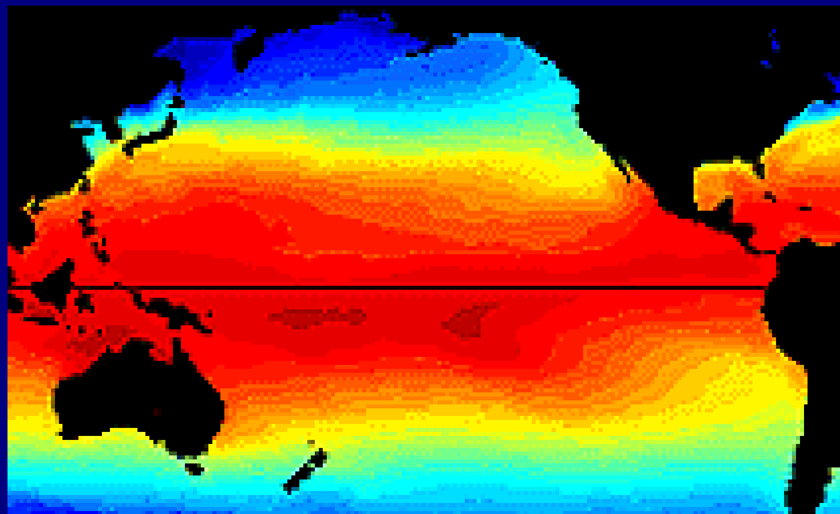

El Niño – December 1997

IMPROVING RESPONSES TO CLIMATE PREDICTIONS

Report of a Policy Forum

Developed by the

Atmospheric Policy Program
American Meteorological Society

in collaboration with

Columbia University

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CONTENTS

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PREFACE

This report of a policy forum on "Improving Responses To Climate Predictions" presents findings and recommendations that, if implemented, could offer considerable benefits to the nation by enabling the providers and consumers of climate prediction services to cooperatively and effectively develop strategies to respond to climate variations.

Recent U.S. experience in responding to the predictions of the 1997/98 El Niño encouraged the AMS Atmospheric Policy Program to join with Columbia University in the planning and development of a forum to address the issues connected with effective use of climate predictions. We invited the participation of representatives from the public, private, and academic portions of the water management and emergency management sectors, the climate information provider community, political and corporate leaders, and policy makers. Nearly 100 representatives of those communities came together on April 23-24, 2003, for intensive discussions of these important policy issues.

The Atmospheric Policy Program of the American Meteorological Society (AMS) remains poised to assist in the further development and realization of the recommendations that have emerged from the Forum.

The AMS Atmospheric Policy Program acknowledges, with thanks, the contributions of numerous individuals and organizations to the success of the Forum. The fact that they were so numerous inhibits my ability to name them all. Of course, the Forum could not have been undertaken without the generous labors of the moderators and panelists. Five organizations, in particular, provided special support: Columbia University provided both intellectual and financial support, in addition to having faculty and staff members participating in many of the core activities of the Forum; ITT Industries and Raytheon provided underwriting support to the AMS Policy Study Series, of which this Forum is the initial undertaking; Space Systems Loral donated financial sponsorship for this Forum; and the Global Programs Division of EPA provided financial and staff support. Carolyn McMahon, AMS staff, very ably handled all of the logistical and administrative details involved in the Forum. Thanks to Chris Elfring, Director of the Board on Atmospheric Sciences and Climate, the National Research Council (NRC) graciously provided the site for the Forum and Diane Gustafson of the NRC staff deserves special recognition for smoothly handling the numerous arrangements within the National Academies building.

I gratefully recognize the outstanding efforts of Bob Landis, with the excellent assistance of Mark Fernau and Genene Fisher of the AMS, and Jason Samenow, EPA, to document the main outcomes of the discussions and to write the initial drafts of this Report. In the course of the review of the initial drafts, several Forum participants offered comments and suggestions that greatly influenced the text in the final Report. In particular, Rick Anthes, Eileen Shea, Jesse Aber, and Chet Ropelewski made significant contributions to the Report. I want to especially note the major contributions that Genene Fisher made to the final version of the Report.

Richard S. Greenfield
Senior Policy Fellow and Associate Director
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EXECUTIVE SUMMARY

One of the most predictable climatic events is El Niño, the development of a warm pool of ocean water in the eastern and central Pacific Ocean that typically persists for 12 to 18 months and recurs approximately every two to seven years. Weather phenomena associated with El Niño have significant societal, economic, and environmental impacts. Moreover, these phenomena are somewhat predictable on a seasonal time scale and, therefore, present decision makers with opportunities to develop response strategies.

Prior to 1997, the strongest El Niño of record (i.e. largest sea surface temperature anomaly) for this century was recorded in 1982/83. Quite significant weather responses to that El Niño in the United States were observed that resulted in large societal impacts on safety, property, and economic development. The *Financial Times* (July 28, 1997) reported that the 1982/83 El Niño led to estimated U.S. losses of $2.2 billion with 161 human deaths. Several retrospective scientific investigations, including model research and development, showed some promise in the prediction of the anomalous climate of 1982/83.

In 1997/98, an even stronger El Niño occurred, and several seasonal predictions made prior to the onset of that event appeared to show statistical skill beyond climatological chance. Decision makers acted on those forecasts, taking measures that abated certain hazardous impacts, and enabled decision makers to capitalize on economic opportunities. The 1997/98 El Niño was the largest and warmest to develop in the Pacific Ocean in the past 100 years, and a milestone for seasonal forecasts. Analysis of 1997/98 El Niño impacts on the U.S. economy suggests that climate predictions have great potential for risk management in several climate sensitive industries, as well as in federal, state, and local disaster preparedness. For example, there is strong evidence that California saved over $1 billion in property damages due to better preparation by state and local officials in response to the 1997/98 El Niño forecast.[1] Based on that estimate, taking advantage of climate predictions could result in potential savings of billions of dollars annually to the public and private sectors of the U.S. economy.

To cope effectively with climate impacts, institutions and organizations require accurate, timely seasonal and longer-term predictions. However, this is only a starting point. To respond effectively to climate predictions that involve significant seasonal variations, governments also require appropriate policies governing public and private decisions – at the local, national, and international levels. However, in most instances, the needed policies are not in place.

In response to this need, the Atmospheric Policy Program of the American Meteorological Society, in collaboration with Columbia University, developed and convened a forum. The Forum was designed to identify improvements in the development of strategies that benefit from effective application of climate information and seasonal climate predictions. The Forum brought together 96 participants representing weather and climate scientists, specialists in

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[1] "Improving El Nino Forecasting: The Potential Benefits," ed. Rodney F. Weiher, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, August 1999.

developing decision strategies, and policy makers. The resulting discussions developed findings, policy options, and recommendations necessary to achieve the improvements.

The General Findings

FINDING 1 - Anticipation and response to seasonal climate variability offer potentially significant societal benefits.

Although the accuracy of climate predictions is still limited, they can be applied in positive ways to benefit society. Application of forecasts of the strong 1997/98 El Niño demonstrated that significant societal benefits could result from anticipating and properly responding to predicted seasonal climate variations. Climate services can enhance many economic and societal sectors such as water resource management, agriculture, emergency preparedness, public health, and natural disaster reduction.

FINDING 2 – Regional and societal climate impacts are significant, but not yet fully understood.

The impacts of climate variations on society can be significant, particularly at the regional level. Some of the phenomena that El Niño affect are drought in northern Australia; temperatures and precipitation on the western coast of tropical South America; and tropical and extra-tropical cyclone frequency and intensity, as well as, precipitation quantity along the California and Gulf coasts, throughout the Pacific and in some interior portions of the United States. However, the regional climate impacts with regard to timing, duration, and specific locations are not fully understood.

FINDING 3 - Seasonal forecasts have a limited, but useful, level of skill and with enhanced infrastructure and research this level can be raised substantially.

Limited objective verification has demonstrated that seasonal forecasting has a small level of skill (accuracy above climatological chance). Improvements in observations, models, and understanding of climate variability hold great promise for higher levels of skill in seasonal forecasts. However, a balanced research effort to achieve these improvements is needed, to improve the forecasts and to make better use of the resulting forecast information.

FINDING 4 – Climate predictions and information are not provided in the most useful way to decision makers.

In many cases, climate predictions and information are not well suited for user needs. Much of the terminology associated with climate information is confusing. In addition, the timing requirements of users are not well understood by the information providers. New or improved methods of communicating climate information need to be considered, including formats and content.

Since climate predicting, particularly on a seasonal basis, is relatively new, decision makers need supporting evaluations of success before making major climate-related decisions that directly affect the public or stewardship of public resources (e.g., water supply). Finally, there is little information available on objective evaluations of successful applications of climate services.

For most decision makers and the public, statistical or probabilistic climate information is poorly understood. To be useful for decision makers, climate prediction information should be provided with certainty (or uncertainty) quantified in a clear, understandable presentation or format.

FINDING 5 – Climate information is most effectively developed and applied through partnerships between climate information providers and decision makers.

Use of climate information can be most effectively developed and applied when scientific data and information are placed in a context and format that is a part of the decision maker's overall management system. Decision maker's input regarding the most useful climate information, as well as timing and formats, must be a part of the overall development and application of climate prediction and information services.

FINDING 6 – Special training is needed to prepare professionals that can communicate information between the providers and consumers of climate information.

A growing number of application oriented scientists have begun to take on the role of "science integrator" in order to bridge a significant gap between the climate scientist and the consumer of climate information. To successfully gain an understanding of the consumer's information needs and applications, education and experience in both applications of climate science and the use of analytic tools is necessary. Academic institutions should develop advanced interdisciplinary opportunities to educate students to undertake roles as science integrators.

FINDING 7 – The use of climate predictions by decision makers is limited by a lack of evaluation of the risks and benefits.

The uncertainty inherent in climate predictions naturally leads to probabilistic formulations and therefore, has the potential to be applied to risk management. For many decision makers risk management is one of the most important aspects of their job. Risk management decisions can involve relatively large investments in order to either avoid large future costs or to take advantage of future opportunities that will reap major benefits at low cost. Using good climate predictions can optimize those decisions that are affected by future weather and climate. However, very few assessments or evaluations have been made regarding climate risk management for most decision-making situations.

The evolution of climate prediction services will, in large part, depend on climate scientists working with users to demonstrate the relevance and utility of climate information by drawing on the results of forecast applications and/or retrospective analyses. Once systematic climate information has become part of an overall decision process, it is important to establish a set of performance metrics. The metrics should effectively quantify the impacts and benefits of applying climate information to the process of decision making. Maximum acceptance of the value of climate information will emerge from objective evaluations of applications that have been adequately documented over a sufficient period of time.

The General Recommendations

RECOMMENDATION 1 – The nation should increase investments in climate science research, climate impact assessments, and strengthening the supporting infrastructure to improve climate predictions resulting in significant societal benefits.

RECOMMENDATION 2 – Providers of climate predictions should include clearly defined uncertainty measures (probabilistic information) that are presented with mutually understood terminology.

RECOMMENDATION 3 – Representatives of government agencies, private sector organizations, and academia should establish a collaborative approach to develop and provide a national capability for climate prediction and information services that would foster mutual trust and useful applications of climate information.

RECOMMENDATION 4 –Academic institutions should establish educational programs to produce "science integrators" who understand how to communicate user needs to providers and facilitate the application of climate information for users.

RECOMMENDATION 5 – Climate service providers and decision makers should work together to develop measures of improved performance resulting from using climate information as part of the decision process.

There are specific recommendations regarding policy issues in responding to climate variability and improving the usefulness of climate prediction services detailed in Sections III and IV of this Report.

The Specific Policy Recommendations

1. Government decision makers should integrate the use of climate information into national and international planning. Tools, based on climate data and analysis, should be developed that help integrate climate information and understanding into planning at all government levels.

2. In partnership, the government, academia, and private sector should identify one or more "grand challenges" to improve climate prediction services and applications. These challenges will provide a strategic focus for organizing shared efforts to advance the mainstreaming of climate information in policy formulation in the near- and long-term. An example of such a grand challenge is an overall study to document and report on the impacts of climate variability on society.

3. Governmental and academic institutions should consider increasing educational opportunities for climate scientists to better understand society and climate. Understanding how society reacts to climate and related forecasts is an important undertaking that can help define needed meteorological research as well as improve the benefits from climate prediction services.

4. Government agencies, resource management institutions, and private sector enterprises should aggressively recruit and retain scientists with science integration skills as part of their programs in climate-sensitive sectors. Providers and potential users of climate information should recognize the important role of *scientific integration*, a relatively new profession. Scientific integrators possess not only knowledge and/or experience in climate science and forecasting, but also an understanding of the processes involved in user decision-making.

5. The government should make balanced investments in research to advance the chances of reaching the theoretical potential in climate predictions to meet national economic and social needs. The investments should be devoted to: enhanced understanding of climate variability; more accurate climate prediction modeling techniques and data assimilation methods; expanded quality and quantity of observations; supporting infrastructure of computers and information systems; and a collaborative modeling focus, both nationally and internationally, among institutions and governments.

6. The U. S. government, in partnership with academia and the private sector, should encourage the World Meteorological Organization (WMO) to provide mechanisms for sharing information on climate services and applications internationally. Ongoing discussions about the emergence of Regional Climate Centres in the WMO provide a special, near-term opportunity. To achieve sustainable development on a global scale, the nations of the world will need to effectively use climate information.

7. The AMS should provide opportunities for continued science-policy dialogues, since climate science policy is a relatively new area. There should be more opportunities for open dialogue that is focused on climate-sensitive sectors. The goals of these dialogues include: identification of critical climate information needs; enhanced understanding of vulnerability; improved assessment methodologies; exploration of response strategies; and increased awareness of current and emerging forecasting capabilities and decision-support tools.

The Specific Recommendations to Improve Climate Prediction Services

1. There should be regular discussions among representatives of the providers of climate services concerning enhancements in those services. In many cases, guidance information widely distributed by the NOAA Climate Prediction Center (CPC) is enhanced significantly and is tailored to be application-specific for users by climate scientists in the private sector and/or academia. By having regular discussions about potential service enhancements, the various providers can continue to build a cooperative partnership.

2. Providers of climate information and forecasts should ensure that the space scales, timescales, and variables of interest to end-users are addressed clearly. It is especially important to convert basic meteorological elements to variables, such as stream flow, that are of interest to end-users.

3. Climate prediction providers should ensure that uncertainty measures are clearly stated to the public and decision makers. The measures should include, at a minimum, information related to probabilities of occurrence of the forecasted variables or quantities, accuracy of recent forecasts, and general physical reasoning behind the forecast.

4. Climate information providers and decision makers should create partnerships that support shared learning (co-production of knowledge) and joint problem solving. These partnerships should be joint, interactive endeavors between participants in climate science/application and in societal decision-making. The partnerships should design and execute pilot projects, and jointly assess the benefits, reliability, and impacts of climate prediction applications in an attempt to "scale-up" the lessons from individual projects to more general, successful applications. In the course of carrying out these projects, the mutual trust necessary to make the partnerships effective will be developed.

Many aspects of the recommendations presented in this Report must be met by the private sector—including corporate decision makers and the value-added meteorological services industry that provides climate information. Other aspects require public sector investments and actions. There are also recommendations that require university actions and research activities. The recommendations developed in this Forum, although directed, for the most part, at specific portions of these interested communities, can be best implemented through cooperative efforts among those communities.

These cooperative efforts, therefore, require effective public-private-academic sector partnerships. As noted in Section III, the Forum participants recommended that the AMS should be proactive in organizing dialogues that could foster the development of effective partnerships between the climate information providers and users. The AMS is prepared to serve in that role.

Implementation of the Forum recommendations would enable the development of effective responses to climate variations, within the United States, as well as internationally.

I. INTRODUCTION

Climate impacts an incalculable range of human activities. Many of these impacts are global in scope and, as a result, require international cooperation, investment, and coordination of planning, services, and response. To cope effectively, nations require accurate, timely seasonal and longer-term predictions. However, this is only a starting point. To respond effectively to climate predictions that involve significant seasonal variations, nations also require appropriate policies governing public and private decisions – at the local, national, and international levels. However, in most instances, the needed policies are not in place. This is not surprising. For virtually all of recorded history, the predictive capability that would require those policies has been lacking. In response to this need, the American Meteorological Society, in collaboration with Columbia University, developed and convened a forum with the following goal and objectives:

GOAL: Provide recommendations that will enable the development of specific strategies to benefit from effective application of climate information and seasonal climate predictions.

OBJECTIVES:

- Bring together weather and climate scientists, specialists in developing decision strategies, and policy makers.

- Identify present seasonal climate observational and predictive capabilities, response strategies, and the information needs of decision makers.

- Discuss, in depth, potential improvements in climate prediction capabilities that could be applied to improve response strategies.

- Develop findings, policy options, and recommendations necessary to achieve the improvements.

Over the past two decades, scientific research has steadily expanded our understanding of the earth's climate system. As this understanding has developed, scientists have grown more confident that skillful meteorological predictions on seasonal and interannual time scales are possible. Deepening knowledge about the interactions between the atmosphere and oceans within the climate system has contributed to that skill, with respect to both tropical and extra tropical climate prediction. Currently, this skill is largely limited to selected locations and during specific seasons (e.g., winter season in North America). Further, forecasts are generally related to one specific, important ocean-atmosphere event, the El Niño, the name that has been attached to the development of a warm pool of ocean water in the eastern and central Pacific Ocean that occurs at irregular intervals, generally between two and seven years. Weather phenomena associated with El Niño have significant societal impacts. Moreover, these phenomena are somewhat predictable on a seasonal time scale and, therefore, present decision makers with opportunities to develop response strategies.

Prior to 1997, the strongest El Niño of record (i.e. largest sea surface temperature anomaly) for this century was recorded in 1982/83. Quite significant weather responses to that El Niño in the United States were observed that resulted in large societal impacts on safety, property, and economic development. The *Financial Times* (July 28, 1997) reported that the 1982/83 El Niño led to estimated U.S. losses of $2.2 billion with 161 human deaths. Several retrospective scientific investigations, including model research and development, showed some promise in the prediction of the anomalous climate of 1982/83.

In 1997/98, an even stronger El Niño occurred, and several seasonal predictions made prior to the onset of that event appeared to show statistical skill beyond climatological chance. Decision makers acted on those forecasts, taking measures that abated certain hazardous impacts, and enabled decision makers to capitalize on economic opportunities. The 1997/98 El Niño was the largest and warmest to develop in the Pacific Ocean in the past 100 years, and a milestone for seasonal forecasts. Analysis of 1997/98 El Niño impacts on the U.S. economy suggest that forecasts are a significant decision variable for management in several climate sensitive industries, as well as disaster preparedness. For example, there is strong evidence that California saved over $1 billion in property damages due to better preparation by state and local officials in response to the 1997/98 El Niño forecast.[2]

This Forum was developed with the recognition that: (1) numerical climate models today make seasonal to annual predictions with a limited, but nonetheless potentially useful, amount of skill; (2) knowledge on how to use the model output to formulate effective forecasts (e.g., use of probabilities) and generate useful climate information for most societal decisions is still evolving; and (3) decision makers and institutions have policy constraints that sometimes preclude the effective use of climate information. In recognition of these factors, the Forum brought together experts and representatives from the science community, all levels of government, and the private sector that were involved in climate predictions and their use. The thought was that society could make effective use of climate predictions only if these three issues can be addressed simultaneously. In order to focus the Forum, the discussions concentrated on one of the most predictable climatic events, El Niño.

The Forum took place over a two-day period on April 23-24, 2003 at the National Academies building at 500 Fifth Street, NW in Washington, D.C. It consisted of three panel discussions, each followed by a period of further reflection on the results of each discussion that led to specific findings and recommendations. The Forum program is Appendix A.

Each panel was composed of public and private sector experts in the respective topic areas and distinguished members of the relevant communities moderated the panel discussions. The names, affiliations, and addresses of the moderators and panelists are available in Appendix B. A list of the attendees is in Appendix C.

The position papers of the panelists are available on the Internet at the site: http://www.ametsoc.org/atmospolicy.

There was a final discussion among a subset of the panelists, moderators, and Forum planners and staff on the day after the close of the Forum. That discussion resulted in a set of general findings and recommendations regarding overall policy matters that emerged from the panel discussions pertaining to improvements in responding to climate predictions. These are presented in Section II. The recommendations that were developed in the three panel discussions

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[2] "Improving El Nino Forecasting: The Potential Benefits," ed. Rodney F. Weiher, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, August 1999.

have been grouped into two areas: Policy Issues In Responding To Climate Variability and Improving The Usefulness Of Climate Prediction Services. A brief background is presented with those recommendations in Sections III and IV.

Meaningful actions in response to these recommendations will require cooperative and collaborative efforts by the organizations and individuals involved in providing climate information and those involved in developing responses to that information at the federal, regional, state, and local levels and within the public, academic, and private sectors.

II. GENERAL FINDINGS AND RECOMMENDATIONS

At the conclusion of the Forum, a representative group drawn from the moderators, panelists, participants and staff met to consider crosscutting findings and recommendations that had emerged from the panel discussions. The group consisted of Jesse Aber, Mark Fernau, Genene Fisher, Richard Greenfield, William Hooke, Robert Landis, Rolf Olsen, Roger Pulwarty, Chet Ropelewski, Jason Samenow, Eileen Shea, and Ellis Stanley. That discussion initiated the process to develop the general Forum findings and recommendations. A draft report was then circulated to the panelists, moderators, and all participants for comment.

Following are the general findings and recommendations that emerged from that process:

FINDING 1 - Anticipation and response to seasonal climate variability offer potentially significant societal benefits.

Although the accuracy of climate predictions is still limited, they can be applied in positive ways to benefit society. Application of forecasts of the strong 1997/98 El Niño demonstrated that significant societal benefits could result from anticipating and properly responding to predicted seasonal climate variations. Seasonal and intra-seasonal predictions, observational monitoring and data, and other climate related information could be integrated into major economic and resource management decisions. Use of these climate services can enhance many economic and societal sectors such as water resource management, agriculture, public health, and natural disaster reduction.

Examples of decision making that can benefit from forecasted seasonal climate variations include:

- reservoir and water storage management decisions;
- agriculture decisions related to crop selection, irrigation, planting and harvesting schedules, and use of chemicals;
- emergency preparedness decisions regarding early logistic deployment of disaster assistance facilities (e.g., mobile homes, portable communication systems) and recovery supplies and personnel; and

An El Niño Forecast Application

In Peru, since 1983, rainy season forecasts have been issued each November. The forecasts are based on numerical model analyses of atmospheric and oceanic observations in the tropical Pacific region and the resulting predictions. The forecasts are presented in terms of four possibilities: (1) near normal conditions, (2) a weak El Niño with a slightly wetter than normal growing season, (3) a strong El Niño with flooding, or (4) cooler than normal waters offshore, with higher than normal chance of drought.

Soon after the forecast is issued, government officials meet with farmers' representatives to decide on the combination of crops to sow that will maximize the overall yield. The quantity and timing of rainfall in northern Peru is critical to the growth of rice and cotton, two of the primary crops grown. A forecast of dry weather suggests a preference for cotton, with its deeper root system. Wet conditions during the growing season followed by drier conditions during the ripening phase benefits the growth of rice. Therefore, farmers would be likely to plant more rice and less cotton in response to a forecast of El Niño weather.

- capital investment decisions regarding seasonal recreation (e.g. additional ski equipment).

FINDING 2 – Regional and societal climate impacts are significant, but not yet fully understood.

The impacts of climate variations on society can be significant, particularly at the regional level. This has been most clear in certain locations such as the countries bordering the eastern and southern Pacific during the occurrence of El Niño/La Niña. In most cases, the full range of processes involved in the impacts is not fully understood. Some of the phenomena that El Niño and La Niña affect are drought in northern Australia; temperatures and precipitation on the western coast of tropical South America; and tropical and extra-tropical cyclone frequency and intensity, as well as, precipitation quantity along the California and Gulf coasts, throughout the Pacific and in some interior portions of the United States. However, the regional climate impacts with regard to timing, duration, and specific locations are not fully understood. In addition, there are indications that other phenomena, besides El Niño/La Niña, also affect regional climate variations. The understanding of how these phenomena impact climate still is largely unknown.

FINDING 3 - Seasonal forecasts have a limited, but useful, level of skill and with enhanced infrastructure and research this level can be raised substantially.

During the last two decades, a limited number of climate predictions, particularly on a seasonal basis, and often related to the El Niño, have been made available to the public and other users. Forecasts of El Niño during 1982/83 and 1997/98 provided useful information on expected climate variations, months in advance. Limited objective verification has demonstrated that seasonal forecasting has a small level of skill (accuracy above climatological chance). Even the present level of skill is potentially useful for many societal applications, but this potential remains unrealized in some sectors for a variety of reasons primarily relating to communication and understanding of climate information. Improvements in observations, models, and understanding of climate variability hold great promise for higher levels of skill in seasonal forecasts. However, a balanced research effort is needed, to improve the forecasts and to make

Climate prediction Skill

In the context of weather or climate predictions, "skill" is a statistical measure of the accuracy of forecasts. A commonly used measure is called a "skill score." The skill score is a measure of how much better or worse a prediction is than merely using a climatological average of the predicted parameter (e.g., temperature).

The skill score for a series of predictions compares the mean differences (disregarding whether they are positive or negative) between the predicted values and the observed values of the predicted parameter to the similarly calculated mean differences between the climatological average of that parameter and the observed values.

For example, if we have a model that forecasted the daily temperatures in Washington, D.C. for last month, the skill score of those forecasts measures how accurate those forecasts were compared to merely using the daily average (climatological) temperatures for that month. Over some period of time (i.e., several months) we would calculate a skill score for the model that was used to make those forecasts.

By knowing the skill score, a potential future user of such forecasts can decide whether the model provides forecasts that are more useful than merely using climatology.

better use of the resulting forecast information. Improvements in one but not the other will have marginal impact.

In response to Findings 1-3, the Forum made the following recommendation:

RECOMMENDATION 1 – The nation should increase investments in climate science research, climate impact assessments, and strengthening the supporting infrastructure to improve climate predictions resulting in significant societal benefits.

FINDING 4 – Climate predictions and information are not provided in the most useful way to decision makers.

In many cases, climate predictions and information are not well suited for user needs. Much of the terminology associated with climate information is confusing. In addition, the timing requirements of users are not well understood by the information providers. Unlike daily weather forecasts, climate predictions and information require much more supporting data to be useful. New or improved methods of communicating climate information need to be considered, including formats and content. For example, graphical comparisons of forecasts with climatology, normals, previous seasons, etc. can be very useful to decision makers.

In addition, climate information terminology, often different than that used in weather forecasting, must be explained clearly. Terminology such as "warning" routinely used in weather forecasts, is not appropriate or useful in denoting risk related to climate variability. Since climate predicting, particularly on a seasonal basis, is relatively new, decision makers need supporting evaluations of success before making major climate-related decisions that directly affect the public or stewardship of public resources (e.g., water supply). Finally, there is little information available on objective evaluations of successful applications of climate services.

For most decision makers and the public, statistical or probabilistic climate information is poorly understood. Such information is intended to convey such things as certainty (or uncertainty) of an event, confidence that an event will occur or not occur, and other characteristics. To be useful for decision makers, climate prediction information should be provided with certainty (or uncertainty) quantified in a clear, understandable presentation or format.

To some degree, the USDA Agricultural Extension Service, with its own field structure of extension agents, has provided statistical climate information to farmers or agricultural managers. The extension agents interact effectively with users of this information, based on commonly understood terminology. The use of such a concept to create "climate extension agents" with at least some familiarity with the activities of the decision makers could be one mechanism for assisting in clarification of statistical measures such as "uncertainty."

RECOMMENDATION 2 – Providers of climate predictions should include clearly defined uncertainty measures (probabilistic information) that are presented with mutually understood terminology.

FINDING 5 – Climate information is most effectively developed and applied through partnerships between climate information providers and decision makers.

Use of climate information can be most effectively developed and applied when scientific data and information are placed in a context and format that is a part of the decision maker's overall management system. The inclusion of the decision maker's input regarding variable and parameter selection, as well as timing and formats, must be a part of the overall development and application of climate prediction and information services. For example, water resource managers need climate information that would impact potential variability in stream flow at a time when decisions can be made to change water releases or flows.

RECOMMENDATION 3 – Representatives of government agencies, private sector organizations, and academia should establish a collaborative approach to develop and provide a national capability for climate prediction and information services that would foster mutual trust and useful applications of climate information.

FINDING 6 – Special training is needed to prepare professionals that can communicate information between the providers and consumers of climate information.

The process of developing an effective national capability for providing climate prediction and information services that are effectively tailored for end users should incorporate all of the capability that exists in private, academic, and governmental institutions. The present nucleus of professionals in this field with experience and expertise is quite limited. Maximum benefit could be attained through a collaborative approach that can help build trust, additional capability, and expanded applications of climate services among the participants for the benefit of society.

A growing number of application oriented scientists have begun to take on the role of "science integrator" in order to bridge a significant gap between the climate scientist and the consumer of climate information. To successfully gain an understanding of the consumer's information needs and applications, education and experience in both applications of climate science and the use of analytic tools is necessary. Such interdisciplinary endeavors have often not been fully accepted or promoted within academic, private, and governmental institutions. Academic institutions should develop advanced interdisciplinary opportunities to educate students to undertake roles as science integrators. In addition, fellowships should be established through professional academic programs along with use of Intergovernmental Personnel Agreements (IPAs) to further develop professionals with these skills and experiences.

RECOMMENDATION 4 –Academic institutions should establish educational programs to produce "science integrators" who understand how to communicate user needs to providers and facilitate the application of climate information for users.

FINDING 7 – The use of climate predictions by decision makers is limited by a lack of evaluation of the risks and benefits.

The uncertainty inherent in climate predictions naturally leads to probabilistic formulations and therefore, has the potential to be applied to risk management. For many decision makers the use of risk management is one of the most important aspects of their job. Risk management decisions can involve relatively large investments in order to either avoid large future costs or to take advantage of future opportunities that will reap major benefits at low cost. Using good climate predictions can optimize those decisions that are affected by future weather and climate. However, very few assessments or evaluations have been made regarding climate risk management for most decision-making situations.

During the past decade, climate-risk management has been applied to agricultural and other weather sensitive commodity markets. In addition, a new weather ("climate") derivatives industry has emerged. However, it has been limited by the availability of assessments of risk and benefit. The trading (buying and selling) of future commodities is largely a function of projected weather conditions, such as in the consumption (price) of heating oil or the availability of certain crops. Knowledge of the risk of crop reduction or loss can be as valuable for pricing as the loss/benefit from under- or over-supply of a commodity. Therefore, knowing these risks and benefits provides a basis for stabilizing supply and/or price.

The evolution of climate prediction services will, in large part, depend on the results of projects that can demonstrate the importance and usefulness of forecast information to decision makers responsible for developing response strategies to climate variability. By working with users, climate scientists should demonstrate the relevance and utility of climate information by drawing on the results of forecast applications and/or retrospective analyses. Maximum acceptance of the value of climate information will emerge from objective evaluations of applications that have been adequately documented over a sufficient period of time.

Once systematic climate information has become part of an overall decision process, it is important to establish a set of performance metrics. The metrics should effectively quantify the impacts and benefits of applying climate information to the process of decision making. The use of performance metrics is an important part of the "feed-back" needed to optimize the process and justify investment. Results of quantifying the benefits of using climate predictions is, perhaps, the most credible evidence necessary to convince executive decision makers to use the climate information. Such evaluations will have a cumulative effect in expanding the use of climate prediction services, particularly in many private industries where there is significant competition.

RECOMMENDATION 5 – Climate service providers and decision makers should work together to develop measures of improved performance resulting from using climate information as part of the decision process.

III. POLICY ISSUES IN RESPONDING TO CLIMATE VARIABILITY

The Forum agreed that the application and benefits of climate predictions must be investigated in the context of existing management policies and institutions. Users must verify forecast reliability and the climate community and policy officials must jointly demonstrate usefulness to the stakeholder community. Both users and climate scientists must jointly demonstrate accuracy, usefulness, and reliability to the stakeholders. Climate information services need to be integrated into existing and future decision making frameworks.

Climate prediction information has the potential to allow for governmental development of preparedness strategies and, in some cases, the application of incentives for certain response actions as opposed to regulations and control. However, in some governmental jurisdictions, there are various policy restrictions that inhibit the application of climate prediction services for long-range planning of responses to climate variability.

Some of the major concerns that decision makers have about using climate predictions include:

- accuracy and reliability of climate predictions;
- assessing benefits of responding to climate predictions;
- quantification and communication of uncertainties;
- presentation of climate prediction information on a continuum of timescales that includes historical climate information;
- geographic and temporal resolution of the predictions;
- presentation of prediction parameters needed by the decision makers; and
- limited management flexibility and/or legal-policy constraints in some sectors or institutions.

While it is important to recognize and deal with these concerns about using climate prediction information, decision makers should be encouraged to adopt policies that enable proactive approaches that move beyond reactive responses to climate variations. Climate services can be viewed as one component of the social, economic, and environmental considerations that decision makers must take into account. This is particularly true in many developing countries where building resilience to climate can contribute to reduction in poverty as well as supporting sustainable development.

The probabilistic nature of climate prediction lends itself especially well to emergency risk management. Combined with vulnerability assessment, risk management using climate information can be an important tool for emergency managers. This can help reduce time stress at the time when extreme events become high priority. In addition, decision-making tools that integrate climate information can help in educating and training the public in areas such as awareness and preparedness. The Forum suggested that there are emerging policy opportunities in climate risk management, namely:

- integration of climate considerations in disaster management,
- management of climate-related risks in key sectors, and
- focusing on extreme events for decision makers.

There are a limited number of professionals with skills in synthesizing and integrating climate sciences and information in a societal context. Therefore, these individuals must be encouraged to seek training not only in climate science, but also in climate socio-economic impacts. In this regard, the Forum recognized an increasing need for a new professional skill that can integrate and merge climate scientific data into decision making processes that improve society's ability to respond to climate variations. The emergence of the profession of "scientific integrators" is an important new component of climate information services. The limitation in the numbers of "scientific integrators" is due in part to a lack of incentives and rewards at academic institutions and, in some cases, actual disincentives for taking on multidisciplinary studies instead of specializing in the traditional disciplines.

RECOMMENDATIONS

The Forum addressed a wide range of topics and opportunities for improvements pertaining to policy issues in managing climate variability. The following recommendations amplify and specify in more detail the broad set of General Findings and Recommendations listed in Section II of this report.

1. Government decision makers should integrate the use of climate information into national and international planning. Tools, based on climate data and analysis, should be developed that help integrate climate information and understanding into planning at all governmental levels.

2. In partnership, the government, academia, and private sector should identify one or more "grand challenges" to improve climate prediction services and applications. These challenges will provide a strategic focus for organizing shared efforts to advance the mainstreaming of climate information in policy formulation in the near-, medium- and long-term. Implementing an integrated program of climate risk management could be an important, near-term framework for such an endeavor. Within that framework, an example of such a grand challenge is an overall study to document and report on the impacts of climate variability on society.

3. Governmental and academic institutions should consider increasing educational opportunities for climate scientists to better understand society and climate. Understanding how society reacts to climate and related forecasts is an important undertaking that can help define needed meteorological research as well as improve the benefits from climate prediction services.

4. Government agencies, resource management institutions, and private sector enterprises should aggressively recruit and retain scientists with science integration skills as part of their programs in climate-sensitive sectors. Public and private climate information providers and potential users should recognize the important role of trusted "scientific integrators" in the effort to integrate climate data with decision making. A relatively new profession, known as scientific integration, has emerged over the past decade. The practitioners of this profession, called "scientific integrators" possess the education and skills that enable them to facilitate the application of climate science information into the nonscientific decision making processes. Scientific integrators require not only knowledge and/or experience in climate science and forecasting, but also an understanding of the processes involved in decision-making by users. These professionals need to be sufficiently objective to earn the trust of decision makers and their institutions.

5. The government should make balanced investments in research to advance the chances of reaching the theoretical potential in climate predictions to meet national economic and social needs. The investments should be devoted to:

- enhanced understanding of climate variability;
- more accurate climate prediction modeling techniques and data assimilation methods;
- expanded quality and quantity of observations;
- supporting infrastructure of computers and information systems; and
- a collaborative modeling focus, both nationally and internationally, among institutions and governments.

6. The U. S. government, in partnership with academia and the private sector, should encourage the World Meteorological Organization (WMO) to provide mechanisms for sharing information on climate services and applications internationally. Ongoing discussions about the emergence of Regional Climate Centres in the WMO provides a special, near-term opportunity. To achieve sustainable development on a global scale, the nations of the world will need to effectively use climate information.

7. The AMS should provide opportunities for continued science-policy dialogues, since climate science policy is a relatively new area. As a result, there should be more opportunities for open dialogue that is focused on climate-sensitive sectors. The goals of these dialogues include:

- identification of critical climate information needs;
- enhanced understanding of vulnerability;
- improved assessment methodologies;
- exploration of response strategies; and
- increased awareness of current and emerging forecasting capabilities and decision-support tools.

IV. IMPROVING THE USEFULNESS OF CLIMATE PREDICTION SERVICES

Since the 1982/83 El Niño, there has been increased use of climate information, primarily seasonal forecasts, by decision makers. Most of the applications have been in support of weather sensitive industries such as agribusinesses, electric-gas utilities, disaster management and water resource management. Assessment of these applications has helped to develop improvements and increased use of climate information in decision making.

The Forum acknowledged that climate predictions are fundamentally probabilistic. Climate by its nature of being a time and space average of weather suggests that its prediction is best presented in statistical terms. Further, there are currently a variety of methods employed routinely to predict El Niño, ranging from fully statistical models, to hybrid statistical-dynamical models, to complex coupled models with sophisticated data assimilation and initialization procedures.

The Forum noted that when the results of several different forecast models are integrated, even in the simplest manner (i.e., an average), the overall performance is generally found to exceed that of all the individual models. As a result, the concept of multi-model based forecasts is now accepted as a preferred prediction technique. A very reasonable hypothesis supports this concept, namely that each forecast model has various systematic errors, and that a multi-model based forecast is more likely to represent the full range of possible outcomes than any individual model.

Ensemble methods are becoming a primary mechanism for preparing probabilistic forecasts from dynamical models. Rather than a single forecast, many forecasts are made, either with slightly different

Forum Opinions of Climate Prediction Skill

Rick Anthes, the moderator of Panel 1 conducted a survey of the views of the Forum participants concerning the present and future skill of climate predictions.

The participants were asked the following questions:

1. On a scale of 0 to 10, where 10 would be "perfect," how accurate (skillful) are seasonal forecasts (forecasts of a season made at least 90-days in advance) today?

RESULTS FROM 29 PARTICIPANTS

Mean: 3.17 Median: 3.00
Standard deviation: 1.36
Maximum: 6.0 Minimum: 1.0

2. On the same scale of 0 to 10, what is the theoretically possible future seasonal forecast accuracy (skill)?

RESULTS FROM 29 PARTICIPANTS

Mean: 6.36 Median: 6.75
Standard deviation: 1.46
Maximum: 9.0 Minimum: 2.0

CONCLUSIONS

Rather strong agreement exists currently that there is a small level of forecast skill.

There was a substantial consensus that significant improvement in climate prediction skill is possible. However, the wide range of extremes (9.0 and 2.0) indicates that the participants included a few extreme optimists and pessimists.

initial states, or some other means of introducing small perturbations. The probabilities associated with specific outcomes of the seasonal climate can then be estimated directly from the ensemble results. Current forecast systems generally use such an approach, and indeed the best results are found with a multi-model "superensemble," for the same reasons as mentioned above for El Niño predictions. Skill levels vary greatly among regions, seasons, and models. Generally, only small shifts in probabilities can be forecasted, and only for very limited regions, due to the inherent limited predictability ("noise influence") or model errors that mask signals that are actually predictable.

At present, probabilistic forecast guidance from numerical models is limited to temperature and precipitation and is expressed in terms of seasonal means. It is clear that additional variables and different time and space scales are needed for climate predictions to be responsive to the requirements of most users.

Noting the probabilistic output of climate predictions, the Forum identified the need to present statistical forecasts in ways that would be most useful to decision makers. In addition, there is a need to describe incorrect or failed forecasts in terms that the decision maker can understand. Some methods of "downscaling" climate predictions have recently been introduced, and in some cases are showing promise; for example, in establishing more realistic local variability patterns associated with topographic effects, and in producing quasi-realistic weather sequences.

Observations in the equatorial Pacific are now adequate for detecting the development of El Niño and providing initial conditions to models, but additional coverage could improve prediction lead-time and accuracy. The Forum noted that satellite observations (e.g., sea surface temperature and altimetry) have great potential to be useful in climate models. In addition, more oceanographic measurements are needed in other tropical basins (Atlantic, Indian) and at higher latitudes.

With appropriate initialization, climate models can make useful forecasts of the evolution and, perhaps, the strength of El Niño, but many issues remain to be fully resolved:

- There is limited skill in forecasting the transition, onset, and strength of El Niño/La Niña, except in extreme cases.

- Intraseasonal variability is important (and may trigger or affect strength of El Niño) but is not yet modeled well.

- Teleconnection predictions, i.e., predictions of weather variations far removed from the phenomenological causes, are not as good as the forecasts of the presumed cause, i.e., El Niño (SST and index).

- Verification tools that capture probability (such as skill scores) are needed in operations and research.

It is clear that climate scientists must take the responsibility to understand user needs, including the context in which application decisions must be made. It is important that the scientist understand product relevance, accessibility, and acceptability by the decision maker. The Forum recognized that in the use of climate information, decision makers depend upon the following factors: sector, scale, timing, experience, perceived impacts of decision, and the decision making context. In turn, decision-making context depends on precedent, institutional boundaries, investment in status quo, training, risk, staff resources and time, value of information, and expectations.

The Forum stressed the importance that providers of climate prediction services ensure that performance is transparent to the user. This includes explaining terminology, such as forecast skill, and working with the decision maker to understand the different impacts resulting from various levels of forecast performance. Ensuring transparency of the forecast process to the user should help in affecting evaluation and feedback regarding the usefulness of the forecast. As a part of providing transparency to the user, the Forum suggested that it is appropriate to document the level of forecast accuracy during an immediate previous time period (e.g., last 5 years).

The Forum discussed important aspects to improving climate prediction information for users, in addition to improving observations and modeling. These include:

- enhancing communication between the forecasting community and the user community;
- providing more useful formats and target variables of the forecast products;
- expanding the use of forecast products; and
- developing a common understanding of terminology (e.g., Watch, Warning, Advisory, Outlook, El Niño).

The Forum agreed that a partnership of representatives from government, the private sector, and academia is necessary to encourage and expand the use of climate prediction services and information in many public and private decision making situations. In this regard, the Forum recognized that, in the United States, the Federal Government (i.e., NOAA/CPC) provides base forecast products and that universities and the private sector can "tailor" products for specific users. In some cases, just a verbal or written explanation of a climate prediction graphic by academia or the private sector could be sufficient to support better decision-making by a user.

RECOMMENDATIONS

The Forum addressed a wide range of topics and opportunities pertaining to methods to improve the usefulness of climate prediction services. The following recommendations amplify and specify in more detail the broad set of General Findings and Recommendations listed in Section II of this report:

1. There should be regular discussions among representatives of the providers of climate services concerning enhancements in those services. Presently, basic prediction guidance that is widely distributed by the NOAA Climate Prediction Center (CPC) makes available climate information to many users and decision makers. In many cases, the guidance information is enhanced significantly and is tailored to be application-specific for users by climate scientists in the private sector and/or academia. By having regular discussions about potential service enhancements, the various providers can continue to build a cooperative partnership.

2. Providers of climate information and forecasts should ensure that the space scales, timescales, and variables of interest to end-users are addressed clearly. It is especially important to convert basic meteorological elements to variables, such as stream flow, that are of interest to end-users.

3. Climate prediction providers should ensure that uncertainty measures are clearly stated to the public and decision makers. The measures should include information related to:

- probabilities of occurrence of the forecasted variables or quantities;
- confidence level of the forecaster in a specific forecast;
- accuracy of recent forecasts;
- conditional relationships of outcomes based on similar historical conditions; and
- general physical reasoning behind the forecast.

4. Climate information providers and decision makers should create partnerships that support shared learning (co-production of knowledge) and joint problem solving. These partnerships should:

- be a joint, interactive endeavor between participants in climate science/application and in societal decision making;
- approach as many problems as possible jointly and share the information and experiences gained;
- design and execute pilot projects to build a body of knowledge and experience;
- jointly assess the benefits, reliability, and impacts of climate prediction applications in an attempt to "scale-up" the lessons from individual projects to more general, successful applications; and
- respect provider-user confidential relationships.

In the course of carrying out these projects, the mutual trust necessary to make the partnerships effective will be developed.

V. CONCLUSIONS

Many aspects of the recommendations presented in this report must be met by the private sector—including corporate decision makers and the value-added meteorological services industry that provides climate information. Other aspects require public sector investments and actions. There are also recommendations that require university actions and research activities. The recommendations developed in this Forum, although directed, for the most part, at specific portions of these interested communities, can be best implemented through cooperative efforts among those communities.

These cooperative efforts, therefore, require effective public-private-academic sector partnerships. As noted in Section III, the Forum participants recommended that the AMS should be proactive in organizing dialogues that could foster the development of effective partnerships between the climate information providers and users. The AMS is prepared to serve in that role.

Implementation of the Forum recommendations by partnerships in the United States and abroad would result in the development of effective responses to climate variations.

APPENDIX A — PROGRAM

A POLICY FORUM: IMPROVING RESPONSES TO CLIMATE PREDICTIONS

Developed by the American Meteorological Society
in collaboration with Columbia University

The National Academies
500 Fifth Street, NW - Room 100
Washington, D.C. 20001

Wednesday – April 23, 2003

0830 Opening Remarks/Welcome: Chris Elfring, Director, BASC, NAS; E. Friday, President, AMS; Ellen Smith, Assistant V.P. for Government Relations, Columbia University

0845 Forum Overview: R. Greenfield, Senior Policy Fellow, Atmospheric Policy Program, AMS

0900 Keynote Address: Ants Leetmaa, Director, GFDL/NOAA

0930 Panel 1: Progress of climate science in providing information to prepare and respond to seasonal variations.

Moderator: Rick Anthes, President, UCAR

Tom Karl, Director, National Climate Data Center, NOAA – climate information
Jim Laver, Director, Climate Prediction Center, NOAA – climate prediction
Jagadish Shukla, Director, Center for Ocean-Land-Atmosphere Studies, George Mason University – international perspective of climate predictions
Steve Zebiak, Interim Director, IRI, Columbia University – research potential for improvements in climate prediction

1030 Break

1100 General Discussion – preliminary findings and recommendations focused on the questions considered by the panel:

1. Which observations support the identification of the El Niño/La Niña, what is the infrastructure that enables those observations, and what are the observational deficiencies?

2. How well do the models predict the time history of the El Niño/La Niña and associated phenomena on a global scale and do the model predictions capture the time scales adequately?

3. How well is the weather and climate information communicated to decision makers and what improvements should be made?

4. What improvements are needed in observational, technological, and modeling capabilities to significantly increase seasonal predictive accuracy?

1230 Lunch

1400 Panel 2: Progress in the development of decisions on regional and sub-regional strategies to respond to information on seasonal variations in climate. The focus will be on the response to El Niño related events, most notably those of 1997/98 and the events currently underway.

Moderator: Roger Pulwarty, Climate Diagnostics Center, NOAA/CIRES

David Changnon, Associate Professor, Northern Illinois University – U.S. agribusiness and utility industry
Kathy Jacobs, Assistant to the Director, Arizona Department of Water Resources – Connecting water management and climate information
Upmanu Lall, Sr. Research Scientist, Columbia University – Water resource management
Ellis Stanley, General Manager, City of LA Emergency Preparedness Dept. – Emergency management

1500 Break

1530 General Discussion – preliminary findings and recommendations focused on the questions considered by the panel:

1. How do decision makers at present manage responses to climate variability?
2. What climate prediction uncertainty measures are critical to response decision makers in the U.S.?
3. How well is information on the probabilistic nature of climate predictions and uncertainties communicated to response decision makers and the general public?
4. In what ways can the experience be utilized in developing countries?

1700 First-day wrap-up

1800 Reception and Dinner (located in the atrium)

Speaker –Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (Ret.)
Undersecretary of Commerce for Oceans and Atmosphere and NOAA Administrator

Thursday – April 24, 2003

0815 Preliminary Remarks (Greenfield)

0830 Panel 3: Policy issues in managing climate variability at relevant levels.

Moderator: Susan K. Avery, Director, CIRES, University of Colorado

Jesse Aber, Water Resources Planner, Montana Governor's Drought Committee
Rolf Olsen, Water Resources Systems Engineer, U. S. Army Corp. of Engineers
Eileen Shea, Climate Project Coordinator, East-West Center
Shiv Someshwar, Research Scientist, IRI, Columbia

The panelists will each make a 20 minute presentation followed by a 10 minute intra-panel discussion of policy issues, options, and opportunities related to the development and effective application of specific strategies to derive greater benefit from climate information and seasonal climate predictions.

1000 Break

1030 General Discussion – preliminary findings and recommendations focused on the questions considered by the panel:

1. What are the key policy issues in managing responses to climate variability?

2. How can the policy/decision-making framework be improved?

1200 Lunch

1300 Discussion of the overarching findings and recommendations of the Forum.

Moderator: William H. Hooke, Director, Atmospheric Policy Program, AMS

Focus on identifying recommendations and policy implementation options necessary to improve responses to climate predictions.

1430 Actions and Next Steps

1500 Status of actions from prior fora in the AMS Atmospheric Policy Program Forum Series and summary of future plans.

1530 Adjourn

APPENDIX B — PANELISTS

Panel 1

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