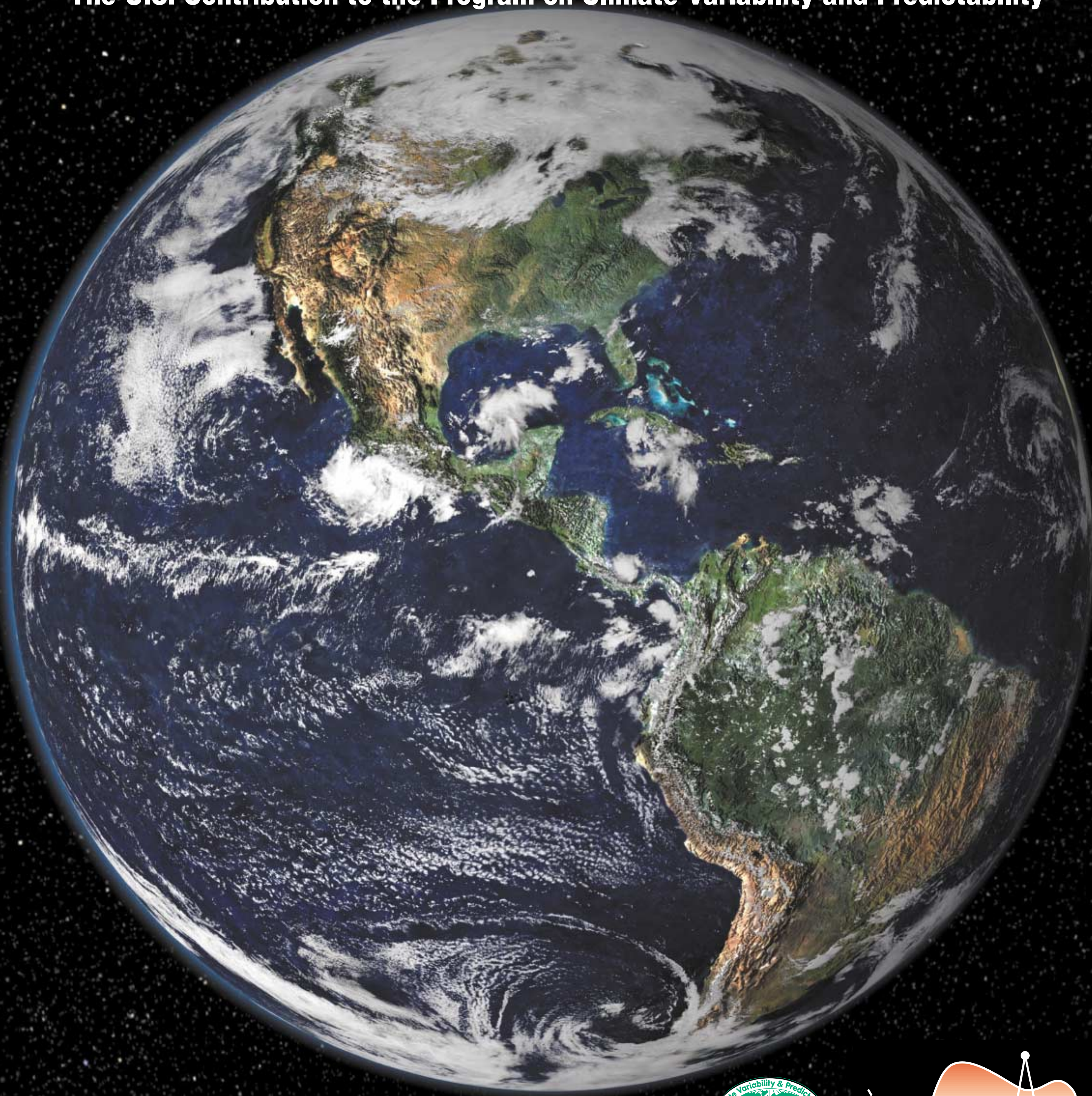
U.S. CLIVAR

The U.S. Contribution to the Program on Climate Variability and Predictability



CLIVAR Climate Variability & Predictability World Climate Research Programme

U.S. CLIVAR Climate Variability & Predictability

Goals of U.S. CLIVAR

U.S. CLIVAR is a research program with several related goals:

- identify and understand the major patterns of climate variability on seasonal, decadal, and longer time scales and evaluate their predictability;
- expand our capacity in short term (seasonal to interannual) climate predictability and search for ways to predict decadal variability;
- better document the record of rapid climate changes and the mechanisms for these events, and evaluate the potential for abrupt climate changes in the future.
- Evaluate and enhance the models used to project climate change due to human activity, including anthropogenically induced changes in atmospheric composition;

U.S. CLIVAR is mainly concerned with natural climate variability. Various aspects of its work will either be approached globally or regionally and will include:

- improving the instrumental record and observing system for documenting ongoing and future climate fluctuations to better elucidate their structures and mechanisms, and to provide initial conditions for model data assimilation and forecasting
- model application and experimentation to develop long-term model data sets to study climate variability, assess inadequacies and improve capabilities of models to simulate and predict climate variability, explore mechanisms of climate variability, develop dynamical hypotheses to help focus observational requirements
- empirical studies of the climate record from instruments, satellites and proxy records, and climate model simulations, to define patterns of climate variability, and to develop and test hypotheses
- regional and process field studies to quantify specific processes that must be included in successful climate models and for which present treatment is inadequate.

Patterns of Climate Variability:
Understanding the Mechanisms and Determining their Predictability

CLIVAR follows from the success of past climate science programs in the U.S., most notably the Tropical Atmosphere Global Ocean (TOGA) program and the World Ocean Circulation Experiment (WOCE). These two programs contributed to increased understanding and prediction capabilities of seasonally averaged climate anomalies associated with El Niño/Southern Oscillation (ENSO) up to one year in advance, and helped to develop, for the first time, a global ocean baseline for analysis and modeling of decadal and longer variability.

CLIVAR will enhance the understanding of ENSO, as well as improve the reliability, and lead-time of predictions of ENSO and its related global climate anomalies.

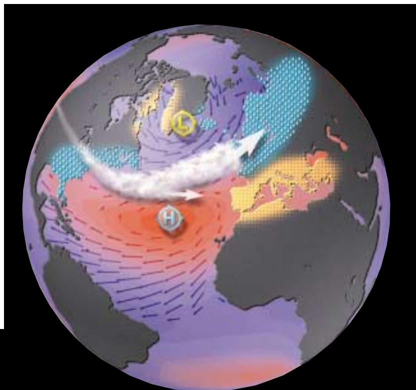
However, ENSO is only the beginning. Several additional patterns of variability have been identified and are noted to have large impacts on a variety of natural systems as well as on numerous socio-economic sectors, and consequently on human activities. One such pattern is the North Atlantic Oscillation (NAO), also known as the Arctic Oscillation (AO), that is responsible for large wintertime climate anomalies throughout the Arctic, Eastern Canada and the United States, Europe, Russia and in the North Atlantic Ocean.

The mechanisms (e.g. atmosphere-ocean coupling) responsible for, and determining the predictability of, the NAO/AO climate phenomenon will be a foci of U.S. CLIVAR.

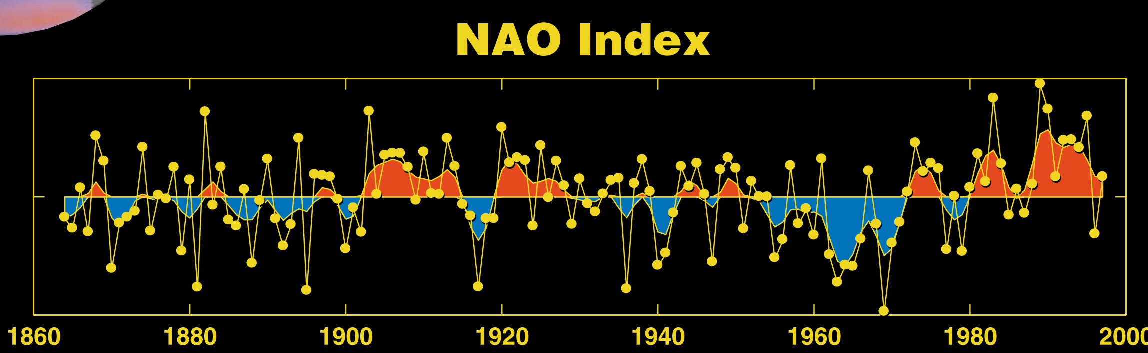
In the instrumental record, there is large variability in the monsoons over the Americas, including the summertime monsoon in the southwest U.S. It has been hypothesized, and empirical evidence suggests that, predictability of the rainfall associated with the monsoon can be derived knowing the state of the tropical Atlantic and Pacific Oceans as well as ocean-atmosphere and local land-atmosphere interactions. As a contribution to the international CLIVAR program Variability of the American Monsoon System (VAMOS), U.S. CLIVAR will achieve a better understanding of the important processes that are responsible for variability in summertime rainfall in the Americas, and will determine the extent to which monsoon rainfall over the Americas is predictable.

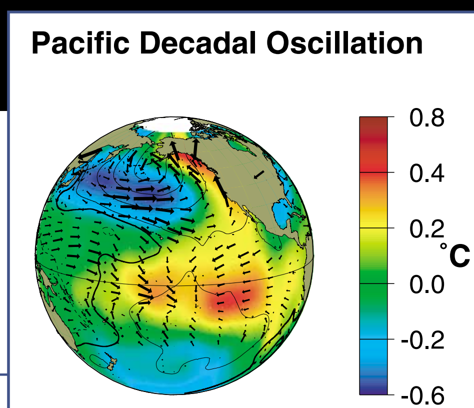
Using a combination of existing instrumental data, available proxy records, and results from numerical models that include representation of the coupled ocean-atmosphere system, scientists have identified a few prominent patterns of variability that occur on decadal and millennia time scales, including the so-called Pacific Decadal Oscillation (PDO). This pan-Pacific pattern of decadal climate variability has impacts across all the Pacific Rim countries. However, the PDO has an unusually large expression in the Northern Hemisphere, particularly North America. It significantly impacts water resources in the western U.S. and Canada, thereby affecting hydropower, agriculture, wild fires brought on by drought conditions, and biological populations, including salmon.

Large decadal variability has also been documented in the Atlantic atmosphere and ocean that is associated with long cycles of drought in the Sahel and in Northeast Brazil, as well as with decadal cycles in North Atlantic fish stocks, occurrences of ice storms, and hurricane activity in the Tropical Atlantic.

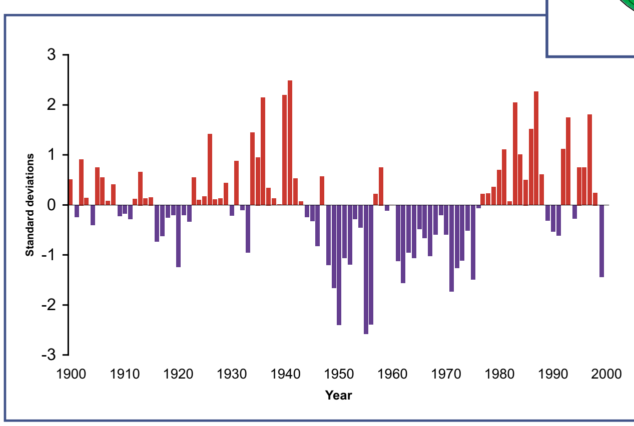


The NAO index as represented by the measured sea level pressure difference between Iceland Low and Portugal during the winter season. The low-frequency component (shaded) indicates recent tendency of a positive state, and its associated wintertime changes of temperatures, precipitation, and storminess. Martin Visbeck, Lamont-Doherty Earth Observatory Earth and Environmental of Columbia University.

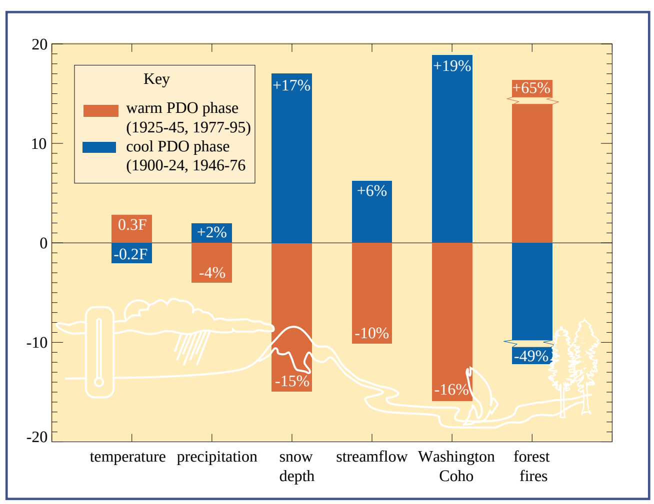




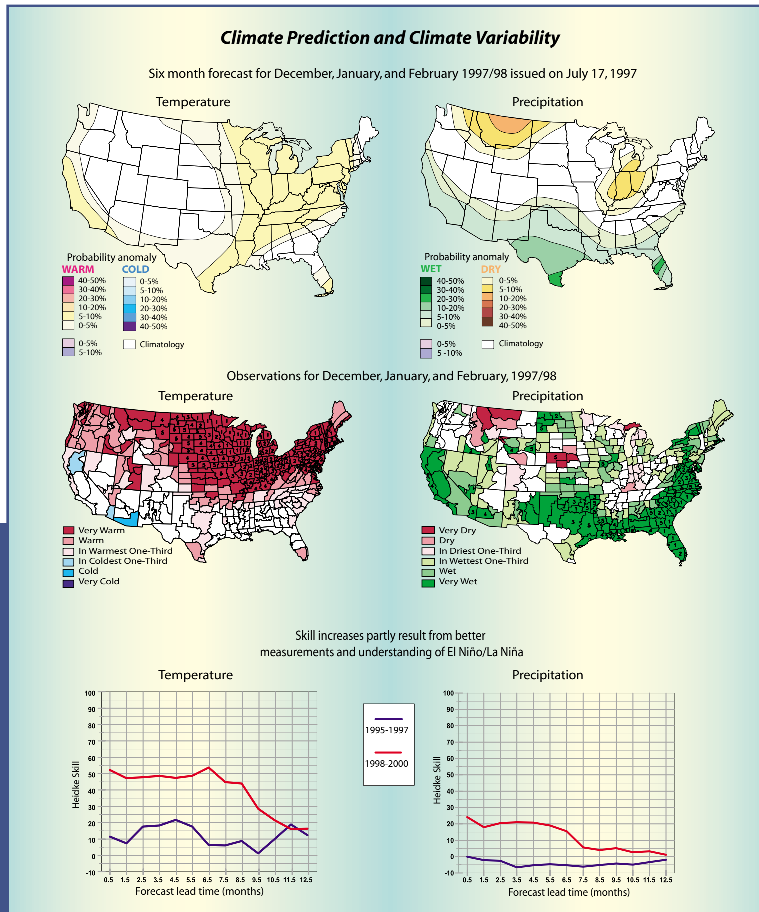
Warm (positive) phase PDO surface climate anomalies: sea surface temperature anomaly pattern in color according to scale; contours depict sea level pressure anomaly- lower than average sea level pressures in the east and north, higher in the west; vectors show wind stress anomalies, the longest wind vectors represent a (pseudo) stress of 10 m^2s^{-2}.



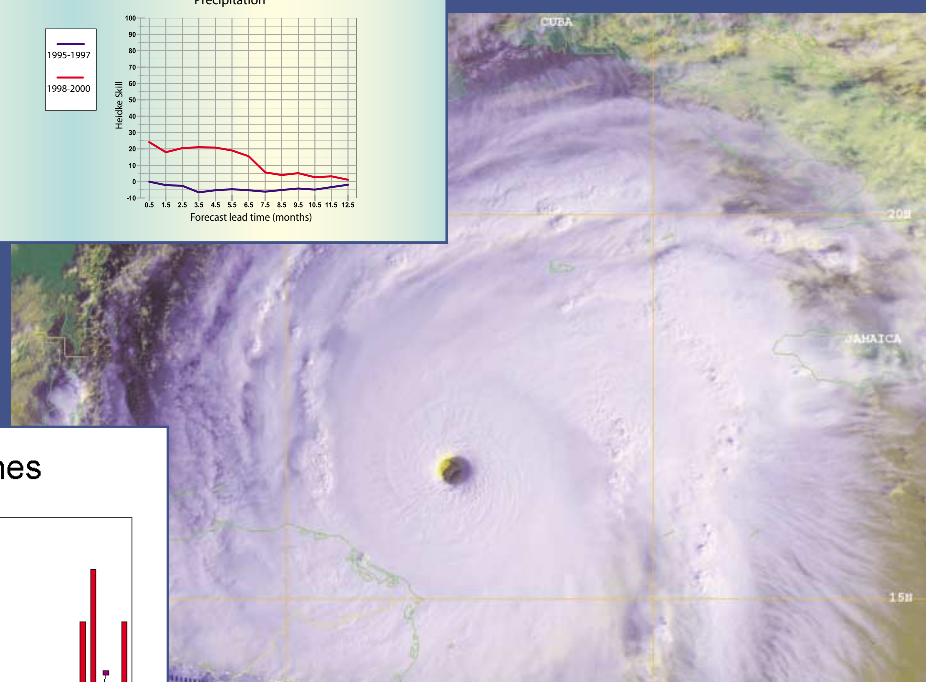
October-to-March averaged PDO indices based upon projections of observed North Pacific SST and SLP patterns onto those shown above. (Hare et al. 1999-Fisheries). Steven Hare, International Pacific Halibut Commission.

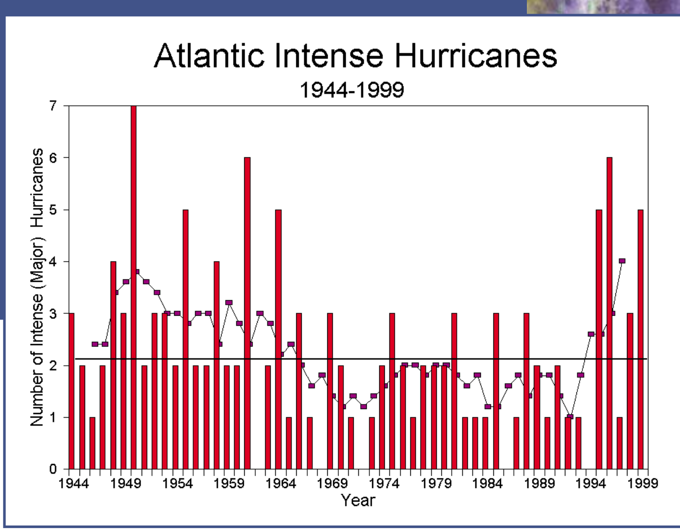


Impacts of PDO climate variations in the Pacific Northwest. Philip Mote, JISAO/SMA Climate Impacts Group, University of Washington.



Six-month lead forecast for seasonal precipitation and temperatures for the peak period of the 1997/98 El Niño. The forecasts indicate anomalous probability that conditions will fall into the upper or lower climatological terciles. The mean forecast skill of 3-month forecasts for U.S. winters by lead time for two different time periods (centered on January of 1995-1997 vs. January of 1998-2000) indicates increased skill, possibly associated with improved understanding of ENSO variability. NOAA, Climate Prediction Center.





Number of intense hurricanes in the Atlantic highlights multi-decadal variability. What is the cause of the recent (post 1994) rise in occurrences of intense storms? Chris Landsea, NOAA AOML/Hurricane Research Division.

Expanding the Predictive Capacity for Climate Variability

A high priority in U.S. CLIVAR will be to enhance the skill of the predictions of climate variability, especially on seasonal-to-interannual time scales. This will be accomplished through a concentrated and systematic program to improve the predictive tools (especially, the coupled climate forecast models), knowledge of the initial conditions used to start these models, and the assimilation procedures by which data are incorporated into the forecast models.

Expansion of predictive capacity beyond 1-2 seasons, in other tropical oceans, and on decadal and longer time scales depends on rigorous identification and quantitative description of the processes that are important for the observed climate and its variability. U.S. CLIVAR will also take steps to improve the instrumentally based record of the climate system to identify patterns of climate variability and develop historical information for testing models and hypotheses. Special emphasis will be placed on developing analysis products for the atmosphere, upper-ocean and hydrologic state of the land surface on the scale of continents and oceans.

U.S. CLIVAR will contribute to the design and implementation of a climate observation system. For the atmosphere, work will include reanalysis activities that will utilize the continually improving numerical weather models and the expanding suite of in-situ and satellite observations, and, where needed, improvement of the climate observing system. For the ocean, the array of existing satellite and in-situ observations is inadequate for accurate ocean state estimation with current procedures. Consequently, sustained in-situ measurements will be implemented to augment the present ocean climate observing system, especially in the Pacific and Atlantic Oceans. Additionally, in cooperation with GODAE (Global Ocean Data Assimilation Experiment) effort will be placed on improving data assimilation techniques and capabilities as well as utilizing new ocean analyses to examine climate dynamics. CLIVAR will also focus on combining satellite observations, routine surface reports, and new scientific-quality measurements to improve the accuracy of global analyses of the air-sea fluxes of heat, water and momentum.

Presently, seasonal climate predictions focus on utilizing the relationships between the slower components of the climate system and seasonally averaged atmospheric quantities (e.g., how the sea surface temperature in the tropical Pacific affects the seasonally averaged temperature and precipitation in the southeastern U.S.). Recent research suggests that in some cases seasonally averaged changes in the frequency of extreme events may also be predictable. While the models used to forecast climate do not have high enough resolution to resolve some of the phenomenon responsible that contribute to extreme events (e.g. hurricanes), they can predict environmental changes that are important for the development, intensity, and pathways of such events. Hence, forecasts of ENSO can be used to predict, in a statistical sense, seasonal changes in paths, as well as the strength and frequency of features such as hurricanes, tornadoes, and winter storms.

U.S. CLIVAR will include efforts to mine historical observational records and results from comprehensive model runs for strong relationships between predictable large scale, low frequency patterns of climate variability and the probability of extreme events.

U.S. CLIVAR is formulating a program to test several hypotheses about the causes of observed decadal variability throughout the Pacific and Atlantic, and to evaluate the extent which climate variability on these time scales is predictable.

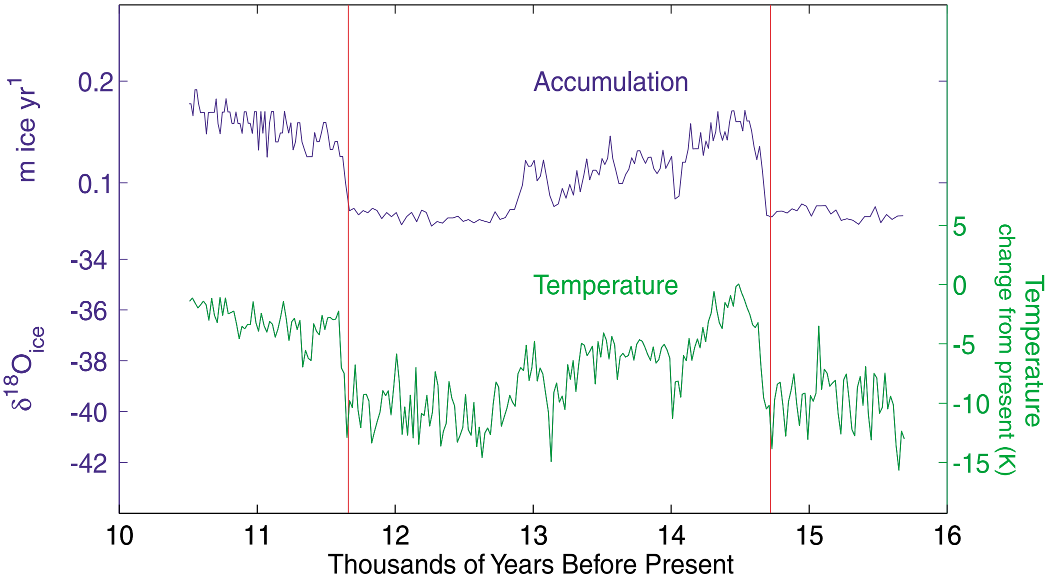
To the Future:
Lessons from Deep Time

The 1930's drought in the U.S. is notable because of its severity, extended duration, and because of the devastating impact that it had on the local economy and psyche of a whole generation. What are the odds that a drought of this duration will happen again in the next 50 years? The answer may be addressed through examination of historical climate data; however, prior to the onset of the twentieth century, the instrumental record of climate over the U.S. is extremely limited. Through a variety of proxy data, we now have a reliable record of drought in the continental U.S. over the past millennium. This record indicates extended periods of drought, including several occurrences of severe drought that are much longer in duration than the Dust Bowl of the 1930's.

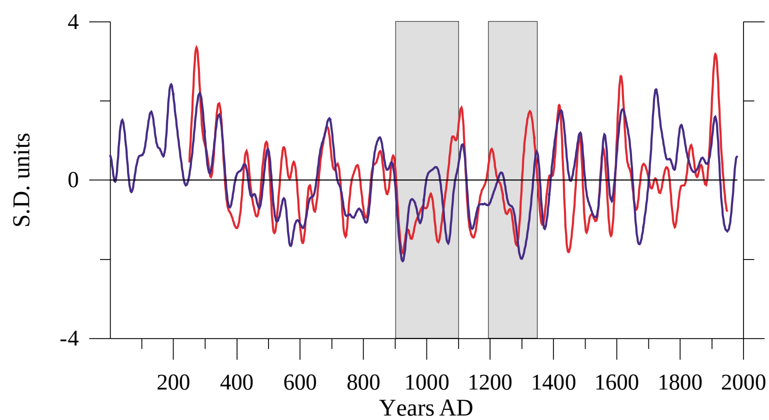
U.S. CLIVAR will further verify and improve the paleo record of severe drought, derive and test hypotheses for the occurrence of extended severe droughts and, to the extent possible, evaluate the likelihood of future severe extended droughts.

In addition to providing evidence for past climate changes that are much larger than any in the instrumental record, the paleoclimate record has also demonstrated that during glacial times the global climate system routinely exhibited extreme and rapid changes. Early hypotheses highlighted ocean thermohaline circulation as the driver for these rapid changes. However, the global synchronicity of the changes and the recent evaluation of methane in the polar ice cores suggests the tropics play an important role in the onset of rapid climate transitions.

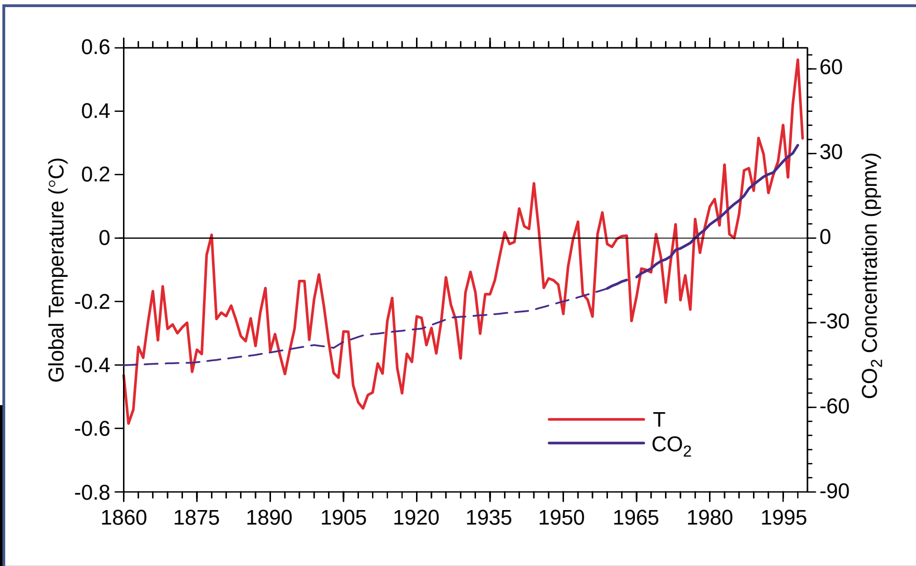
Activities in U.S. CLIVAR will better document rapid changes in the climate system, and formulate and test hypotheses for how and why they happen by developing improved climate models and more complete spatio-temporal records during these remarkable rearrangements in the climate system.



Evidence for large abrupt climate changes is found in proxy records of climate. Illustrated here is the record of ice accumulation and d18Oice, a proxy for temperature, in the Greenland ice cores. Recent studies demonstrate large climate transitions, such as those at 11.6 and 14.7 kyr BP (red vertical lines), are echoed through (at least) the northern hemisphere, with changes in temperature of 5-10°C over a few decades, or less. After Severinghaus et al. (1998-Nature). David Battisti, University of Washington/J. P. Severinghaus, Scripps Institution of Oceanography.



Variability of precipitation in the Great Basin reconstructed from moisture sensitive tree rings. The vertical axis shows smoothed July-June precipitation for Nevada Division 3 as reconstructed from a single site in the White Mountains of California (blue) and from 6 sites from throughout the Great Basin (red). The gray areas indicate periods of low stands of Mono Lake as reconstructed by Stine (1993-Nature) from radiocarbon-dated submerged trees and geomorphological evidence. The two records support one another, indicating much more severe and sustained multidecade droughts before AD 1500 than after. From Hughes and Funkhouser, (1998-The Impacts of Climate Variability on Forests). Malcolm Hughes, Institute for the Study of Planet Earth, The University of Arizona.



Annual average global in-situ surface temperatures for 1860-1999 (red) and CO2 concentration anomalies from ice cores 1860-1957 and from Mauna Loa since 1958. All anomalies are relative to 1961-1990. Jim Hurrell, NCAR.

Anthropogenic Induced Climate Change

The earth's climate is changing in many ways. Global surface temperatures are rising. The Arctic Oscillation is intensifying in an apparently secular trend. Regions are desertifying, like Amazonia, while others are becoming wetter. Arctic ice is thinning and the shallow Arctic Ocean is becoming fresher. Various models describe these changes with varying degrees of fidelity, and some indicate that more significant changes are possible if, for example, warming and increased precipitation reduce the vigor of the ocean convection that drives the ocean's global thermohaline circulation.

There is a societal need to learn which of the observed climate changes are primarily a result of natural variability and which are significantly affected by anthropogenic factors (attribution). Similarly there is a need to accurately forecast the results of various scenarios for future human activity (prediction). It is unlikely that attribution and prediction of climate change can be accomplished outside the context of comprehensive climate models. This places a very high priority on verifying the accuracy of comprehensive climate models.

The scales and processes associated with identified climate variability phenomena like ENSO, the NAO and the PDO are very similar to those involved in climate changes on much longer time scales, i.e., those that most demand attribution and prediction. In fact there is model evidence that one of the primary mechanisms for anthropogenic climate change may be modulation of the patterns (e.g. frequency, amplitude) of variability previously thought to be excited primarily by natural forcing.

U.S. CLIVAR will seek to test, verify and improve comprehensive climate models through their ability to simulate the record and processes of the major patterns of natural variability.

Long-term data sets for evaluation of these models will be assembled. This effort will also require collaboration between scientists and modelers studying natural variability, and the community developing and evaluating the comprehensive climate models that will be used in the Intergovernmental Panel on Climate Change (IPCC) process.

Global Climate Variability

While the primary foci of U.S. CLIVAR will be on the Pacific, Atlantic, and Americas, other regions and components of the earth's climate system will also receive attention. U.S. CLIVAR will contribute efforts to better understand the variability and predictability of the Asian-Australian monsoon and its relationship with other climate components, e.g. ENSO. Other efforts will focus on expanding the knowledge of the role of the southern ocean region in global climate. Targeted efforts will also address the African climate system, its relationship to its land surface as well as to the surrounding ocean-atmosphere and global climate systems.

Opportunities
and Challenges

The goals of CLIVAR will require developing suites of highly coordinated activities to meet the significant challenges it faces:

Modeling Capabilities. A significant expansion of modeling and assimilation capabilities and infrastructure is needed to allow the U.S. community to develop, test, and exercise models of climate-system components (e.g. cryosphere or ocean) and the fully coupled comprehensive climate models that are required for assessing the predictability of climate changes. Additionally, interaction between modelers and observationalists must be optimized to insure model parameterizations, based on results of process experiments and extensive analysis of observations of the coupled climate system, are improved.

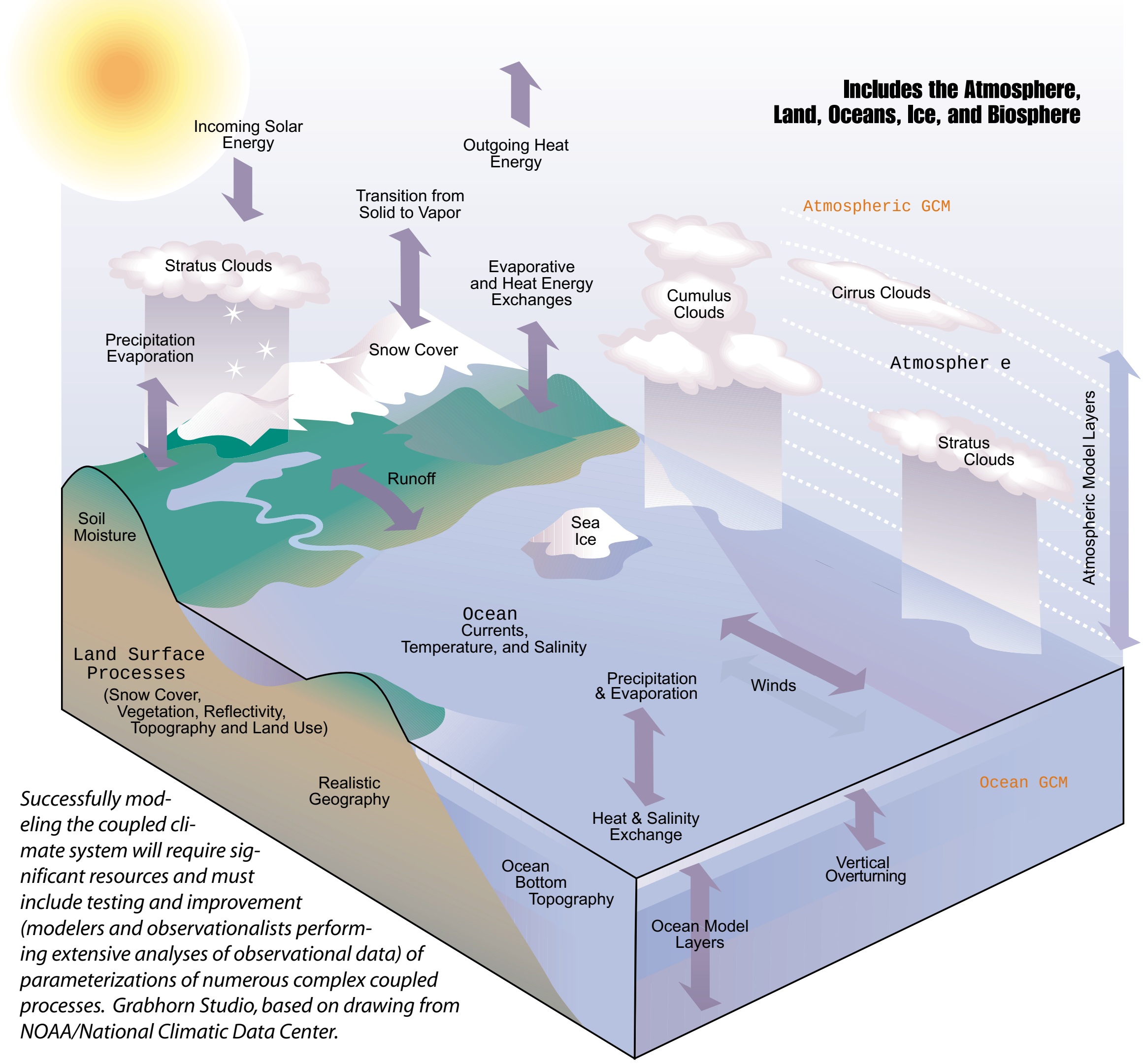
Climate Observing System. The present climate observing system is fashioned largely from components implemented initially for weather forecasting and military oceanography. Except for ENSO, the present observing network does not supply adequate data to monitor the state of the climate system, or to initialize prediction models. Internationally coordinated efforts to rationally improve and expand the climate observing system are underway, and the U.S. will play a significant part. CLIVAR will work with the National Weather Service (NWS) to identify possible improvements of the weather observing system (both in situ and satellite) to foster significant improvements in our understanding of climate. New technologies will be sought to cost-effectively and reliably expand and improve the observing systems of the global atmosphere, upper-ocean, ice, and land surfaces.

Information Systems. Understanding and predicting climate variability and change involves mastering enormous volumes of heterogeneous observational data and combining these data with potentially much larger volumes of output from a number of different climate models. To progress rapidly in climate research U.S. CLIVAR will build the software and infrastructure to facilitate open and efficient access to the enormous and diverse volumes of model output, instrumental data bases and proxy data bases required to accomplish its goals.

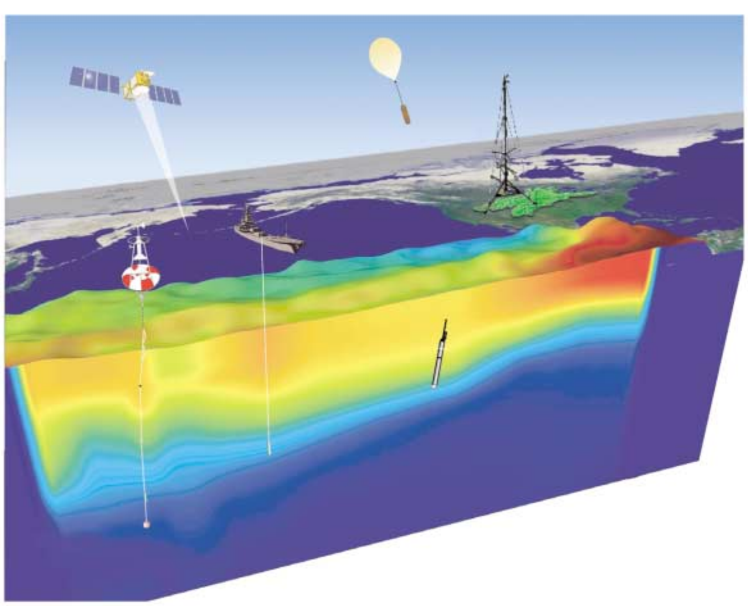
The success of CLIVAR requires sustained contributions from, and coordination across, a variety of traditional scientific disciplines and existing U.S. government funding agencies. The broad nature of CLIVAR requires increased levels of coordination with other U.S. research efforts (e.g. USGCRP Water Cycle and Carbon Cycle initiatives). Additional benefits will also be derived by teaming with other U.S. activities under complementary international research programs such as GEWEX, SPARC, CLIC, and IGBP-PAGES. The predictive modeling in U.S. CLIVAR will be done through close cooperation with groups that are developing robust climate prediction models and applications, e.g. NWS/National Center for Environmental Prediction (NCEP), International Research Institute for Climate Prediction (IRI).

The U.S. will establish a rational multi-agency procedure for prioritizing and implementing improvements to meet the requirements of climate research and prediction.

Modeling the Climate System



Successfully modeling the coupled climate system will require significant resources and must include testing and improvement (modelers and observationalists performing extensive analyses of observational data) of parameterizations of numerous complex coupled processes. Grabhorn Studio, based on drawing from NOAA/National Climatic Data Center.



U.S. CLIVAR will help improve and expand observation systems for the atmosphere, upper-ocean, ice, and land surfaces. Background courtesy of NASA/Goddard Space Flight Center.

Outlook

CLIVAR is the most ambitious climate research program ever envisioned. Built on a firm foundation established by enormously successful previous science programs, U.S. CLIVAR, working with our partners within the international CLIVAR program, will identify and understand climate changes on time scales of seasons and longer and on regional to global spatial scales. Through its global focus on observing, modeling, and analyzing the physical aspects of the coupled climate system, CLIVAR will provide a better understanding of the interactions between the atmosphere and the ocean, land, biosphere and cryosphere. Consequent to this understanding, it will provide models capable of improved predictions of climate variability and more accurate predictions of climate changes. These improvements will rely on the climate observing system that U.S. CLIVAR and others help build.

The robust knowledge and enhanced forecast skills embodied within CLIVAR's improved models will be embraced by a wide variety of climate prediction practitioners who, along with stakeholders and other interested parties, will ultimately demonstrate the practical and long-lasting value of CLIVAR's research program.

Further information

U.S. CLIVAR is a major contributor to the international CLIVAR program, an element of the World Climate Research Program (WCRP). U.S. CLIVAR is also a component of the U.S. Global Change Research Program (USGCRP).

Major contributors to the U.S. CLIVAR Program include, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE).

For additional information on he U.S. CLIVAR Program

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