment, Colwell demonstrated solutions that have been successful in reducing disease incidence. A new form of epidemiology may emerge from the integration of such factors.

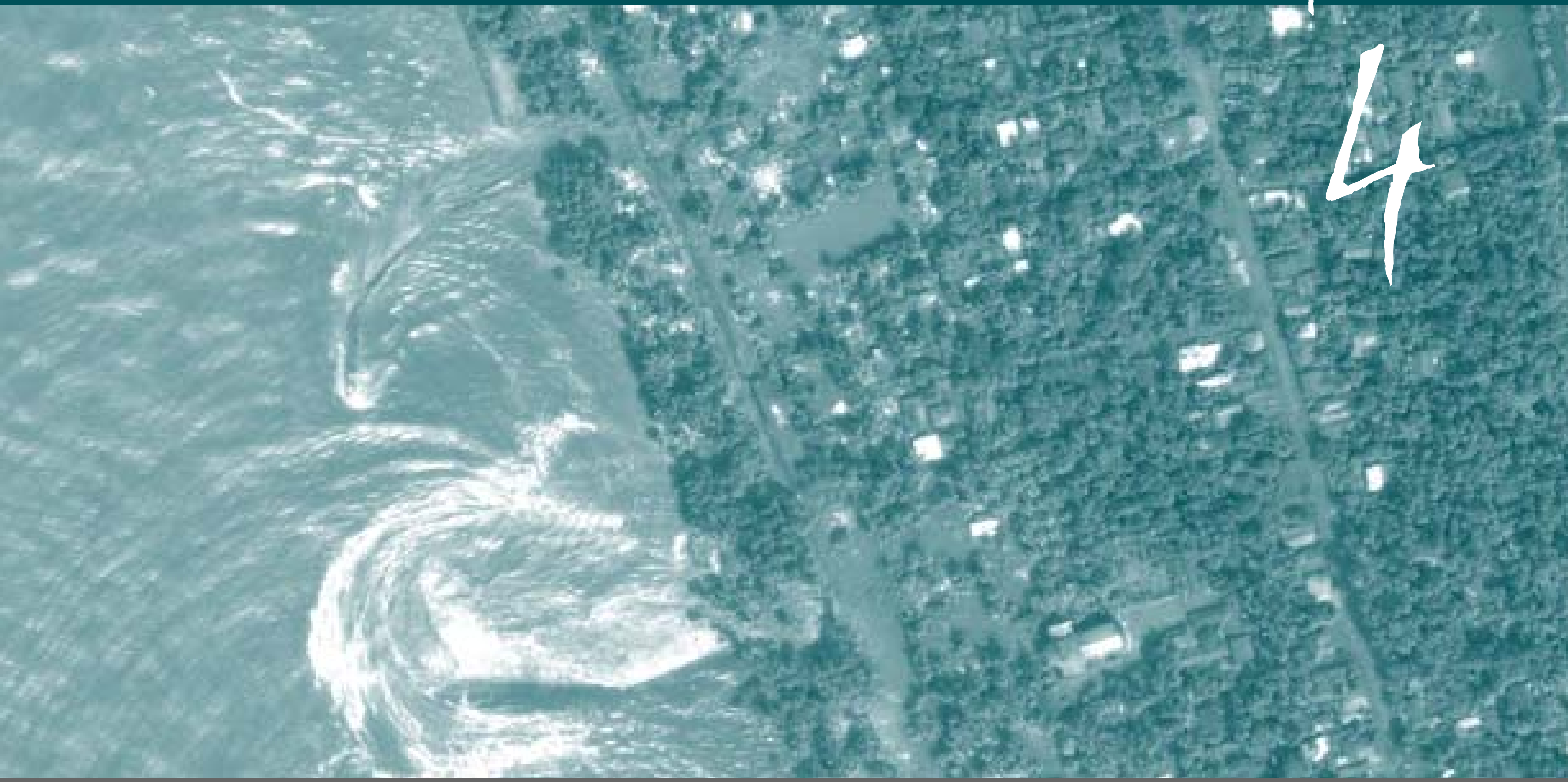
Ray Anderson addressed the subject of environmental forecasting from the perspective of a self-described "industrialist." He said that ecology tells us we are part of nature, not above or outside it; it also tells us that what we do to the web of life we do to ourselves. Industrial ecology tells us the industrial system, as it operates today, simply cannot go on if it abuses the web of life. The industrial system takes too much, extracting too much of Earth's natural capital, Anderson said.

The rate of material throughput—the metabolism of the system—is now endangering our prosperity, rather than enhancing it, and also endangering the biosphere and human health, he continued.

Anderson said a sustainable society depends totally and absolutely on a mind shift— one mind at a time, one organization at a time, one building, one company, one community, one region, one industry at a time, until the entire industrial system has been transformed into a sustainable system living ethically, in balance with Earth's natural systems.

Dave Jones formed StormCenter Communications, Inc., to provide global environmental information products to media partners. Operating at the interface between environmental forecasting and communications, his company provides monitoring and visuals to help the media, government agencies, emergency managers and others better understand environmental issues and to enable the media and educators to increase public awareness. It provides environmental content that is easy to understand, scientifically accurate, and personally relevant. It adds value by making the content relevant and understandable to the general public and decisionmakers, which is an essential step in applying environmental forecasting to environmental decisionmaking.

Chapter 4



SYMPOSIA

Creating a Global Earth Observation System of Systems (GEOSS): Benefits for Environmental Forecasting

Creating a National Ecological Observatory Network (NEON): Developing the Capacity for Ecological Forecasting

Environmental Change: An Interactive Discussion About the Future

Engaging Users in Environmental Forecasting

Symposium

Creating a Global Earth Observation System of Systems (GEOSS): Benefits for Environmental Forecasting

Panelists

Charles Groat (Chair), *Director U.S. Geological Survey; Alternate U.S. Representative to the Group on Earth Observations*
Roberta Balstad, *President, Center for International Earth Science Information Network*
Rosalind Helz, *Associate Program Coordinator, Volcano Hazards Program, U.S. Geological Survey*
K. Bruce Jones, *Senior Scientist, U.S. Environmental Protection Agency*
Greg Withee, *Assistant Administrator for Satellite and Information Services, NOAA; Co-Chair, Interagency Working Group on Earth Observations*

The Global Earth Observation System of Systems (GEOSS) is a transformative initiative that would "take the pulse of the planet" and revolutionize our understanding of the Earth. It is an initiative endorsed by 55 nations to achieve comprehensive, coordinated, and sustained observations of the planet's natural systems.

GEOSS is being explicitly designed to inform environmental decisionmaking and achieve specific societal benefits (Boxes 4.1 and 4.2). A global system of Earth observations "would transform the way we relate and react to our environment, providing significant societal benefits through improved human health and well-being, environmental management, and economic growth," according to the *Strategic Plan for the U.S. Integrated Earth Observation System* (2005), which outlines the U.S. contribution to GEOSS.

In order to maximize the benefits to society, Charles Groat emphasized the need to consider carefully the needs of end users when designing the system. He also stressed the importance of making data available to the scientific community on a timely basis and of improving the delivery of warnings and other critical information to users. In the aftermath of the December 26, 2004, earthquake and tsunami in the Indian Ocean, the international community is working to develop a global tsunami monitoring system and to improve the capacity to deliver timely warnings that can avert disasters.

Groat provided an overview of GEOSS. As described in the *GEOSS 10-Year Implementation Plan* (2005), GEOSS would build on and add value to existing Earth observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements and improving delivery of information to users. In addition to facilitating the prediction, mitigation, and response to catastrophic natural hazards, GEOSS is being designed to address a wide range of other challenges (Box 4.2).

Greg Withee said that more than $3 trillion of the U.S. economy is affected by the environment, including such sectors as agriculture, energy, transportation, and water. In a statement to the 2003 Earth Observation Summit, President George Bush noted that an integrated Earth observation system would benefit people around the world, particularly those in the Southern Hemisphere, by allowing us to make better informed decisions affecting our environment and economies. Bush said, "Our cooperation will enable us to develop the capacity to predict droughts, prepare for weather emergencies, plan and protect crops, manage coastal areas and fisheries, and monitor air quality."

Withee focused on the need to transform Earth observation data into an Earth *information* system that has the potential to improve significantly our understanding of Earth processes and our ability to forecast future changes to the Earth's systems. Withee noted the difficulty of transcending disciplinary, institutional, and geographic boundaries within the United States. Coalescing interoperable, transparent data internationally poses an even greater challenge. However, the political will to make GEOSS a reality is strong in the United States and the recent series of Earth Observation Summits has demonstrated the global interest and commitment necessary to succeed.

Bruce Jones focused on the need to build capacity to understand and eventually forecast short- and long-term ecological changes. Some ecological threats, such as forest fires, can benefit from relatively short-term forecasts. Enhanced forest fire vulnerability assessments can reduce the cost and improve the effectiveness of efforts to manage the nation's forests. Longer-term forecasts based on specific trends and management scenarios must be developed to address issues such as global climate change and urban sprawl. Decisionmakers must be equipped with forecasting tools to develop effective management strategies to prevent or reverse ecological degradation and to avoid catastrophic losses of valuable ecological services.

Roberta Balstad said that socioeconomic data should be integrated into GEOSS in order to achieve the expected societal benefits. Balstad cited the recent tsunami as an example where socioeconomic data became vital in aiding immediate response, short-term relief, and reconstruction efforts. By combining population density data with topography and bathymetry, the United Nations anticipated where to expect the highest level of human devastation. Understanding where populations live, their livelihoods, and levels of malnourishment will greatly aid in addressing near- and long-term recovery from natural disasters. Socioeconomic data are crucial to efforts such as mitigating and adapting to climate change, assessing the demand for water resources, developing sustainable agriculture and forestry policies, and combating land degradation and desertification.

Rosalind Helz illustrated the essential role of communication networks and public education in preventing natural hazards from becoming devastating natural disasters. Helz discussed the danger of volcanic ash plumes to aircraft and the successful global advisory network that was developed to address this hazard. Invisible clouds of volcanic ash can destroy an airplane engine hundreds of miles away from a volcanic eruption. Since 1980, nearly 100 commercial jets have inadvertently flown into volcanic ash plumes, including a 747 jumbo jet that temporarily lost power in all four engines. To improve air traffic safety, a global network of Volcanic Ash Advisory Centers was established to serve as a valuable intermediary among volcano observatories, meteor-

Box 4.1 GEOSS Vision and Purpose

"The vision for GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information."

"The purpose of GEOSS is to achieve comprehensive, coordinated, and sustained observations of the Earth system, in order to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behavior of the Earth system. GEOSS will meet the need for timely, quality long-term global information as a basis for sound decision making..."

Source: *The Global Earth Observation System of Systems 10-Year Implementation Plan*, final version endorsed by the participants of the Third Earth Observation Summit held in Brussels, Belgium, on February 16, 2005.

Box 4.2 Earth Observation System—Societal Benefits

**GEOSS Implementation Plan—
Societal Benefit Areas**

GEOSS will enhance delivery of benefits to society in the following initial areas:

1. Reducing loss of life and property from natural and human-induced disasters.
2. Understanding environmental factors affecting human health and well-being.
3. Improving management of energy resources.
4. Understanding, assessing, predicting, mitigating, and adapting to climate variability and change.
5. Improving water resource management through better understanding of the water cycle.
6. Improving weather information, forecasting, and warning.
7. Improving the management and protection of terrestrial, coastal, and marine ecosystems.
8. Supporting sustainable agriculture and combating desertification.
9. Understanding, monitoring, and conserving biodiversity.

Source: *The Global Earth Observation System of Systems 10-Year Implementation Plan*, final version endorsed by the participants of the Third Earth Observation Summit held in Brussels, Belgium, on February 16, 2005.

U.S. Strategic Plan—Societal Benefit Areas

1. Improve weather forecasting.
2. Reduce loss of life and property from disasters.
3. Protect and monitor our ocean resource.
4. Understand, assess, predict, mitigate, and adapt to climate variability and change.
5. Support sustainable agriculture and forestry, and combat land degradation.
6. Understand the effect of environmental factors on human health and well-being.
7. Develop the capacity to make ecological forecasts.
8. Protect and monitor water resources.
9. Monitor and manage energy resources.

Source: *Strategic Plan for the U.S. Integrated Earth Observation System*, as released by the U.S. Interagency Working Group on Earth Observations.

ological agencies, air traffic control centers, and pilots. The location and projected path of volcanic ash plumes is relayed through the advisory network to pilots flying near the affected area in time to avoid the hazard. The design of GEOSS can benefit from the success of the Volcanic Ash Advisory Centers by incorporating education and communication as key elements of hazard mitigation. This could greatly improve the effectiveness of new and existing warning systems.

Symposium

Creating a National Ecological Observatory Network (NEON): Developing the Capacity for Ecological Forecasting

Panelists

Bruce Hayden (Chair), *Professor, University of Virginia; Co-Director, NEON Project Office*
Jeffrey Goldman, *NEON Project Manager*
Pauline Luther, *Education Director, Environmental Distance Learning*
William Michener, *Co-Director, NEON Project Office*
Ronald Pulliam, *Regents Professor, University of Georgia; Former Director, National Biological Service; Former President, Ecological Society of America*

The National Ecological Observatory Network (NEON) is envisioned as an unprecedented platform that will transform ecological research, address grand challenges in ecology and the environmental sciences, and achieve credible ecological forecasting and prediction (Box 4.3).

Bruce Hayden outlined the history and mission of NEON and provided an overview of the current status of the planning and design. In September 2004, the National Science Foundation (NSF) made a two-year, $6 million award to the American Institute for Biological Sciences to set up a NEON Design Consortium to develop a blueprint for the network and a plan for its implementation. Pending the availability of funds, construction of NEON is being planned for 2006 through 2011.

Hayden said NEON will focus on the six core research areas identified in a 2003 National Research Council report, *NEON: Addressing the Nation's Environmental Challenges*. These research challenges include the ecological aspects of biological diversity, biogeochemical cycles, climate change, infectious diseases, invasive species, and land use and habitat alteration. The NEON design team also plans to focus on hydrological forecasting and will maintain a special category for emerging ecological issues.

William Michener discussed NEON's place within the context of other major initiatives supported by the National Science Foundation. Implementation of NEON would be funded through the NFS's Major Research Equipment and Facilities Construction account, which supports transformative "big science projects" that require massive infrastructure and involve large teams of scientists. In addition to developing a blueprint for NEON that will transform ecological science, the NEON Design Consortium is satisfying institutional priorities set by NSF as well as national priorities set by Congress.

Michener said the NEON Design Consortium consists of the project leadership and the committees and subcommittees that will design every facet of NEON, from the questions that will be addressed and that will guide the design of the research and education platform to the creation of the community-based legal entity that will own and run NEON. A national network design committee is charged with synthesizing the plans of all other committees into a final reference design for NEON. It will make the final decisions on prioritizing candidate NEON science missions and observatory functionalities, geographic distribution of observatories, and the scheduling plan for NEON implementation. It will ensure that NEON is not built as one observatory at a time, but as a national network from the beginning. The NEON Design Consortium will also develop a budget for full implementation of NEON.

Jeffrey Goldman discussed plans for improving our ecological forecasting capacity in the decades ahead. It is necessary to understand user needs in order to provide the most valuable ecological forecasts, he emphasized. The NEON design team is asking broad constituencies what they will need to forecast, what science should be undertaken to make those forecasts, and what kinds of decisions will be made based upon these forecasts. Examples of possible forecasting needs include: which organisms might become health risks or transmit pathogens, which ecosystems are at greatest risk for invasion by non-native species, and what are the effects of interactions between land change and biodiversity in coupled human-environmental systems. Once the scientific questions have been identified, Goldman said it will be possible to identify the infrastructure needed to conduct the necessary research.

Pauline Luther discussed the educational component of NEON and provided a set of criteria for designing successful K-12 environmental distance learning programs. New education tools should comply with existing educational standards and should be tied to curricula that teachers are required to cover in their classes, she said. In order to document that teachers and students satisfy state educational standards, education programs should generate reliable data and facilitate accountability. To ensure that the tools will be useful, Luther said, it is important to involve K-12 teachers in building education programs from the beginning of the process. Distance learning programs should be available at no cost and should be easy to use, versatile and accessible. Many teachers are working with old computers, she noted, and they will need educational software that is compatible with their hardware. Environmental distance learning education should include partnerships with aquariums, zoos, and museums. Environmental

Box 4.3 NEON Mission and Vision

"NEON will be the first national ecological measurement and observation system designed both to answer regional- to continental-scale scientific questions and to have the interdisciplinary participation necessary to achieve credible ecological forecasting and prediction. As such, NEON will transform the way we conduct science by enabling the integration of research and education from natural to human systems, and from genomes to the biosphere. Social scientists and educators will join ecologists and physical scientists in NEON planning and design and participate as observatory users, recognizing that we live on landscapes that are, to varying degrees, human-dominated ecosystems" (source: www.NEONinc.org).

NEON is envisioned as "a continental-scale research instrument consisting of geographically distributed infrastructure, networked via state-of-the-art communications. Cutting-edge lab and field instrumentation, site-based experimental infrastructure, natural history archive facilities, and/or computational, analytical, and modeling capabilities, linked via a computational network, will comprise NEON. NEON will transform ecological research by enabling studies on major environmental challenges at regional to continental scales. Scientists and engineers will use NEON to conduct real-time ecological studies spanning all levels of biological organization and temporal and geographical scales. NSF disciplinary and multidisciplinary programs will support NEON research projects and educational activities. Data from standard measurements made using NEON will be publicly available" (source: NSF 04549, 2004).

learning should focus on the students' local environment in order to make the experience more concrete.

Ronald Pulliam emphasized out that the National Ecological Observatory Network is intended to operate over a period of approximately thirty years. In order to succeed as a collaborative multi-decadal initiative, the next generation of investigators should be engaged in the planning and research, and we need to provide resources for them to participate.

Symposium

Environmental Change: An Interactive Discussion About the Future

Panelists

Michael Brody (Co-Chair), *Office of the Chief Financial Officer, U.S. Environmental Protection Agency*
Robert Olson (Co-Chair), *Institute of Alternative Futures*
Skip Laitner, *Office of Air and Radiation, U.S. Environmental Protection Agency*
David Rejeski, *Foresight and Governance Program, Woodrow Wilson International Center for Scholars*
Terry Welch, *Director, Environmental Technology Center, Dow Chemical*

This symposium session explored environmental challenges that may emerge between now and 2025. The speakers stimulated the discussion by identifying several environmental and technological issues that they believe will come to the fore over the generation ahead—issues so significant that they will force major changes in our approach to environmental protection. Then all attendees at the session (approximately 125 people), working in small groups of about 10 to 12 people, had an opportunity to share their own forecasts, views, and critical uncertainties for emerging challenges that are not yet "on the radar screen" because of disconnects within and among institutions—and disconnects among fields of science, technology, and policy. This summary also builds upon the results of NCSE's online solicitation of views of the future as part of the conference registration process.

Well-Known Environmental Concerns. When asked what well-known environmental concerns could have the largest environmental impacts between now and 2025, participants most frequently mentioned climate change, energy (availability, impacts of production, and use), water (availability and quality), and loss of biodiversity. Other concerns shared by many participants include global air pollution, toxic chemicals, soil erosion, environmental impacts of demographic change, and emergent infectious diseases.

Potential Surprises. Participants identified synergistic interactions among environmental problems as an area where emerging challenges could have surprisingly large impacts. For example, climate change, habitat destruction, water quality deterioration, the spread of invasive species, and biodiversity loss could have mutually amplifying impacts, causing general ecosystem deterioration and loss of critical ecosystem services. Other potential surprises include sudden climate change, conflicts over oil and water, unexpected impacts of developments in nanotechnology and biotechnology, environmental terrorism, and larger than expected effects of ocean pollution.

Emerging Environmental Opportunities. Participants identified energy efficiency, alternative energy technologies, and cradle-to-cradle industrial design as the three most important areas of environmental opportunity not yet receiving enough attention. Other areas viewed as important include improved testing of chemicals (fast and inexpensive), the growth of corporate sustainability, positive applications of nanotechnology and biotechnology, and the potential to help developing countries leapfrog environmentally damaging technologies.

Risks from Emerging Technology. Participants highlighted risks associated with emerging developments in biotechnology and nanotechnology, rising e-waste, the combined effects of new chemicals introduced into the environment, and transportation technology (especially growing global auto use). Alternative energy technologies like nuclear energy, clean coal, and hydrogen could have unintended consequences.

Risks from Technology Associated Behaviors. Participants identified many risks from behavior related to technological development or the misuse of technologies. Examples include: inadequate assessment of potential impacts of new technologies, addiction to media and technology and disconnection from nature, an over-reliance on technological fixes with little attention to other options, a loss of individual liberties resulting from unwise applications of information technology, and a loss of cultural diversity as standardized media and technologies spread worldwide.

Environmental Benefits from New Technology. Participants identified renewable energy and energy efficiency technologies as the emerging technologies that could do the most to reduce environmental impacts over the generation ahead. Sustainable design practices including zero waste industrial technologies and green buildings were seen as important, as were transportation-related changes such as clean vehicles and better public transit (complemented by smart growth). Advances in information technology (monitoring and sensing, mapping, and visualization) and in bioremediation could create new capabilities for improving environmental protection.

Improving Environmental Forecasting Models. Participants identified factors missing from current environmental forecasting models that, if included, might significantly alter the forecasts they produce. Key factors include human behavior (value systems, environmental literacy, risk perception, etc.), insufficient attention to communicating model results to the public, limitations on the completeness and quality of data, political and socioeconomic factors, and catastrophic events.

Key Choices Needed Over the Next 10 Years. In light of the challenges and opportunities they see ahead, participants identified key choices and initiatives needed over the next 10 years: increasing press coverage and education on environmental issues and science; finding ways to motivate corporate change toward more sustainable practices and individual change toward sustainable purchasing choices; moving beyond political barriers in energy policy; enhancing the U.S. role in environmental protection internationally; and creating larger financial incentives for environmental protection.

Symposium

Engaging Users in Environmental Forecasting

Panelists

Nathalie Valette-Silver (Chair), *Coordinator, National Centers for Coastal Ocean Science Ecological Forecasting Activities, National Ocean Service, NOAA*
Otto Doering, *Professor of Agricultural Economics, Purdue University; on sabbatical at USDA Natural Resources Conservation Service*
Ann Fisher, *Professor of Agricultural and Environmental Economics, Pennsylvania State University*
Gregory Hernandez, *NOAA Spokesman and Online Editor; former journalist, ABC Radio News*
Robert Lempert, *Senior Physical Scientist, RAND Pardee Center*
Gary C. Matlock, *Director, National Centers for Coastal Ocean Science, NOAA*

The effectiveness of an environmental forecast depends upon its value and accessibility to the user community, according to Nathalie Valette-Silver. Improvements in user engagement can increase the societal benefits of environmental forecasts. This symposium explored opportunities for building user engagement across a wide range of scales, contexts, and perspectives.

Using the Consortium for Atlantic Regional Assessment (CARA) as a case study, Ann Fisher provided insights about engaging stakeholders in projecting and communicating potential environmental futures. CARA is a consortium of higher education institutions that provides scientific information and tools that stakeholders can use to support decisions regarding potential changes in climate and land cover in the Atlantic region from Virginia to Massachusetts. A goal of the consortium is to identify actions that can reduce vulnerability to environmental changes. CARA also provides resources that decisionmakers can use to develop and evaluate options for adaptation to environmental changes at local and regional scales.

Fisher said that a significant outcome of CARA was the establishment of an actively engaged regional stakeholder network. She noted that engaging the user community from the outset of a study leads to a sense of ownership among stakeholders. Specific goals for stakeholder involvement include aiding in the identification of important questions of study, enhancing the technical quality of the product and the technical capacity of the users, sharing ideas, legitimizing the process, adding credence to the results when they are released, disseminating the findings, and increasing the potential for implementation. Fisher said that stakeholder groups have a shared desire to make uncertainty as explicit as possible in the analysis and communication of results.

Otto Doering discussed the challenges of engaging users in a scientific assessment in an adversarial climate. Drawing upon his experience with the National Hypoxia Assessment, he said it can be very difficult to work with users in a situation in which tensions are flared and battle lines are drawn from the start. Hypoxia occurs when dissolved oxygen concentrations in water are below those necessary to sustain most aquatic species, causing seasonal “dead zones” (such as in the Gulf of Mexico). The National Hypoxia Assessment was undertaken in the late 1990’s after environmental advocacy groups alleged that the federal government was mismanaging the nation’s waters. The assessment was intended to provide scientific information as a basis for an action plan, but it was not intended to make recommendations for action nor was it the only source of information considered in developing the action plan. By drawing affected parties and local experts into the process from the start, Doering said participants are more likely to develop a sense of ownership, which tends to breed cooperation. Doering stressed that establishing an action plan was a political activity, but the policy decisions in the action plan were based on scientific forecasting and assessment. Therefore, carrying over participants from the assessment process to the development of an action plan was critical to successfully reducing, mitigating, and controlling hypoxia.

Gregory Hernandez discussed the role of scientists in communicating environmental forecasts during significant media events, such as natural disasters. Reporters prefer going straight to the source for focused expertise. They recognize that scientists are key providers of accurate and timely information. Although reporters often have a set of preferred scientists, on any given day circumstances may require them to contact a new expert with little notice. In the midst of chaotic events, it may be difficult for a large organization to coordinate a consistent message to the media. In selecting a 'media-worthy' scientist, a large organization should consider experts who have experience with the media, have been briefed on all aspects of the story, have communicated with the organization's public affairs staff, and have authority to speak on behalf of the organization. Hernandez provided guidelines for scientists in speaking with the media, such as remaining calm, being aware of leading questions, providing short, declarative statements, avoiding expressing personal opinions, and leaving scientific jargon behind. He added that the phrase "no comment" may be the most honest and appropriate response to a question.

Robert Lempert portrayed the challenges of effectively engaging decisionmakers when forecasts are uncertain. The traditional view has been that good science leads to good forecasts, which lead to good policy. However, we are now realizing that good science does not necessarily produce reliable forecasts—especially when situations are deeply uncertain or there are competing factors based on differing assumptions. The manner in which scientists portray uncertainty can complicate the engagement of decisionmakers. While probabilistic forecasts may successfully describe well-characterized risks, unexpected outcomes may still arise. Decisionmakers tend to remember the "misses" of forecasts more than the "hits." Therefore, providing diverse sets of scenarios, rather than one "mainstream" projection, can help transform conversations with decisionmakers—leading to the identification of robust, adaptive strategies.

Gary Matlock summarized the key recommendations for engaging users in environmental forecasting: identify the goals for the forecast at the beginning of the process; identify stakeholders and nurture their participation; develop specific processes for interactions among scientists, decisionmakers, and other stakeholders; solicit and incorporate stakeholder feedback at multiple points in the process; provide regular summaries and ongoing education to interested parties; adapt to forecast "hits" and "misses"; and provide decisionmakers with ensembles of forecasts—explicitly stating the role of uncertainty when communicating the results—in order to allow decisionmakers to plan for the most likely outcome while remaining flexible to respond to expected outcomes.

Chapter 5

Targeted Recommendations

Attendees at the 5th National Conference on Science, Policy and the Environment, *Forecasting Environmental Changes*, engaged in one of 19 simultaneous breakout sessions, each addressing a different aspect of environmental forecasting. Conferees generated a set of science-based recommendations for each topic. The recommendations are grouped under three major themes: Linking Systems and Users; Connecting Institutions; and Scientific and Technological Connections.

Sessions on Linking Systems and Users

1. Connecting forecasts with policymakers

Environmental forecasts can help policymakers and the public understand the implications of current trends and the potential implications of alternative policy choices. But the information needs of different policymakers often vary widely. How can scientists provide forecasts that policymakers find useful, timely, and credible? How can information from forecasts best be incorporated into environmental law and policy? How should scientists characterize the uncertainty inherent in many forecasts? How can decision support systems and other tools be used and configured to more effectively provide information to policymakers?

Targeted Recommendations

- Skilled translators are needed to communicate among policymakers, the business community, nongovernmental organizations, the public, and researchers.
- The National Council for Science and the Environment and other organizations should create more venues for researchers, policymakers, and the media to connect.
- Colleges and universities, scientific and professional organizations, and other groups should train more scientists to communicate effectively with decisionmakers.
- Colleges, universities, and other organizations should create new incentives for researchers to communicate science-based forecasts to decisionmakers and society at large.
- Educators should make innovative use of technologies to help make environmental issues understandable to students from K-12 through post-graduate levels.
- Colleges, universities, and funding agencies should provide incentives for interdisciplinary training of students.
- The Science and Technology Policy Fellowship Program of the American Association for the Advancement of Science (AAAS) should be expanded with an eventual goal of placing Congressional Fellows on the staff of every Representative and Senator who desires them.
- Mechanisms analogous to the AAAS Fellowship Program should be created to provide more scientific input at the state and local level.
- Forecasters should use visualization tools, interactive systems, and other new capabilities to help make forecasts more accessible to policymakers.
- Forecasters should characterize uncertainty in forecasts in ways that help decisionmakers reduce risks.

Sessions on Linking Systems and Users

2. Improving the usefulness of environmental information for personal decisionmaking

Members of the public are looking for information they can use in their daily lives. At the same time, they feel overwhelmed by the vast quantity and often unhelpful presentation of information available. They need the right information in formats they can use. Government agencies and other information providers need to understand the information needs of diverse potential users in order to design systems and products that are relevant and valuable.

The process of information generation and dissemination involves multiple stages that may not be shared by all of the target organizations. Thus the process has been divided into the component stages and detailed recommendations are provided for each stage.

Targeted Recommendations

Data Collection and Processing

- Public organizations should involve representatives of public user sectors in data collection. Government agencies should provide repositories for scientific data collected by citizens.
- Government agencies and other organizations should

move toward distributed, interoperable data collection and dissemination systems.

- Data providers should consider the needs of the information consumers.

Content and Interpretation

- Providers of environmental information should analyze their audience—its level of knowledge and information needs—before selecting content and methods for interpretation.
- Environmental information intended to help with public decisionmaking should be integrated with both social and economic data to provide a holistic view.
- Government agencies and partner organizations should work toward standardization of key environmental indicators for use in interpreting environmental data and for assessing environmental changes. The suite of major economic indicators may serve as a model.
- Websites with environmental information should include simplified datasets so that science teachers, students, and others can do their own calculations.
- Conclusions about environmental data should be accompanied by sufficient data for citizens to perform their own analyses.
- The content and interpretation of environmental information should provide a coherent story that is of interest to non-scientists and assists in personal decisionmaking.

Presentation

- Presentation is key to the acceptance of environmental information. The choice of technology for information dissemination should be based on a focused analysis of the intended audience and the needs of information consumers. In some cases, print media is more appropriate than a website.
- Environmental information should be provided at spatial and temporal scales of interest to the consumer. Information providers should include a local perspective whenever possible. Information should be presented at multiple spatial and temporal scales if appropriate.
- Websites should provide information about subjects at several levels of complexity (e.g., information on drinking water quality should provide explanations and definitions of contaminant risk and criteria).
- Information providers should strive for simplicity, using extensive visual and graphical content and avoiding complex presentation of data.

Use

- Providers of environmental information should focus on enhancing its usefulness for personal decisions or actions.
- Providers of environmental information should develop dissemination approaches for a variety of audiences.
- Providers of environmental information should develop content that can be used by students and educators to explore the analysis and interpretation of the data.
- Environmental information providers should coordinate their efforts to provide specialized information for different uses and different user groups.

Marketing

- Providers of environmental information should better analyze audience characteristics and needs of various customer groups to increase success in generating interest and affecting personal decisionmaking.
- Distributors of environmental information should recognize differences among users, meet the needs of different users for differing types of information, and use the most appropriate technology to deliver information to each group.
- Organizations that provide information to the public should build alliances with the media, while recognizing potential conflicts between news and entertainment.
- The impact of environmental information can be increased if the message is delivered by a credible spokesperson with high public recognition.

Sessions on Linking Systems and Users

3. Sharing forecasting information with users

Scientists and non-scientists need to work together to design environmental forecasting networks and public interfaces that foster public interest and meet public needs. Society benefits when people think ahead and know what environmental issues to watch out for. How can both long- and short-term environmental forecasts contribute to public understanding and action? What tools are needed to allow citizens to use the environmental forecasting data and networks? What do recent natural disasters (e.g., Indian Ocean tsunami and California floods) teach about environmental forecasting?

Targeted Recommendations

- The media, educators, and scientists should work together to help the public personalize environmental issues. Environmental information should be made clear and relevant to people and offer solutions or actions.
- Science communicators should work with the media on education and outreach campaigns including:
  - Packaging information for media outlets.
  - Working with practitioners to develop unified messages.
  - Working with educators to transfer knowledge in appropriate formats.
  - Incorporating positive messages instead of negative, fear-inducing messages.
- Science communicators should provide a context for scientific information that allows the public to understand how science is conducted, including:
  - Opportunities for hands-on and curiosity-based learning.
  - Incorporating hands-on learning using real-time data and predictions.
  - Improving the visualization of science, ideas, and concepts.
  - Using current events as learning opportunities.
  - Linking information for K-12 educators to national and state standards.
- The media and universities, with help from scientists and feedback from the public, should foster the professional development of journalists who cover science.
- The White House Office of Science and Technology Policy should establish an interagency committee to coordinate the public outreach and educational components of the Global Earth Observation System of Systems (GEOSS) and other environmental forecasting programs. Such a committee should:
  - Provide feedback to scientists and engineers who are analyzing forecasting data.
  - Identify and collaborate with programs for communicating environmental forecasting to the public.
- NCSE should, in collaboration with conference participants, undertake a marketing study to:
  - Discover the public's needs for scientific information.
  - Discover the public's sense of environmental place, values, and use.
  - Investigate whether public needs match those assumed by scientists.
  - Discover what motivates and empowers the public to use environmental forecasting data.
- NCSE and related organizations should identify and disseminate a small number of fundamental concepts in environmental science that can help elevate scientific literacy. These concepts can become a platform for future understanding.

Sessions on Linking Systems and Users

4. Improving academic programs to prepare the next generation of forecasters

Environmental forecasting includes a variety of activities from the creation and use of technologies for collecting data to the transformation of data into useful information to its communication to the public and decisionmakers. Although individuals may specialize in a single activity, they should have some understanding of the overall process and the roles of others in the process. What skills should forecasters of various types have? What kinds of education and training should colleges and universities provide? What preparation is useful at the pre-college and post-graduate levels?

Targeted Recommendations

- Institutions of higher education should overcome disciplinary barriers to effective instruction by:
  - Creating incentives for hiring and promoting interdisciplinary faculty.
  - Developing interdisciplinary courses and seminars.
  - Promoting interdisciplinary research.
  - Facilitating inter-college collaboration (especially for education and science faculty).
  - Establishing curricula that incorporate problem-based learning.
  - Incorporating concepts of probability, uncertainty, and temporal/spatial change into environmental curricula.
  - Encouraging internships and fieldwork aimed at solving environmental problems in partnership with private and public sector organizations.
  - Infusing general education curricula with environmental examples, forecasting concepts, and data use.
  - Building leadership, teamwork, and communication skills among faculty and students.
  - Providing professional development opportunities to infuse interdisciplinary approaches into K-12 curricula.
  - Preparing forecasters to integrate relevant disciplinary insights into their forecasts.
- Schools and others involved in K-12 education should increase environmental science literacy by:
  - Integrating environmental science into reading, math, and writing units.
  - Improving enrichment outreach programs (e.g., summer camps and after-school programs) by recruiting subject-matter experts (university faculty, graduate students, and practicing professionals).
  - Informing students about career opportunities and career paths in environmental forecasting and decisionmaking.
  - Encouraging the adoption of state-level mandates to teach concepts of environmental science and environmental change forecasting.
  - Incorporating instruction on probability and uncertainty as well as change across temporal and spatial scales.
- Higher educational institutions should strengthen the link between researchers and policy officials through communication and political strategies.
- The environmental science community should utilize backcasting, nowcasting, and forecasting as an alternative means to visualize the future over various temporal and spatial scales.
- NCSE's Council of Environmental Deans and Directors should establish and maintain a clearinghouse of educational exemplars and best practices for educational instruction.

Sessions on Linking Systems and Users

5. Providing real-time forecasts—How to assess and meet user needs

Real-time forecasts are special cases where short-term needs of users must be met. Real-time forecasts can literally save lives or cost lives depending upon the effectiveness of communicating an accurate, timely, and understandable forecast to the users. What can be learned from successful real-time forecasting programs? How can these lessons be applied in other situations?

Targeted Recommendations

- The private sector should initiate partnerships to help identify user communities and their technical and functional requirements for receiving real-time forecasts.
- The private sector should establish an iterative approach to balance the immediate needs of users with limitations of current technologies and approaches; it should facilitate the development of new technologies and approaches to meet user needs.
- The research community, government agencies, and the private sector should collaborate with users to develop "intelligent" indices of change that would synthesize and evaluate inputs of multiple types and sources of data to provide relevant information for individual and organizational decisionmaking.

Sessions on Connecting Institutions

6. Integrating U.S. efforts with international initiatives

The United States has extensive experience integrating environmental science efforts with international initiatives. The success of the Global Earth Observation System of Systems (GEOSS) will depend on the leadership of the United States and other nations in creating transparent global systems with maximum sharing of data. The following recommendations are designed to improve environmental forecasting through improved integration of U.S. efforts with international initiatives.

Targeted Recommendations

- U.S. organizations embarking on international environmental forecasting projects should build on existing in-country science programs, utilize and expand local forecasting capacity, and respect indigenous environmental knowledge.
- The U.S. government and the scientific community, in cooperation with international partners, should design and maintain appropriate forecasting technologies and ensure the delivery of appropriate information products for decisionmaking.
- The U.S. government, in cooperation with international partners, should ensure that key information, such as forecasts and warnings, is delivered to local stakeholders.
- U.S. organizations should ensure that their in-country partners have capacities (e.g., training, infrastructure, fundraising capability) that facilitate the long-term sustainability of their joint initiatives.
- Data providers should ensure that data are fully documented in order to be applicable to multiple current and future uses.
- The U.S. government, academia, nongovernmental organizations, and other institutions should recognize and support international efforts to bridge the gap between research and decisionmaking.
- The U.S. government should continue to encourage reciprocal "free and open" data policy as a basis for promoting science for societal benefit.
- The U.S. government should support the United Nations and its agencies to implement international projects for environmental forecasting.
- The U.S. government should act to allow passage of appropriate scientific instrumentation across international borders without delay or confiscation of materials.
- U.S. organizations should promote international environmental education programs as a way to secure future scientific capacity necessary for forecasting environmental changes.

Sessions on Connecting Institutions

7. Linking levels of government: Federal-state-local

Successful environmental forecasting requires strong collaboration within and across federal, state, and local governments. Invasive species, water pollution, and air pollution are examples of environmental changes that readily cross political boundaries using air currents, water flow, and other means of dispersal. In some cases, environmental forecasting and intergovernmental collaboration can foster preventative measures that limit the spread of environmental problems.

Different levels of government collect environmental data for a variety of uses, including forecasting. Although government agencies have different uses for data of different types, quality, and applications, there is great value in sharing data and information within and across levels of government. The National Environmental Exchange Network (NEEN), a data-sharing partnership that links state and federal environmental agencies, provides a model for collaboration. Successful collaboration requires understanding the characteristics and needs of the partnering organizations, engaging partners at the beginning to build systems of mutual utility, and providing incentives for participation.

Targeted Recommendations

- Governments at all levels (federal, state, and local) should refine environmental data exchange networks through continual, cross-disciplinary, cross-community dialogue. This will educate and encourage contributors, decisionmakers, and other users of the network. It will also help develop standards and a common language to better ensure the accuracy, reliability, and integrity of the network data.
- Through cross-community dialogue, governments should identify and develop incentives to aid in the nationwide acceptance and use of environmental exchange networks.
- Developers of environmental forecasting systems should involve users from the beginning of the design process, ensuring that such systems will meet user needs and provide direct societal benefits.
- A cross-disciplinary and cross-media intergovernmental framework should be established to promote an open and ongoing dialogue between scientists and decisionmakers to determine what data are needed for reliable environmental forecasting and to set priorities for data needs.
- National councils and interagency bodies should work with state and regional government councils and governmental associations, such as the National Association of Counties (NACo) and the Environmental Council of the States (ECOS), to enhance horizontal and vertical communication.
- A single baseline standard should be established for collecting and reporting metadata (the data that describe the data), leveraging existing efforts, and providing financial incentives to ensure participation.
- Universities should convene local conferences—modeled after NCSE's national conference, the extension network of the National Sea Grant College Program, or similar activities—to create bridges with their communities at the state and local levels.
- Environmental forecasters should explore opportunities for expanded uses of technologies like GIS by decisionmakers at all levels of government.
- A federal-state-local governmental partnership should create a clearinghouse of environmental forecasting data and provide public access to the data in ways that do not require advanced technical knowledge.

Sessions on Connecting Institutions

8. Cross-sectoral connections: Engaging the private sector as a partner with the government

The private sector has the potential to become an equal partner with government agencies in creating environmental forecasting systems. However, a variety of structural, financial, cultural, and knowledge barriers are currently limiting partnerships with the private sector. Concerted efforts by educators, researchers, policymakers, government managers, and industry leaders are needed to improve the situation. What are successful examples within the United States? What lessons can be learned from them? How should they be applied in other situations?

Targeted Recommendations

- Congress should place environmental observing systems on the list of critical infrastructure of national importance. Environmental observing systems provide information needed to safeguard the nation's environmental resources and economic infrastructure, such as the power grid, water systems, and transport corridors. The critical infrastructure designation will facilitate funding for the full deployment and long-term operation of an integrated environmental forecasting system. The NOAA NEDSIS satellites have already been placed on the critical infrastructure list.
- Guidance documents should be prepared to inform national, state, and local governments how to incorporate environmental forecasting information into useful products for achieving their development goals (e.g.,. Millennium Development Goals of nations and economic goals of states). Such documentation would enhance support from international, national, state and local interests for funding of observing systems.
- A long-term financial investment strategy and timeline should be developed to demonstrate the changing nature of the funding sources as environmental observing and forecasting systems transition from research to operations. This timeline could be based on an accepted "commercialization strategy." All potential funding partners (federal, state, local, and business) should be at the table in the initial stages to plan their investment. The funding strategy should be based on realistic cost analyses.
- All stakeholders in public/private partnerships should be involved early in the design phase. This will ensure that the development of environmental information and forecasting systems is based on user requirements and user concepts of operations, scale, and format.
- Developers of forecasting systems should place greater emphasis on developing economic performance metrics, success stories, and other means of demonstrating economic value and social performance to users and partners. Such information can help to educate the business community about the utility of environmental forecast information and inform government agencies about the value and outcomes of the public investment.
- Business and management schools should develop courses and curricula to train the next generation of business leaders to use forecasts in their business decisions and planning. This education will help to ensure continued business applications of environmental forecasting information.
- Government agencies should support the development of sector-specific, decision-support systems. This will help to create demand for environmental forecasting information from the business community.
- A partnership development entity or "Council of Councils" should be established to develop protocols and processes for complex, multi-sectoral, multi-stakeholder partnerships. The Council of Councils would provide a high-level systems view with multidisciplinary input in development of guidance and procedures for partnership development and operation.
- University business and management faculty should conduct research to develop optimal strategies for the formation and maintenance of cross-sectoral global partnerships for environmental forecasting.
- Congress or the Department of Commerce should create an award analogous to the Malcolm Baldridge National Quality Award that would recognize successful public/private partnerships in environmental forecasting.
- Groups involved in environmental forecasting should work with business associations (e.g., Business Round Tables, World Business Council on Sustainable Development, and international, national, state, and local chambers of commerce) to educate their membership about the relevance of environmental forecasting.
- The federal government should provide short- and long-term incentives for businesses to participate in environmental forecasting partnerships.
- The federal government should create a program modeled after the Small Business Incentives for Research program to provide transitional funding for commercialization of large-scale forecasting systems.
- Congress should support pilot projects such as modeling test beds for the design and development of envi-

ronmental forecasting systems prior to funding large-scale operational projects.

- Government agencies should examine the structural arrangements in projects and programs involving public/private partnerships to foster equal partnerships.
- Business should present sector-specific business plans addressing environmental forecasting for economic development to Congress, the Organization for Economic Development and Cooperation, and other relevant organizations.

Sessions on Scientific and Technological Connections

9. Linking ocean, atmospheric, and terrestrial observation and forecasting systems

Many oceanic, atmospheric, and terrestrial observation systems exist. However, few of these systems are interoperable. There are major opportunities for system integration but major challenges in achieving it. How can the infrastructure be more compatible? What efficiencies and economies of scale exist? What cyberinfrastructure components can be shared and what aspects require customization or unique solutions? Can members of the Interagency Working Group on Earth Observations (IWGEO) obtain the data they need by coordinating existing environmental observatories and long-term data streams (from USGS, USDA, NOAA, and other agencies) or do they need new platforms that could be implemented through the National Ecological Observatory Network or the ocean observing platforms that are under development? What other systems are needed? Can global observation systems be built by accretion, and can they become more than the sums of their parts?

Targeted Recommendations

- A national, multi-stakeholder dialogue should be established to discuss a system of environmental observations and indicators for documenting and forecasting/predicting environmental conditions and trends.
- The federal government should ensure that long-term, institutionalized homes for critical datasets are sustained. This need should be recognized in any future planning for observational and forecasting systems.
- A public dialogue is needed to develop a system of indicators of environmental conditions that is analogous to the commonly used economic indicators. Such a system is feasible, but it is clearly a research and development task at this time.
- A national clearinghouse for environmental data should be established within an institutional framework that provides appropriate expertise and independence from political influence. The clearinghouse would provide objective, unbiased information (including a system of indicators of environmental conditions) for use by any interested party in ways that they specify.
- Additional research and development are needed to provide the cyberinfrastructure necessary to support a system (or systems) for environmental observations and forecasting.
- Organizations involved in environmental observation and forecasting systems should work with users in a coordinated effort to educate Congress about the societal benefits of these forecasting systems and the need for sufficient and sustained investment.
- The development of any environmental observation and forecasting system—including those that would be built on existing networks—needs case studies, demonstration studies, and experiments to determine what is feasible and to identify the limiting factors for further expansion.

Sessions on Scientific and Technological Connections

10. Integrating economic, social, and environmental forecasting

One of the biggest challenges in the environmental field is to effectively engage social scientists in areas that have been traditionally dominated by natural scientists. A first step is to recognize existing economic and social forecasting systems and demonstrate that our ability to forecast the conditions of humanity and the planet will be improved when these forecasting systems are integrated with forecasting systems for the natural environment. Where has this integration been done effectively? What are the barriers and how can they be overcome? What lessons can be applied to future collaboration?

Targeted Recommendations

Group A Recommendations:

- Universities should alter their reward systems in order to facilitate integration among disciplines. The National Science Foundation should expand and increase support for programs that foster collaborative interdisciplinary integration, such as the Integrated Graduate Education, Research and Training (IGERT) program. The National Academy of Sciences should foster additional collaborative, interdisciplinary environmental research and elect more members who conduct this type of research. These changes should be spearheaded by leaders of these institutions and by individuals involved in the collaborations.
- Improvements in communications are needed to achieve better integration of social and environmental forecasting:
    - Funding agencies should develop simple visualization tools that clearly communicate the state of science and levels of risk with respect to particular issues. Visualization tools are likely to aid in the discovery of new knowledge in addition to conveying information to the public.
    - The media should play a greater role in communicating information about environmental conditions and forecasts.
    - NCSE and other non-governmental organizations should educate Members of Congress about the state of knowledge on the environment (e.g., global change) and the applicability and usefulness of forecasts. Explanations of environmental change or impacts should be provided in economic terms and quantified at the local level.
- Organizations should work together to develop metrics of sustainability that could be used to evaluate a wide range of products. These metrics should integrate social and environmental factors, building on the USDA's organic food certification program and other examples.
- The National Science Foundation should further recognize the value of interdisciplinary environmental research and increase funding for research on complex environmental systems, including NSF's priority area on biocomplexity in the environment. NOAA and other mission agencies should increase investments in and support for interdisciplinary environmental research.
- A high-level interagency initiative should be established to explore connections between homeland security and environmental forecasting, including agriculture, development, and environmental health.
- The social sciences should play a role from the outset in merging variables of complex natural and social systems; this requires disciplinary depth and interdisciplinary integration.
- Universities should become more engaged in integrated environmental, social, and economic forecasting in the regions in which they are located.
- Researchers involved in environmental forecasting should understand the role of national and local political systems as barriers to, or supporters of, effective environmental management. The role of the social sciences in achieving this understanding should be defined clearly.
- NASA, USGS, NSF, and NOAA should study how envi-

ronmental information at multiple spatial and temporal scales is communicated at various institutional levels.

- Government agencies should expand their efforts to evaluate the societal impacts of environmental changes. For example, NOAA should increase its efforts to explain the impacts of events such as coastal storm surges. NIH should further examine the costs of increases in childhood asthma by region under different scenarios of environmental change.

Group B Recommendations:

- Federal agencies should allocate significant funding for interdisciplinary environmental research that incorporates physical and social sciences and local knowledge in ways that build local capacity to better manage local resources. This research should be used to understand broader geographic impacts and to develop or support public education campaigns. For example:
  - Science agencies should increase investments in research that identifies meaningful indicators of human health, animal health, and environmental change that can be useful on a local level and that may have global implications.
  - Science agencies should increase investments in research that identifies alternative solutions and incentives as substitutes for practices that are hazardous to human health and the environment.
  - Science agencies should increase investments in social science research to better understand decisionmaking processes related to the environment.
  - The environmental education community should assess, update, and develop environmental education expectations and standards—at all levels—to build and increase common knowledge.
  - The U.S. Department of Education and other education agencies should support interdisciplinary studies (integrating natural and social sciences) at the primary and secondary education levels. Relevant fields of study include human and physical geography, biogeography, sustainability (including resource consumption), and ecology.
  - College and university presidents, deans, and appropriate governing associations should encourage faculty, students, and administrators of interdisciplinary programs to collaborate in developing and applying relevant coursework, content, and research.
- Researchers should engage local communities in the processes of gathering biological information that indicates climate and environmental changes as well as related health risk factors and translating and sharing that information for local, regional, and global use.

Sessions on Scientific and Technological Connections

11. Working across spatial scales: From molecular to global

Environmental forecasting will benefit from an extraordinary variety of new molecular techniques that have become available in recent years and additional techniques that will become available soon. These techniques provide opportunities for connecting researchers working at the molecular level and the plot level, along with others who are bringing together work at the plot level and the landscape/regional level. How can we overcome the challenges of linking environmental models and forecasts across a broad range of spatial scales?

Targeted Recommendations

- The federal government should create a national center for studying spatial scaling across molecular, landscape, regional, and global levels of environmental forecasting.
- Government agencies should support workshops to develop connections among ecological data from different scales:
  - The National Science Foundation should support post-doctoral fellowships and sabbatical

  - leave opportunities to define scaling needs in environmental forecasting.
  - Government agencies should improve connections among scientists in different fields who are working on environmental forecasting.
- The scientific community should determine which large-scale environmental questions are amenable to molecular approaches:
  - Federal agencies should support workshops to address this issue.
  - Federal agencies should support research to identify important knowledge gaps in environmental forecasting based on molecular processes.
- Federal agencies should increase support for bioinformatics research on gene-environment interactions:
  - An interagency initiative should be established to explore variations in gene expression and other molecular processes across the environmental range of an important species.
- Universities should strengthen multidisciplinary environmental training by exposing students to multiple fields, rewarding faculty for conducting interdisciplinary research, building on the success of NSF's Integrated Graduate Education, Research and Training (IGERT) program, and other mechanisms.

Sessions on Scientific and Technological Connections

12. Forecasting environmental change of the landscape at a regional scale

Modeling climate, environmental, and landscape change at *regional* scales can provide the high spatial resolution forecasts needed for many decisionmaking activities. A wealth of regional data on vegetation, wildlife, surface and ground water hydrology, human activities, and other natural resources is available in government, state, nonprofit, and university databases. Integration of these diverse databases with regional climate change model simulations can provide a powerful forecasting tool for communities, businesses, state and federal government planners, and policy makers.

Targeted Recommendations

- Federal science agencies should support research and tools that improve our ability to incorporate nonlinearity, feedback, and threshold changes in regional environmental forecasting.
- To improve environmental forecasting at regional scales, federal science agencies and universities should increase support for interdisciplinary environmental research and education.
- Federal science agencies should be encouraged to convene interdisciplinary peer review panels to evaluate interdisciplinary research proposals (especially regional scale projects). Disciplinary peer review panels may not be able to provide adequate reviews of interdisciplinary proposals.
- New ways of visualizing regional forecasts are needed to improve communication with decisionmakers and the public.
- Decisionmakers should be educated about decision analysis models and encouraged to use appropriate models to explore regional forecasting scenarios.
- Improvements in data collection and data management are needed to improve regional environmental forecasting:
  - Researchers should develop data sets for working across scales and for validating results.
  - Researchers should develop tools to extrapolate from existing data sets and to integrate disparate data sets.
  - Science agencies should provide incentives to improve data sharing and data management.
  - Decisionmakers should work with researchers to assess acceptable levels of uncertainty in forecasts that serve as the basis for decisions or warnings and to determine the quality and quantity of data required for such forecasts.

- Federal science agencies should support multi-scale approaches to regional environmental forecasting, including:
    - Multiple spatial and temporal scales.
    - Multiple levels of biological organization (e.g., species and ecosystems).
    - Interactions across scales.
    - Interactions across disciplines (e.g., physical, biological, and social sciences).
- Federal science agencies should support multi-scale approaches in order to understand system dynamics that emerge at different scales.
- Scientists should help conservation and natural resources managers adopt multi-scale approaches.
- To improve the use and effectiveness of regional scale environmental forecasts:
    - A diverse range of stakeholders (e.g., public, private, and business) should be involved in the forecasting process from the outset.
    - Researchers and decisionmakers should agree at the outset to define safe ranges for systems parameters within which there is an acceptable likelihood of safety, such as resilience to climate change or natural hazards.

Sessions on Scientific and Technological Connections

13. Working across temporal scales—Integrating short-term and long-term approaches

The users of environmental forecasts vary with the temporal and spatial scale of the conclusions. Community planners and businesses may be interested primarily in forecasts at local spatial scales and at time scales that range from several seasons to several years into the future. Government policy makers may be interested in forecasts over a broad range of scales of time and space. How can the needs of various users efficiently be met? How can measurements of short-term or local change be incorporated into long-term, large-scale observation and forecasting systems? How can long-term data sets and time-series analyses provide information for short-term needs?

Targeted Recommendations

- Organizations engaged in ecological forecasting should consider temporal and spatial scales in an integrated fashion when developing models and monitoring systems.
- The White House Office of Science and Technology Policy (OSTP) should adopt the 1997 report, *Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework*, by the Environmental Monitoring Team of the Committee on Environment and Natural Resources of the National Science and Technology Council. All federal agencies should describe their environmental monitoring activities within that framework.
- OSTP should summarize the monitoring efforts of all federal agencies and describe the type of monitoring, the tools used, and the participants in various levels of decisionmaking.
- Federal and state agencies using adaptive management approaches should include both monitoring and ecological forecasting as part of adaptive management.
- Federal and state agencies should accelerate implementation of systems approaches in ecological monitoring and forecasting.
- Practitioners in ecological forecasting should involve stakeholders in setting explicit timeframes for the forecasts.
- The National Science Foundation should support social science research on the perceived value of ecosystem services to various societal components as well as the factors that affect the credibility of an ecological forecast.
- NCSE should work to bring together representatives of businesses that are utilizing ecological forecasts in their business decisions in order to determine their forecasting needs.

SESSIONS ON SCIENTIFIC AND TECHNOLOGICAL CONNECTIONS

14. Facilitating the development of environmental sensors and sensor networks

Sensors are important components of environmental forecasting systems. Deployment of evolving sensor networks will provide the varied data necessary to develop models that will apply across multiple scales. Achieving the necessary sensors will require multidisciplinary collaboration among engineers, natural and social scientists, and computer scientists.

Targeted Recommendations

- New partnerships should be fostered to optimize the evolution of sensor technologies for environmental forecasting. Creative partnerships with the biomedical field, the commercial sector (e.g., forestry, energy, and fisheries), and government agencies should be developed to leverage emerging and existing innovations in sensor technology and to exploit unanticipated opportunities.
- Environmental sensors and sensor networks should be recognized as critical tools enabling environmental managers and decisionmakers in the private and public sectors to make informed decisions critical to the economic, security, and environmental interests of the nation.
- Decisionmakers and other stakeholders should be engaged in the design and deployment of environmental sensors and sensor networks to maximize their value to users and the general public. The needs and capabilities of data users and decisionmakers should be recognized and addressed as central to the value of sensors and sensor networks.
- Local community groups and educators should be engaged, where possible, to advance education and citizen science and to build understanding and support for initiatives utilizing environmental sensor networks.
- Researchers should communicate the value of new environmental sensor networks to the economic, security, and environmental interests of the nation.
- Researchers should be careful to recognize and address challenges in the broad deployment of sensors and sensor networks that would provide data for fundamental research, modeling, forecasting, and decisionmaking. Challenges include capturing adequately the spatial and temporal variability of the environment, consistent measurements across various media (e.g., nitrate in water, soils, and air), long-term continuity, sensor comparability, and system and sensor integrity (e.g., biofouling or failure).
- Fundamental research is needed to achieve robust coupling of sensors, modeling, and forecasting. Advances in cyberinfrastructure are needed to effectively capture data from sensors and incorporate data into models. Tools need to be developed to better simulate, visualize, and make predictions and communicate results to the full range of users.
- Additional environmental synthesis centers should be established. One such center should focus on assessing and synthesizing data from diverse sensors, networks, and observing systems.

SESSIONS ON SCIENTIFIC AND TECHNOLOGICAL CONNECTIONS

15. Fusion and integration of satellite remote-sensing and ground-based observations and presentation for environmental policy

Satellite remote sensing represents a tremendous resource for monitoring and forecasting environmental change, but these complex datasets often need to be integrated with ground-based data that have direct relevance to policy, the environment, and human health. Data from satellite sensors often exist in formats that are difficult for scientists from other fields and the public to use and understand, even though their application has been demonstrated for problems as diverse as air and water pollution, desertification, habitat destruction, ocean dead zones, and climate change, among many others.

Targeted Recommendations

- The Collectors of ground-based data should ensure that their data are high quality, standardized, geo-referenced, and distributed in a timely way to users. Adequate data continuity and funding for collection and distribution of key ground-based datasets also needs to be ensured.
- Data providers—including such agencies as NASA, NOAA, and USGS—should better serve end-users and operational communities in addition to research communities. Data providers should develop more products that meet end user needs by using both remote sensing and ground-based data streams.
- The Group on Earth Observations and the world community should develop products and services to demonstrate the status and trends of the health of various environmental media (air, land, and water) and environmental goods and services for decisionmaking and policy development. These products and services should be usable by and useful for the entire world community.
- Data providers should meet the needs of end users who rely on consistent and continuous time series data for policy-based environmental monitoring and decisionmaking.
- The natural resource research, management, and regulatory communities should place greater emphasis on the generation, interpretation, and integration of geobotanical remote sensing and ground-based data for use by environmental decisionmakers.
- Researchers should develop data visualization techniques for presentation of integrated satellite remote sensing and ground-based data to high-level decisionmakers. These techniques and templates should be distributed widely.
- The public and private sectors should develop on-line systems to enable remote sensing data streams to be used by a wide range of end users.
- The White House and Congress should issue a challenge and provide funding to create a complete, integrated, Earth-system model (including oceans, atmosphere, biosphere, and land).

Sessions on Scientific and Technological Connections

16. Examining the role of eco-informatics in environmental decisionmaking

Environmental decisionmakers at all levels of government (local, state, national, and international) seek to integrate ecological and environmental information (eco-informatics) into resource management, oversight, and policy decisions. While decisionmakers may explore a wide variety of information sources through information providers and data managers, they are faced (often indirectly) with many information challenges, including data gaps, data integration, data presentation, and how to use or create appropriate indicators.

Targeted Recommendations

- The federal government should increase its investment in interagency collaboration and partnerships involving eco-informatics tools to improve applications for environmental forecasting and decisionmaking.
- Government agencies engaging in joint environmental research projects should use appropriate eco-informatics tools.
- Researchers should take a more collaborative approach to their forecasting research and planning to ensure that the resulting information is meaningful to a broad range of decisionmakers and the general public. The

involvement of broad user groups is critical from the onset and throughout the collaborative process.

- To improve environmental forecasting capabilities, U.S. agencies should foster closer eco-informatics collaborations with international environmental organizations, particularly in areas that impact health, trade, and economics.
- U.S. science agencies should work more closely with academia to create and sustain a viable national forum on the nexus between research and innovation in the area of eco-informatics and forecasting.
- In order to facilitate the transition from research to operations, researchers engaged in eco-informatics applications for environmental forecasting should be encouraged to collaborate with potential users who have a stake in supporting implementation beyond the research and prototype phases.

Sessions on Scientific and Technological Connections

17. Cyberinfrastructure for all: Connectivity, content, and collaboration

The emerging cyberinfrastructure (CI) will be an integrated system of computation, communication, and information elements that supports a range of applications such as data sharing, remote operation of scientific instruments, and high-performance computing. Cyberinfrastucture will make e-science possible by tying together researchers, educators, and students from around the globe. Cyberinfrastructure will create major opportunities and challenges for environmental forecasting. In order to achieve the CI vision, those involved must identify and overcome barriers in resources or knowledge that might hinder the development or use of CI in some settings. Developers of CI need to take advantage of the opportunities that CI presents to enable broader participation in cutting edge education and research activities.

Targeted Recommendations

- A multi-stakeholder working group should be established to define the role of cyberinfrastructure in environmental forecasting.
- A university mentoring and exchange program should be established between domestic and international higher education institutions to address common goals in environmental forecasting.
- A multi-organization initiative should be created, perhaps through the Global Earth Observation System of Systems, to document the development of each nation's CI, identify obstacles for advancement, and provide constructive suggestions for future development and applications for environmental forecasting.
- The Institute for Higher Education Policy should establish a working group to explore the opportunity for tribal colleges to play a larger role in developing international CI applications of environmental forecasting, both because of their cultural connection to the environment and recent examples of success in this area.
- An organization such as the Environmental Information Coalition should develop an online database of environmental data sets in order to promote greater awareness and use of existing information.

Sessions on Scientific and Technological Connections

18. Linking environmental indicators with forecasting

There are an enormous number of environmental indicators. Many of them are indicators of process rather than indicators of outcome. Environmental indicators can play an important role in environmental assessments, models, forecasts, and decisions. To be useful in forecasting, indicators should be presented in usable forms for the public.

Targeted Recommendations

Communication

- Organizations should use the most effective mechanisms to communicate about indicators, using simple and clear language.
- Organizations using indicators should clearly identify and understand their target audiences.
- Communication on indicators should involve discussion among researchers, policymakers, and the public.
- Universities should teach communication skills about indicators as part of the curriculum.
- Organizations should develop communication strategies for indicators that focus on popular topics—such as air, water, and birds—in order to capture the public imagination and generate enthusiasm about indicators.

Leadership and Coordination

- A clearinghouse or series of clearinghouses on indicators should be established. Clearinghouses should be recognized as neutral entities that involve multiple organizations and enable broad comparability across a wide array of data sets.
- A multi-stakeholder group should consolidate the wide spectrum of indicators into a smaller set of core indicators that drive improved environmental policy, planning, and management.
- A multi-stakeholder group should develop a common language and approach for indicators. This would enable crosscutting analyses of a wide range of indicators.

Attributes of Effective Indicators

- Government agencies and other organizations and agencies should strive for robust, efficient, and effective environmental indicators. Environmental indicators should be:
    - Grounded in sound science.
    - Have a clear rationale.
    - Be temporally and spatially explicit.
    - Have clear thresholds that are linked to ecological thresholds.
    - Drive improved behavior.
    - Be linked to issues of public concern and interest.
    - Be robust, measurable, repeatable, and quantifiable.
    - Be sensitive to change over time.
    - Be easy to communicate and understand.

Aggregation of Indicators

- Organizations that aggregate indicators should strive to develop models that:
    - Integrate ecological, social, economic, and human health issues.
    - Borrow from other types of data modeling.
    - Are transparent in how data are aggregated, and list assumptions.
    - Recognize synergistic relationships.

Forecasting Models

- Organizations developing forecasting models should strive to develop models that:
    - Incorporate historical context into their models.
    - Fully reflect the complexity of systems.
    - Account for non-linear patterns, processes, and pathways.
    - Establish benchmarks and baselines to enable accurate forecasting.
    - Use the full range of forecasting tools, including risk assessment, vulnerability analyses, and predictive analyses.

Decision Support Systems and Tools

- Organizations using and developing indicators should strive to develop effective decision-support tools and systems that use the indicators to tell a story. Such decision support systems should:
    - Enable adaptive management.
    - Meet user needs.
    - Enable performance measurement (e.g., scorecards).
    - Enable target setting.
    - Prioritize data and information according to the end use.

- Incorporate cost-benefit analyses.
- Consider using "trend" and "key" indicators as one way of ensuring efficient and timely decisions.

Scale

- Organizations developing and using indicators should ensure that the indicators are matched to the appropriate scale of the issue. For example, different audiences will be interested in environmental indicators at different spatial scales, such as neighborhood, city, county, state, national, and continental levels. Organizations should seek whenever possible to link indicators across appropriate scales (e.g., linking local riparian condition indicators to watershed-scale water quality indicators).

Appropriate Indicators

- Since many issues are intertwined, organizations developing indicators should strive to consider linkages among ecological, social, economic, and human health issues. An example of such linkages can be found in private companies that have adopted a "triple bottom line" indicator system that takes into account financial, environmental, and social considerations.
- Where possible, organizations should seek to develop indicators that cut across multiple issues, such as water quality.
- Academic institutions should conduct research on how to choose effective indicators.
- Organizations focusing on ecological indicators should not shy away from complex data, but they should strive to develop indicators that effectively reduce this complexity.

Continuity of Data and Indicators

- Academic institutions and other organizations that collect and manage environmental data should ensure long-term data continuity in order to facilitate long-term studies.
- Organizations that develop and use indicators should strive to use the same indicators over time in order to detect trends.
- Indicator development is emerging as an important area of research in itself. Academic institutions should actively foster research related to the development and use of indications (e.g., choosing key indicators and aggregating multiple data).
- Agencies that support environmental observations and forecasting should ensure that the time horizons for funding are sufficient to match the time horizons of long-term monitoring and indicator projects. Institutionalization of key indicators may be beneficial to developers and users of the indicators.

Sessions on Scientific and Technological Connections

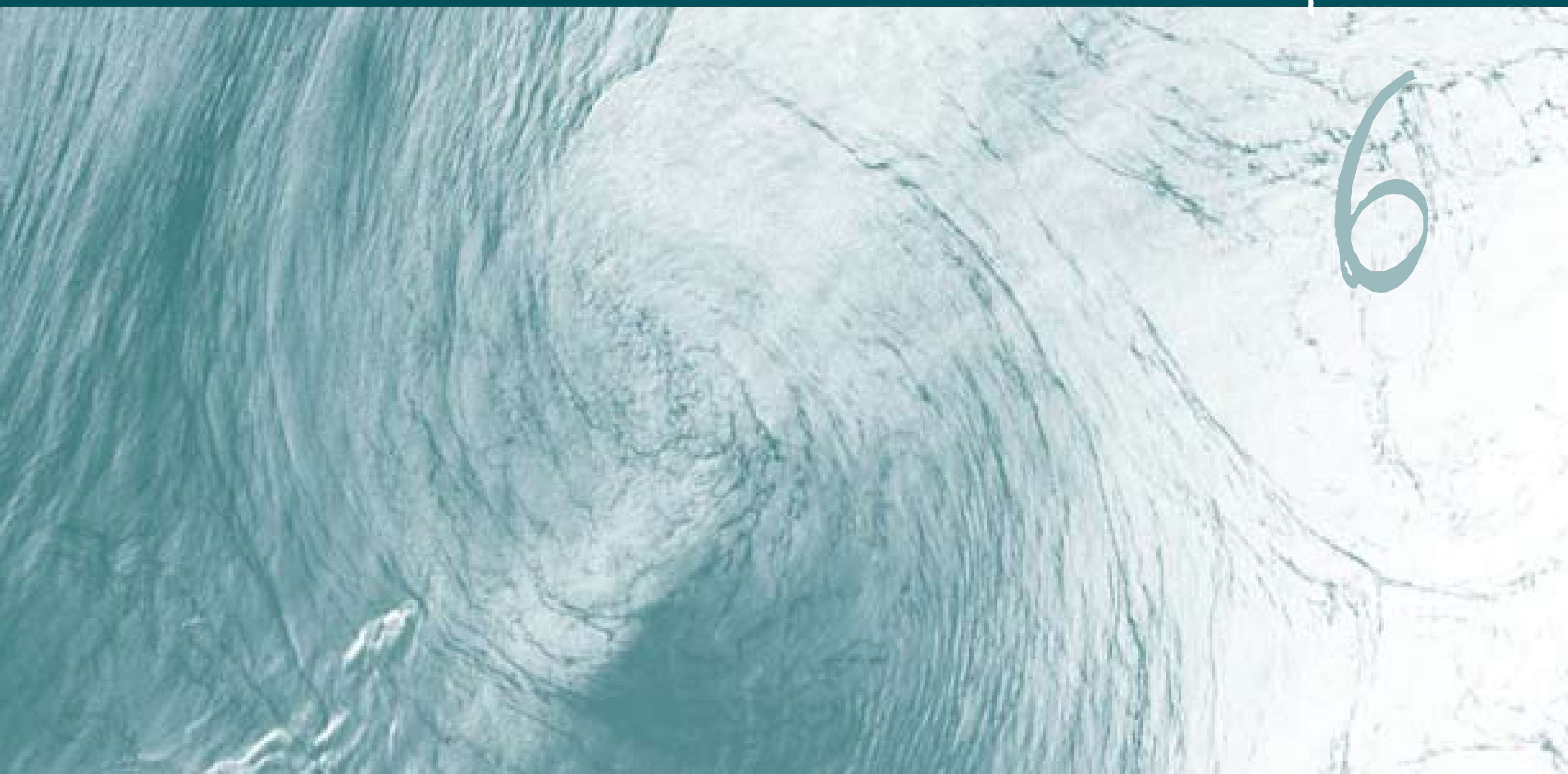
19. Moving from observation to forecasting systems: Linking characterization, process research, modeling, prediction, and delivery

There are often major disconnections among the different elements necessary for environmental forecasting. For example, the types of data needed to develop models may differ from the types needed to provide a forecast. Earth observatory platforms designed by basic researchers may not incorporate environmental forecasting tools that are appropriate to the needs of policymakers. Some platforms should be designed to answer specific research questions and others to gather "baseline" data that are usable by many communities. There is much important research to be done using long-term data sets of all types. Long-term data sets can be used to address more complex research questions through modern integration and synthesis of data. There are examples of successful approaches that address all the needs for useful forecasting. Designers of forecasting systems need to learn from previous efforts and move to a more unified approach.

Targeted Recommendations

- Environmental forecasters should improve messaging capabilities by:
    - Enhancing public environmental literacy.
    - Better "packaging" and communicating the value of forecasting.
    - Seeking diverse, non-traditional partners.
    - Improving quality and timeliness of information transfer to media.
    - Targeting messages to a K-12 audience and to a 6th grade literacy level.
    - Identifying and developing the most popular indicators for stakeholders.
    - Focusing on user-based, bottom-up approaches.
    - Drawing in social scientists to help forecasters think in interdisciplinary terms.
    - Including caveats and/or probabilities where appropriate in environmental forecasts.
- Environmental forecasters should build modeling frameworks that can accommodate change and evolution of environmental forecasts.
- Environmental forecasters should support reimbursable funding projects to better engage local communities.
- Environmental forecasters should use separate data sets for model development and for model evaluation.
- Environmental forecasters should ensure that different modeling systems and data inputs are interoperable across different scales and linkable across platforms.

Chapter 6



Conclusion: Primary Recommendations

The 5th National Conference on Science, Policy and the Environment: *Forecasting Environmental Changes* has resulted in a call for action: Now is the time to fully implement an integrated environmental forecasting system that will take the pulse of the planet, revolutionize our understanding of the Earth and its biosphere, and provide a broad range of societal and environmental benefits.

The general recommendations in this chapter have been drawn from a synthesis of the targeted recommendations in the previous chapter, focusing on the theme of making connections and improving integration. Several crosscutting recommendations emerged from the conference, including the need to engage user communities in environmental forecasting; to strengthen partnerships among multiple stakeholders; to develop data and information management systems to meet the needs of diverse user communities; to advance multidisciplinary research on complex environmental processes, to develop innovative technologies for environmental forecasting, and to improve education and outreach in order to achieve the intended societal benefits of the observing systems.

Recommendation 1

Engage Users in the Design, Development, and Operation of Environmental Forecasting Systems

Effective user engagement is essential to the success of environmental forecasting systems.

- Engaging users in the design, development, and operation of environmental forecasting systems is essential for meeting user needs and achieving the intended societal benefits.
- A diverse range of stakeholders from the public sector, private sector, academic institutions, civil society, and community groups should be involved from the outset in identifying user requirements for environmental forecasting systems.
- Ongoing user involvement is essential because user needs and forecasting capabilities will evolve over time.

Recommendation 2

Build Strong Partnerships to Facilitate Environmental Forecasting

Strong partnerships among multiple stakeholders are necessary for building and sustaining environmental forecasting systems.

- Strong partnerships across sectors—including government, business, academia, and civil society—are needed to optimize the design, development, operation, and impact of environmental forecasting systems.
- Strong partnerships across levels of government—local, state, and national—are needed to maximize the societal benefits of environmental forecasting systems.
- Partnerships among U.S. federal agencies should be expanded and strengthened to achieve the goals of the *Strategic Plan for the U.S. Integrated Earth Observation System* (2005) and related planning documents.
- Building on the rapid success of the Group on Earth Observations, international partnerships should be expanded and strengthened to achieve the goals of the *Global Earth Observation System of Systems 10-Year Implementation Plan* (2005) and related international initiatives.
- Incentives are needed to facilitate partnerships:
  - The federal government should provide short- and long-term incentives for businesses to participate in environmental forecasting partnerships.
  - Science agencies and institutions of higher education should provide incentives to overcome barriers to interdisciplinary research and education.

Recommendation 3

Improve Data and Information Management Systems for Environmental Forecasting

Environmental forecasting systems will produce unprecedented quantities of data and information. Managing and integrating this data and information to meet the needs of diverse user communities will present enormous technical, financial, and management challenges.

- Environmental forecasting systems should integrate data across a wide variety of observing systems, disciplines, institutions, spatial and temporal scales, and levels of biological organization.
- Large and sustained investments in data and information systems are needed to ensure data continuity and stability, data access and integration, data and metadata standards, coordination of data providers, and interpretation of data for policymakers, educators, and other non-technical users.
- The federal government should ensure that long-term, institutionalized repositories for critical datasets are sustained. This need should be recognized in any future planning for observational and forecasting systems.
- A national clearinghouse for environmental data should be established within an institutional framework that provides appropriate expertise and independence from political influence. The clearinghouse would provide objective, unbiased information—including a system of indicators of environmental conditions—for use by any interested party in ways that they specify.
- Government agencies and other organizations should move toward distributed, interoperable data collection and dissemination systems.

Recommendation 4

Advance Interdisciplinary Research on Environmental Forecasting

Improvements in environmental forecasting depend on advances in fundamental scientific research.

- New resources, incentives, and institutional structures are needed to improve the integration of the social and natural sciences in forecasting environmental changes and in addressing the impacts of environmental changes on humans.
- Science agencies should support additional research on linkages across scales, disciplines, and media, including:
  - Multiple spatial scales (e.g., molecular to global).
  - Multiple temporal scales (e.g., short- to long-term)
  - Multiple levels of biological organization (e.g., species and ecosystems).
  - Interactions across scales.
  - Interactions across disciplines (e.g., physical, biological, Earth, and social sciences).
  - Interactions across media (e.g., land, water, and air).
  - Fusion of ground-based observations with satellite remote-sensing observations.
- Additional research is needed to improve our fundamental understanding of processes that cause environmental changes. Improvements in environmental forecasting are driven by advances in our fundamental understanding of environmental processes.
- Additional research is needed to build robust models that have the capacity to forecast environmental changes. Process studies should be incorporated into environmental forecasting models.
- Federal science agencies should increase their investments in the interdisciplinary environmental research that forms the foundation for environmental forecasting.
  - Additional research and tools are needed to improve our ability to incorporate nonlinearity, feedback, and thresholds in models of complex environmental systems.

Recommendation 5

Develop and Deploy Innovative Technologies for Environmental Forecasting

Recent and planned environmental observing systems will involve the design and deployment of new technologies.

- Cyberinfrastructure will create major opportunities and challenges for environmental forecasting. A multistakeholder working group should be established to define the role of cyberinfrastructure in environmental forecasting.
- Sensors and sensor networks are important components of environmental forecasting systems. Rapid development and deployment of evolving sensor networks, including nanonets, are needed to provide the data essential to capture the temporal and spatial variability necessary to develop models that will allow scientists to answer questions across multiple scales.
- Developing the necessary sensors will require multidisciplinary collaboration among engineers, natural and social scientists, biomedical researchers, and computer scientists.
- Additional fundamental research is needed to achieve robust coupling of sensors, cyberinfrastructure, modeling, process studies, and forecasting.
- New molecular techniques have tremendous potential for facilitating integration across spatial scales and for improving environmental forecasts. The scientific community should determine which large-scale environmental questions are amenable to molecular approaches.

Recommendation 6

Improve Education, Outreach and Communications to Increase the Societal Benefits of Environmental Forecasts

Effective communication and education are essential for achieving the intended societal benefits of environmental forecasting systems.

- A forecast is not complete until it has been communicated effectively to the user communities. Enormous efforts are needed to improve the communication of warnings and environmental forecasts to local populations and to educate local populations how to respond to warnings and forecasts. Improvements in communication and education are necessary for achieving the expected societal benefits of environmental forecasting systems.
- Researchers should explain how environmental forecasting systems will benefit the economic, health, security, and environmental interests of the nation.
- New ways of visualizing environmental forecasts are needed to improve communication with decision makers and the public.
- Domestic and international multidisciplinary environmental education and outreach programs should be expanded as a way to secure future scientific capacity necessary for forecasting environmental changes and to improve personal decisionmaking.
- Greater emphasis should be placed on developing performance metrics and other means of evaluating the economic value and societal benefits of environmental forecasting systems.
- Environmental forecasters should communicate information about the uncertainty of their forecasts as well as limitations of the data, models, and interpretations.

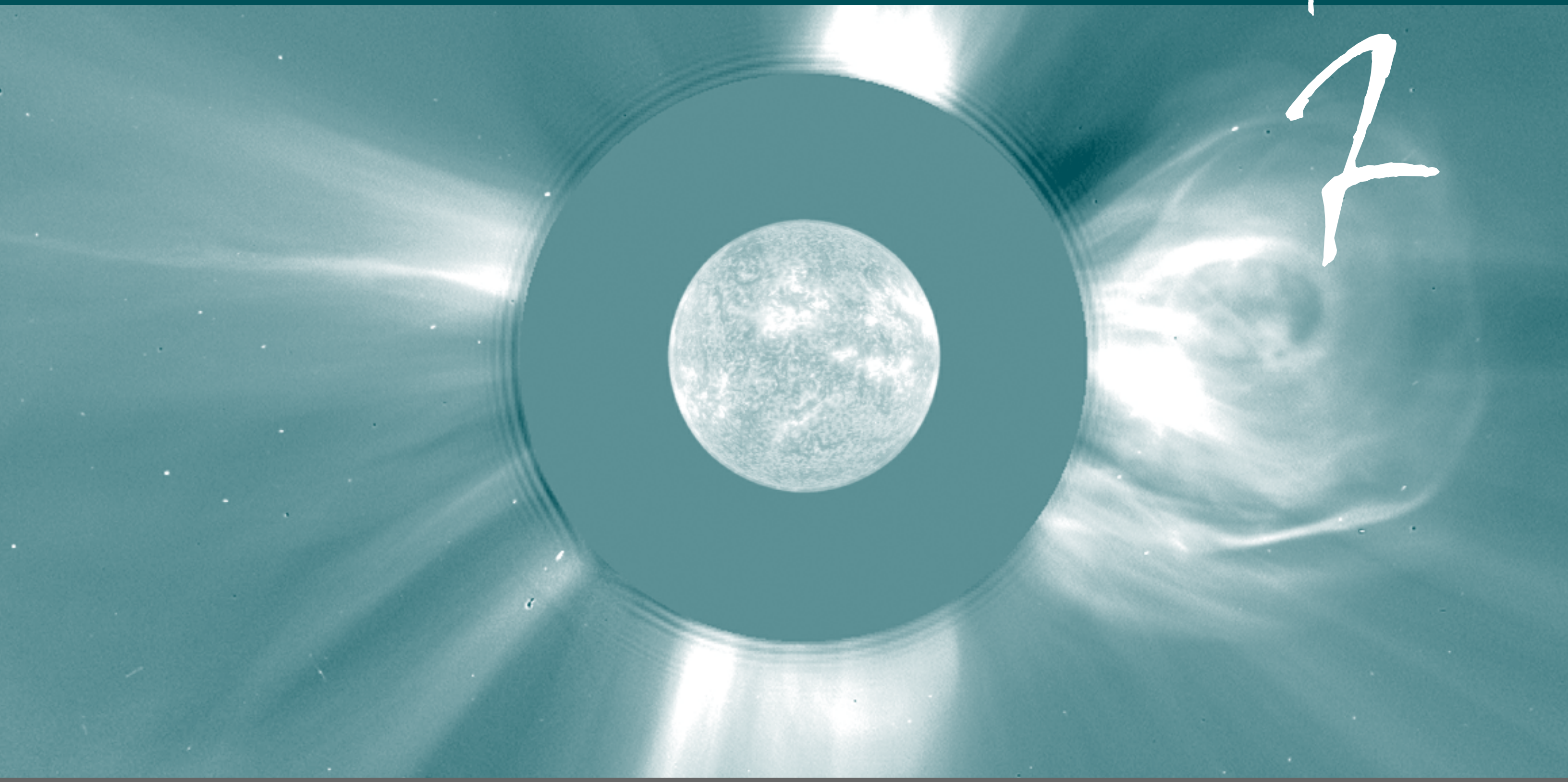
Recommendation 7

Implement an Integrated Environmental Forecasting System

A coherent vision for environmental forecasting has been articulated by leading scientists and policy makers. Specific societal benefits and user requirements have been identified. While national and international bodies have endorsed strategic plans and implementation plans, it is now essential to move from planning to action.

- Now is the time to fully implement an integrated environmental forecasting system that will take the pulse of the planet, revolutionize our understanding of the Earth and its biosphere, and provide a broad range of societal and environmental benefits. It should be a seamless system that integrates:
  - Observations, characterization, process research, and model development.
  - Forecasts, predictions, decision support tools, education, and communication.
  - Policy and management decisions.
- An integrated environmental forecasting system should evolve over time in response to advances in science and technology and changes in societal needs.

Chapter 7



Appendices

Appendix A

Agenda

Forecasting Environmental Changes

Fifth National Conference on Science, Policy and the Environment
February 3-4, 2005, Washington, DC

THURSDAY, FEBRUARY 3, 2005

8:00 AM

REGISTRATION & CONTINENTAL BREAKFAST

9:00 AM

WELCOME

Craig Schiffries, Conference Chair, National Council for Science and the Environment
Amb. Richard Benedick, President, National Council for Science and the Environment

9:15 AM

KEYNOTE ADDRESS

James Gustave Speth, Dean, Yale School of Forestry & Environmental Studies; Former Chair, White House Council on Environmental Quality; Recipient, Blue Planet Prize

10:00 AM

PLENARY ROUNDTABLE — Lessons Learned from Successful Environmental Forecasting Approaches

Mohamed El-Ashry (Moderator), Former President and CEO, Global Environment Facility
D. James Baker, President and CEO, Academy of Natural Sciences; Former Administrator, NOAA
Charles Groat, Director, U.S. Geological Survey
Charles Kennel, Director, Scripps Institution of Oceanography; Former Associate Administrator, Mission to Planet Earth, NASA
Margaret Leinen, Assistant Director, Geosciences, National Science Foundation

11:00 AM

PLENARY ROUNDTABLE — Designing Ecological Forecasting Systems

Ronald Pulliam (Moderator), Regents Professor, University of Georgia; Former Director, National Biological Service; Former President, Ecological Society of America
Ann Bartuska, Deputy Chief for Research and Development, U.S. Forest Service; Former President, Ecological Society of America
Gary Foley, Director, National Exposure Laboratory, U.S. Environmental Protection Agency
Bruce Hayden, Professor, University of Virginia; Co-Director, National Ecological Observatory Network (NEON) Project Office
Thomas Lovejoy, President, The H. John Heinz III Center for Science, Economics, and the Environment; Former President, American Institute of Biological Sciences
Steven Stanley, Professor of Paleobiology, Johns Hopkins University; Former President, American Geological Institute

12:15 PM — LUNCH

1:30 PM

BREAKOUT SESSIONS — 19 CONCURRENT SESSIONS (SEE APPENDIX B FOR CHAIRS AND SPEAKERS)

Sessions on Linking Systems and Users

1. Connecting Forecasts with Policymakers
2. Improving the Usefulness of Environmental Information for Personal Decisionmaking: EPA's Public Report on the Environment, the Earth Portal, and More
3. Sharing Forecasting Information with Users
4. Improving Academic Programs to Prepare the Next Generation of Forecasters
5. Providing Real Time Forecasts - How to Assess and Meet User Needs

Sessions on Connecting Institutions

6. Integrating U.S. Efforts with International Initiatives
7. Linking Levels of Government: Federal-State-Local
8. Cross-Sectoral Connections: Engaging the Private Sector as a Partner with the Government

Sessions on Scientific and Technological Connections

9. Linking Ocean, Atmospheric and Terrestrial Observation and Forecasting Systems
10. Integrating Economic, Social and Environmental Forecasting
11. Working Across Spatial Scales - From Molecular to Global
12. Forecasting Environmental Change of the Landscape at a Regional Scale
13. Working Across Temporal Scales - Integrating Short-term and Long-term Approaches
14. Facilitating the Development of Environmental Sensors and Sensor Networks
15. Fusion and Integration of Satellite Remote-Sensing and Ground-Based Observations and Presentation for Environmental Policy
16. Examining the Role of Eco-Informatics in Environmental Decisionmaking
17. Cyberinfrastructure for All: Connectivity, Content, and Collaboration
18. Linking Environmental Indicators with Forecasting
19. Moving From Observation to Forecasting Systems: Linking Characterization, Process Research, Modeling, Prediction and Delivery

5:30 PM

RECEPTION AND POSTER SESSION

7:00 PM

FIFTH JOHN H. CHAFEE MEMORIAL LECTURE ON SCIENCE AND THE ENVIRONMENT

INTRODUCTION
Jeffrey Leonard, President and CEO, Global Environment Fund

LECTURE
Choosing Our Common Future: Democracy's True Test
William D. Ruckelshaus, First and Fifth Administrator, U.S. Environmental Protection Agency; Chairman Emeritus, World Resources Institute; Chairman, Meridian Institute

FRIDAY, FEBRUARY 4, 2005

9:00 AM

PLENARY ADDRESS

INTRODUCTIONS
Randy Johnson, Chair, Board of Commissioners, Hennepin County, Minnesota
Rita Colwell, Distinguished University Professor, University of Maryland and the Johns Hopkins University Bloomberg School of Public Health; Chairman, Canon U.S. Life Sciences, Inc.; Director Emeritus, National Science Foundation

Lecture
Jack Dangermond, Founder and President, ESRI

10:00 AM

SYMPOSIA — 4 Concurrent Sessions

Creating a Global Earth Observation System of Systems (GEOSS): Benefits for Environmental Forecasting

Charles Groat (Chair), Director, U.S. Geological Survey; Alternate U.S. Representative to GEO
Roberta Balstad, President, Center for International Earth Science Information Network
Rosalind Helz, Associate Program Coordinator, Volcano Hazards Program, U.S. Geological Survey
K. Bruce Jones, Senior Scientist, U.S. Environmental Protection Agency
Greg Withee, Assistant Administrator for Satellite and Information Services, NOAA; Co-Chair, Interagency Working Group on Earth Observations

Creating a National Ecological Observatory Network (NEON): Developing the Capacity for Ecological Forecasting

Bruce Hayden (Chair), Professor, University of Virginia, Co-Director NEON Project Office
Jeff Goldman, NEON Project Manager
Pauline Luther, Education Director, Environmental Distance Learning
William Michener, Co-Director, NEON Project Office
Ron Pulliam, Professor, University of Georgia

Environmental Change: An Interactive Discussion About the Future

Michael Brody (Co-Chair), Office of the Chief Financial Officer, U.S. Environmental Protection Agency
Robert Olson (Co-Chair), Institute of Alternative Futures
Skip Laitner, Office of Air and Radiation, U.S. Environmental Protection Agency
David Rejeski, Foresight and Governance Program, Woodrow Wilson International Center for Scholars
Terry Welch, Director, Environmental Technology Center, Dow Chemical

Engaging Users in Environmental Forecasting

Nathalie Valette-Silver (Chair), NOAA National Ocean Service, Coordinator, the National Centers for Coastal Ocean Science Ecological Forecasting Activities
Otto Doering, Purdue University; on sabbatical at USDA Natural Resources Conservation Service
Ann Fisher, Department of Agricultural Economics & Rural Sociology, Pennsylvania State University
Gregory Hernandez, NOAA Public Affairs, previously a journalist with ABC News
Robert Lempert, Senior Physical Scientist, RAND Pardee Center
Gary C. Matlock, NOAA, Director of the National Centers for Coastal Ocean Science

12:00 PM

BUFFET LUNCH

1:30 PM

PLENARY ADDRESS

Introduction
James C. Renick, Chancellor, North Carolina A&T State University

Lecture
Arden Bement Jr., Director, National Science Foundation

2:00 PM

SIGNING CEREMONY

NOAA - USGS Joint Memorandum of Understanding
Charles Groat, Director, U.S. Geological Survey
Brigadier General John J. Kelly, Jr., Deputy Undersecretary of Commerce for Oceans and Atmosphere

2:15 PM

PLENARY ROUNDTABLE—APPLYING ENVIRONMENTAL FORECASTING TO ENVIRONMENTAL DECISIONMAKING

Dave Jones (Moderator), President and CEO, StormCenter Communications, Inc.

Ray Anderson, Founder and Chairman, Interface, Inc.; Former Co-chair, President's Council on Sustainable Development

Rita Colwell, Distinguished University Professor, University of Maryland and the Johns Hopkins University Bloomberg School of Public Health; Chairman, Canon U.S. Life Sciences, Inc.; Director Emeritus, National Science Foundation

Brigadier General John J. Kelly, Jr., Deputy Undersecretary of Commerce for Oceans and Atmosphere

Walter Reid, Director, Millennium Ecosystem Assessment

3:30 PM

CLOSING REMARKS

Ambassador Richard Benedick, President, National Council for Science and the Environment

ADJOURN

Appendix B
Breakout Sessions

Sessions on Linking Systems and Users

1. Connecting forecasts with policymakers

Session Chair
Robert Lempert, Senior Scientist, RAND Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition

Discussants
Mark Schaefer, President and CEO, NatureServe
Nancy J. Wheatley, Water Resources Strategies

2. Improving the usefulness of environmental information for personal decisionmaking: EPA's Public Report on the Environment, the Earth Portal, and more

Session Chair and Discussant
Jim Lester, Environment Group Director, Houston Advanced Research Center; Chair, NCSE Earth Portal Stewardship Committee

Discussants
Bruce Stein, Vice President for Programs, NatureServe; Representative, Office of Environmental Information, U.S. Environmental Protection Agency
Nancy Wentworth, Director, Environmental Analysis Division, Office of Information Analysis and Access, U.S. Environmental Protection Agency

3. Sharing forecasting information with users

Session Chair
Elaine Hoagland, National Council for Science and the Environment

Discussants
Kevin Coyle, President, National Environment Education and Training Foundation
Dave Jones, President and CEO, StormCenter Communications, Inc.
Leigh Welling, Director, Crown of the Continent Research Learning Center, Glacier National Park

4. Improving academic programs to prepare the next generation of forecasters

Session Chair
Will Focht, Director, Environmental Institute, Oklahoma State University; Co-Chair, Council of Environmental Deans and Directors (CEDD) Curriculum Committee

Discussants
Ronald Baird, Director, SeaGrant Program
Sandra Henderson, GLOBE Chief Educator, University Corporation for Atmospheric Research
Sonia Ortega, Education and Human Resources Directorate, National Science Foundation

5. Providing real-time forecasts—How to assess and meet user needs

Session Chair
Denice Shaw, Office of Research and Development, U.S. Environmental Protection Agency

Discussants
John E. White, U.S. Environmental Protection Agency
Chris Owen, Apprise Technology
Pauline Luther, Director, Environmental Distance Learning

Sessions on Connecting Institutions

6. Integrating U.S. efforts with international initiatives

Session Chair
Nancy Colleton, President, Institute for Global Environmental Strategies; Co-Founder, The Alliance for Earth Observations.

Discussants
Eliot Christian, U.S. Geological Survey
Fernando R. Echavarria, Bureau of Oceans, International Environmental and Science Affairs, U.S. State Department
Teresa Kennedy, Director of International and U.S. Partnerships, GLOBE Program
D. Brent Smith, Chief, International and Interagency Affairs, NOAA

7. Linking levels of government: Federal-state-local

Session Chair
Randy Johnson, Chair, Hennepin County (MN) Board of Commissioners

Discussants
Kevin Neimond, GIS Program, National Association of Counties
Molly O'Neill, State Director, Network Steering Board, Environmental Council of the States

8. Cross-sectoral connections: Engaging the private sector as a partner with the government

Session Chair
Mary G. Altalo, Corporate Vice President, Science Applications International Corp.

Discussants
James Cooper, Earth Satelite Corporation
Steve Hauser, Director, Gridwise Alliance

Sessions on Scientific and Technological Connections

9. Linking ocean, atmospheric, and terrestrial observation and forecasting systems

Session Chair
Anthony Janetos, Vice President, H. John Heinz III Center for Science, Economics and the Environment

Discussants
Ronald Birk, Program Director, Applied Sciences Program, NASA
John Orcutt, Deputy Director, Scripps Institution of Oceanography; President, American Geophysical Union

10. Integrating economic, social, and environmental forecasting

Session Chair
Caitlin Simpson, Office of Global Programs, NOAA

Discussants
William Karesh, Director, Field Veterinary Program, Wildlife Conservation Society
Dan Osgood, Economist, International Research Institute for Climate Prediction, Columbia University

11. Working across spatial scales: From molecular to global

Session Co-Chairs
Jeff Amthor, Program Manager, U.S. Department of Energy Office of Science, Climate Change Research Division
Woody Turner, Program Scientist, Office of Earth Science, NASA

Discussants
Gary Jacobs, Oak Ridge National Laboratory
John Paul, Professor of Marine Science, the University of South Florida
Stan Wullschleger, Oak Ridge National Laboratory

12. Forecasting environmental change of the landscape at a regional scale

Session Chair
Sarah Shafer, Earth Surface Processes Team, U.S. Geological Survey

Discussants
Thomas Crow, National Program Leader, Ecological Research, Wildlife, Fish, Water, and Air Research, USDA
John Wiens, Chief Scientist, The Nature Conservancy

13. Working across temporal scales: Integrating short-term and long-term approaches

Session Chair
Sue Haseltine, Associate Director for Biology, U.S. Geological Survey

Discussants
Ann Bartuska, Deputy Chief for Research and Development, USDA Forest Service
Jim Nichols, Patuxent Wildlife Research Center, U.S. Geological Survey

14. Facilitating the development of environmental sensors and sensor networks

Session Chair and Discussant
Elizabeth Blood, Program Officer, Division of Biological Infrastructure, National Science Foundation

Presentation
Peter Arzberger, University of California, San Diego, "Sensors for Environmental Observing: Highlights and Key Observations from an NSF Funded Workshop"

Discussants
Pat Brezonik, Henry Gholz, Alex Isern, Doug James and **Steve Meacham**, National Science Foundation

15. Fusion and integration of satellite remote-sensing and ground-based observations and presentation for environmental policy

Session Chair
Jill Engel-Cox, Senior Research Scientist, Battelle Memorial Institute

Discussants

Ashbindu Singh, Regional Coordinator, Division of Early Warning & Assessment—North America, United Nations Environment Programme
Lawrence Friedl, Program Manager, National Applications, Sun-Earth Systems Division, NASA
Alan Rush, Policy Analyst, Office of Air Quality Standards, U.S. Environmental Protection Agency

16. Examining the role of eco-informatics in environmental decisionmaking

Session Co-Chairs

Mike Frame and **Tyrone Wilson**, National Biological Information Infrastructure, U.S. Geological Survey

Discussant

John Schnase, Lead, Information Sciences & Technology Research, NASA Goddard Space Flight Center

17. Cyberinfrastructure for all: Connectivity, content, and collaboration

Session Chair

Ann Zimmerman, Research Fellow, University of Michigan

Discussants

James Gosz, Professor, University of New Mexico; Director for the New Mexico Experimental Program to Stimulate Competitive Research
Arnold Kee, Director of Programs, Institute for Higher Education Policy
Lori Perine, Executive Director, Agenda 2020 Technology Alliance, American Forest and Paper Association

18. Linking environmental indicators with forecasting

Session Chair

Brenda Groskinsky, ORD Science Liaison for Region 7, U.S. Environmental Protection Agency

Presentations

Rick Linthurst, Office of the Inspector General, U.S. Environmental Protection Agency
Chase Huntley, Senior Analyst, National Resources and Environment Department, U.S. General Accounting Office

Discussants

Jamison Ervin, Ecoregional Measures Manager, The Nature Conservancy
H. Theordore Heintz, Jr., White House Council for Environmental Quality
Bruce Jones, Office of Research and Development, U.S. Environmental Protection Agency
Douglas M. Muchoney, Program Coordinator, Geographic Analysis and Monitoring, U.S. Geological Survey

19. Moving from observation to forecasting systems: Linking characterization, process research, modeling, prediction, and delivery

Session Chair

Gary Foley, Director, National Exposure Laboratory, Office of R&D, U.S. Environmental Protection Agency

Discussants

Michele Aston, National Exposure Research Laboratory, U.S. Environmental Protection Agency
Mathew Sobel, Professor, Weatherhead School of Management Case Western Reserve University
Dorsey Worthy, National Exposure Research Laboratory, U.S. Environmental Protection Agency

Appendix C
Poster Presentations

Ashby, Steven; Barko, John and Dave Richards. U.S. Army Corps of Engineers. **Environmental Forecasting and Decision Making in Comprehensive Water Resource Management.**

Bell, J. Bruce; and Stuart L. Pimm. Duke University. **Predicting Tropical Deforestation from Road Proximity and Land Cover History in the Amazon Basin.**

Billett, Clare[1] and Robert Cheetham.[2] [1]Natural Lands Trust; [2]Avencia, Inc. **Smart Conservation: Prioritization Program.**

Clagett, Peter[1]; Reilly, James[2]; Jantz, Claire[3] and Scott Goetz.[3] [1]USGS; [2]Maryland Department of Planning; [3]Woods Hole Research Center. **Urban Growth Modeling in the Chesapeake Bay Watershed.**

Diane Debinski. Iowa State University. **Using Remotely Sensed Habitat Classification and Species Distribution Patterns to Define Ecological Indicators of Climate Change.**

Dierauf, Leslie A.; Meteyer, Carol U.; Slota, Paul and F. Joshua Dein. USGS, Biological Resources Discipline—National Wildlife Health Center. **Thirty Years of Data Demonstrating Changes in Wildlife Health—U.S. Geological Survey's (USGS) National Wildlife Health Center, Madison, WI.**

Efroymson, Rebecca[1]; Virginia H. Dale[1]; Latha M. Baskaran[1]; Matthew Aldridge[2]; Michael Berry[2]; Michael Chang[3]; Catherine Stewart[4] and Robert A. Washington-Allen.[1] [1]Oak Ridge National Laboratory; [2] University of Tennessee; [3]Georgia Institute of Technology; [4]Aberdeen Proving Ground. **RSim: A Simulation Model to Explore Impacts of Resource Use and Constraints on Military Installations and in Surrounding Regions.**

Fisher, Ann and Rachael Dempsey. Penn State University. **Improve Local and Regional Decisions with Projections and Tools About Climate and Land Use: The Consortium for Atlantic Regional Assessment (CARA).**

Gray, Stephen T. and Julio L. Betancourt. U.S. Geological Survey—Desert Laboratory. **Assessing the Importance of Decadal-to-Multidecadal (D2M) Climate Variability in Forecasting Ecological and Hydrologic Change Across the Interior West.**

Gross, Thomas[1]; Brown, Christopher[2]; Hood, Raleigh[3]; Ramers, Douglas[4]; Tango, Peter[5]; Michael, Bruce[5] and Alexey Voinov.[6] [1]Chesapeake Research Consortium; [2]National Oceanic and Atmospheric Administration; [3]University of Maryland Center for Environmental Science, Horn Point Laboratory; [4]University of North Carolina, Charlotte; [5]Maryland Department of Natural Resources; [6]University of Vermont. **Integrating Environmental Models to Predict Spatial Distribution of Harmful Algal Bloom Occurrence.**

Heyck-Williams, Shannon and Jacob Scherr. Natural Resources Defense Council. **Connecting Policy Makers with Environmental Knowledge: The Earth Legacy Commission on U.S. Leadership in the Global Environment.**

Ierardi, Michael and Toni M. Johnson. U.S. Geological Survey. **The National Water Quality Monitoring Council.**

Jenicek, Elisabeth[1]; Gorgan, William[1]; Fournier, Donald[2] and Natalie Downs.[3] [1]U.S. Army, Engineering Research Development Center; [2]University of Illinois; [3]PERTAN Associates. **Strategic Sustainability Assessment Regional Evaluation.**

Kavanagh, Kathleen[1]; Link, Tim [1]; Marshall, John D.[1]; Braatne, Jeff[1]; Han, Han-Sap[1]; Cundy, Terry [2]; Daley-Laursen, Steven [1] and Woodam Chung.[3] [1]University of Idaho; [2]Potlatch Corporation; [3]University of Montana. **Collaborative Watershed Studies of Ecosystem Responses to Current Forest Harvest Practices in the Rocky Mountains, USA.**

Khan, Mohammed; Ahmad, S.A.; Erogbogbo, U. and J. Kyle. University of Illinois at Chicago and City Colleges of Chicago. **Global Warming and Survival of Aquatic Animals in Toxic Environments.**

Kuby, Lauren; Redman, Charles, L.; Buizer, James and Brenda Shears. Arizona State University. **Arizona State University's International Institute for Sustainability: Research with a Purpose.**

Lucy Bennison Laffitte. North Carolina State University. **What Does Environmental Sustainability Have in Common with Homeland Security? Deep Pockets of Social Capital.**

McManus, John W.; Gayanilo, Felimon; Hazra, Amit; Kool, Johnathan; Langdon, Chris; Yñiguez, Aletta; Brandt, Marilyn; and Wade Cooper. University of Miami—National Center for Caribbean Coral Reef Research (NCORE). **The Challenge of Building Forecasting into the New Online Data Navigator for South Florida.**

Mubenga, Kamonayi[1]; Jordan, Nikisa[1]; Engel-Cox, Jill[2]; Raymond Hoff[1]; Kevin McCann[1] and Ray Rogers.[1] [1]University of Maryland Baltimore County; [2]UMBC—Battelle Memorial Institute. **Blogging Smog: The U.S. Air Quality Weblog.**

Nemani, Ramakrishna[1]; Golden, Keith [1]; Votava, Petr[2]; Michaelis, Andy [2]; White, Michael[3]; Melton, Forrest[2]; Glymour, Clark[4]; Running, Steve[5]; Myneni, Ranga[6] and Joseph Coughlan.[1] [1]NASA Ames Research Center; [2]CSU Monterey Bay; [3]Utah State University; [4]Carnegie Mellon University; [5]University of Montana; [6]Boston **University. Biospheric Monitoring and Forecasting Using Ecosystem Modeling and Satellite Data.**

Rabinowitz, Peter[1]; F Joshua Dein[2]; Zimra Gordon[1] and Lynda Odofin.[1] [1]Yale University School of Medicine; [2]USGS National Wildlife Health Center. **Animals as Sentinels of Human Environmental Health Hazards.**

Smith, Richard; Alexander, Richard B.; Schwarz, Gregory E. and Michael C. Ierardi. U.S. Geological Survey. **Effects of Structural Changes in U.S. Animal Agriculture on Fecal Coliform Contamination of Streams.**

Harold Stone. East Carolina University. **A Graphic Model to Aid Sustainable Decision Making in Environmental Policy.**

Takle, Eugene S.; King, Catherine L.; CRUSE, Rick; Arritt, Raymond W.; Gassman, Phil; Gutowski, Jr., William J.; Asbjornsen, Heidi; Debinski, Diane; Jha, Manoj; and Mahesh Sahu. Iowa State University. **Basing Policy on Sound Science: Using Human Behavior Models Coupled with Physically Based Models.**

Valette-Silver, Nathalie J. and Gary C. Matlock. National Oceanic and Atmospheric Administration. **The Integration of Science and Management.**

D. Rick Van Schoik. Southwest Consortium for Environmental Research and Policy. **Eventualities in the US-Mexican Border Region: Harbinger for the Nation?**

Waggett, Caryl E.[1]; Waggett, James A.[2]; Wilmore, Seth B.[1] and Robert S. Lane[3] [1]Allegheny College; [2]IEEE; [3]University of California, Berkeley. **Assessing Risk of Lyme Disease Using Satellite Imagery in Northern California: Efficacy of Predicting Disease Risk in an Era of Land Use Changes.**

Welling, Leigh[1]; Thomas, Julie[2]; Fagre, Dan[3] and Karen Scott.[4] [1]National Park Service, Glacier National Park; [2]Air Resources Liaison; [3]USGS, Rocky Mountain Research Station, Glacier Field Station; [4]Environmental Protection Agency—Office of Air & Radiation, Climate Change Division. **Climate Change in National Parks: Moving from Knowledge to Action.**

Appendix D
Exhibitors

The following organizations exhibited their educational programs and products at the conference.

Department of Defense

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Island Press

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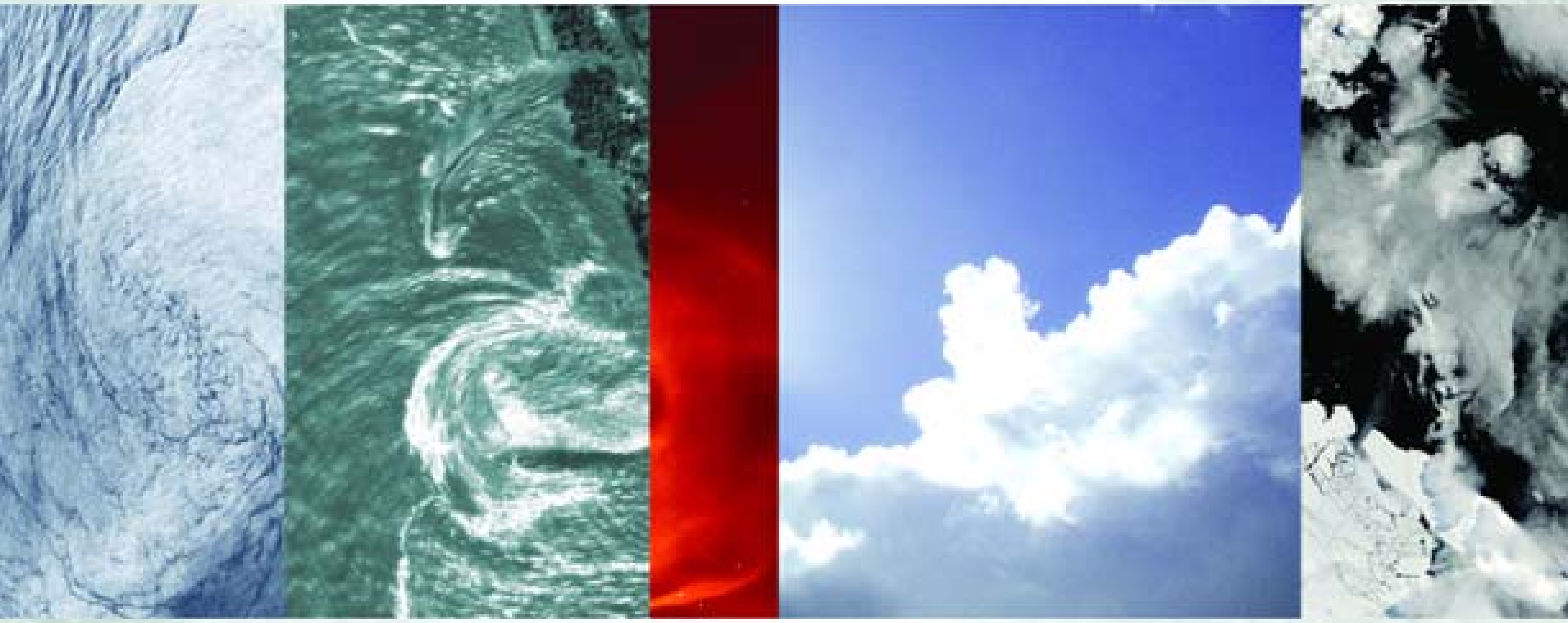

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