A PROPOSAL TO LAUNCH A SEASONAL – TO – INTERANNUAL CLIMATE PREDICTION PROGRAM

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P R E F A C E

On behalf of the National Oceanic and Atmospheric Administration, and in partnership with other U.S. agencies, I am pleased to present this U.S. proposal as a contribution to the establishment of a Seasonal-to-Interannual Climate Prediction Program. This is a transitional program, one that builds on research results and links research and operations to take the next steps toward reliable operational forecasts of global and regional climate variations on seasonal to interannual time scales. The Program will provide experimental forecasts and analyses of climate variations on a regular basis, and will contribute to the infrastructure by which this information can be used for social and economic benefits by all countries.

The scientific base for the SCPP derives from the enormous amount of work done over the past two decades in understanding the interaction between the ocean and the atmosphere in the tropical regions and the links between the tropics and mid-latitudes. The experimental forecasts carried out by many different climate modeling groups have begun to show real and useful skill in the seasonal to interannual time frame. The forecasts are increasingly being used by decision makers in many countries for policy formulation.

The SCPP is also presented in response to the call at the 1992 United Nations Conference on Environment and Development for global responses to shared environmental challenges. The U.S. and other countries that have already invested in climate prediction have come to recognize the urgent need to extend this scientific capability. The SCPP proposal recognizes that the understanding of global scientific problems requires information and insight from every region of the world, and that it is time to invest, as partners, in scientific capacity building within all interested countries. The proposal is a U S. national commitment to a shared international effort with all who wish to participate in, contribute to, and benefit from production of scientific products designed to make our social and economic systems more compatible with climate fluctuations.

The SCPP provides a mechanism for the advancement of experimental forecasts, enhanced research, observations and data management, and applications of information on seasonal to interannual time scales through a multinational network of Research Centers and Applications Centers Anticipatory U S. plans include the enhancement of NOAA's National Meteorological Center's interaction with the international research community so that research results can be smoothly translated into operational systems.

The SCPP proposal as presented here represents an evolution of the concepts expressed in the earlier proposal from an international group of scientists for an International Research Institute for Climate Prediction That group, led by the Chairman of the Intergovernmental TOGA Board, eloquently addressed the critical need for international collaboration and focused efforts in climate modeling, prediction, and application of forecast information. The SCPP proposal is a vision of how the U.S., through its Global Change Research Program, would implement these concepts and is offered as a framework from which a multinational dialogue can be launched

The objective of this proposal is to lay the foundations of a transitional structure to lead us toward an operational program that systematically produces and disseminates climate forecasts for application in social and economic planning. As described in the pages that follow, the Program that I envisage will not be possible without carefully developed cooperative planning across many different scientific disciplines and national borders. Working together, nations of the world can thus meet their economic, social, and environmental needs long into the future.

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EXECUTIVE SUMMARY

The ability to skillfully predict climate variability on seasonal to interannual time scales represents a scientific accomplishment of historical dimensions with profound implications for advancing our understanding of the interaction of environment and society.

Successful simulation of the mutual evolution of the atmosphere and ocean through coupled modeling has provided the means to predict, with significant skill, the behavior of the El Niño-Southern Oscillation (ENSO) cycle, known to be central to short-term variability in the earth's climate system. This understanding is fundamental to the scientific issues of climate dynamics and therefore carries implications important not only to an enhanced understanding of short-term variability, but also for efforts to predict climate change on longer time scales. Such predictions represent a major new tool for sustainable development, as they offer opportunities to more effectively manage natural resources and improve the quality of human life, especially for those living in regions most vulnerable to the impacts of climate variability.

In this document, the United States is proposing an international framework for a multinational Seasonal-to-Interannual Climate Prediction Program (SCPP) designed to provide reliable forecasts and analyses of climate variations on seasonal to interannual time scales, and to develop the infrastructure by which this information can be used for social and economic benefit by all countries of the world. This proposal outlines a transitional program envisaged to lead ultimately to a long-term operational program for the systematic production and application of regionally tailored climate forecasts. The SCPP is based on an end-to-end integrated approach to address interannual climate variability from its origins through its physical manifestations to its socioeconomic impacts. It includes four essential components: Integrative Modeling and Prediction, Scientific Assessment focused on the application of climate predictions, Observation and Data Management, and Process Research

The SCPP is intended to assemble participants from around the world to achieve a task no single country could accomplish on its own: the creation of a global climate forecast system with the capacity to employ regional analyses to refine forecasts and apply them for the benefit of human societies. As an integrated multinational system with a wide range of participants contributing data, information, and scientific talent, the benefits available to each participant will no doubt far exceed the sum of the individual contributions.

The U.S. is committed to contribute to a multinational planning process intended to lead to the early establishment of the multinational infrastructure needed to generate and transfer useful climate information and forecasts. The desire for such a system has been expressed by scientists and decision makers from a number of countries affected by the consequences of climate variability. These nations have widely varying scientific infrastructure and computational capacity; a system is needed which will serve all of them Continuing efforts by countries which already have built capacity in this area will be encouraged as they can provide an essential contribution to a global climate forecast system. National operational centers in existence now are utilizing research results and are beginning to institutionalize operational seasonal forecasts for the regions they serve. This proposal also addresses a new and fundamental component of such a system: the establishment of a network of centers operating on behalf of those countries that do not currently have the infrastructure required to produce national climate forecasts. The comprehensive system will benefit from the interaction of both existing and new operational and research facilities.

As envisioned, the system would include a network of Research Centers, within which an International Research Institute for the Seasonal-to-Interannual Climate Prediction Program would be established with the responsibility for generating and distributing experimental forecasts multinationally. The U.S. plans a formal process for identifying Research Centers, largely at existing research institutions and will accept proposals from one or a group of such Centers to establish a host site for the International Research Institute. The U.S. Centers will be largely funded by NOAA. In addition to generating experimental guidance products, the Institute will conduct model research and development and provide a net assessment of the various operational and experimental guidance products available to users. The Research Centers will enhance the development of climate forecast models and forecast methodologies and sponsor training of scientists and decision makers from participating countries. These Research Centers will necessarily draw upon a wide range of research efforts including those supported by a number of U.S. agencies through the U.S. Global Change Research Program and those within the broad-based international scientific community. The Centers will also work closely with national and international facilities, such as the U.S. National Meteorological Center, which have the responsibilities for operational delivery of climate products. The forecast system will also include Regional Applications Centers established and funded by participating countries to develop localized forecasts and distribute products of immediate social and economic value.

The shared ownership and shared benefits inherent in these multinational arrangements imply that the success of the effort depends upon shared responsibility for its financial security. Governments and other entities with a vested interest in the products of this multinational network of centers will be the source of financial resources required to support the institute's operational expenses. The United States is prepared to take a leadership role on behalf of a group of partner nations and has initiated the process of identifying, within the context of the U.S. Global Change Research Program, resources to represent a U.S. contribution to this multinational endeavor. Since the SCPP is proposed to be a fully multinational initiative, it is expected that all participating entities would contribute to one or more network component activities in the form of both in-kind and financial resources.

SEASONAL-TO-INTERANNUAL CLIMATE PREDICTION PROGRAM

I. INTRODUCTION

Coping with variability within the natural climate system is one of the most fundamental factors affecting the course of human development. Societies, economies and cultures throughout the world have developed based in large part on their ability to adapt most effectively to their anticipated climates. When temperatures and precipitation patterns depart significantly from expected historical seasonal averages, the results, if unanticipated, can be catastrophic. Global implications associated with year to year climate variability include periodic incidents of extreme drought such as that experienced throughout southeastern Africa in 1991-92; severe flooding, including the recent deluge in the Midwestern U.S.; and severe impairment of critical sectors of national economies, such as the 1972/73 collapse of the Peruvian anchoveta fisheries.

The proposal that follows outlines a comprehensive, multinational program to advance research and prediction of climate variability on seasonal to interannual time scales and to enhance the social and economic relevance of such information in order to develop a dialogue with decision makers for whom climate information will be a valuable asset.

Scientific Background

The El Niño-Southern Oscillation (ENSO) phenomenon refers to a coupled oceanic and atmospheric interaction known to be a central factor in short-term climate variability throughout the globe, particularly in the tropics. The capacity to predict climate anomalies is currently linked to the ability to forecast, as much as a year in advance, the onset and intensity of a warm phase or a cold phase of the ENSO cycle through the advent of coupled models of the Pacific Ocean and the atmosphere above it.

Because of limited observational capabilities, before the 1980s it was not even possible to know if an ENSO event (warm or cold phase) was underway until several months into the event. Progress in climate prediction in the 1980s and early 1990s has been stimulated by the development of a variety of models used for ENSO prediction; by empirical studies that have better defined the global impacts of ENSO; by theoretical studies that have elucidated the underlying oceanic and atmospheric processes accounting for the predictability of ENSO; and by the establishment of an ocean observing system (primarily in the Pacific) for initializing and verifying models under development for ENSO prediction Compared to the early 1980s when observational techniques were inadequate to simply monitor the evolution of an ENSO event once underway, we are now able to observe day-to-day changes in surface winds, sea surface temperature (SST), upper ocean thermal structure and ocean currents on a basin scale in the tropical Pacific, and routinely issue experimental forecasts with useful skill at up to one-year lead times.

Applications for Sustainable Development

This new ability to forecast climate variability with improved accuracy, along with strong indications of continued progress, represents a seminal contribution to our understanding of earth systems processes. Yet, it is the application of this new technology which affords the opportunity to turn a scientific breakthrough into a tool to promote sustainable development by employing scientific information to improve the quality of human life, to increase economic efficiency, and to live effectively and efficiently with the finite resources of the earth. At the same time, applying our increased understanding of the climate system affords us the ability to gain experience in identifying and adjusting societal responses to climatic fluctuation. Adaptation and mitigation on seasonal to interannual time scales will prove critical in light of the possibility of longer term climate change

History of the Climate Prediction Initiative

The proposal to establish an end-to-end (research to prediction to application), multinational Seasonal-to-Interannual Climate Prediction Program (SCPP) is based on the evolution of existing efforts to observe, understand, predict, and assess oceanic and atmospheric processes, and their interactions. These distinct yet highly interrelated efforts provided the foundations which enabled the research community to arrive at the capability to predict climate variability on seasonal to interannual time scales and are each a component of a comprehensive program. Added to these existing efforts is a new component intended to advance our understanding of societal impacts of variability and the nature of possible social and economic adjustment.

A key component of these existing efforts is the Tropical Oceans/Global Atmosphere (TOGA) Program scheduled to end in 1994 TOGA, an international research program designed to describe the tropical oceans and the global atmosphere as a time-dependent system and to understand and model the mechanisms underlying its predictability, has developed two capabilities vital to climate prediction:

(1) models that couple the ocean and atmosphere to successfully forecast ENSO up to a year in advance; and
(2) an observing system spanning the Pacific Ocean to facilitate prediction and analyze the development of ENSO.

As TOGA comes to a close, its research results are ready to be implemented on a long-term sustained basis. The remarkable achievements that have been made over the past ten years in the ability to forecast short-term climate variability associated with the ENSO phenomenon have led to the call by many nations for a coordinated multinational effort to produce and distribute experimental forecasts. The concept was endorsed four years ago by the U.S National Research Council of the National Academy of Sciences, through its Advisory Panel for the interagency TOGA Program. The international TOGA Scientific Steering Group and the Intergovernmental TOGA Board have also promoted the concept of a focused data assimilation and experimental prediction effort coupled with a distributed network of regional centers which would interpret and validate model predictions for regional applications. TOGA research is conducted under the auspices of the World Climate Research Program (WCRP) and sponsored by the World Meteorological Organization (WMO), the International Council of Scientific Unions (ICSU) and the Intergovernmental Oceanographic Commission (IOC). In the U.S., TOGA is an interagency program which benefits from multi-agency coordination, particularly among the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Office of Naval Research (ONR) As the SCPP evolves, management of U.S. participation will depend on continued coordination among these agencies.

In 1992, the U.S. included among its programs and activities tabled at the United Nations Conference on Environment and Development (UNCED) an invitation to "government officials and scientists from all interested nations to join in developing an International Research Institute for Climate Prediction". The U.S. proposal to lead a multinational effort takes into consideration a broad range of both research and operational resources within the U.S. scientific structure, particularly the U S. National Oceanic and Atmospheric Administration (NOAA), as well as the proactive position of the U.S. government. Support for this endeavor, expressed in many parts of the world by individuals from scientific communities as well as decision makers, indicates that it is indeed timely to launch a comprehensive program which integrates the activities that have led to progress in prediction and will each be essential to continued achievement.

II. STATE OF THE SCIENCE

Background

The key insight in understanding the ENSO phenomenon was made in 1969 by a prominent Norwegian meteorologist, Jacob Bjerknes. He grasped that the ENSO phenomenon is to be understood not only as simply an atmospheric phenomenon or an oceanic phenomenon, but as a phenomenon which depends intrinsically on the interaction between the atmosphere and the ocean. A theory of ENSO would therefore accurately describe how atmospheric winds change the oceanic sea surface temperature (SST) which is simultaneously producing changes in the atmospheric winds. When a model of the ocean is coupled successfully to a model of the atmosphere, the ENSO arises spontaneously, with the proper surface winds and the proper SST.

By 1987, this idea had been encapsulated into simplified coupled models of the Pacific Ocean and the atmosphere above it. The models were able to simulate correctly the major large scale features of ENSO and, more remarkably, to predict the future state of the ENSO from information about the current state of the ocean. The prediction scheme was first tested using past years to see if warm events that had already occurred could be successfully reproduced. The models first proved successful at such retrospective forecasts and then successfully predicted the onset of warming in the Pacific in 1986 more than a year in advance. This and the 1991-92 case, also correctly predicted more than a year in advance, constitute a remarkable achievement in the Earth sciences.

We now understand that the spontaneous nature of the ENSO cycle is rooted in an instability of the coupled atmosphere-ocean system. The instability produces repetition of an irregular, quasi-periodic cycle which is slow by weather standards but all too fast when severe regional drought and flooding accompany the cycle. The recurrence time varies between three and seven years with long runs of regular warm or cold events interspersed with long runs of no (or weak) events.

Readiness

The key quantities to be predicted are time and space averages of precipitation and sea surface temperature. The recognition that such predictability exists and the ability to predict climate variability a season to several years in advance is a major intellectual achievement. The challenge of short term climate prediction may be considered the ultimate test of our knowledge of the circulation of the atmosphere and its interaction with the ocean and land surface in producing the climate of the earth.

Models used in ENSO prediction range from purely statistical models to fully coupled dynamical ocean-atmosphere models. The dynamical models range in complexity from tropical Pacific basin intermediate physics models (e.g., Cane et al., 1986) to global coupled ocean-atmosphere General Circulation Models (GCMs). Most experience in dynamical forecasting is based on the intermediate class of models which simulate only climate anomalies to avoid problems with climate drift that often affect coupled GCMs (Neelin et al., 1992). Cane et al. (1986), using an intermediate model, made the first successful forecast of an ENSO one year in advance of the 1986-87 event. This accomplishment was later reinforced by statistical and hybrid statistical-dynamical model-based forecasts as described in Barnett et al. (1988). The Cane-Zebiak model also successfully forecasted the 1991-92 ENSO one year in advance (Kerr, 1992). Similarly, despite some empirical indicators suggesting that 1990 would be an ENSO year, the Cane-Zebiak model successfully predicted normal sea surface temperature in the eastern and central equatorial Pacific. Predicting cold "La Niña" conditions, as in 1988, has been less successful (Palmer and Anderson, 1993). Moreover, with the exception of the recently implemented coupled ocean-atmosphere GCM at NOAA's National Meteorological Center (NMC), most models failed to predict the secondary warming in the equatorial Pacific in early 1993 following the 1991-92 ENSO.

There is reason to be optimistic about the continued progress in predicting short-term climate variability. Most climate forecast schemes do not at present make full use of available data for initialization. The Cane-Zebiak model for instance, makes use of only surface winds but not SST or subsurface information. The NMC ocean GCM on the other hand assimilates Expendable Bathythermograph (XBT) data, Tropical Atmosphere Ocean Array (TAO) buoy data and blended satellite *in situ* SST products into analyses used for initialization. The superior performance of the NMC coupled model relative to the Cane-Zebiak model in predicting the early 1993 warming in the equatorial Pacific may have been related to differences in data sets used for ocean model initialization.

Finally, in order to improve forecasting at higher latitudes it will be necessary to increase our understanding of land-atmosphere and ice-atmosphere interactions

Linkages to Climate Change

Currently, the key to predicting ENSO-related variations in precipitation and temperature lies in the ability to predict sea surface temperatures (SSTs). SSTs represent the atmospheric lower boundary condition provided by the ocean and can be used to simulate the statistics of atmospheric weather. In a Summer 1992 Oceanus article, Edward Sarachik described current and future predictive capacity:

> In particular, seasonal variation of the atmospheric statistics, the "climatology," is determined by seasonal variations in the quantities external to the atmosphere, in particular solar radiation and the lower boundary condition, the SST. We see that if it were possible to predict the SST (and other slowly varying boundary conditions) a year or so in advance, then the statistics of the atmosphere could also be partially determined a year or so in advance. If it were possible to predict all the slowly varying boundary conditions (land surface conditions and SST), then the best possible prediction of climate could be made. The ocean enters the climate prediction problem through the determination of SST, the only oceanic quantity that the atmosphere sees. The tool for predicting SST is a coupled atmosphere-ocean model.
>
> Natural variability on seasonal to interannual time scales is a key aspect of evaluating decadal scale or longer term trends and predicting long-term system behavior. The development of understanding, measurement, and predictive capabilities for seasonal and interannual time scales will directly influence our capabilities in predicting decadal variability and in predicting the effects of the growth of radiatively active ("greenhouse") gases on time scales of 100 years or more. Accurate knowledge of the climatological mean state is crucial to modeling of longer term climate change Interannual variability is an important part of that climatological mean state: in particular, a world without interannual variability would have a mean surface temperature different than the actual world.

Generalizing, we assert that climate models must be able to assess seasonal to interannual variability correctly in order to accurately model the current climate. They will also need to accurately predict changes in interannual variability in order to correctly model longer term climate change. It has often been pointed out that a change in the intensity and frequency of

ENSO would have an important effect on the mean climate and that changes in the mean climate, e.g. greenhouse warming may express themselves partially through such changes in seasonal to interannual variability. In fact, there is increasing evidence that the heat-transport processes associated with ENSO may play a direct role in longer-term warming trends in the Earth system.

III. PROGRAM STRUCTURE

Programmatic Approach

As the capability to predict climatic fluctuations with useful lead time became demonstrable, the international scientific community, through member bodies organized under the TOGA Program, began to call for a focused multinational effort for data assimilation and experimental prediction. As noted in the final statement of the 1990 Second World Climate Conference (Jäger and Ferguson, eds., 1991):

> Further development of methods for predicting short-term variations in climate and the environmental and social impacts should be vigorously pursued. These advances would provide enormous economic and other welfare benefits in coping with droughts, prolonged rain, and periods of severe hot and cold weather. Such predictions will require major steps forward in ocean-atmosphere-biosphere observing systems Much greater efforts are also needed to increase involvement in these fields by developing countries, especially through increased education and training

The SCPP is designed to address international climate variability from its origins in coupled atmospheric and oceanic behavior through its physical manifestations and socioeconomic impacts. The initiative is based on four cornerstones: Integrative Modeling and Prediction, Scientific Assessment focused on the application of climate predictions, Observations and Data Management, and Process Research. A review of implementation options reveals that the effectiveness of a prediction effort would be enhanced by the establishment of firm ties to the activities and communities upon which it will depend, namely observation and data management and process research. Coordination among these components would not only provide the means to create an infrastructure designed to facilitate further development of climate research, but will also foster the maintenance and enhancement around the world of an observational and monitoring network required to underpin climate research in the decades ahead While these four components of a distributed program are quite separate in terms of requisite technical capabilities and expertise, it is critical that they further develop in an interactive manner towards an integrated objective.

A crucial element of this proposal is the creation of a multinational network of research and application centers in the context of this broader program to focus international efforts in modeling and applications of forecasts. We believe that these new institutional arrangements are necessary in order to take us through the transition from research to operations and to lay the groundwork for the establishment of a regularized system for interpretation and validation of model predictions for regional application. The information that follows describes the suggested design for the SCPP. A plan for multinational implementation is addressed in the Program Management section.

Program Design

The goal of the Seasonal-to-Interannual Climate Prediction Program (SCPP) is to take the next steps toward reliable forecasts and analyses of climate variations on seasonal to interannual time scales, and to develop the infrastructure by which this can be used for social and economic benefit by all countries of the world. The Program would initially focus on forecasting ENSO and its related climatic impacts (atmospheric circulation, precipitation, and surface temperature) and will expand based on the results of continuing research. It is suggested that the following four parallel streams of activities would be supported and implemented in a coordinated effort:

i) Integrative modeling and experimental short-term global climate predictions regularly delivered, a season to a year or two in advance and the computational infrastructure needed to implement such predictions;

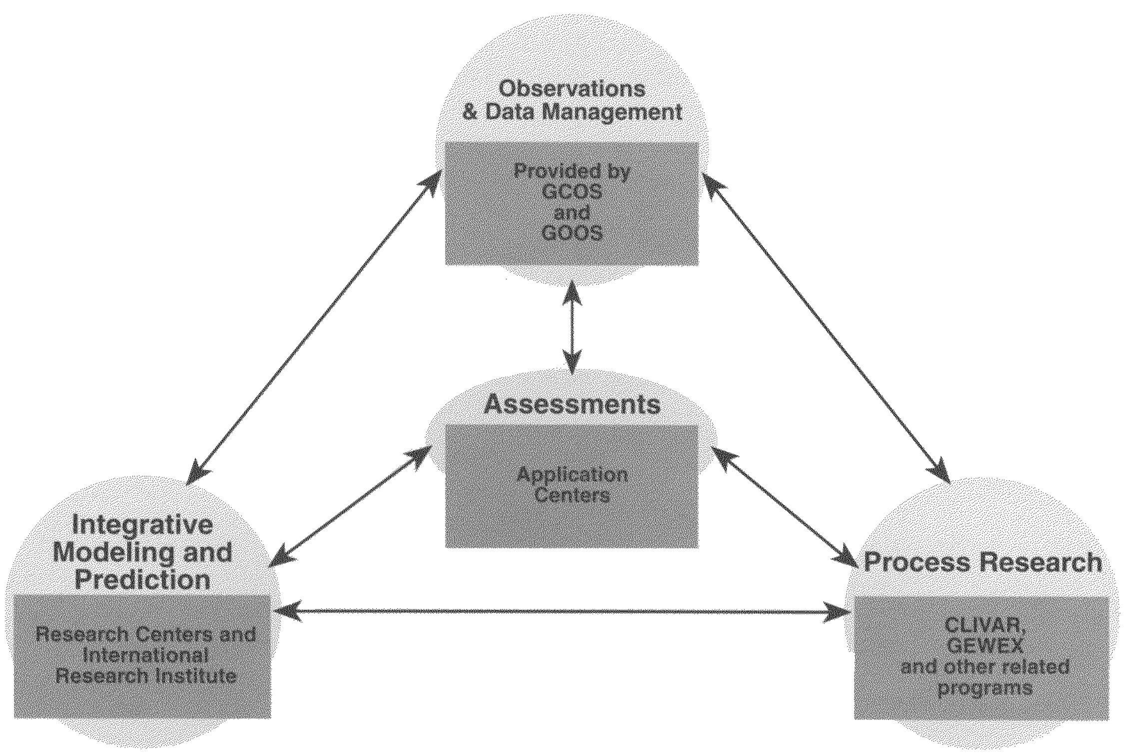
ii) Assessment and applications programs wherein the understanding of the effects of short term global climate variations and the responses based on predictions can be studied, while these predictions are being applied to improve the social well-being in affected regions and sectors;

iii) Regular and systematic global observations of the upper ocean in regions defined by modeling and process research; and

iv) Process research programs that utilize new observational systems in order to improve understanding of processes important to climate variability and the limits of climate prediction, and the development of new models and model improvements.

The four activities and their interaction are schematically presented in the figure below. Each activity would be implemented through national participation in emerging international programs.

Seasonal to Interannual Climate Prediction Program
Program Architecture



Integrative Modeling and Prediction

Research efforts around the world have successfully developed models of the atmosphere-ocean system which have demonstrated skill in predicting sea surface temperatures in the equatorial Pacific Ocean and associated distribution of precipitation in the tropics. Experimental forecasts provided by such models are proving to be useful in a number of countries, however the forecasts are limited and rudimentary, due primarily to the limited physics and resolution of the models. Moreover, forecasts are presently conducted in a research mode, without a routinized system for production and distribution that is required for worldwide use. A key component of the proposed SCPP is the establishment of an end-to-end forecasting system to develop, improve and transfer climate modeling technology from research centers to centers which routinely produce and disseminate climate forecasts to affected local communities and local decision makers.

This proposal assumes that governments which have already invested in model development and are beginning to venture into operational climate predictions will continue to support efforts in these fields at their national facilities. In the case of the U.S., model development will be supported within federal facilities and the university community as currently supported through the U.S. Global Change Research Program (USGCRP). Operational climate prediction efforts, such as those currently underway at the U.S. NMC, will be enhanced through accelerated development and implementation of a multi-season forecast system based upon models of the coupled ocean-atmosphere, expansion of systems to process and assimilate observations, and delivery of prediction services to a wide range of U.S. users.

In parallel to the enhancement of a national operational climate forecast system, the U.S. will initiate a multinational planning process intended to lead to the early establishment of a multinational infrastructure to generate and transfer climate information and forecasts and in effect extend modeling, predictive and applications capacity to the affected world community. The desire for such a system has been expressed by scientists and decision makers in a number of countries affected by the consequences of climate variability. Such a system includes as a fundamental component the establishment of a network of centers operating on behalf of those countries that do not currently have the infrastructure required to produce or to apply national climate forecasts.

As envisioned, the network would include Research Centers, within which an International Research Institute for the Seasonal-to-Interannual Climate Prediction Program would be established with the responsibility of producing, assessing and distributing experimental climate forecast guidance products to interested nations on a regular basis. As preparation for a multinational dialogue, the U.S. plans to identify U.S. Research Centers at existing research institutions. The U.S. will work with the international community to review proposals from one or a group of these Centers to establish a host site for the International Research Institute.

In addition to generating experimental guidance products, the Institute will conduct model research and development and provide a net assessment of the various operational and experimental guidance products available to users. The Research Centers will enhance the development of climate forecast models and forecast methodologies and sponsor training of scientists and decision makers from participating countries. These Centers will necessarily draw upon the range of physical and social science research efforts undertaken within the broad-based international scientific community and will work closely with national and international facilities, which have responsibilities for operational delivery of climate products. The U.S. proposes to assist in the establishment of Regional Applications Centers in participating countries to develop regional forecasts and distribute products of social and economic benefit.

Cooperative interaction between the International Research Institute for SCPP and national operational centers is a critical element of the SCPP proposal. Such interaction will include providing feedback on the quality of data and products exchanged, offering advice on optimizing the distribution of data platforms, and offering to the operational centers the Institute's forecasts for research use. Rather than developing independent and duplicative data processing efforts, the Institute will receive much of its atmospheric and oceanic data from operational global forecast and data management centers worldwide. The Institute will also seek collaboration in development of models, initialization schemes, and forecast methodologies. The interests of the Institute and existing operational agencies is highly complementary and thus interaction of the type described above should prove to be beneficial to all participating entities.

An important aspect of the proposed network of Research Centers is a training program designed to prepare scientists from participating countries in the theory of coupled ocean-atmosphere modeling and the practical use of seasonal to interannual forecasts. Trainees will be taught state-of-the-art techniques in model development and interpretation. After training, they will return to their home institution to develop forecast products tailored to the needs of their country or region.

Applications and Assessments

Several government agencies and local decision makers in tropical countries have already begun to use available information on ENSO conditions and existing experimental forecasts. Substantial improvements in agricultural yields have been the result. Climate forecasts have in this fashion already had some impact on tropical societies by reducing uncertainties in important policy decisions. However, these forecasts are still limited and rudimentary. They are carried out by small research groups which lack the resources to make use of all available observational data. Similarly, they cannot take full advantage of the advanced modeling and data handling techniques developed in oceanography and meteorology, most notably for numerical weather prediction.

Included within the context of SCPP is the establishment of Regional Application Centers that will tailor global forecasts for local application, analyze the social context affecting potential climate impacts, provide guidance and distribute products of social and economic benefit to users. Although Regional Application Centers will have a common mission, design and establishment of application centers will derive from the unique characteristics and capabilities of the regions they will serve. Furthermore, some Regional Application Centers may serve a multinational region, while others might be concerned with a single nation, or a region within a nation. In order to reap the maximum benefits, it is important to maintain flexibility in defining a Regional Application Center.

In particular, Regional Application Centers will pursue the following:

- develop regional assessment capabilities for ocean, atmosphere, and land processes relevant to their own specific environment;
- focus on integrating scientific, social, economic and any other appropriate data to construct information products to support the end-user in the decision processes in various member countries; and

- establish and maintain a data management and information system to support research within the participating country and facilitate international data exchange between the participating country and the International Research Institute for SCPP.

Regional Application Centers will add specific knowledge about the current mean climatic conditions within the region to the global forecast guidance products, as well as knowledge about historical climate patterns. This information will be combined to give the best possible local and regional assessments of physical climate conditions. Researchers will be trained to assure that resulting climate assessments would then provide information useful to a broad range of social, economic and environmental concerns. Although regionally-specific climate forecasts are of obvious value to farmers, water managers, energy suppliers, and public policy makers, climate assessments also will be important components of our efforts to provide integrated assessments of global change to policy- and decision-makers. An improved ability to forecast climate variability will make an essential contribution to efforts to address such pressing environmentally related issues as desertification, wetlands deterioration, preservation of biological diversity, and food production problems. Furthermore, it is envisioned that the experience of applying climate forecasts to practical problems of public policy, economics, and development, will yield important feedback information relevant to those involved in observations, data management and the direction of process research.

Observations and Data Management

A long-term observing and data management system will be required to efficiently and effectively provide data for initialization and validation of the models that will be used to predict the seasonal to interannual climate variations of the coupled air-sea system. The overall planning framework of the Global Climate Observing System (GCOS) is being looked to for guidance in the development of this observing and data management system. GCOS planning has identified that the atmospheric component of the observing and data management system will rely on the observations and data management functions supplied by the World Weather Watch (WWW) while the oceanographic component will rely on the observations and data management of the TOGA Observing System (TOS). The *in situ* measurements supplied by the WWW and TOS will be combined with observations from operational and research satellites to produce higher order products that will be utilized by the models.

The most critical component of the observing and data management system is the TOS. Presently TOS is, at best, a sparse network supplying what is believed to be the minimal requirements necessary to produce useful seasonal to interannual climate predictions. The TOS is concentrated in the Pacific Ocean and provides basin-wide real-time measurements, principally of surface and subsurface ocean temperatures, surface and upper level atmospheric winds, sea level, and sea level pressure TOS is composed of five elements: the Tropical Atmosphere Ocean Array (TAO), the Surface Velocity Program (SVP), the Voluntary Observing Ship Expendable Bathythermograph Program (XBT), the Indo-Pacific Sea Level Network, and the Trans-Pacific Profiler Network (TPPN). TOS in the Pacific is a fully multinational effort, supported by over two dozen countries.

In order to produce the useful predictions of seasonal to interannual climate variability that society needs, at the very least, the present observing and data management system will have to be maintained and, in all likelihood, expanded. A three pronged approach will be used to address this problem: (1) provision of stability for the existing system for the next five years while a gradual transition to operations is undertaken, (2) implementation of a program of evaluations including cost/benefit studies to determine the "optimum" system for producing useful predictions, and (3) development of criteria for expansion and modernization.

To endeavor to ensure that an observing and data management system is maintained, the U.S. will continue to support TOS as its initial, highest priority, contribution to the Global Ocean Observing System (GOOS) while inviting other nations to do the same. The climate module of GOOS is viewed as the oceanic component of the Global Climate Observing System (GCOS) that is being developed as the dedicated observation system to meet the scientific requirements for monitoring the climate, detecting climate change, and predicting climate variations and change. Within the U.S. scientific planning infrastructure, a high priority is placed on the development of GCOS and GOOS.

Process Research

TOGA, while successfully demonstrating the predictability of seasonal to interannual climate variations, has left much to be accomplished. In particular, TOGA concentrated on ENSO, the largest interannual signal in the Pacific, to the exclusion of other interannual signals in other tropical oceans and at higher latitudes. The connection of the tropics to mid-latitude variability remains to be explored and the extension of predictability to the Atlantic and Indian Oceans need to be investigated Furthermore, the nature of mid-latitude variability needs to be examined and the amount of such variability, both locally and remotely generated, needs to be delineated.

Working collaboratively in the context of the USGCRP, U.S. federal agencies are investing in two major research programs to further our understanding and predictive capability of seasonal to interannual climate variations. As a U.S. contribution to the international Climate Variability and Predictability (CLIVAR) Program of the WCRP, Global Ocean Atmosphere Land System (GOALS) is being formulated to continue improvements in prediction of ENSO, extend our understanding and predictive capability to include global seasonal to interannual climate variations, and develop the observational and computational means for predicting these variations. The central hypothesis of GOALS is that the variations in the global boundary forcing of SST, soil moisture, sea ice and snow exert a significant influence on seasonal to interannual variability and potentially enhance predictability. Both understanding variability and predicting climate require GOALS to provide accurate measurements of global atmospheric boundary conditions and improved measurements and models to simulate their future evolution.

The Global Energy Water Cycle Experiment (GEWEX) is an international program focusing on the characteristics of the global hydrological cycle and related energy fluxes. Climate prediction requires knowledge of these fluxes and, in particular, needs parameterizations of physical land surface processes for use in predictive models. GEWEX Continental-Scale International Project (GCIP)is being conducted in the Mississippi River basin to determine the variability of the hydrological cycle and energy exchange budget over a continental scale, to develop and validate techniques for coupling atmospheric and land surface processes in climate models, and to provide a basis for translating the effects of future climate change to impacts on regional water resources.

Together CLIVAR and GEWEX will work to move predictive ability beyond forecasts of ENSO in the tropical Pacific to global forecasts of seasonal to interannual climate variations and their associated temperature and precipitation distributions.