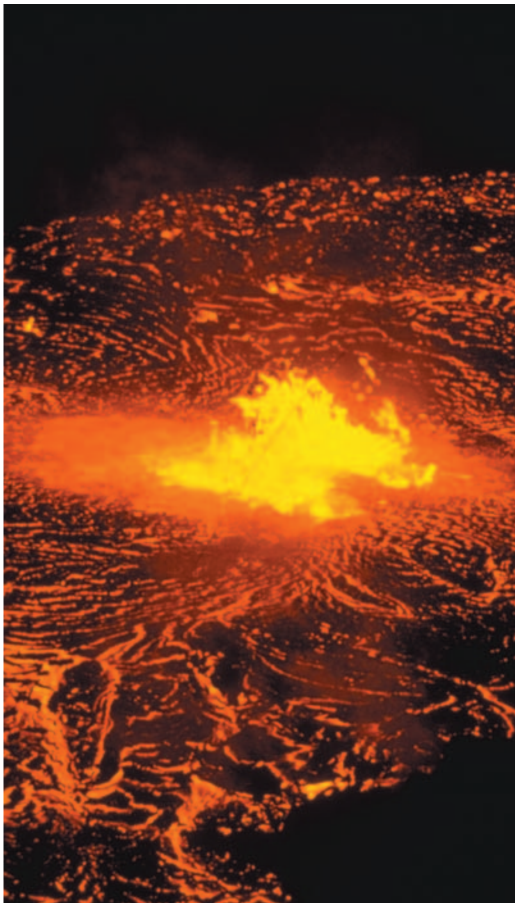


2 | Climate Variability and Change

Strategic Research Questions

4.1 To what extent can uncertainties in model projections due to climate system feedbacks be reduced?

4.2 How can predictions of climate variability and projections of climate change be improved, and what are the limits of their predictability?

4.3 What is the likelihood of abrupt changes in the climate system such as the collapse of the ocean thermohaline circulation, inception of a decades-long mega-drought, or rapid melting of the major ice sheets?

4.4 How are extreme events, such as droughts, floods, wildfires, heat waves, and hurricanes, related to climate variability and change?

4.5 How can information on climate variability and change be most efficiently developed, integrated with non-climatic knowledge, and communicated in order to best serve societal needs?

See Chapter 4 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Climate variability and change can profoundly influence social and natural environments throughout the world, with consequent impacts on natural resources and industry that can be large and far-reaching. For example, seasonal to interannual climate fluctuations strongly affect agriculture, the abundance of water resources, and the demand for energy, while long-term climate change may alter agricultural productivity, land and marine ecosystems, and the goods and services that these ecosystems supply. Recent advances in climate science are providing information for decisionmakers and resource managers to better anticipate and plan for potential impacts of climate variability and change. Further advances will serve the nation by providing improved knowledge to enable more scientifically informed decisions across a broad array of climate-sensitive sectors.

Research on climate variability and change focuses on two overarching questions:

- How are climate variables that are important to human and natural systems affected by changes in the Earth system resulting from natural processes and human activities?
- How can emerging scientific findings on climate variability and change be further developed and communicated in order to better serve societal needs?

Addressing these questions requires recognition that the problems of climate variability and change cannot be cleanly separated, and that the success of understanding each will require improved understanding of both. Future changes in climate variability—for example, a variation in the frequency and nature of ENSO events or the severity and duration of droughts—will depend partly on changes in global (and regional) mean conditions. Conversely, climate variations influence global and regional heat and moisture distributions, and hence can substantially alter the global and regional mean response of the climate system to either natural or anthropogenic forcing. Further, demands for improved climate information span a broad range of time scales, ranging from assessments of current conditions and seasonal forecasts of climate variability that support resource management decisions, to longer term decadal- to centennial-scale projections of climate change that help inform infrastructure planning and policy development.

Current research activities on climate variability and change are directed toward understanding and, to the extent possible, reducing uncertainties in climate model projections; improving climate predictions on seasonal to interannual time scales; improving capabilities to detect, attribute, and project longer term climate changes; advancing understanding on the causes of past abrupt climate changes and the potential for future rapid changes; determining whether and how climate variations alter the frequencies, intensities, and locations of extreme events; and improving the development and communication of climate information to better the needs of the public and decisionmakers. Over the past year, significant advances have been made in several of these areas. Some of the research highlights are summarized below.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Observed Arctic warming trend over the last 20 years. Observations of Arctic-wide surface temperatures using satellite data have shown that, over the period 1981-2001, the Arctic region warmed at an annual average rate of 0.3°C per decade over sea ice (considering those portions of the Arctic Ocean where 80% of ocean surface is covered by ice), 0.5°C per decade over the high latitude (poleward of 60°N) region of Eurasia, and 1.0°C over the high latitude region of North America. Temperature trends derived from surface data are similar over much of the Arctic, but differ in some sub-regions. In comparison, during the last 20 years the global annual average surface temperature has increased by about 0.2°C per decade. At the high northern latitudes, the warming trends are more pronounced in the spring and are also evident in summer and fall, resulting in a longer melt season for snow and ice on land and for annual sea ice.

Satellite data also show that the portion of the Arctic Ocean covered by perennial sea ice has declined by about 9% per decade since 1978. The longer melt season and loss of perennial sea ice cover can have large-scale climate consequences. They permit an increase in the amount of energy absorbed in the previously ice- or snow-covered

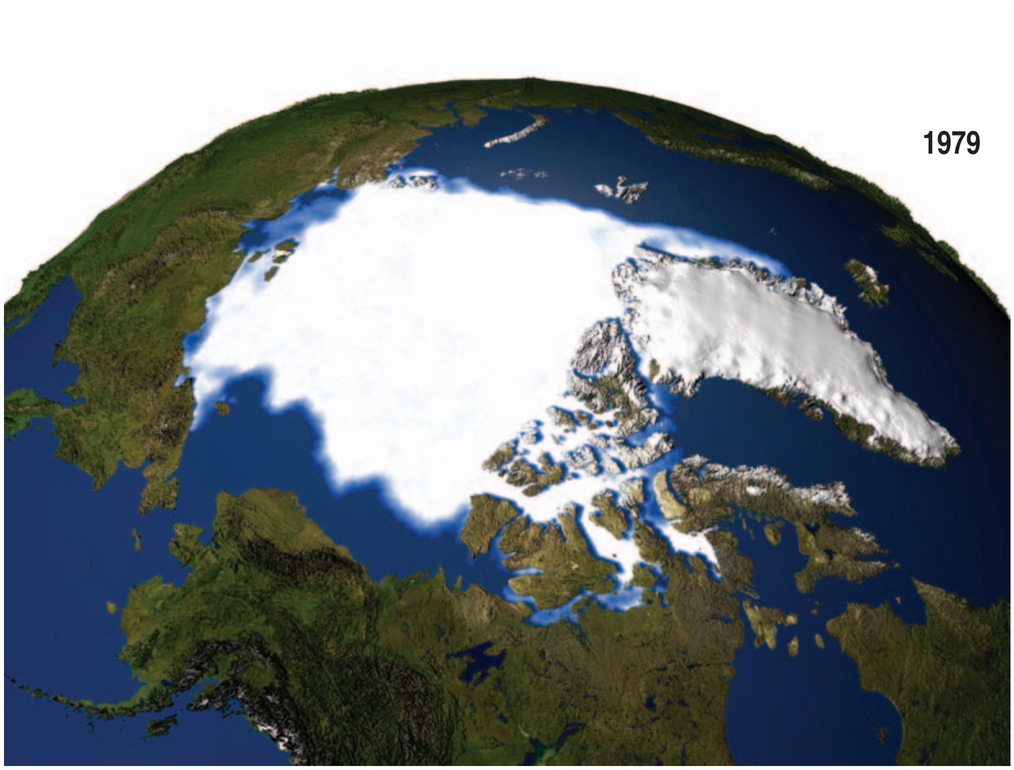


Figure 8: Between 1979 (left panel) and 2003 (right panel), Arctic perennial sea ice has been decreasing at a rate of 9% per decade. The lefthand image shows the minimum sea ice concentration for the year 1979, and the righthand image shows the minimum sea ice concentration in 2003. The data used to create these images were collected by the Defense Meteorological Satellite Program (DMSP). *Credit: NASA Goddard Space Flight Center.*

areas and, on land, permit increased growth of vegetation that also has a lower albedo (lower light reflectivity) than snow covered areas.

Climate models project that the high latitude regions are particularly sensitive to climate change because of the positive albedo feedback effects associated with reduction of ice and snow cover, and the reduction of thermal insulation of the ocean that sea ice cover provides, allowing increased heat transfer from the ocean to the atmosphere. However, there is as yet no direct evidence that greenhouse gas forcing, which drives the climate models, is responsible for the melting of sea ice and snow cover in the Arctic region.

The data also show regional differences that suggest there are other influences in addition to global-scale climate warming. A natural weather pattern called the North Atlantic Oscillation/Northern Annular Mode (NAO/NAM) may have contributed to regional variations as well as the overall decrease in Arctic sea ice cover over the last 20 years. Whether the ice cover as a whole will continue to exhibit the decreases that it experienced over the 1979 to 2003 period (see Figure 8) might depend on the strength and phase of the NAO/NAM, as well as on long-term trends in the climate system.

Increasing ocean heat storage. Simulations with an improved version of the NASA/GISS Global Climate Model indicate that the rate of heat storage by the world's oceans has increased from about 0.2 Wm^{-2} in 1951 to a present value of

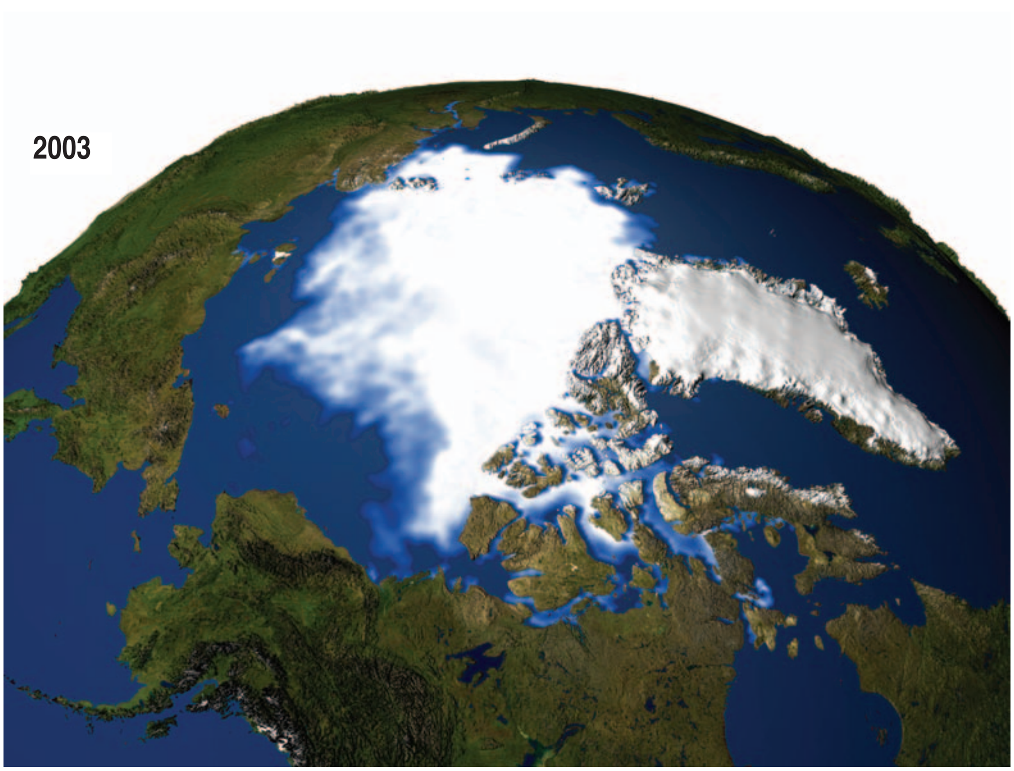
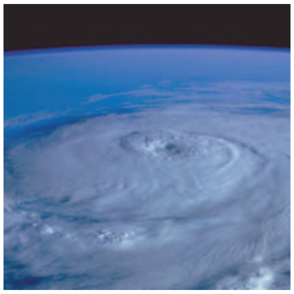


Figure 8 (continued):
Arctic sea ice cover, 1979 and 2003.

about 0.7 Wm^{-2} net downward flux (convergence) of heat into the ocean surface. This is the third independent climate model to produce such an increase, and compares well with observational analyses of changes in ocean heat storage. Since the ocean stores a large portion of the excess heat due to the imbalance of the radiation budget of the Earth's climate system, this work indicates that careful monitoring of the global distribution of ocean heat storage will be a key indicator for identifying changes in the climate system.



Change in the freshwater balance of the Atlantic Ocean. The distribution of salinity in the Atlantic Ocean has been sampled over a broad area during the last half-century. These historical data can be used to diagnose rates of surface freshwater fluxes, freshwater transport, and local ocean mixing—important components of climate. Recent research comparing observed salinities on a long transect through the western basins of the Atlantic Ocean between the 1950s and the 1990s found systematic increases in freshwater at high latitudes (at both poleward ends), contrasted with large increases of salinity at low latitudes. Although the observational record is insufficient to quantify a number of factors that may have contributed to these long-term trends, a growing body of evidence suggests that shifts in the oceanic distribution of fresh and saline waters are occurring in ways that may be linked to global warming and possible change in the global water cycle. Parallel changes in ocean salinity and temperature are occurring in other oceans as well.

20th century global sea-level rise. The rate and causes of 20th century global sea-level rise are subjects of intense debate. Direct observations, based on tide gauge records, suggest that the rate of sea-level rise is between 1.5 and 2.0 mm yr^{-1} (0.6 to 0.8 inches per decade). The two largest contributors to sea-level rise are thought to be volume changes due to ocean warming (thermal expansion) and the addition of mass due to the melting of polar ice sheets, although the magnitudes of these contributions are not well known. Scientists at NOAA's Laboratory for Satellite Altimetry analyzed tide gauge records, which reflect both volume and mass changes, and ocean temperature and salinity data, which reflect only volume changes, in the North Pacific and North Atlantic Oceans. They found that measurements of sea-level rise from tide gauges are two to three times higher than those from temperature and salinity measured regionally and near gauge sites. The data support earlier estimates of the 20th century rate of sea-level rise and, more importantly, also provide the first evidence suggesting that addition of mass due to the melting of polar ice sheets can play an important, perhaps dominant, role in sea-level rise.

Simulating 20th century climate. Multiple ensemble simulations of the 20th century climate have been conducted using climate models that include new and

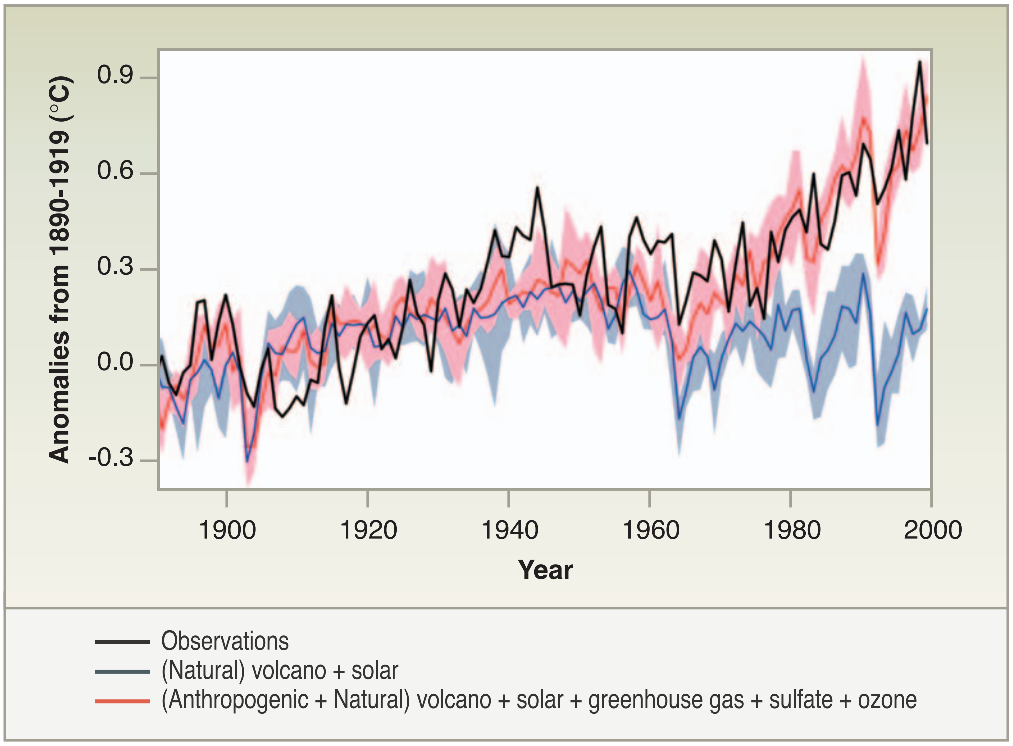


Figure 9:
Climate model simulations of the Earth's temperature variations compared with observed changes. Ensemble simulations were run with the global fully coupled DOE Parallel Climate Model (PCM) employing five forcing agents that influence the time evolution of globally averaged surface air temperature during the 20th century. Two of the forcings are natural (volcanoes and solar) and the others are anthropogenic [greenhouse gases, ozone (stratospheric and tropospheric), and direct effect of sulfate aerosols]. The figure shows global average temperature, relative to the 1890-1919 mean, over the time period 1890-1999. The black line shows observed temperature; the blue line shows ensemble mean temperature based on simulations using natural forcings only; and the red line shows ensemble mean temperature based on simulations using both natural and anthropogenic forcings. The shadings denote the ensemble ranges.
Credit: Meehl, G.A., et al., 2004: Combinations of natural and anthropogenic forcings and 20th century climate. J. Climate, in press. Observed temperature data (black line) from Folland, C.K., et al., Geophys. Res. Lett., ***28****, 2621-2624.*

improved estimates of natural and anthropogenic forcing. The simulations show that observed globally averaged surface air temperatures can be replicated only when both anthropogenic forcings—for example, greenhouse gases—as well as natural forcings such as solar variability and volcanic eruptions are included in the model. These simulations improve on the robustness of earlier work. Comparisons of model results with observations indicate that regionally concentrated increases in precipitation can occur as a function of variability in solar forcing (see Figure 9).

Detecting a human influence on North American climate. A recent study shows that the average global results reported above also pertain over the North American region. Several indices of large-scale patterns of surface temperature variation were used to investigate climate change in North America over the 20th century. The observed variability of these indices was simulated well by several climate models. Comparison of index trends in observations and model simulations shows that North American temperature changes from 1950 to 1999 were unlikely to be due only to natural climate variations. Observed trends over this period are consistent with simulations that include anthropogenic forcing from increasing atmospheric greenhouse gases and sulfate aerosols. However, most of the observed warming from 1900 to 1949 was likely due to natural climate variation.

Long-term drought reconstructions for North America. Tree-ring paleo-proxy records have been used to develop an animated atlas of North American drought for the last ~1,000 years. The data show annual (and even within-year) resolution of drought/wetness conditions across the United States and parts of Mexico and Canada. This synthesis provides a dramatic visual representation of changing climatic and environmental conditions over the region, including an indication that significantly more arid conditions existed in parts of the western United States prior to AD 1500. Such paleoclimate data help aid the understanding of climate mechanisms and impacts.

Origins of recent severe droughts in the Northern Hemisphere. Recent work provides compelling evidence that severe droughts that affected the United States, the Mediterranean region, and Southwest Asia simultaneously during 1998-2002 were part of a persistent climate state that was strongly influenced by the tropical oceans. The oceanic conditions of importance were unusually cold sea surface temperatures (SSTs) in the eastern tropical Pacific (i.e., persistent La Niña conditions) that occurred together with sustained above normal SSTs in the western tropical Pacific and Indian Oceans. The persistence of this abnormal tropical SST pattern was unprecedented in the instrumental record. A large suite of model simulations showed that this SST pattern was ideally suited to force atmospheric circulation anomalies that

CCRI PRIORITY - CLOUD AND WATER VAPOR FEEDBACKS AND OCEAN CIRCULATION AND MIXING PROCESSES

The Climate Change Science Program will address targeted climate processes known to be responsible for large uncertainties in climate predictions and projections. A new paradigm for conducting the research—Climate Process and Modeling Teams (CPTs)—will be used and evaluated.

Important processes that are inadequately represented in climate models include atmospheric convection, the hydrological cycle, and clouds and their net radiative forcing. Water vapor is the most important of the greenhouse gases, and clouds affect both vertical heating profiles and geographic heating patterns. Results from climate models suggest that there will be an overall increase in water vapor as the climate warms. However, scientists know neither how the amounts and distributions of water vapor and clouds will change as the total water vapor in the atmosphere changes, nor how the associated changes in radiative forcing and precipitation will affect climate. Improved representation of the distribution of and processes involving water vapor in climate models is therefore critical to improving climate change projections.

Ocean mixing plays a pivotal role in climate variability and change, and is a primary source of uncertainty in ocean climate models. The highly energetic eddies of the ocean circulation are not well resolved and cannot be sustained for the multiple thousands of years of simulations required to assess coupled climate sensitivity. This leaves the problem of parameterization of eddy fluxes as a key issue for improving coupled model simulations.

Accelerating improvements in climate models requires observational, process, and modeling programs coordinated by teams of scientists—that is, CPTs, an approach first proposed by the U.S. elements of the program on Climate Variability and Predictability (CLIVAR). A complete description of CPTs can be found on the U.S. CLIVAR website, <http://www.usclivar.org>. CPTs will rapidly identify, characterize, and ultimately reduce uncertainties in climate model projections as well as determine observational requirements for critical processes. For problems that are generic to all climate models (e.g., cloud processes and ocean mixing), CPTs will consist of teams of climate process researchers, observing system specialists, and modelers working in partnership with designated modeling centers.

were conducive to producing abnormally dry conditions in those regions where severe and sustained drought was observed.

Causes of the 1930s Dustbowl. A NASA atmospheric general circulation model was used to investigate the North American dustbowl drought during the 1930s. Ensemble simulations using observed sea-surface temperatures show that principal causes of the Great Plains drought were the anomalous tropical SSTs during the 1930s in the Pacific and, to a lesser extent, the Indian and Atlantic Oceans. Land-surface feedbacks were also essential to the development and maintenance of the severe drought conditions.

Role of stratosphere. Recent observational analyses suggest that, together with the tropical oceans, the stratosphere increases the 'memory' of the climate system, and also may influence long-term variations in the polar ice pack, sea surface temperatures, and the deep ocean circulation. This stratosphere-troposphere connection has important implications for the prediction of the response of tropospheric climate under increasing concentrations of greenhouse gases. Currently, sophisticated climate models differ as to whether the stratospheric polar vortex, a key part of the connection, will strengthen or weaken with increasing concentrations of greenhouse gases.

Role of aerosol infrared forcing. A crucial factor limiting the predictability of global climate is the large uncertainty about the precise effects of aerosols on Earth's radiation balance. Most large-scale global climate models include the direct radiative effects of aerosols at higher wavelengths, but few consider aerosol radiative properties in the infrared (IR) region. Measurements of clear-sky IR spectra, performed during a cruise across the western Pacific Ocean, revealed aerosol forcings of up to 10 Wm^{-2}. These values are quite large compared to the 1-2 Wm^{-2} forcing estimated for greenhouse gas accumulations since the beginning of the industrial revolution. Based on these measurements and analyses, aerosol IR effects will be included in the next version of the National Center for Atmospheric Research (NCAR) Community Climate System Model.

Effects of Indo-Pacific ocean mechanisms. A new multi-year assimilation of *in situ* and satellite data into an ocean model highlighted the importance of the interior ocean mechanisms (as compared to boundary currents such as the Gulf Stream) on time scales of weeks to months. Investigators found these mechanisms in the interior ocean play a critical role in altering the water mass exchanges between the midlatitude eastern Pacific Ocean and the the tropical Pacific where El Niño develops, suggesting that remote effects on El Niño should be more carefully considered by prediction models. Further, these relatively fast mechanisms were found to govern more generally

CCRI PRIORITY - POLAR FEEDBACKS

The Climate Change Research Initiative will leverage existing USGCRP research to address major gaps in understanding climate change. Polar systems may be especially sensitive to climate change and might provide early indications of climate change as well as interact with climate variability and change through several important feedback processes.

The CCRI will support research to improve understanding of processes that determine the behavior of slowly varying elements of the physical climate system, especially the oceanic and cryospheric portions. Particular foci include the processes by which the ice-covered regions of the high latitude Earth behave, the processes by which the distribution of sea ice varies, and the way in which knowledge of ocean circulation can be enhanced through use of global observations of ocean state and forcing parameters. The development and testing of new capabilities for measuring climatic properties, such as ocean surface salinity, mixed layer depth, and ice sheet thickness also will be carried out.

The CCRI will support the obtaining of systematic data sets for a limited number of Earth system parameters such as ice thickness, extent, and concentration in the case of sea ice, and mass balance and surface temperatures in the case of land ice and snow cover. It will shortly enable the initiation of regular observations of ice sheet thickness. Data assimilation systems using satellite data that provide for accurate, geophysically consistent data sets will also be carried out through this program. The polar feedbacks research will contribute to decision support through cryospheric observations and associated models that enable the initialization and verification of climate models, and the reduction in uncertainty of model output. The models also will provide real-time information for use by the U.S. Navy and commercial maritime interests in high latitude regions.

the transports and exchanges between the tropical and midlatitude ocean and thus could be an important factors for observing and modeling the longer term changes (e.g., interannual to decadal variability) of the Pacific Ocean.

Diagnostic for evaluating climate model performance. Scientists developed the Broadband Heating Rate Profile (BBHRP), a new model diagnostic that will help reduce a significant obstacle to improving the predictive accuracy of climate models—the ability to accurately quantify the interaction of the clouds, aerosols, and gases in the atmosphere with radiation. Because direct observation of these interactions is extremely difficult, there has been no observation standard with which to compare and judge the accuracy of climate model simulations. The BBHRP, which is based on an assimilation of detailed field measurements from the Atmospheric Radiation Measurement program, provides a realistic estimate of radiative heating or cooling impact of clouds, aerosols, and gases. This diagnostic can be directly compared to the model-predicted impacts, thus enabling model uncertainties to be evaluated.

CCSP CLIMATE MODELING STRATEGY

The CCSP strategy to accelerate climate model development and increase climate modeling capacity has three goals:

1) Improve the scientific basis of climate and climate impacts models.
2) Provide the infrastructure and capacity necessary to support a scientifically rigorous and responsive U.S. climate modeling activity.
3) Coordinate and accelerate climate modeling activities and provide relevant decision support information on a timely basis.

See Chapter 10 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of the CCSP modeling strategy.

HIGHLIGHTS OF PLANS FOR FY 2004 AND FY 2005

The CCSP will continue to enhance observational and modeling capabilities for improved understanding, prediction, and assessment of climate variability and change on all time scales. Climate Variability and Change modeling activities will be linked with the CCSP climate modeling strategy.

Key Climate Modeling Research Plans for FY 2004 and FY 2005

Continue development of next generation climate models. Work is underway to develop the next generation of global climate models at the major modeling centers in the United States. The research will produce improved representation of physical processes (e.g, convection and clouds) and more complete and improved representations of coupled interactive atmospheric chemistry, terrestrial and marine ecosystems, biogeochemical cycling, and middle atmospheric processes. This work is being initiated in FY 2004 and will be ongoing in FY 2005.

These activities will address Goal 1 of the CCSP modeling strategy.

Improve climate model evaluation and modeling infrastructure. Infrastructure for major model evaluation and improvement will be provided, coordination of model intercomparisons will be conducted, and model testbeds for parameterization testing will be maintained by the DOE Program for Climate Model Diagnosis and Intercomparison. A major effort will be dedicated to providing a robust and extensible software engineering framework for the Community Climate System Model, a code used by hundreds of researchers on many different high-end computing platforms. This work is now underway and will continue in FY 2005.

These activities will address Goal 1 of the CCSP modeling strategy.

Enhance computer capabilities at the Geophysical Fluid Dynamics Laboratory (GFDL) to support the Climate Change Technology Program. The NOAA GFDL supercomputing capability will be enhanced in FY 2004 to enable additional climate projections for research and assessment based on emissions scenarios developed through the CCTP. Likely case studies will include exploring the range of plausible future environmental consequences of different emission rates resulting from combinations of new technologies.

These activities will address Goal 2 of the CCSP modeling strategy.

Perform multi-century simulations and projections for the IPCC Fourth Assessment Report. Scientists at GFDL, NCAR, and six DOE National Laboratories will complete the production of ensemble multi-century global simulations and projections of climate variability and change for use in the Intergovernmental Panel on Climate Change Fourth Assessment Report. Some of these simulations will be modeled at twice the resolution used in the past in order to provide more useful information for downscaling results to regional scales. This, in turn, can enhance the capability of climate impacts scientists and other researchers to produce environmental information to support informed resource management and policymaking. This work will begin in FY 2004 and continue through FY 2005.

These activities will address Goal 3 of the CCSP modeling strategy.

Further implement the Earth System Modeling Framework. The Earth System Modeling Framework project will be enhanced and will produce initial climate simulation experiments in FY 2004, continuing through FY 2005. Several existing ocean and atmospheric models from NASA, NOAA, NSF, DOE, and university labs will be connected and coupled to produce new prototype modeling systems. This is a major milestone to enable full interoperability among atmosphere, land, ocean, and other models to improve the fidelity and predictive capability of the models.

These activities will address Goal 3 of the CCSP modeling strategy.

Key Observations and Process Studies Research Plans for FY 2004 and FY 2005

Continue research by Climate Process and Modeling Teams. DOE, NASA, NOAA, and NSF have jointly initiated three CPTs. These CPTs are focusing their research on cloud feedbacks and ocean mixing—high-priority climate processes that are responsible for climate model deficiencies and thus uncertainties in climate change projections. This work will continue through FY 2005.

These activities will address Question 4.1 of the CCSP Strategic Plan, and Goals 1 and 3 of the CCSP modeling strategy.

Assess aerosol impact on cloud and water vapor feedbacks and climate change. A focused research effort on the aerosol impact on cloud-radiation feedback and climate change will be initiated by coupling atmospheric chemistry, radiation science, and global modeling. The focused effort, which will continue through FY 2005, will develop improved representations of the aerosol impact on cloud and water vapor feedback processes in climate models. This is a collaborative effort with the CCSP Global Water Cycle research element.

These activities will address Question 4.1 of the CCSP Strategic Plan.

Assess impact of climate forcings on long-term climate change. NASA's Goddard Institute for Space Studies (GISS) will systematically change the climate forcings in its modeling experiments to evaluate the relative impact on long-term climate change and to understand the climate sensitivities to the various forcings. This research, initiated in FY 2004 and continuing until at least FY 2006, is an important step in building capability to provide answers to "if…then" questions relevant to resource management and environmental policy.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Improve subsurface ocean observations. The international Argo collaboration will establish a global network of free-drifting floats equipped with sensors for measuring the temperature and salinity of the upper 2000 meters of the oceans. Argo will allow, for the first time, continuous monitoring of the climate state of the oceans, with all data being relayed and made public within hours after collection. Data from the Argo floats will be used both operationally and in climate research programs. Argo float deployments began in 2000 and will continue during FY 2004 and FY 2005, with completion of the full array to be achieved over the next several years.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Obtain new high-density global observations of atmospheric temperature and water vapor. The United States—with participating agencies NSF, DOD (Space Test Program, U.S. Air Force, U.S. Navy), NASA, and NOAA—in partnership with Taiwan will launch six low Earth orbit (LEO) satellites, each carrying a set of instruments designed to measure high-resolution vertical profiles of atmospheric temperature and water vapor. This Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) project will provide approximately 3,000 vertical soundings per day, uniformly distributed over the globe. This will be an improvement over the current global radiosonde network of balloon-borne instruments, especially over the oceans and polar regions. The current system, which is the mainstream observational network for operational weather and climate prediction and research, obtains about 600 soundings twice a day. COSMIC will complement rather than replace the current system. Launch is scheduled for September 2005.

These activities will address Questions 4.1 and 4.2 of the CCSP Strategic Plan.

Develop an assimilated long-term global ocean circulation data set. Researchers working on the Estimating the Circulation and Climate of the Ocean (ECCO) project, formed under the National Ocean Partnership Program (NOPP), will initiate the production of an assimilated decadal ocean data product at near-eddy-resolving scale (1/4 degree) in FY 2004. Data analysis will continue into FY 2005.

These activities will address Question 4.2 of the CCSP Strategic Plan.

Continue research on thinning and acceleration of sensitive glaciers in Antarctica. Satellite radar data have shown that the area around the Thwaites and Pine Island Glaciers—known as the "weak underbelly of the West Antarctic Ice Sheet"—has experienced thinning in recent years in a manner that is consistent with observed glacier acceleration. This thinning appears to be contributing to sea-level

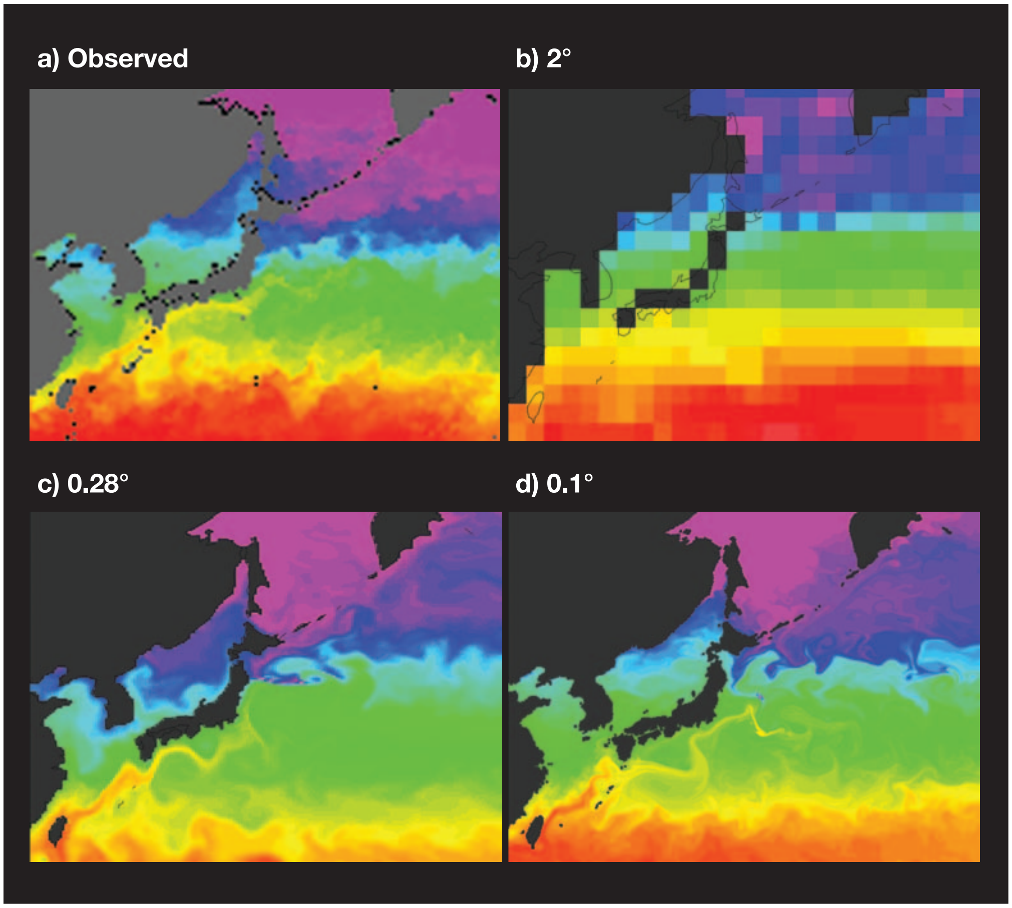


Figure 10: Sea surface temperature in the northwest Pacific Ocean from (a) satellite data, (b) a 2x2-degree non-eddy-resolving simulation, (c) a 0.28-degree eddy-permitting simulation, and (d) a 0.1-degree eddy-resolving simulation. All simulations were performed using the Parallel Ocean Program (POP). The detail is much more realistic in the two high-resolution cases, but only the eddy-resolving case can simulate the Kuroshio current separation—the point at which the warm Kuroshio current separates from the coast of Japan and extends into the Pacific. Currents like the Kuroshio and the Gulf Stream are responsible for transporting heat and other quantities to high latitudes and strongly affect the climate in regions including northern Europe. Accurate simulations of these current systems are required for understanding how climate change would affect global ocean circulation and how ocean circulation changes would affect climate in northern Europe and other regions.
Credit: Mathew Maltrud, Los Alamos National Laboratory, DOE Climate Change Prediction Program.

rise, but the extent to which the ice sheet as a whole is influencing sea level has yet to be accurately assessed (given the large spatial variability of this thinning and observed thickening of ice in other regions). NASA's Ice Cloud and Land Elevation Satellite (ICESat), which was launched in January 2003, is expected to help provide a reliable estimate of these changes. Analysis will continue through FY 2005.

These activities will address Question 4.2 of the CCSP Strategic Plan.

Provide new Arctic paleoclimate products. Based on a new synthesis of data from the Holocene Thermal Maximum (~9,000 years ago), warming is asynchronous and asymmetric across the North America Arctic region. Warming begins in the west and sweeps eastward. A georeferenced database of annually resolved records of Arctic temperature over the past 1,000 years is under development and is scheduled for completion and on-line availability in late FY 2004. Such maps, data, and manuscript references will provide spatially detailed information about Arctic temperature trends over the last millennium, which can be used to compare more recent changes with the patterns of change from the mid-Holocene geologic epoch.

These activities will address Questions 4.2 and 4.3 of the CCSP Strategic Plan.

Perform deep time paleoclimate research. Researchers supported by NSF, along with researchers at NASA and USGS, have begun a multi-year data analysis and climate modeling effort to create three-dimensional global data sets of middle Pliocene epoch (~3 million years ago) ocean temperature and salinity. This will create the most comprehensive global reconstruction for any warm period of Earth's climate prior to the most recent past. Estimates of middle Pliocene global warming suggest that temperatures were approximately 2°C greater than today. This level of warming is within the range of projected global temperature increase in the 21st century. No other time period in the past 3 million years approaches this level of warming. Analysis of this period challenges the science community's understanding of the sensitivity of key components of the climate system and how the system is simulated—that is, polar versus tropical sensitivity, the role of ocean circulation in a warming climate, the hydrological impact of altered storm tracks, and the regional climate impacts of modified atmospheric and oceanic energy transport systems.

These activities will address Question 4.2 and 4.3 of the CCSP Strategic Plan.

Key Decision Support Resources Development Activities for FY 2004 and FY 2005

Report on understanding of vertical temperature trends. A CCSP synthesis report on understanding and reconciling differences in observed temperature trends in the lower atmosphere will be produced for publication in FY 2005. In October 2003, 55 scientists from academia, the U.S. Government, and several other countries participated in a workshop at the National Climatic Data Center on the current state of knowledge and scientific uncertainties on this subject. Follow-on activities will include coordination with a workshop to be held at the UK Hadley Centre in June 2004. A solid foundation has been laid to proceed with the delivery of a synthesis report, with NOAA as the lead CCSP agency and DOE, NASA, and NSF contributing.

This activity will address Questions 4.1 and 4.5 of the CCSP Strategic Plan.

Develop, evaluate, and provide new probability forecasts of seasonal climate anomalies resulting from ENSO. In FY 2004 and FY 2005 major R&D efforts will continue on improving probabilistic intra-seasonal to interannual climate forecasts, and on developing new and improved climate forecasting products with regional and sectoral applications to water resource management and agriculture.

This activity will address Questions 4.4 and 4.5 of the CCSP Strategic Plan.

Provide improved climate information products for resource management. Regional integrated research will develop climate information products in FY 2004 and FY 2005 for the agricultural, wildfire, and water management sectors.

These activities will address Questions 4.4 and 4.5 of the CCSP Strategic Plan.