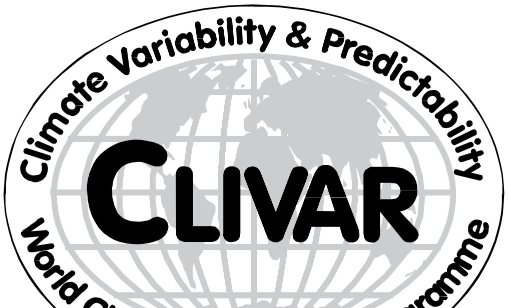
U.S. CLIVAR Position Paper

International CLIVAR Conference

UNESCO, Paris
December 2-4, 1998



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Introduction

The Climate Variability and Predictability (CLIVAR) science program offers the United States an opportunity to cooperate in a comprehensive study of climate variability and change. This World Climate Research Program (WCRP) project aims to understand the causes of climate variability, to improve predictability of this variability, to extend pre-instrumental climate records into the past, and to understand and predict the climate changes caused by growth of radiatively active gases and aerosols in the atmosphere. These goals are accepted by U.S. climate scientists and funding agencies as scientifically timely and of great importance to the U.S. and the world.

There is U.S. interest and scientific activity in all the CLIVAR Principal Research Areas (PRAs) described in the Initial Implementation Plan (IIP)[1] as well as in connecting and expanding some PRAs. A coordinated international effort, however, is required to meet the scientific objectives of CLIVAR. A focus of the U.S. effort will be understanding seasonal-to-interannual climate variability and enhancing its prediction, but appropriate efforts in decadal variability and anthropogenic change will have a similarly high priority.

While the time scale distinctions between seasonal-to-interannual and decadal-to-centennial have helped frame the initial science questions to be addressed, the importance of the interaction of variability across time scales is sufficiently compelling to consider the acceleration of an ultimate intent of CLIVAR: to enhance predictive capability on multiple time scales and to apply forecasts on regional spatial scales. Each of the Global Ocean-Atmosphere-Land System (GOALS) and Decadal-to-Centennial (DecCen) PRAs has specific regional domains and address phenomena that exhibit variability from subseasonal to centennial. As CLIVAR is being implemented, the U.S. recommends that the CLIVAR Scientific Steering Group consider reformulating the PRAs, to the extent appropriate, so that they focus on the variability and predictability of regional climate phenomena across the range of time scales.

This U.S. Position Paper has been developed with extensive input from the U.S. Science community. The U.S. initiated in 1993 the planning of programs intended to contribute directly to CLIVAR. The U.S. National Research Council (NRC) established two Panels, for GOALS and DecCen, to develop consensus U.S. science plans[2,3]. U.S. funding agencies also sponsored a number of meetings and workshops to draft more detailed U.S. science and implementation plans for specific research areas within CLIVAR, including Pan American Climate Studies (PACS)[4], Pacific Basin-scale Extended Climate Studies (BECS)[5], the Atlantic Climate Variability Experiment (ACVE)[6], and the Asian-Australian (AA) Monsoon[7]. An interagency group of program managers from the National Aeronautic and Space Administration (NASA), the National Science Foundation (NSF), the National Oceanographic and Atmospheric Administration (NOAA), and the Department of Energy (DOE) started meeting regularly earlier this year to begin more formal coordination of CLIVAR-relevant projects among the agencies and to discuss the mechanisms for implementing CLIVAR research in the U.S. One of the first activities of the interagency group was to establish a U.S. CLIVAR Science Steering Committee (SSC) to provide overall scientific guidance, to recommend priorities and effective sequencing of U.S. CLIVAR activities, and to ensure balance within the various elements of the program. At its first meeting in September 1998, the SSC reviewed program plans and forwarded recommendations to the interagency group on specific actions that should be undertaken. The position paper reflects those recommendations and the plans of agencies.

Within the U.S., the best developed plans are in the G1 and G3 PRAs, in decadal modulation of El Niño Southern Oscillation (ENSO) (bridging G1 and D4), and in seasonal-to-decadal variability in the Atlantic sector (PRAs D1, D2 and D3). Efforts in G1 include global modeling and empirical studies coupled with enhanced observations in the Pacific Ocean. Efforts in G3 are integrated with the Variability of the American Monsoon System (VAMOS) program and new tropical ocean and atmosphere observations. Modest expansions of the modeling, empirical and observational studies needed for these efforts will support studies of decadal variability (under D1, D2, D3 and D4). A majority of the U.S. work in PRAs A1 and A2 will be based on a coordinated modeling effort. Planning and pilot studies for G2 will be initiated. Other areas, such as G4, extending D3 to study Arctic changes, and D5, are of great interest and current activity, but the U.S. hopes other nations will take the lead in developing and implementing a strategy to satisfy CLIVAR objectives.

Many ingredients of research in the individual PRAs are common to them all. The U.S. will support integrating efforts such as development of models and data assimilation techniques, design and implementation of improved observing systems, and continuation of present satellite and in-situ observations. The U.S. also recognizes the interdisciplinary nature of the climate research - close cooperation with operational activity in the World Weather Watch (WWW), the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the Global Ocean Data Assimilation Experiment (GODAE), and with complementary research programs such as the Global Energy and Water Cycle Experiment (GEWEX) and Past Global Changes (PAGES) is required. In particular, the U.S. CLIVAR program is predicated on continuation and evolutionary improvement of (a) satellite and in situ measurements that support operational analyses of the atmosphere, (b) satellite measurements of sea surface topography and surface winds over the ocean, and (c) the Tropical Atmosphere Ocean (TAO) array.

For the past several years, U.S. agencies have been providing support both for pilot projects exploring the actual use of climate forecasts and social science research on the incorporation of climate information into decisions that improve adaptation to climate variability. In recent years, effort has increased to draw actual decision-makers into a process to better articulate and define their information needs regarding their coping strategies for variability in climate conditions. To the extent that CLIVAR's mission is to provide information useful to society, these ongoing research efforts should offer guidance for the relative benefits of different forms of climate analysis and predictive information. An enhanced and sustained dialogue between CLIVAR's science planning efforts and applications/adaptation research programs should result in clear examples of adjustment strategies around the world.

The following summarizes U.S. plans more completely described in the full document:

1. Global Seasonal-to-Interannual Predictability: ENSO and Monsoons

The present efforts in diagnosis and experimental forecasting of ENSO will continue. Maintenance and evolution of the TAO array and satellite measurements of the surface wind field and sea surface topography are crucial to this effort. Changes to these systems should have sufficient overlap for careful assessment. Deliberate expansion of studies of the American Monsoon will proceed, extending first to the Pacific cold-tongue and stratus region because of relevance for ENSO prediction, and then to the American Monsoon region and into the tropical Atlantic. Studies of the Austral-Asian Monsoon system will proceed through a phased approach, beginning with pilot studies and development of international collaborations.

2. Decadal Modulation of ENSO

The U.S. will contribute significantly to the study of decadal modulation of ENSO in the Pacific sector throughout the life of CLIVAR. This study will involve a coordinated observational and data assimilation study, empirical and paleoclimate studies, and research with a spectrum of climate models. Continuation and evolution of TAO array time series are vital elements of this program.

3. Atlantic Climate Variability

The U.S. will contribute significantly to the study of climate variability in the Atlantic sector, focusing specifically on the North Atlantic Oscillation (NAO) and, especially, Tropical Atlantic Variability (TAV). A coordinated upper ocean observing system will be required in the tropical

Atlantic extending throughout the North Atlantic Ocean coupled with a basin-wide ocean data assimilation effort. Modeling and limited observations to define and understand climate-scale variability in the deep ocean will be included. Progress on the variability in the North Atlantic will require close collaboration with existing national and international programs of research in the Arctic.

4. Anthropogenic Climate Change

U.S. CLIVAR, in conjunction with other related programs, will develop a coordinated national effort toward the modeling of natural climate variability and its connections to the climate change associated with forcing of the climate system by both natural (e.g., volcanic and solar variations) and anthropogenic (e.g., land use and aerosol loading) sources. This research will require ongoing evaluations of the observational data on the variability of the climate system and its forcing functions. It will also require a rigorous program for the continual evaluation and development of the climate models that are used to evaluate and predict the decadal to centennial change in the climate system due to natural and anthropogenic forcing

5. African Climate Variability and Southern Ocean Thermohaline Circulation

Understanding the variability of the African climate system involves studying at least three distinct regions of the African continent, east and central Africa, north and west Africa, and southern Africa. A limited number of U.S. scientists are engaged in observational and numerical modeling studies to gain insights into these scientific questions. It is expected that these investigations will continue with increasing collaboration with researchers in Africa.

The Southern Ocean may be a significant role in climate variability through dense water formation, exchanges between ocean basins and abrupt changes through ice sheet dynamics. Since the observational base and modeling capabilities are not as well developed as in other regions, the U.S. endorses the recommendation in the IIP that initial emphasis be put on exploratory investigations of this region.

6. Climate Modeling

In addition to a continuing aggressive program of numerical experimentation, effort will be put into improving coordination of modeling efforts. Efforts will be made to facilitate open and ready access to well-documented models, data assimilation systems, simulations, and observations. A common programming paradigm should be adopted to facilitate exchange of model modules such as physical parameterizations. Modeling, assimilation and observation programs need close coordination and interaction.

7. Sustained Observations

Success of CLIVAR depends, in part, on the continuation and enhancement of the atmospheric observing network (including the WWW network), and this will be a high priority for U.S. CLIVAR. Improvements are needed to this and other observing systems in order to accomplish the CLIVAR research objectives. The legacy of CLIVAR must be a global climate observing system that is evolutionary, providing adequate observations for operational and research purposes and a capability for assessing the impact of its elements. Priorities for observations that are not yet available in an operational context are:

(i) Enhancement of the atmospheric weather observation network to make it adequate for long term monitoring of climate variability.

(ii) Measurements of temperature and salinity in the upper 1500 meters focused in the subtropical Pacific (35°S to 40°N) and Atlantic (35°S to 65°N).

(iii) Sea level of sufficient accuracy (1-2 cm) and duration (at least the next 20 years) to detect decadal changes in ocean circulation, changes in the mass balance of the polar ice sheets, and changes in mean sea level.

(iv) Sustained, accurate measurements of surface vector winds over the ocean.

(v) Estimates of surface fluxes of heat, freshwater, energy and momentum at selected ocean and land sites, including improved measurements of cloud properties and soil moisture.

(vi) Collection of long time series from the ocean at select Eulerian stations and from repeat ocean sections.

Two implementation activities are planned. First, there will be phased deployments of instruments aimed at meeting the needs of particular CLIVAR PRAs. Second, in coordination with international and non-CLIVAR programs, U.S. CLIVAR should build toward a sustained, global climate observing system. In both these activities, U.S. CLIVAR will promote strong ties between observational, modeling and data assimilation activities. In particular, the upper ocean observing system will be assessed, and will evolve, in the context of the value added by data assimilation. There must be free, open and timely exchange of data from all sustained observing systems.

8. Data Set Development

A fundamental objective of the U.S. CLIVAR policy on data management will be the free, open and timely exchange of CLIVAR related data and products. The U.S. will have a strong policy of keeping as much data as possible in the public domain and limiting the time that data can be restricted. U.S. CLIVAR will support development of comprehensive, long-term data sets by improving the quality and volume of the historical database through data archeology, supporting the development and evaluation of data sets, development of integrated proxy records and continuing to reanalyze historical data for the atmosphere and ocean, as well as satellite-based products.

Scientific Overview

1. GLOBAL SEASONAL-TO-INTERANNUAL PREDICTABILITY

1.1 El Niño-Southern Oscillation (ENSO)

The U.S. will continue, as a high priority focus, research to improve the understanding, monitoring, modeling, and prediction of ENSO. The ENSO cycle is recognized as the only demonstrably predictable climate variability signal, and its impacts around the globe are profound. The 1997-98 El Niño has demonstrated again that we have significant skill in forecasting the evolution of the tropical Pacific at least six months ahead, especially once a warm event has begun. Furthermore, the atmospheric response in several regions throughout the globe was also relatively well predicted and usefully applied for resource and disaster planning. This success has strengthened the U.S. commitment to the International Research Institute (IRI) for seasonal to interannual climate prediction in order to improve, communicate, and exploit ENSO-based predictions. The U.S. is also committed to maintaining its contributions to the multi-nationally supported tropical Pacific ENSO Observing System, including the TAO array, to facilitate real-time monitoring, prediction, and research of ENSO.

It is recognized that the understanding of ENSO is incomplete and prediction skill is limited. Research is required both to improve the understanding and predictability of ENSO and to understand how the ENSO signal is communicated through the atmosphere.

The U.S. will continue several areas of research that are important for improving our understanding of ENSO physics and prediction skill. For example, the coupled atmosphere-ocean general circulation models (GCMs) used to forecast ENSO inadequately resolve the crucial physics and circulations in the atmosphere and ocean boundary layers. Deficiencies in the boundary layer physics in these models give rise to serious biases in the climatology of the coupled models and they are thought to be sources of error in ENSO forecasting. In ocean models, the problems include lateral mixing by instability waves and diapycnal fluxes and mixing below the mixed layer. Research will be undertaken to address these problems, including coordinated model studies and field process studies of the ocean and equatorial maritime boundary layers.

The U.S. will also vigorously continue research to understand how the ENSO signal is communicated through the atmosphere in the tropics and extratropics. ENSO teleconnections throughout the tropics and into the extratropics will continue to be explored. Specifically, efforts are being undertaken to determine the limits in predictability of the atmosphere induced by tropical Pacific sea surface temperature changes, to diagnose and model the global response to warm, cold and neutral events, and to examine the changes in probabilities of extreme events induced by ENSO. Furthermore, it is not fully understood how, and to what extent, the local ocean atmosphere interaction in the midlatitudes modulates the anomalies in the midlatitude circulation that are "teleconnected" from the tropics. The intellectual framework for addressing this, and related issues of low-frequency atmospheric variability, is well established, but further progress is needed.

Experimental predictive modeling using a hierarchy of coupled modeling approaches will continue to be pursued, with attention to improvements in initialization and assimilation techniques. In addition to supporting individual research projects, U.S. agencies have established several dedicated modeling and analyses centers to assess the potential predictability of ENSO and to determine the optimal observing system to achieve this level of predictability. Coordination among such centers around the world will be essential to accelerating predictive understanding.

1.2 American Monsoon

The extension of ENSO studies to studies of the American monsoon has a high level of interest to the U.S. community. The U.S., therefore, intends to make significant contributions to the emerging international VAMOS Program through activities supported primarily under the PACS Program. PACS, initiated in 1995, is undertaking research to extend the scope and improve the skill of seasonal-to-interannual climate prediction over the Americas with particular emphasis on understanding the mechanisms associated with warm season rainfall and its potential predictability. Monitoring, data set development, data management, empirical, diagnostic and modeling projects have been initiated to promote a better understanding and more realistic simulation of (1) the role of boundary processes in forcing of seasonal-to-interannual climate variability over the Americas, (2) the structure and evolution of tropical sea surface temperature (SST) fields, (3) the seasonally varying mean climate over the Americas and adjacent ocean regions, (4) the structure and variability of the cold tongue/ inter-tropical convergence zone (ITCZ) complex (CTIC) and subtropical stratus cloud decks and their influence on climate over the Americas, and (5) the relevant land surface processes that shape the distribution of continental precipitation.

Changes in the SST in the eastern Pacific and tropical Atlantic are a significant source of variability for rainfall over the tropical and subtropical Americas. While these SST changes produce regional and large scale atmospheric circulation anomalies, the expression of these anomalies can be highly localized by the severe orographic gradients in Central America and equatorial South America. Hence, research in this area will require knowledge of the coupled large scale atmosphere-ocean processes, and enhanced efforts in understanding the mesoscale dynamics associated with orography and coastal geometry.

Land-atmosphere feedbacks are recognized as being particularly important for understanding the variability of the American Monsoon, especially in the Amazon basin and during the warm season in the southern U.S.. Observation and modeling studies have shown that changes in the land surface characteristics (vegetation) can have strong impacts on the local climate in Brazil. It has been hypothesized that anomalies in the soil moisture at the beginning of the warm season over the southern U.S. are amplified through the course of the summer via a local moisture recycling, which can be a significant source for warm-season continental precipitation, and that this may be a source of significant interannual variability in warm season rainfall. To better simulate the variability during the warm season over the Americas, an extension of the present research efforts within GEWEX to document and model land-atmosphere fluxes of energy and water will be required. This includes the development of models which have substantially improved representations of the pathways of water and energy in the near-surface land and in the biosphere, and ultimately of the models that simulate the interaction between the biosphere and the climate system. Interactions between the biosphere and the climate could contribute significantly to the climate variability on decadal and longer time scales.

Through VAMOS, the U.S. has begun and is interested in expanding its collaboration with parties in other nations in the Americas to (1) implement process studies to elucidate the crucial physical mechanisms that relate particular climate phenomena, such as warm-season rain, to the features like ENSO and, more generally, to variability of SST in the tropical American seas, (2) develop a multinational coordinated research agenda for the North and South American monsoons, and (3) work with the Atlantic PRAs of CLIVAR to explore the variability of the tropical Atlantic and its influence upon precipitation over the Americas.

1.3 Asian-Australian (AA) Monsoon

The AA monsoon is a key component in the earth's climate system affecting the livelihood of more than 60% of the world's population. Better prediction of this phenomenon will greatly benefit not only the population of the region, but also the rest of the world. There is scientific interest in the

U.S. in ENSO-monsoon interactions and how the AA monsoon may impact the climate outside the monsoon region, including North America.

Extending ENSO studies to the AA monsoon has a high level of interest to the American community; however, its current status in the U.S. from the programmatic point of view is less well developed than the American monsoon. There is a need for further pilot studies (including analyses of existing data sets and modeling efforts), and implementation planning to focus the objectives of this research prior to the development of a full-scale experiment. Interactions and collaboration with the GEWEX Asian Monsoon Experiment (GAME) community is expected to enhance understanding of the relative importance of ocean versus land heating in the interannual variability of the AA monsoon.

1.4 U.S. CLIVAR Objectives

- The present efforts in diagnosis and experimental forecasting of ENSO will continue, in partnership with other nations. The U.S. is pursuing IRI as a multilateral contribution to CLIVAR.

- The U.S. contribution to the TAO array will be continued and refined with continued attention to the needs of operational ENSO prediction and CLIVAR research. Research observations (cf. Decadal Modulation of ENSO below) should be designed to assist operational and research ENSO use.

- The U.S. will continue with the deliberate expansion of studies concerning the American Monsoon and extend these to the Pacific cold-tongue and stratus region and the tropical Atlantic. Consideration of the role of land-surface processes and orography on the climate variability associated with the American monsoon will be included and would most appropriately be incorporated by partnership with GEWEX.

- Pilot studies and development of international collaborations in the Austral-Asian region will be initiated to lay the foundation for later studies of the AA monsoon.

2. DECADAL MODULATION OF ENSO

We observe that over the 100-year instrumental record the ENSO cycle has exhibited different modes of variability, including periods of relatively regular El Niño events (e.g. the 1980s), periods in which warm events were absent (the 1930s), and the series of repeated warm events of the early 1990s. There is evidence that predictive skill is a function of these different epochs of ENSO variability, but we now lack the ability to understand or predict the slower changes of the ENSO cycle itself, which imposes a severe limitation on the predictability of the onset of warm events.

On timescales of months, the ENSO cycle involves the adjustment of the tropical thermocline through relatively well understood planetary waves that link the basin-scale winds to thermocline depth that governs the capacity of local upwelling to induce SST variations. Thermocline depth is also changing on longer (decadal) time scales, and experience has shown that successful prediction of El Niño depends on correctly simulating the background state of the tropical thermocline. Therefore, understanding and modeling the conditions that determine the slow evolution of the tropical thermocline is crucial to extending our ability to predict the turns of the ENSO cycle beyond individual events.

Modern hypotheses for the slow variation of this background state all involve oceanic propagation of information from the extratropics. Unlike individual ENSO events that are dominated by wave dynamics, modulation of the thermocline on slower timescales is probably significantly affected by diabatic and advective processes. Hypotheses include variation of water properties subducted in the subtropics (due to changes in rainfall, evaporation and Ekman pumping) and carried along complex three-dimensional pathways to the equator in the western Pacific. There the subducted water flows east in the equatorial undercurrent, and the properties it carries help determine the stratification of the equatorial thermocline. Other hypotheses suggest advection of SST anomalies around the subtropical gyres, to eventually reach the equator via the low-latitude western boundary currents, or wave propagation across the gyres on timescales of a decade or more before modulating the western boundary flows that feed the undercurrent.

Testing these hypotheses will require extended broad scale observations of the upper subtropical Pacific, interpreted using assimilating dynamical ocean models, as well as process studies (for example to estimate better the air-sea fluxes that determine subducted water properties) and focused observational programs in crucial areas (such as the low-latitude western boundary currents). Since variations of salinity are observed to contribute to interannual changes in pycnocline stratification, observation of the vertical structure of salinity will be necessary. Data assimilating models are essential in this context since we must represent advective processes accurately, but will be unable to deploy sufficient instrumentation to depict the full three-dimensional current or property fields from observations alone.

There is substantial U.S. interest in studying decadal variability of ENSO and in other decadal variability in the Pacific sector. A number of recent advances now make it feasible to study these phenomena on a sector-wide basis. These include:

(i) Regular global satellite observations of surface winds, sea-surface height (SSH)and SST,

(ii) Rapid progress in the development of models and data assimilation techniques;

(iii) Development of the autonomous profiling float for broad-scale measurement of temperature, salinity and velocity fields in the upper ocean;

(iv) Deployment on buoys and Volunteer Observing Ships (VOS) of improved meteorological sensors capable of accurately measuring air-sea fluxes and thereby removing bias from operational analyses;

(v) Development of high temporal-resolution paleoclimate records (e.g. corals, varves) that record the evolution of past ENSO cycles.

The concept of a Pacific sector study built around observations supported by assimilating models is endorsed CLIVAR IIP[1] and U.S. interest in implementing such a study of decadal modulation of ENSO and other decadal variability is reflected in a science plan[5]. The ocean aspects of such a study are closely related to GODAE and its in-situ adjoint Array for Real-time Geostrophic Oceanography (Argo).

If successful, a study of ENSO modulation would accomplish the following:

(i) Define the specific feedback mechanisms by which air-sea coupling leads to decadal variations of the background state of the tropical ocean, and hence of ENSO evolution and perhaps of the skill of ENSO prediction;

(ii) Provide a data set of unprecedented coverage and quality in the tropical and subtropical Pacific sector for diagnosis of other processes of decadal climate variability like the Pacific Decadal Oscillation (PDO) or another regime shift like that seen in 1976;

(iii) Produce a rapid improvement in dynamical modeling of the climate system, and in techniques for assimilation of ocean data. These improvements will lead to better prediction of ENSO and possibly of decadal variability; and

(iv) Design and implement an observing system suitable for efficient monitoring of climate variability and initialization of predictions.

2.1 U.S. CLIVAR Objectives

- U.S. CLIVAR will contribute significantly to the study of decadal modulation of ENSO in the Pacific sector throughout the life of CLIVAR. This study should involve a coordinated observational and data assimilation study as well as empirical and paleoclimate studies and research with a spectrum of climate models.

- The U.S. effort will contribute to, and should be closely coordinated with, other research in ENSO prediction (G1), variability of the AA and Pan American Monsoons (G2 & G3) and decadal variability in the Indo-Pacific sector (D4).

- U.S. CLIVAR will encourage modeling and empirical studies of other decadal variability in the Pacific sector.

- Focused experiments to elucidate specific processes (e.g. evolution of the cold tongue) will be supported as they are justified for model development.

3. ATLANTIC CLIMATE VARIABILITY

The climate of the Atlantic sector and surrounding continents exhibits considerable variability on a wide range of time scales. Improved understanding of this variability is essential to assessing the likely range of future climate fluctuations, the extent to which these fluctuations are predictable, and the potential impact of climate change due to anthropogenic forcing.

3.1 Tropical Variability

In the tropical Atlantic, substantial surface temperature variability with associated changes in the ITCZ and the Hadley circulation occurs on interannual to decadal time scales, phenomena which are collectively referred to as Tropical Atlantic Variability (TAV). Research has clearly linked TAV to the well-known droughts of Northeast Brazil, droughts in sub-Saharan Africa, and rainfall variations over Central America and the Caribbean. Of particular importance to decadal rainfall variability in Northeast Brazil and, to a lesser extent, in the Sahel region is the variation of the Atlantic interhemispheric SST gradient. However, the origin of the decadal variability in the cross-equatorial SST gradient is not yet understood.

Two competing hypotheses have been put forward. One postulates that decadal variations of the interhemispheric SST gradient stem from regional ocean-atmosphere positive feedbacks involving primarily SST and wind-induced latent heat flux. The other hypothesis argues that the development of SST anomalies on either side of the equator is dynamically independent and controlled by processes in each hemisphere.

Although the tropical Atlantic and higher latitudes are frequently considered separately, they overlap and are not independent. The NAO may be sensitive to subtropical SST anomalies through teleconnections akin to those acting in the Pacific. Variability of the NAO, for example, can change the intensity of the trades in the eastern subtropical North Atlantic and hence SST. On decadal time scales the variability in the TAV and the NAO may also be linked through tropical-subtropical ocean gyre exchanges.

Forecasting studies of Atlantic climate variability are in their infancy. Rainfall prediction studies suggest that seasonal rainfall variability in Northeast Brazil is predictable a few seasons in advance. Preliminary prediction studies using regional coupled ocean-atmosphere models indicate that low-frequency SST variability in the subtropics of the North Atlantic is predictable several years ahead, albeit with modest skill.

3.2 The NAO

Interannual variations of the NAO are responsible for large local changes from year-to-year in surface temperature and precipitation from North America to Europe, Asia and North Africa. In fact, in winter the NAO accounts for one-third of the interannual variance of surface temperature averaged over the Northern Hemisphere. The NAO also exhibits large variability on decadal and longer timescales. Over the past twenty years, for example, the NAO has remained in one extreme phase, accounting for a substantial portion of the observed global warming.

Several arguments have been proposed to explain the observed low-frequency variability of the NAO. One hypothesis is that the NAO fluctuations are a response to changes in the oceans, in particular SST changes. This suggestion has been difficult to verify, however, since there is no consensus regarding the atmospheric response to middle and high latitude SST anomalies. An alternative hypothesis is that NAO variability on all time scales is generated solely by internal atmospheric processes. Recent investigations show that the NAO is essentially the local expression of the Arctic Oscillation (AO), which is a pattern of climate that extends beyond the North Atlantic, occurring throughout the troposphere and stratosphere in the high latitudes of the northern hemisphere. This broadened view of the NAO has expanded the possibilities for the mechanisms that drive the low frequency variability in the NAO/AO to include the low frequency exchange of energy and momentum between the troposphere and stratosphere throughout the northern hemisphere. Other hypotheses for low-frequency variations in the NAO involve responses to changing external forcings such as solar insolation, volcanic eruptions, or anthropogenic emissions of climatically important trace gases. Given the large societal, economic and ecological impact of NAO/AO variability, distinguishing among these hypotheses is a high priority goal.

3.3 The Meridional Overturning Circulation and Abrupt Climate Change

Model results and paleo-oceanographic data indicate long-term fluctuations in the overall strength of the ocean's meridional overturning circulation (MOC) with transitions between fundamentally different states taking place within decades. Although the MOC is a global phenomenon of basin-to-global scale, its dynamics and in particular its variability is affected by smaller-scale processes associated with the formation of deep waters. In models relatively small changes, particularly in the freshwater cycle, can stop this water formation and the MOC. In the modern era NAO variability has changed formation of deep water in the Greenland/Iceland/Norwegian and Labrador seas, which in turn may have influenced the Atlantic MOC. Although changes in the MOC occur naturally, there is the possibility that they could be triggered by anthropogenic emissions. A breakdown of the MOC could lead to drastic changes in European climate and, perhaps, global climate.

Dramatic changes are occurring in the Arctic Ocean: a 1.5°C warming of the Atlantic layer, an apparent regime shift between the Pacific and Atlantic domains, large shifts in sea ice distribution, and a weakening of the halocline that insulates the sea ice from the warm Atlantic water. No similar changes can be detected in the past 4 to 5 decades. Are they natural decadal variability of unusually large or amplitude or do they represent an anthropogenic change? Could the changed water cycle affect the MOC?

3.4 A Coordinated Study

The hypotheses about Atlantic climate are ready to be tested. This will require (a) improved models of the global atmosphere, the upper tropical and extratropical Atlantic Ocean, (b) expanded in-situ observations of the Atlantic Ocean (especially in the upper ocean), (c) improved data assimilation techniques to integrate all observations, and (d) adequate computational resources. This readiness is especially evident in the case of the variability of the tropical Atlantic, where testable mechanisms are well developed, and the connections to the climates of neighboring land masses are clear.

A substantial U.S. interest in such a program is evident in a science and implementation plan[6] for a focused study of NAO/AO, TAV and variations of the MOC and in the prominent discussion of Atlantic climate variability by the NRC[3]. This interest is shared by the international science community as reflected in the CLIVAR IIP[1] and a recent joint U.S./Euroclivar workshop[8]. The philosophy of such a program would be to adopt a basin-wide perspective in an intensive study of climate variability in the Atlantic sector on seasonal to decadal time scales, closely connected with a lower level effort on the MOC and Arctic variability.

U.S. CLIVAR research on Atlantic climate variability will leave a legacy. In particular, it is expected to:

(i) Establish predictability and implement short-term climate predictions of the tropical Atlantic with relevance to the surrounding land masses;

(ii) Determine the potential for climate predictions of the midlatitude Atlantic;

(iii) Design and implement an observing system for climate variability in the Atlantic, including monitoring long-time-scale variability in the thermohaline circulation through time series measurements at key locations;

(iv) To the extent possible, assess the probability of future abrupt climate change.

By developing improved understanding of the NAO and TAV, an Atlantic climate variability program would directly addresses CLIVAR goals. It combines into a coherent, focused effort the DecCen elements D1, D2, and D3, and it contributes greatly to G1, G3 and G4. An Atlantic climate variability program also provides part of the necessary foundation that is required to accomplish A1 and A2.

3.5 U.S. CLIVAR Objectives

- The U.S. will contribute significantly to the study of climate variability in the Atlantic sector throughout the life of CLIVAR. A majority of the work will focus on potential climate predictability associated with NAO and TAV with a smaller investment of resources in MOC variability. An Atlantic climate variability program will require (a) improved modeling, (b) continued empirical studies of instrumental and proxy data, (c) a coordinated upper ocean observing system covering the tropical Atlantic and extending throughout the

North Atlantic Ocean, (d) a basin-wide ocean data assimilation effort, and (e) close collaboration with the Arctic research community and programs in the U.S.

4. ANTHROPOGENIC CLIMATE CHANGE

The US will strengthen its program to advance the modeling of long term climate change from human activities including supporting observational and diagnostic studies. U.S. CLIVAR recognizes that it cannot come to an adequate understanding of natural variability and develop a successful basis for its prediction without also accounting for changes of climate from human activities. This is because both the present climate and climate forcing factors resulting from human activity are undergoing large changes relative to the long term climate record. Hence, U.S. CLIVAR will address the following scientific objectives:

- Determine the appropriate parameterizations for processes that are key to assessing the sensitivity of the climate system on decadal to century time scales. Some of the important parameterizations that must be improved upon in the climate models are found in the treatment of clouds, sea ice, moist convection, and land surface processes.
- Analyze the historical and future forcing of the system by changing greenhouse gas concentrations, by the direct and indirect effect of aerosols, and by changes in land use, and then to compare these forcing functions to those associated with the natural forcing of the climate system (e.g., the forcing by volcanic aerosols and solar variability)
- Assemble long term data sets from the existing observational data bases that can be most effective for evaluating the ability of the climate models to simulate and predict the state of the climate system on decadal to century time scales.
- Determine the theoretical limits to predictions of the forced climate change on the decadal to century time scale, in light of the natural variability in the system.

The development of more reliable parameterizations for key sub-grid scale processes in the climate models will be achievable through programs that are predicated on the triumvirate of activities: a process oriented observational and analysis program, a program for the development and evaluation of parameterizations for the sub-grid scale, and a modeling program to incorporate and further test the parameterizations.

With respect to the role of clouds and radiation the DOE Atmospheric Radiation Measurement (ARM) program provides a paradigm for this approach. Further, a coordinated program for model development and evaluation must be ongoing throughout CLIVAR for these objectives to be met (see section 6). Comparisons between models are presently conducted under the aegis of several cooperative efforts. These efforts should be encouraged and brought together as much as practical. The Program for Climate Model Diagnosis and Intercomparison provides a de facto central point that could be utilized to bring these into stronger focus. Overall, a sustained and rigorous program of model development, comparison and evaluation is necessary for the success of all of the CLIVAR PRAs.

5. AFRICAN CLIMATE VARIABILITY AND SOUTHERN OCEAN THERMOHALINE CIRCULATION

Understanding the interannual variability of the African climate system involves studying at least three distinct regions of the African continent, east and central Africa, north and west Africa, and southern Africa. A tropical Atlantic SST influence is known to be present in tropical north Africa, the NAO has an influence over the northern rim of the continent, and ENSO based predictability appears to be highest for southern Africa. Several aspects of the African climate system need to be explored further both through empirical and modeling studies. Some of the additional pre-requisites to improved seasonal to interannual predictions of African rainfall are the better understanding of the influence of the Indian monsoon and Indian Ocean SST, the influence of coupled ocean-atmosphere variations in the equatorial Atlantic, extratropical influences such as mid-latitude blocking, and finally the role of the boundary layer and land-surface boundary conditions such as vegetation on the decadal variability of precipitation in the Sahel.

About ten U.S. scientists are engaged in observational and numerical modeling studies to gain insights into the scientific questions enunciated above. It is expected that these investigations will continue with increasing collaboration with researchers in Africa. Through training and exchange programs sponsored by the IRI, the U.S. is engaged in the process of establishing research expertise and infrastructure in Africa. U.S. CLIVAR will continue its present level of activity and partnership with African scientists in basic studies of processes that contribute to the understanding of climate of the African continent, mainly through the research of various individual scientists and small groups.

Like its Arctic counterpart, the Southern Ocean may play a significant role in climate variability through dense water formation, exchanges between ocean basins and abrupt changes through ice sheet dynamics. Since the observational base and modeling capabilities are not as well developed as in other regions, the U.S. endorses the recommendation in the IIP that initial emphasis be put on exploratory investigations.

6. STRATEGY FOR CLIMATE MODELING

Modeling will be the backbone of a program on Anthropogenic Climate Change and efforts to improve seasonal-to-interannual prediction as well as an essential element in studies of decadal change and decadal modulation of ENSO. In addition to a continuing aggressive program of numerical experimentation in all these areas, effort will be put into improving coordination of modeling efforts. Efforts will be made to facilitate open and ready access to well-documented models, data assimilation systems, simulations, and observations. A common programming paradigm should be adopted to facilitate exchange of model modules such as physical parameterizations. Modeling, assimilation and observation programs need close coordination and interaction. A beginning has been made in developing appropriate grounds (variables and conditions) for model intercomparisons in the Atmospheric Model Intercomparison Project (AMIP) and Climate Model Intercomparison Project (CMIP) efforts; however a much more thoroughgoing course leading to intermodel compatibility and exchangeability of process models should actively be pursued.

6.1 Background

Using climate models to simulate and understand climate variability and climate change is a theme connecting all CLIVAR research. While models with a spectrum of sophistication are needed to accomplish U.S. CLIVAR objectives, a primary tool is the fully coupled ocean-atmosphere-land model. These models are the most comprehensive available to study climate phenomena. A diversity of such models exists, varying in their physical parameterizations, spatial resolutions and applications.

Significant progress in the goal of understanding climate mechanisms and prediction depends on a combination of modeling, observations and empirical studies. Observations are essential for model initialization, model evaluation, and for improving model parameterizations. Similarly, models are essential for evaluating the quality and impact of measurements, for integrating diverse collections of data, and for development of observational sampling strategies. Hypotheses formed from empirical studies are tested in models, and the models are designed to simulate the physical, chemical, and biological processes that are involved. These models can then be run for times much longer than the observational record, exploring phenomena that cannot be feasibly observed.

The modeling infrastructure should encompass three broad categories of models: (i) models for ocean, atmosphere, land, and cryospheric data assimilation, (ii) coupled ocean-land-atmosphere-ice models as well as component models with prescribed forcing, and (iii) high resolution regional models nested in global models or, alternatively, variable resolution global models. While useful for a variety of diagnostic studies, the main purpose of such models is simulating the behavior of the climate system in the past and predicting its behavior in the future. For seasonal-to-interannual time scales, the goal is to predict ENSO and other significant climatic variations and their global climatic teleconnections. A part of this effort is to determine the predictability of such variations and the ability to regionalize global-scale predictions. For decadal-centennial time scales, the goal is to identify and predict naturally occurring variability on this scale. For anthropogenic climate change, the goal is to predict the most likely behavior of the climate system over long time scales given a variety of scenarios about the atmospheric concentration of greenhouse gases and aerosols.

Given the complementary importance of observations and models, mechanisms for optimizing interaction between the associated research communities are important. Developing a better understanding of the mechanics of the climate system requires a closer interaction between modelers and observers. In particular, global modelers need to be better integrated into observational programs, and observational programs need to be directed toward providing useful input to modelers.

Communication among modelers is especially important because climate biases are often generic to a wide class of global coupled models. For example, in most coupled models the eastern tropical Pacific cold tongue extends too far to the west. Similarly, in subtropical regions many models severely underestimate the amount of marine stratus that forms on the eastern boundaries of the Pacific and South Atlantic Oceans. This underestimate leads to severe biases in simulated sea surface temperatures in these regions, biases that also affect the interannual variability simulated by these models. With effective communication, correction of a generic bias in one model can lead to correction in them all.

Communication among modelers will be enhanced if a policy of open and ready access to well-documented model codes and model simulations is adopted. Use of a common programming paradigm will facilitate exchange of model modules such as physical parameterizations and other climate system model components.

6.2 Global Seasonal-to-Interannual Predictability

While studies of seasonal-interannual variability are underway, the U.S. will establish a program to facilitate modeling and empirical studies of global seasonal-to-interannual (S-I) predictability. There is growing evidence that the various S-I phenomena (e.g. ENSO, monsoons, NAO, and the

Pacific North American teleconnection pattern (PNA)) are connected and that it may necessary to take them all into account to fully exploit the intrinsic predictability.

Some of the scientific questions a well-coordinated infrastructure consisting of the S-I modeling and diagnostic community will address are:

- What is the global distribution of "internal" (presumably unpredictable) and "forced" (potentially predictable) variability on S-I time scales? What are the relative contributions of internal dynamics and slowly varying boundary conditions (tropical, extratropical SST, soil wetness, snow, etc.)?

- What is the geographical, seasonal regime and initialization-field dependence of S-I predictability?

- Is ENSO predictability limited by high-frequency (unpredictable) atmospheric "noise", or, the chaotic dynamics of the large scale coupled system?

- What is the predictability of regional climate variations? How do the errors in predicting SST influence planetary waves and regional climate anomalies?

- How do we design and develop an optimal observing system for S-I prediction?

6.3 Modeling and Anthropogenic Climate Change

Some of the modeling activities for anthropogenic climate change simulations have been discussed in section 4 of the Introduction. Many of the model developments that are required to achieve more reliable estimates of the response of the system to forcing (both natural and anthropogenic) overlap with those that are required for improving the prediction of seasonal-to-interannual variability, summarized in sections 6.1 and 6.2. However, research activity that is particularly important for advancing the research program on natural and anthropogenically induced climate variability on decadal and longer time scales is the development of climate models that include a better treatment of the effects and evolution of the radiatively active gases and aerosols in the atmosphere (and of their sources and sinks). Such a treatment is expected to necessitate introducing more sophisticated biogeochemical models into GCMs to provide iterative feedbacks.

The execution and analysis of the climate model simulations that are necessary for accomplishing the U.S. CLIVAR objectives will require computational resources that are beyond the outer limit of what is currently technologically possible. Thus, U.S. CLIVAR will seek partnerships between scientists, government agencies and (potentially) private industry that will develop the technology to significantly expand the present upper-boundary for the computational throughput of the state-of-the-art climate models (e.g., the joint NSF/DOE computational initiative).

6.4 U.S. CLIVAR Objectives

- U.S. CLIVAR will strive to coordinate the activities of the major U.S. modeling centers with those of the international community.

- U.S. CLIVAR will provide open access to observations and model simulations and well-documented climate model codes that are germane to CLIVAR; work toward the development of a common infrastructure framework for climate modeling; and facilitate communication and interactions between observationalists and climate modelers.

- To exploit the newly discovered potential predictability of S-I variations, U.S. CLIVAR seeks to establish a modeling infrastructure for global S-I predictability research.

- U.S. CLIVAR will define linkages and joint work with GEWEX continental-scale experiments to improve representation of land-atmosphere interactions in coupled models, to develop requisite data sets and, ultimately, to elucidate the relative roles of land and ocean process in S-I predictability.

7. SUSTAINED OBSERVATIONS

Long-term observations are an essential element of CLIVAR. They are required to monitor and detect climatic variability, to identify what variability is natural or anthropogenic, and to develop and test predictive ability. An integrated approach, taking advantage of the strengths and limitations of both satellite and in situ capabilities, is required.

The present in situ sustained observing system is sparse and incomplete for studies of climate. CLIVAR must add to this system. Observations made in support of particular PRAs should be evaluated for their value to the sustained observing system and incorporated where appropriate. Success of CLIVAR depends, in part, on the continuation and enhancement of the atmospheric observing network (including the WWW), and this will be a high priority for U.S. CLIVAR.

Space-based measurement platforms have a relatively long time scale for planning and deployment (~5 years). The 1998-2003 period will be richly endowed with earth observing satellites. CLIVAR must elaborate its requirements for further observations beyond 2003.

Two parallel observational activities are to be undertaken by U.S. CLIVAR. First, resources will be devoted to fielding elements of the sustained observing system to support U.S. participation in the CLIVAR PRAs of greatest interest. Second, because the goals of CLIVAR and GCOS are closely linked, U.S. CLIVAR seeks to coordinate with international partners to initiate a sustained observing system for climate.

This approach recognizes that the current observing system is sparse and incomplete and some elements are in decline or being rationalized. Weather ships, VOSs and radiosonde stations are declining[9] while on land changes (e.g. automation of weather stations) have lead to measurement accuracies that are inadequate for climate monitoring[9]. CLIVAR should bring the system up to strength in support of the PRAs, improve its global coverage and assess the adequacy/efficiency of different (new and old) observing elements. It should contribute to the design of an optimal observing system for global climate forecasts, for climate monitoring, and for detecting climate change.

7.1 Contributions to the Sustained Observing System

Without further prioritization, the following elements of the observing system are identified as being of great importance to U.S. CLIVAR:

- Enhancement of the atmospheric weather observation network to make it adequate for long term monitoring of climate variability.

- Measurements of temperature and salinity in the upper 1500 meters focused in the subtropical Pacific (35°S to 40°N) and Atlantic (35°S to 65°N).

- Satellite altimetry of sufficient accuracy (1-2 cm) and duration (at least the next 20 years) to detect decadal changes in ocean circulation, changes in the mass balance of the polar ice sheets, and changes in mean sea level.

- Sustained, accurate measurements of surface vector winds over the ocean.

- Complete and accurate estimates of surface fluxes of heat, freshwater, energy and momentum at select ocean and land sites, including improved measurements of cloud properties and soil moisture.

- Collection of long time series from the ocean at select Eulerian stations and from repeat ocean sections.

The high priority of these elements is based on feasibility, impact as climate observations, and requirements of the CLIVAR PRAs of greatest U.S. interest. Feasibility and impact were explored in depth by the Ocean Observing System Development Panel (OOSDP)[10]. CLIVAR's needs were assessed by review of the PRAs as discussed in the Initial International CLIVAR IIP and individual documents about the PRAs.

For many observables, satellites provide the only effective means of achieving regular, global coverage. The mission strategies to achieve this should benefit from technology improvements which lead to improved accuracy, reduced weight and power requirements, and greater flexibility in mission design parameters without compromising time series continuity[10,11,12,13]. Blending satellite with in-situ observations through data assimilative models is crucial for full utilization and interpretation of the satellite measurements[12,13].

Sensor calibration and continuity of observations are crucial elements of a climate observing system. It is, therefore, important when new (in-situ or satellite) instruments are placed in service that the new measurements significantly overlap with proven technology.

7.2 Implementation

Modeling and observational programs in CLIVAR are inextricably interconnected. Thus the above observational efforts should be guided by, and linked to, modeling efforts. Strategies for the implementation and evaluation of the observing system should reflect this.

Two implementation activities are planned. First, there will be phased deployments of instruments aimed at meeting the needs of particular CLIVAR PRAs. Second, in coordination with international and non-CLIVAR programs, U.S. CLIVAR should build toward a sustained, global climate observing system. In both these activities, U.S. CLIVAR will promote strong ties between observational, modeling and data assimilation activities. In particular, the upper ocean observing system will be assessed, and will evolve, in the context of the value added by data assimilation. There must be free, open and timely exchange of data from all sustained observing systems.

Essential elements of implementing the phased, PRA-related, sustained observations are:

- Pilot observations may be required in advance of other PRA field work. In the many data sparse regions, these observations are needed to support the planning and modeling done to develop the implementation strategy for intensive field work.

- Observations coincident with a PRA will require significant commitments to ensure their continuity and completeness throughout CLIVAR.

- When a PRA ramps down, consideration must be given to transitioning elements of the observing system to GCOS. To avoid interruption of data collection, then, CLIVAR results needed to evaluate the utility of observations should be made available in a timely manner and interaction with potential supporting agencies begun before the end of PRA field work.

In many ways the objectives and oceanic methodology of CLIVAR parallel those of GODAE. U.S. CLIVAR endorses the global aspects of GODAE in developing the infrastructure to demonstrate the feasibility and practicality of near real-time ocean data assimilation providing useful, regular and complete depictions of the ocean. Central observations for GODAE are satellite altimetry and scatterometers, the Argo float array and surface-flux reference sites.

U.S. CLIVAR endorses regional implementation of Argo, of surface flux reference sites, and of long time series in an implementation phased to satisfy the priorities of the PRAs with a particular emphasis on observing the band 35°S to 40°N in the Pacific and 35°S to 65°N in the Atlantic. These observational elements, with the existing observing network (TAO, VOS, surface drifters) and supplemented by satellite observations of surface height, surface wind and SST will allow assimilation to play its promised role of improving ocean models and motivating model development, much as it has done in atmospheric models.

An operational infrastructure for GCOS that might result in global coverage of the priority observing elements is not yet in place. It is probable, therefore, that a partnership between a nascent, operational GCOS and CLIVAR will be required to bootstrap a sustained, global observing system and to provide the needed human and hardware resources.

There must be free, open and timely exchange of data from the sustained observing system. There should be real-time or near-real-time transmission from the collection platforms whenever possible, both to permit ongoing evaluation of data quality and to make the data available for other uses such as assimilation into Numerical Weather Prediction (NWP) models. Data and data products should be quality controlled and archived in a manner that makes them readily accessible for model-data syntheses and comparisons. In support of this, the infrastructure for assembling, archiving, and distributing data should be put in place in parallel with the start of the observations.

8. DATA SET DEVELOPMENT

Development of reliable data sets is of vital importance not only for empirical studies, but also for model initialization and verification. Measurements of climate variability must be consistent, continuous in duration and of sufficient accuracy and resolution that climate signals can be distinguished from instrumental noise and from high-frequency geophysical signals unrelated to climate variability. U.S. CLIVAR seeks partnership with other countries to support a comprehensive, long-term data set development effort.

8.1 Historical Data

Because CLIVAR is concerned with time scales ranging from seasons to several decades, it is important to make the historical record as long as possible so that multiple occurrences of important climate variations are captured. To facilitate this, continued efforts will be needed to improve the quality, length, completeness, and comprehensiveness of the historical database through data archeology and support for the development and evaluation of data sets. Support should also be given to ongoing efforts to extend the historical database (e.g. Comprehensive Ocean-Atmosphere Data Set (COADS), Comprehensive Aerological Reference Data Set (CARDS)).

Many data are believed to exist in developing countries that could, for their own benefit, help in reconstructing the climate record locally and at the same time contribute to the understanding of global climate. The U.S. will consider support for efforts to put these data into computer compatible forms and make them available to the research and applications communities.

Where different compilations of historical data have been prepared, such as for COADS and the U.K. Meteorological Office marine database, continuing efforts should be made to resolve differences and, where feasible, merge them.

8.2 Reanalyses

Reanalysis of historical observations has proven to be a valuable tool in climate research, particularly in the diagnosis of various climate processes. For the atmosphere, it is recommended that reanalyses be undertaken at regular intervals as the historical database, models, and assimilation systems continue to improve. Future reanalyses should address research needs on decadal-to-century timescales and the problem of the continually changing database. Accurate detection of long-term trends and decadal fluctuations may require use of a consistent data base in reanalysis.

Presently three reanalysis data sets are available. The ability to contrast these has assisted detection of deficiencies and permitted the analysis producers to find errors in their analysis-forecasting schemes and in the data themselves that limit the utility of the reanalyses. For these and other reasons, reanalysis should be supported as an ongoing activity, and future efforts should be made with improved models and assimilation techniques. Particular attention must be given to improving the hydrologic cycle and energy transfers.

One of the most difficult tasks in carrying out reanalysis is the organization of the input data base, and the U.S. CLIVAR must continue to recognize that such efforts are extremely valuable activities for climate research. A key issue is the need for all existing observed data to be acquired, checked for quality, and entered into a master global data base that can be accessed by all participating reanalysis centers. This effort will require a high degree of international cooperation. U.S. CLIVAR can be an effective means to bring about this cooperation.

Similar to the need for reanalysis of atmospheric fields is the need, first, for analyzed ocean data such as GODAE will produce and, second, reanalysis of the GODAE fields. Similar comments apply to land surface data (including vegetation and hydrology) and to cryospheric data.

8.3 Paleoclimate Data

Instrumental records are too short to record the full range of natural climate variability. Consequently, paleoclimatic data sets need to be generated in order to provide a comprehensive record of seasonal to interdecadal variability and to put the instrumental record in the context of the last millennium. Proxy records (e.g. corals, tree rings, ice cores, varved marine and lake sediments) are particularly useful for studying continental climate and its relation to oceanic conditions[14].

Interpretation of proxy climate records is an area where models, suitably equipped with tracer or other specialized capabilities, will be of substantial utility. For example, atmospheric models with isotopic water-vapor/tracer capabilities can be used to synthetically generate ice core records; this will strengthen our understanding of the relationship between the observed ice-core records and climate variability.

Time series of proxy data covering the full length of the last millennium with an annual resolution will be derived from only a few locations. However, fields of proxy data for air or sea surface temperature and precipitation will be developed at a global-scale for at least the last 400 years using information provided by corals, tree rings, ice cores, marine and lake sediments, historical data and a few other innovative proxies. The U.S. will continue to support ongoing efforts in these areas, such as Earth System History (ESH), the PAGES-CLIVAR effort, Annual Records of Tropical Systems (ARTS) and the World Data Center for Paleoclimatology (including the International Tree-ring Data Bank).

8.4 The U.S. CLIVAR Data Exchange Policy

A fundamental objective of the U.S. CLIVAR policy on data exchange is the free and open sharing and exchange of CLIVAR related data and products, in concurrence with the World Meteorological Organization (WMO) Resolution 40. Much of the data required by CLIVAR needs to be made available in near-real time so that it can be assimilated into models to provide fields of physically relevant variables.

Global data sets are required for the success of CLIVAR. Because there are often scattered collection efforts, there is a need to merge data from multiple countries, regions, and separate archives. Technology is making it possible to open up the access of data, but the data policies of many world governments are defeating the gains that could be made.

U.S. CLIVAR recommends a strong international policy of keeping as much data as possible in the public domain and limiting the amount of time new data can be restricted. Once in the public domain, data should remain there, and only recoverable costs for accessing such data should be charged non-profit users. Data should also be quality controlled and provided with full documentation (metadata) so as to be useful for climate monitoring and for use in future reanalysis efforts.

Preservation of all data needed by CLIVAR is required. Internationally agreed standards must be used for the acquisition, processing, archival and distribution to the extent possible. Where feasible, existing mechanisms for the exchange and storage of data should be utilized, and advantage should be taken of existing data centers.

Addressing the key scientific issues will require an interdisciplinary research effort. Such efforts, unfortunately, are too often limited by the availability of data to individual researchers. U.S. will lead an international effort to improve data accessibility, documentation and archaeology.

8.5 U.S. CLIVAR Objectives

- U.S. CLIVAR will participate in an international effort to enhance and extend the available global data base for climate variability research and applications, including both historical data and paleoclimatic proxy data.

- U.S. CLIVAR will participate in an international effort to develop a master global climatic data base that can be used by centers performing reanalyses as well as by other research and applications users.

- U.S. CLIVAR will continue a lead role in the periodic provision of reanalyzed data fields, with a future emphasis on decadal and longer time scales. These reanalyses will be extended to include the ocean, land surface, and cryosphere.

- U.S. CLIVAR will help implement an international policy that promotes open exchange of all available climatic data at minimal cost to non-profit users.

Present U.S. CLIVAR Contributions

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

UNIFYING THEME: GLOBAL OBSERVATIONS

NASA's Earth Science Enterprise [http://www.hq.nasa.gov/office/ese/] remote sensing missions provide a wealth of information that contributes to CLIVAR programs at a fundamental level. It is expected that focused efforts on analysis of these data sets will also constitute one element of many of the PRAs. The principal NASA missions of significance to CLIVAR are summarized below. The full range of missions associated with NASA's Earth Science Enterprise may be explored on the World Wide Web [http://www.hq.nasa.gov/office/ese/missions/spacecraft.html]

Ocean Observations

Sea Level
The Ocean Topography Experiment (TOPEX)/Poseidon and Jason-1 altimetry missions will provide high quality sea level estimates for interpretation in climate studies. SSH data provide information about the ocean geostrophic flow-field near surface and when assimilated into an ocean circulation model, in the interior ocean as well. SSH data also provide a measure of upper ocean heat and haline variability. NASA and Centre National d'Etudes Spatiales (CNES) have combined forces to build and operate altimetric missions for obtaining high accuracy SSH data since August 1992. Jason-1 will be the follow-on mission to TOPEX/Poseidon and is slated for launch in May 2000. [http://topex-www.jpl.nasa.gov/]

Surface Vector Winds over the Ocean
Seawinds instruments on the QuikSCAT and Advanced Earth Observing System (ADEOS-II) satellites provide estimates of vector wind over the ocean. Wind stress is the primary mechanical forcing function of the ocean circulation. Remote sensing observations of surface winds are the only way to assure a truly global coverage of wind data over the ocean and to assure that meteorological models provide high-quality wind-stress fields. NASA launches its Seawinds scatterometer on the QuikSCAT mission in late 1998 to provide 25 km resolution of vector surface winds over 90% of the ice-free ocean each day. A second Seawinds instrument is slated for launch in late 2000 on the Japanese ADEOS-II satellite. [http://seawinds.jpl.nasa.gov/]

Gravity
Gravity Recovery and Climate Experiment (GRACE) satellite is slated for launch in March 2001. It will provide a high accuracy measurement of the time varying gravity field. Knowledge of the marine geoid is fundamental for using altimeter data to study the absolute ocean currents. This mission also provides information about variable distribution of the ocean water mass, equivalent to bottom pressure data from which the vertical-mean ocean circulation may be derived. [http://essp.gsfc.nasa.gov/esspmissions.html]

Salinity
NASA is currently developing the technology to remotely sense the ocean surface salinity from low earth orbit. The scientific issues are succinctly discussed in a report of the Salinity and Sea Ice Working Group

Cryospheric Observations

Among the important variable elements of the Earth's climate system are the polar ice sheets and sea-ice cover. Changes in the volume of the large ice sheets directly affect sea level and the global ocean thermohaline circulation. Changes in sea-ice coverage directly affect heat, freshwater, and momentum fluxes at the boundary between the ocean and atmosphere, the absorption of solar radiation at the Earth's surface, and the salt fluxes in the ocean.

Ice Sheet Topography

Technology exists to obtain ice-sheet topography from space. A new laser altimeter is slated for launch on ICESAT in 2001 as part of the Earth Observing System (EOS). This altimeter will measure ice-sheet topography from space and thus allow analysis of the ice-sheet mass balance.

Sea Ice

Sea-ice concentrations (percent areal coverages) to a resolution on the order of 30 km have been obtainable from satellites since the early 1970's using passive microwave radiometer technology. The record from the early and mid 1970's contains many large data gaps, but since Oct. 1978 is reasonably complete in terms of obtaining a consistent global sea ice coverage dataset every 1-3 days. This record demonstrates significant seasonal and interannual variability in the sea-ice cover and its dynamics. This dataset is currently being continued with the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) and will be further continued with the Advance Microwave Scanning Radiometer (AMSR) on both EOS Passive Microwave (EOS-PM) platform and the Japanese ADEOS-II platform, both scheduled for launch in the year 2000.

Atmospheric and Land Observations (Climate Forcing Factors)

Total Solar Irradiance

The first long-term solar monitoring instrument in space utilized an electrically self calibrating cavity sensor, part of the Earth Radiation Budget (ERB) experiment on the Nimbus 7 spacecraft. The ERB database, beginning in late 1978 and continuing to early 1993, is the longest currently available. Unambiguous evidence of total solar irradiance (TSI) variability was first detected in the highly precise results of the Active Cavity Radiometer Irradiance Monitor (ACRIM I) experiment on NASA's Solar Maximum Mission (SMM) in 1980. The mutually corroborative function of the ACRIM I and ERB results has played an important role in verifying TSI variability on the solar activity cycle time scale.

The precision TSI climate database is currently being sustained by two experiments; namely, (1) the Upper Atmosphere Research Satellite (UARS)/ACRIM II, launched in 1991, and (2) the Differential Absolute Radiometer (DIARAD) on the European Space Agency's (ESA) Solar Heliospheric Observer (SOHO)/Variability of solar Irradiance and Gravity Oscillations (VIRGO), launched in late 1995. NASA planned TSI experiments are EOS/ACRIM (October 1999) and the TSI Mission (December 2001). NASA's interest in continuing total solar irradiance measurements is in considering the effect of this variability on the Earth's climate.

Stratospheric Aerosols

NASA maintains an active program of measuring stratospheric aerosols through a variety of platforms. The major current space-based platform used for measurement of stratospheric aerosols is the Stratospheric Aerosol and Gas Experiment (SAGE II) instrument, which has been taking data since late 1984. SAGE II uses the technique of absorption of visible and near infrared radiation at solar occultation to determine atmospheric extinction as a function of altitude. These data are converted to information on abundance of aerosols through inversion methods. Information on particle abundance and some sense of particle size can be obtained in this way. Data on aerosol concentrations are also obtained using the Halogen Occultation Experiment

(HALOE) instrument aboard UARS. NASA also carries out analysis of historical data sets for aerosol concentrations, including that from the Stratospheric Aerosol Monitor (SAM II) mission, which obtained high latitude aerosol and polar stratospheric cloud data over an approximately 15 year period (1979-1994), the Atmospheric Trace Molecule Spectroscopy (ATMOS) instrument, which flew four times on the Space Shuttle (1985, 1992, 1993, 1994), and several other instruments aboard UARS.

In situ measurements of aerosol distributions and properties are made using the ER-2 aircraft, and lidar measurements are made from the DC-8. These measurements are made as part of major focused aircraft campaigns, such as the recently completed Photochemistry of Ozone Loss in the Arctic Regions in Summer (POLARIS) campaign, carried out in 1997 using the ER-2, and the planned SAGE Ozone Loss and Validation Experiment (SOLVE), which will take place in late 1999 and early 2000 using the DC-8 and ER-2. In addition, ground-based measurements of stratospheric aerosol distributions are made using lidar instruments associated with the Network for Detection of Stratospheric Change (NDSC). Such observations are made routinely. Data for all are made available to the scientific community.

Land-cover and Land-use Change

In 1992, the U.S. Congress authorized the procurement, launch and operation of a new Land Remote Sensing (Landsat) satellite. This new system, Landsat 7, is now under construction and is scheduled for launch in April 1999. It will be the latest in a series of earth observation satellites dating back to 1972. The twenty-two year record of data acquired by the Landsat satellites constitutes the longest continuous record of the earth's continental surfaces. Preservation of the existing record and continuation of the Landsat capability were identified in the law as critical to land surface monitoring and global change research.

Landsat 7 will have a unique and essential role in the realm of earth observing satellites in orbit by the end of this decade. No other system will match Landsat's combination of synoptic coverage, high spatial resolution, spectral range and radiometric calibration. In addition, the Landsat Program is committed to provide Landsat digital data to the user community in greater quantities, more quickly and at lower cost than at any previous time in the history of the program.

The earth observing instrument on Landsat 7, the Enhanced Thematic Mapper Plus (ETM+), replicates the capabilities of the highly successful Thematic Mapper instruments on Landsats 4 and 5. The ETM+ also includes new features that make it a more versatile and efficient instrument for global change studies, land cover monitoring and assessment, and large area mapping than its design forebears.

UNIFYING THEME: MODELING, ASSIMILATION, AND PREDICTION

NASA funds research and applications in global climate modeling, global assimilation of climate data, and experimental predictions and scenario projections that support all of the CLIVAR PRAs. The major research activities are summarized below.

NASA Seasonal-to-Interannual Prediction Project (NSIPP):

The goal of NSIPP is to develop a capability to make improved predictions of seasonal-to-interannual climate variability using a coupled climate system model. The successful development of such a capability will provide alternative prediction capability to operational centers such as NOAA's Climate Prediction Center (CPC) and the IRI. NSIPP will build on existing modeling capability and will especially seek to maximize the useful input of satellite-based observations for climate prediction. The NSIPP core activity at the Goddard Space Flight Center consists of coupling together oceanic and atmospheric GCMs, coupling a parameterized land surface/hydrology model to the atmospheric GCM, and eventually adding a sea-ice model that couples to both the atmospheric and oceanic GCMs. Contributing activities from the broader community are being considered and will likely include assimilation of oceanic and land surface data, improved parameterizations of atmospheric radiation and convective precipitation processes, and diagnostic evaluation of experimental predictions.

NSIPP expects to produce experimental ENSO predictions for the tropical Pacific region within the next 1.5 years. Subsequently, NSIPP will broaden its activity to include prediction of the global response to ENSO forcing in the Pacific basin and will also examine the predictability of other major climate variations on seasonal-to-interannual time scales (e.g., Quasi-Biennial Oscillation, North Atlantic variability, land-atmosphere moisture exchange, and sea-ice feedback to climate variations).

The CLIVAR PRAs addressed by this project are G-1 through G-4, with possible linkages to the Decadal-Centennial PRAs.

NASA-GISS Global Climate System Modeling Project:
This project at the Goddard Institute of Space Studies (GISS) is focused primarily on decadal through multicentennial climate change as well as on climate change induced by stratospheric volcanic aerosol and chemical constituent variability. Over the last few years, the GISS global climate system model has undergone several significant improvements, including coupling with a more realistic ocean GCM and using improved model physics and more efficient numerical schemes. Further improvements to ocean/atmosphere coupling, and to land surface-hydrology, sea ice, and atmospheric and oceanic boundary layer representations are in progress or planned.

The GISS climate system model has been used for long-term climate integrations to study the response of the climate system to various scenarios of greenhouse gas forcing. It has also successfully predicted the approximate climate change caused by the presence of volcanic aerosols in the stratosphere from the Mt. Pinatubo major eruption of 1991.

Future studies with the GISS model system will include modeling the climatic effects of tropospheric aerosols on global and regional climate, modeling long-term changes in land surface hydrology caused by climate change, and modeling the climatic effects of trace chemical constituents in the atmosphere. With a realistic oceanic GCM fully coupled to the atmospheric GCM, GISS will be able to study the nature and causes of natural variability on decadal-to-centennial time scales.

The CLIVAR PRAs addressed by this project are D-1 through D-5, A-1, and A-2.

Atmospheric Chemistry Modeling for Climate Applications
NASA has a significant effort in the development of atmospheric models that can simulate the distributions of tropospheric ozone and tropospheric aerosols, changes of which could provide important contributions to changes in radiative forcing. Realistic simulation of tropospheric ozone and aerosols, whose concentrations can be highly variable in space and time, are necessary if realistic distributions are to be included in climate models (especially if the effects of their changes over time are to be modeled). Both tropospheric ozone and sulfate aerosols are formed in the troposphere as a result of photochemical processes involving naturally and anthropogenically-produced precursors, so a reasonably complete simulation of chemistry is needed for realistic simulation.

Other models, emphasizing realistic representation of stratospheric chemistry, are developed to simulate the concentrations of radiatively important lower stratospheric ozone. Decreases in lower stratospheric temperature driven by ozone decreases are among the largest observed temperature changes in the atmosphere, and if climate models are to be compared with the observed temperature record they must realistically simulate the observed lower stratospheric ozone changes.

The CLIVAR PRAs addressed by these modeling activities are primarily A-1 and A-2.

Related Climate Modeling Research Supported by NASA:
NASA funds a large number of other atmospheric, oceanic, land surface, sea ice, and coupled climate modeling research activities that contribute to a national modeling effort and to overall CLIVAR goals. These include climate predictability studies, certain process modeling studies that lead to improved representation of smaller scale processes in global models, other improvements of model physics and dynamics, more efficient numerical schemes for models, diagnostic evaluations of model performance, and some specific model applications.

The breadth of these related research activities contributes to all of the CLIVAR PRAs.

Ocean Data Assimilation for Climate Research and Applications:
In addition to NSIPP, NASA supports a number of related contributing activities at other institutions. In particular, a new effort at the Jet Propulsion Laboratory (JPL) is developing methodologies for the assimilation of remotely sensed ocean surface data, in conjunction with ocean in situ observations, into oceanic general circulation models. This activity will contribute to GODAE.

Contributing efforts at other institutions are investigating assimilation techniques and performing systematic evaluations of assimilated data sets.

These data assimilation activities potentially contribute to all CLIVAR PRAs.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

Principal Research Areas

G1, Extending and Improving ENSO Predictions (26 projects)
NOAA's GOALS Program will continue, as a priority focus, projects to improve the understanding, modeling, and prediction of ENSO. Key areas of investigation include the sensitivity of ENSO to initial values, the seasonality of predictability and its origins, the role of non-linearity in limiting predictability, the influence of intraseasonal variability, and the nature of the annual cycle and its interaction with interannual variability. NOAA also continues to exploit observational efforts including intensive field campaigns (e.g. TOGA COARE) in order to improve the understanding of ENSO processes, improve estimates of heat, momentum, mass and moisture budgets, and test and improve model parameterizations of key processes that are essential in the coupling of the ocean and atmosphere. Experimental predictive modeling using a hierarchy of coupled modeling approaches will continue to be pursued, with attention to improvements in initialization and assimilation techniques.

ENSO teleconnections throughout the tropics and into the extratropics will continue to be explored. NOAA has a particular interest in understanding and modeling the response over North America. Specifically, efforts are being undertaken to determine the limits in predictability of the atmosphere induced by tropical Pacific sea surface temperature changes, to diagnose and model the global response to warm and cold ENSO events, and to examine the changes in probabilities of extreme events induced by ENSO.

G2, Variability of the Asian-Australian Monsoon System (8 projects)
NOAA's GOALS Program supports a limited number of projects investigating the variability of the Asian-Australian monsoon. Primary emphasis has been on the interannual variability of the monsoon and its relationship to ENSO. Other analyses and modeling work will continue to explore the influence of boundary forcings, including land surface processes, snow and ice cover over the Himalayas and Central Asia, and sea surface temperature anomalies in the Pacific and Indian Oceans, on the variability and predictability of the monsoon.

G3, Variability of American Monsoon Systems (37 projects)
NOAA intends to make significant contributions to the emerging international VAMOS Program through activities supported under the PACS Program. NOAA PACS is undertaking a broad research agenda to extend the scope and improve the skill of seasonal-to-interannual climate prediction over the Americas with particular emphasis on understanding the mechanisms associated with warm season rainfall and its potential predictability. Monitoring, data set development, data management, empirical, diagnostic and modeling projects have been initiated to promote a better understanding and more realistic simulation of (1) the role of boundary processes in forcing of seasonal-to-interannual climate variability over the Americas, (2) the structure and evolution of tropical SST fields, (3) the seasonally varying mean climate over the Americas and adjacent ocean regions, (4) the structure and variability of the CTIC and subtropical stratus cloud decks and their influence on climate over the Americas, and (5) the relevant land surface processes that shape the distribution of continental precipitation.

While undertaking research throughout the regional domain of PACS, the principal initial regional foci have included the eastern tropical Pacific regime (including the ITCZ, cold tongue and stratus regions) and the North American monsoon system. PACS will soon initiate additional enhanced monitoring efforts including an expanded upper air sounding network in the eastern Pacific and surrounding land regions, and enhanced oceanic and atmospheric observations near 95°W from 12°S to 12°N extending from under the stratus deck, across the cold tongue, the equatorial front, and across the ITCZ into the warm pool. Complementary modeling and empirical investigations will be continued and expanded to investigate large-scale atmosphere-ocean interactions in the tropical eastern Pacific in the context of the climatological-mean annual march and seasonal-to-interannual climate variability. NOAA will also support new modeling and empirical investigations into the annual mean and interannual variability of warm season rainfall in the North American monsoon system, emphasizing links between that variability and the adjacent oceans. A near-term priority is to address the difficulty that current-generation global and regional climate models have in predicting the space and time distribution of precipitation.

NOAA is interested in working with its partner agencies in the U.S. and interested parties in other nations in the Americas through VAMOS to (1) implement the Eastern Pacific Investigations of Climate (EPIC) field campaign in the eastern Pacific, a five-year process study to improve the description and understanding of the CTIC and key physical processes that must be parameterized for successful simulation of the CTIC with dynamical ocean-atmosphere models, (2) develop a multinational coordinated research agenda for the North and South American monsoons, and (3) work with the Atlantic PRAs of CLIVAR to explore the variability of the tropical Atlantic and its influence upon precipitation over the Americas.

G4, African Climate Variability (4 projects)
While having no focused program effort on climate variability in Africa, NOAA supports a limited number of research and applications activities that may contribute to improved understanding and prediction of climate over Africa. Through its contributions to the IRI and Regional Application Projects, NOAA supports the development, implementation, and application of ENSO-based experimental climate predictions for African regions. NOAA research focused in the Atlantic and Indian Oceans and the AA monsoon will necessarily overlap with research on African Climate Variability. Investigations of the Atlantic ITCZ within PACS and the NAO within the CLIVAR Atlantic Programs will advance understanding of processes important to variability over northern and western Africa. Research on the AA monsoon region will necessarily include the monsoon regions of eastern Africa that are included in the continental-scale phenomena. Research will also continue on the potential influence of the Indian Ocean SST variability on the rainfall over southern Africa.

D1-D3, Atlantic Climate Variability (18 projects)
Through its CLIVAR-Atlantic Program, NOAA will seek to improve the understanding, modeling and prediction of natural coupled ocean-atmosphere climate variability on seasonal to decadal timescales in the Atlantic basin (with relevance to surrounding land masses). As an initial emphasis, NOAA will focus on understanding and assessing the predictability of natural climate variability in the coupled ocean-atmosphere tropical Atlantic system and its interaction with higher latitude variability, such as the NAO. NOAA's research is aimed at providing a focused, coherent approach that is directly responsive to CLIVAR PRAs D1 (NAO), D2 (TAV) and D3 (Atlantic Thermohaline Circulation).

D4, Pacific and Indian Ocean Decadal Variability (9 projects)
NOAA's contribution in this research area is presently focused on investigating the decadal modulation of ENSO. Included are the generation of ocean data sets covering several decades, empirical analyses of Pacific decadal variability, and a number of modeling efforts to explore specific hypotheses including the influence of: low-frequency equatorial sub-surface waves, subtropical-tropical wave interactions, random atmospheric forcing, and anthropogenic radiative forcing (greenhouse warming response).

D5, Southern Ocean Climate Variability (1 project)
The focus of Southern Ocean field work will be the Weddell Sea where air-sea interaction affects both the deep thermohaline overturning circulation and the shallower intermediate-depth circulation that is involved in overturning circulations in all three subtropical oceans. The Southern Ocean

theme is a complete research program addressing climate problems of the ocean's southern regions including special problems of deep water formation, climatic fluctuation of ice, variability of Antarctic air-sea interaction and its teleconnections to the global climate.

A1, Climate Change Prediction (1 project)
NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) supports climate change prediction research, which includes developing long climate runs to analyze CO_2 forcing at 2X-4X CO_2 levels as well as understanding the role of ocean circulation and marine and terrestrial biota in global response to CO_2 forcing.

A2, Climate Change Detection and Attribution (12 projects)
The climate change detection and attribution activity supported by the Climate Change Data and Detection (CCDD) sub-element of NOAA Climate and Global Change Program has several objectives. The first is to document changes and variations in the instrumental climate record. This sub-element focuses on the documentation of changes and variations of forcings, feedbacks, and responses on time scales from days to centuries including extreme weather and climate events. The second is the use of this information along with model simulations and the paleoclimatic record to assess the role of specific forcings in the observed climate record. The separation of climate variability and changes among a suite of possible forcings and feedbacks is the most challenging part of this project. All of the uncertainties of our data sets, models and analysis methods are manifest in the work of this program sub-element.

Unifying Themes

Global Modeling and Prediction (7 projects)
The IRI Core facility will provide the necessary scientific and institutional focus for an end-to-end program of climate prediction on seasonal-to-interannual time scales. It will provide the nucleus of a network of prediction and applications research centers and programs. A now-forming network of IRI research centers will support the IRI Core in its development of new modeling activities and applications by incorporating the results of new prediction and applications research into the IRI's end-to-end prediction and applications program. This key research and development role will be served, in part, by many of NOAA's Applied Research Centers (ARCs).

NOAA's ARCs include contributions to National Centers for Environmental Prediction (NCEP)/CPC, Center for Ocean-Land-Atmospheric Studies (COLA), Florida State University (FSU)/Center for Ocean0Atmospheric Prediction Studies (COAPS), Scripps Institution of Oceanography (SIO)/Experimental Climate Prediction Center (EPCP), the Climate Diagnostics Center (CDC), and the GFDL/University Consortium. The ARCs focus on: (1) operational and experimental seasonal to interannual forecast systems, including multiple model consensus forecast systems, improved ocean data assimilation and validation, and the development of new methods for tropical and mid-latitude ocean prediction; (2) intercomparison of seasonal to interannual models and dynamical prediction, which includes the Dynamical Seasonal Prediction Project and the use of model intercomparisons to develop ensemble systems; (3) the role of oceans in climate variability with particular emphasis on atmospheric response to observed SST anomalies, and the role of ENSO mechanisms in determining the ultimate limit of ENSO predictability; (4) downscaling, which involves developing multiple systems to nest regional to local models within global model systems and applying downscaling techniques to improve hydrologic forecasts; and (5) paleoclimate data assimilation, which addresses the expansion of gridded multiproxy datasets for model intercomparison at critical time periods.

Global Sustained Observations (6 projects)
NOAA will make climate observations that contribute to international efforts to build a sustained, global observing system. Central to organizing the PRA efforts into a global system will be the

concept of building global data sets; i.e., the field elements of each network will report to a global data stream available real-time and delayed mode to serve both CLIVAR research and operational forecast programs. The infrastructure for assembling, archiving, and distributing data will be considered an integral component of the observing system. Real-time reporting, quality control, and long-term data continuity will be of paramount importance. In order to build toward an international, global, sustained GCOS, NOAA will coordinate its CLIVAR observational efforts through Intergovernmental Oceanographic Commission (IOC)/WMO implementation bodies such as the Data Buoy Cooperation Panel.

NOAA's in situ efforts will concentrate on extending (in space and time) the present networks of moorings, surface drifting buoys, VOS XBT/SST/surface met, geodetically positioned tide gauge stations, and autonomous profiling floats. Immediate enhancements will focus on extending the present ENSO Observing System and the Atlantic pilot arrays into the North Atlantic, North Pacific, and eastern Indian Ocean to provide the sustained, basin-scale observations needed to describe the background upper ocean and atmospheric fields of interest to the PRAs, and to calibrate the satellite observations. NOAA's remote-sensing efforts will concentrate on maintaining the U.S. contribution to the geostationary and polar orbiting environmental satellite constellations, and to developing new and improved capabilities in observing atmospheric variables such as water vapor, wind, and chemical constituents from commercial aircraft.

Data Set Development and Management (Including Paleoclimate) (52 projects)
NOAA's CCDD Program focuses on the development, analysis, and stewardship of high-quality reference data sets to further our understanding of climate variability and change on time scales from days to centuries. This requires a broad ensemble of data management projects that: (1) develop, quality control, quantify time dependent biases (homogeneity), and evaluate data sets for cross-cutting science needs necessary to improve our ability to describe, understand, and predict seasonal, interannual, decadal, and longer term climate variations and changes; and (2) calibrate, validate, and blend existing data sets from a variety of observing systems, including space-based, in-situ, and model data (data set enrichment).

NOAA's Paleoclimatology Program supports the use of environmental paleorecords (derived from tree-rings, corals, ice cores, lake and marine sediments, etc.) to develop high-resolution reconstructions of past climate in order to acknowledge the full range of societally relevant climate variability, thus providing valuable input to climate models and forecasts. As a direct contributor to and supporter of national and international PAGES/CLIVAR research efforts, this program supports investigations of key phenomena such as ENSO, North Pacific variability, tropical and North Atlantic variability, Asian/African Monsoon dynamics, North American drought and flood dynamics, and shallow meridional ocean circulation and other processes linking tropical and exratropical climate variability. This program also focuses research efforts on the use of long (centuries to millennia) time series to examine major abrupt climate transitions of the past.

NATIONAL SCIENCE FOUNDATION (NSF)

Background

NSF is responsible for promoting and advancing scientific progress in the U.S.. NSF-CLIVAR supports climate research through ad-hoc projects proposed by individual investigators at universities, private laboratories and the National Center for Atmospheric Research (NCAR), and evaluated/reviewed by their peers. A portion of NSF's CLIVAR budget supports organized, directed research, usually related to process oriented field observing programs, e.g., TOGA COARE.

NSF funding decisions are strongly influenced by our community of researchers, both in terms of their collective ideas of the most fruitful science areas to pursue (through, e.g., the CLIVAR planning process), and also through the peer review process for deciding which specific programs and projects we will support.

Activities within CLIVAR will include, but not be limited to:

- Coupled ocean/atmosphere modeling with the primary objective of developing and advancing the predictive capability;

- Separate ocean and atmosphere modeling efforts designed to better understand the impacts of physical processes that most affect medium and long-term predictability of the ocean, the atmosphere, and, ultimately, the coupled system.

- Sustained observations, in both the ocean and atmosphere, of parameters that most directly affect the coupled models, and that are necessary for initializing and maintaining long-term model runs.

- BECS to address phenomena that have been identified as affecting long-term climate variability, which have defined signals that appear subject to systematic study, and that may have a degree of predictability.

- Smaller-scale process studies, but of such a magnitude that requires some degree of coordination and management beyond the individual investigators.

- Empirical studies, using existing (particularly historical) data to address issues outlined above.

- Large-scale data management and coordination.

- Some degree of project management to ensure that the components work together to address the overall objectives.

Approximately 60% of NSF's CLIVAR funds are currently invested in process research and empirical studies, about 20% in modeling, mostly global modeling, and about 20% in sustained observations.

What Exists Now

Following are the numbers of NSF-supported research projects tabulated as a function of the 11 CLIVAR PRAs. Many of these projects do not conform to the GOALS and DecCen scale separation, but rather examine climate processes across these time scales. Nonetheless, we have adhered to the current list of PRAs.

Principal Research Areas		**No. of Projects** **CLIVAR**	 **Contributing**
G1	ENSO. Expanding and Improving Predictions	35	2[a]
G2	Variability of the AA Monsoon System	1	0
G3	Variability of the American Monsoon System	1	1
G4	Interannual Variability of the African Climate System	3	5
D1, 2, 3	Atlantic Climate Variability	5	24[b]
D4	Indo-Pacific Decadal Variability	10	0
D5	Southern Ocean Thermohaline Circulation	1	0
A1, 2	Climate Change Prediction, Detection and Attribution	1	10[c]
Unifying Themes			
Global Observations and Data Set Development		6	7
Global Modeling		9	12
Meetings, Workshops, Committees		3	2

[a] Many of these projects overlap with G2-4

[b] An additional 25 projects relevant to D1-3 are supported under the World Ocean Circulation Experiment (WOCE)/ACCE

[c] The projects listed under A1 and A2 are supported under NSF's Climate Modeling, Analysis and Prediction initiative of its Global Change Program, which is a counterpart to CLIVAR. Included is the NCAR-university community Climate System Model initiative.

In addition to the above, NSF supports ship, aircraft and ground- based platforms and instrumentation, through its ongoing facilities, e.g., NCAR, University National Oceanographic Laboratory System (UNOLS).

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4. Esbensen, S., T. Mitchell and C. Gudmunson. ed. Pan American Climate Studies: A Scientific Prospectus and Implementation Plan, 40 pp.

5. Lukas, R., R. Davis and W. Kessler, 1998. Prospectus for a Pacific Basinwide Extended Climate Study, draft plan. WOCE Project Office.

   In addition, several U.S. scientist-generated planning documents and reports on the American monsoon have been generated under the Pan American Climate Studies (PACS) Program. They are available on-line at the PACS homepage: http://tao.atmos.washington.edu/pacs/plans.html.

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Acronym List

AA Monsoon	Asian-Australian Monsoon
ACCE	Atlantic Circulation and Climate Experiment
ACRIM I	Active Cavity Radiometer Irradiance Monitor (JPL)
ACVE	Atlantic Climate Variability Experiment
ADEOS-II	Advanced Earth Observing System
AMIP	Atmospheric Model Intercomparison Project
AMSR	Advance Microwave Scanning Radiometer
AO	Arctic Oscillation
ARCs	Applied Research Centers
ARGO	Array for Real-time Geostrophic Oceanography
ARM	Atmospheric Radiation Measurement
ARTS	Annual Records of Tropical Systems
ATMOS	Atmospheric Trace Molecule Spectroscopy Experiment
BECS	Basin-scale Extended Climate Studies
CARDS	Comprehensive Aerological Reference Data Set
CCDD	Climate Change Data Detection
CDC	Climate Diagnostics Center
CLIVAR	Climate Variability and Predictability
CLIVAR IIP	CLIVAR Initial Implementation Plan
CMIP	Climate Model Intercomparison Project
CNES	Centre National d'Etudes Spatiales (France)
COADS	Comprehensive Ocean-Atmosphere Data Set
COAPS	Center for Ocean-Atmospheric Prediction Studies
COLA	Center for Ocean-Land-Atmospheric Studies
CPC	Climate Prediction Center
CTIC	Cold Tongue-ITCZ Complex
DecCen	Decadal-to-Centennial
DIARAD	Differential Absolute Radiometer
DMSP SSM/I	Defense Meteorological Satellite Program Special Sensor Microwave/Imager
DOE	Department of Energy
ENSO	El Niño Southern Oscillation
EOS	Earth Observing System
EOS-PM	EOS Passive Microwave
EPCP	Experimental Climate Prediction Center
EPIC	Eastern Pacific Investigations of Climate
ERB	Earth Radiation Budget
ESA	European Space Agency
ESH	Earth System History
ETM+	Enhanced Thematic Mapper Plus
FSU	Florida State University
GAME	GEWEX Asian Monsoon Experiment
GCM	Global Climate Model
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute of Space Studies
GOALS	Global Ocean-Atmosphere-Land System
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GRACE	Gravity Recovery and Climate Experiment

HALOE	Halogen Occultation Experiment
ICESAT	Ice, Cloud and Land Elevation Satellite
IOC	Intergovernmental Oceanographic Commission
IRI	International Research Institute
ITCZ	Inter-Tropical Convergence Zone
JPL	Jet Propulsion Laboratory
Landsat	Land Remote-Sensing Satellite
MOC	Meridional Overturning Circulation
NAO	North Atlantic Oscillation
NASA	National Aeronautic and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDSC	Network for Detection of Stratospheric Change
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
NSIPP	NASA Seasonal-to-Interannual Prediction Project
NWP	Numerical Weather Prediction
OOSDP	Ocean Observing System Development Panel
PACS	Pan-American Climate Studies
PAGES	Past Global Changes
PDO	Pacific Decadal Oscillation
PNA	Pacific North American
POLARIS	Photochemistry of Ozone Loss in the Arctic Regions in Summer
PRA	Principal Research Area
SAGE II	Stratospheric Aerosol and Gas Experiment
SAM II	Stratospheric Aerosol Monitor
S-I	seasonal-to-interannual
SIO	Scripps Institution of Oceanography
SMM	Solar Maximum Mission
SOHO	Solar Heliospheric Observer
SOLVE	SAGE Ozone Loss and Validation Experiment
SSC`	Science Steering Committee
SSH	Sea Surface Height
SST	Sea Surface Temperature
TAO	Tropical Atmosphere Ocean (TOGA moored array)
TAV	Tropical Atlantic Variability
TOGA	Tropical Ocean and Global Atmosphere
TOGA COARE	TOGA Coupled Ocean Atmosphere Response Experiment
TOPEX	Ocean Topography Experiment
TSI	Total Solar Irradiance
UARS	Upper Atmosphere Research Satellite
UNOLS	University National Oceanographic Laboratory System
VAMOS	Variability of the American Monsoon System
VIRGO	Variability of Solar Irradiance and Gravity Oscillations
VOS	Volunteer Observing Ships
WCRP	World Climate Research Programme
WOCE	World Ocean Circulation Experiment
WMO	World Meteorological Organization
WWW	World Weather Watch
XBT	Expendable Bathythermograph

Web Site List

ACRIM	http://www.jpl.nasa.gov/mip/acrim.html
ACVE	http://www.ldeo.columbia.edu/~visbeck/acve/
ADEOS-II	http://www.eoc.nasda.go.jp/guide/guide/satellite/satdata/adeos2_e.html
AMIP	http://www-pcmdi.llnl.gov/amip/
AMSR	http://www.ghcc.msfc.nasa.gov/AMSR/
ARM	http://www.armocean.bnl.gov/index.html
ATMOS	http://remus.jpl.nasa.gov/atmos/atmos.html
CARDS	http://www.ncdc.noaa.gov/cards/cards_homepage.html
CLIVAR	http://www.dkrz.de/clivar/hp.html
CMIP	http://www-pcmdi.llnl.gov/cmip/
CNES	http://www.cnes.fr/
CPC	http://www.nnic.noaa.gov/cpc/
DIARAD	http://estirm2.oma.be/solarconstant/virgo/virgo.html
DMSP	http://leonardo.jpl.nasa.gov/msl/Programs/dmsp.html
EOS	http://eospso.gsfc.nasa.gov/
EOS-DIS	http://fairmont.ivv.nasa.gov/it/
EOS-PM	http://mtpe5.gsfc.nasa.gov/eos-pm1/PM1PROJ1.htm
ESA	http://www.esrin.esa.it/
EUROCLIVAR	http://www.knmi.nl/euroclivar/
FSU	http://www.fsu.edu/
GCOS	http://www.wmo.ch/web/gcos/gcoshome.html
GEWEX	http://www.cais.com/gewex/gewex.html
GISS	http://www.giss.nasa.gov/
GRACE	http://essp.gsfc.nasa.gov/esspmissions.html
HALOE	http://haloedata.larc.nasa.gov/home.html
ICESAT	http://icesat.gsfc.nasa.gov/index.htm
IOC	http://ioc.unesco.org/iocweb/
IRI	http://iri.ldeo.columbia.edu/
JPL	http://www.jpl.nasa.gov/
LANDSAT	http://sun1.cr.usgs.gov/landdaac/pathfinder/pathpage.html
NAO	http://www.ldeo.columbia.edu/NAO/
NASA	http://www.nasa.gov/
NCAR	http://www.ncar.ucar.edu/
NOAA	http://www.noaa.gov/
NRC	http://www.nas.edu/nrc/
NSF	http://www.nsf.gov/
NSIPP	http://nsipp.gsfc.nasa.gov/
PACS	http://www.tao.atmos.washington.edu/pacs/
PAGES	http://www.pages.unibe.ch/
POLARIS	http://cloud1.arc.nasa.gov/espo/polaris/
QuikSCAT	http://winds.jpl.nasa.gov/missions/quikscat/quikindex.html
SAGE II	http://arbs8.larc.nasa.gov/sage2/sageii.html
SMMR	http://outside.gsfc.nasa.gov/SAVB/SH93/Article15.html
SOHO	http://sohowww.nascom.nasa.gov/
SSM/I	http://wwwdaac.msfc.nasa.gov/userservices/pathfdr_ssmi_readme.html
TAO	http://www.pmel.noaa.gov/toga-tao/home.html
TOGA	http://www.cms.udel.edu/coare/index.html
TOPEX/Poseidon	http://topex-www.jpl.nasa.gov/
UARS	http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/UARS_project.html
UNOLS	http://www.gso.uri.edu/unols/unols.html

USGCRP	http://www.usgcrp.gov/
USGS	http://www.usgs.gov/
VAMOS	http://www.clivar.ucar.edu/vamos.html
VIRGO	http://seal.nascom.nasa.gov/descriptions/experiments/virgo/virgomain.html
WCRP	http://www.wmo.ch/web/wcrp/wcrp-home.html
WMO	http://www.wmo.ch/
WOCE	http://www.soc.soton.ac.uk/OTHERS/woceipo/ipo.html
WWW	http://www.wmo.ch/web/www/www.html

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This report was prepared by the U.S. CLIVAR Interagency Group and the U.S. CLIVAR Science Steering Committee, whose membership is listed below. Chair of the delegation to the International CLIVAR Conference is J. Michael Hall of the National Oceanic and Atmospheric Administration.

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