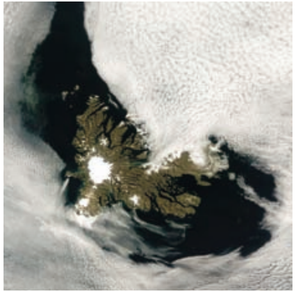
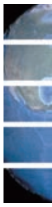


CCSP GOALS AND ANALYSIS OF PROGRESS TOWARD THESE GOALS

At the highest conceptual level, five goals have been identified to provide focus and facilitate programmatic integration (see accompanying box). These goals encompass the full range of climate-related issues. The program's detailed objectives, milestones, products and payoffs complement these overarching goals, and are articulated in the program's *Strategic Plan*. CCSP-participating agencies and departments coordinate their work through discipline-related "research elements," which together support scientific research across a wide range of interconnected issues of climate and global change. The goals address the most common questions concerning climate change, which include:

- To what extent and how is the climate system changing?
- What are the causes of these changes?
- What will the future climate be like and what effects will a changed climate have on ecosystems, society, and the economy?



CCSP GOALS

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

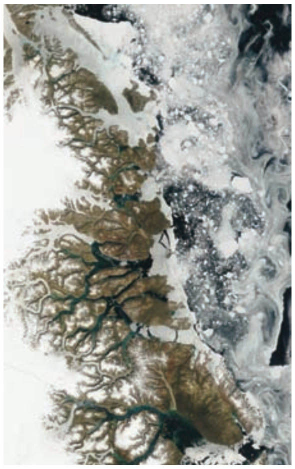
- How can we best apply knowledge about ongoing and projected changes to decisionmaking?

This section provides a high-level overview of progress made toward the program's goals in the 12 to 18 months prior to the preparation of this report. Because of the program's breadth and wide-ranging progress, this overview gives only a sampling of the advances made. In addition, this section does not purport to provide a thorough assessment of climate change or the extent of the scientific uncertainties that remain. Instead, it provides examples that illustrate the scope and significance of the progress that CCSP has made in expanding and applying understanding of climate.

The primary focus of U.S. climate research has historically been on Goals 1 through 3, which emphasize improvements in fundamental understanding of the climate system, its driving forces, and the tools to make predictions of short-term climate variability and potential long-term climate change more reliable. As the science matures and its societal utility becomes more evident, the importance of Goals 4 and 5 has become more significant. Examples of progress provided under each of the goals are often the result of coordinated research activities from many disciplines conducted or supported across the participating CCSP agencies.

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Analyses based on observations provide a solid foundation for the program. These analyses contribute to improved understanding of Earth system processes, help determine the extent of climate variations, and provide objective comparisons to test and advance model veracity. In the past year, analyses have enabled several important advances in understanding the nature and variability of the Earth system. The illustrative examples below of progress toward CCSP's Goal 1 are drawn from and integrate a variety of different CCSP research elements.



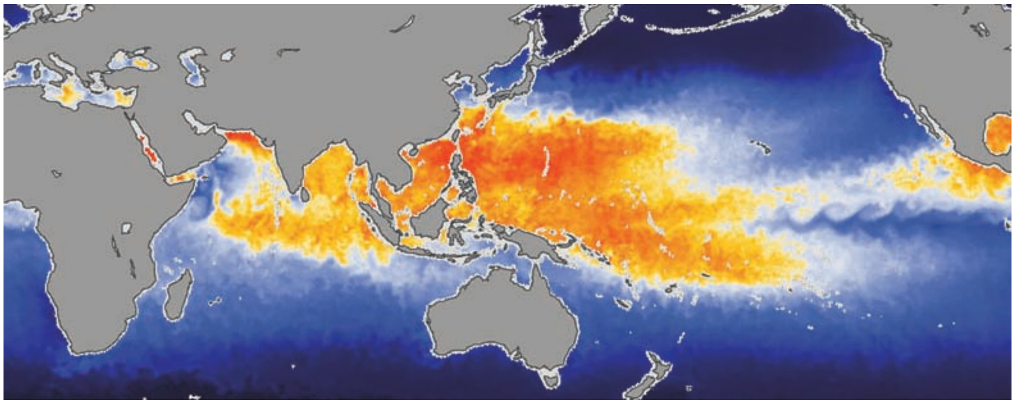
One example of these integrated analyses is the progress made in understanding climate change at high latitudes. Temperature and moisture patterns over North America and Europe are experiencing an earlier transition from winter to summer. The warmer spring temperatures produce earlier spring green-up of vegetation and longer growing seasons.[3] Satellite, airborne, and ground-based observations suggest that significant changes are occurring in the mass balance of the Greenland and Antarctic Ice Sheets that are inferred to be caused by warming at high latitudes.[4,5] Analyses of observations and climate model simulations suggest that the pattern of high latitude temperature change is more readily explained by estimated human activity and natural climate forcing than by internal variability alone.[b] These wide-ranging sets of analyses tie together findings from traditionally disparate disciplines including hydrology, glaciology, and ecology.

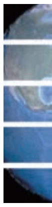
Two recent studies demonstrate progress made in improved understanding of climate influences on ozone distribution. Using satellite measurements corroborated by surface measurements, one study found increases in ozone in the Antarctic middle stratosphere during southern hemisphere summer (December). Model simulations showed that these increases were caused by the delayed transition from dynamic springtime conditions to more stable summer conditions due to the springtime ozone hole. The continuation of springtime dynamics forces descent of ozone-rich air from higher levels of the atmosphere to the lower, mid-stratosphere (about 30-km altitude). This study also found that future greenhouse gas increases would produce similar ozone increases.[6] The second study found that doubling of carbon dioxide (CO_2) caused a strengthening of the circulation responsible for the global distribution of ozone. The results of this study reveal that total ozone will increase at high latitudes of the Northern and Southern Hemispheres, and decrease in the Tropics.[7]

In the past decade, measurements from a variety of platforms, including satellites and ocean buoys, show warming in the top layers of the ocean, with strong evidence that the warming is due to increases in human-produced greenhouse gases.[1] Ocean heat storage is the largest component of the Earth's climate system for storing the energy imbalance between the sources and sinks of thermal energy. Even though the methods of observations are quite different, the matching magnitude and annual variability of

---

[b] Climate forcing is a process that directly changes the average energy balance of the Earth-atmosphere system by affecting the balance between incoming solar radiation and outgoing or "back" radiation.





the satellite-derived energy imbalance and the ocean heat storage is considered to be quite remarkable and lends confidence to the interpretation of the underlying climate process.[8]

The basic research conducted in CCSP Goal 1 is directly relevant to society. An example is work on identifying relationships between hurricane activity and climate variability and change. Theoretical and modeling studies suggest that increasing tropical sea surface temperatures are likely to be associated with more intense, but not necessarily more frequent, hurricanes.[9] Over the North Atlantic Ocean, there is strong observational evidence for an increase in intense tropical cyclone activity since 1970 that is correlated with increasing sea surface temperatures.[10] However, in basins other than the North Atlantic, trends in tropical cyclone activity have varied considerably during this period, although most basins have also experienced warming sea surface temperatures.[11] In the Atlantic and Pacific tropical cyclone genesis regions, the sea surface temperature changes appear to be due to a combination of natural variations and anthropogenic forcing.[12] Aside from differences between basins, results of tropical cyclone trend calculations appear sensitive to the length of the observational record and the techniques used to identify and characterize hurricanes. Consequently, considerable debate remains over present abilities to detect global trends in tropical cyclone activity.[13]

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

In making long-term climate projections, an understanding of the factors responsible for global environmental change is necessary. These forcing factors include greenhouse gases, land-cover changes, tiny airborne particles (aerosols), and solar variability. As in the previous goal, the following examples of progress toward CCSP Goal 2 result from the integrated focus of multiple CCSP research elements.

Recent climate warming has been particularly intense in boreal and Arctic regions, leading to concern that increasing air temperature in these ecosystems may indirectly increase the incidence of forest fires. Beyond the emission of CO_2 and other greenhouse gases, understanding the consequences of large-scale fires for climate is challenging due to the many additional ways in which they influence the atmosphere and surface. A recent study in Alaska found that there was intensification in the climate warming in the first year after a major fire but a slight decrease in the local climate warming when averaged over the 80 years of the study. The long-term result, which was primarily due to plant regrowth increasing the summer reflectivity of the burned surface, appeared to be more significant than the fire-emitted greenhouse gases.[14] The result suggests that future increases in wildfire in some parts of the boreal zone of Alaska may have different feedbacks to global warming than previously thought.

CCSP's interdisciplinary research on the carbon cycle has produced a set of analyses using long-term observations of several young and mature forests. Results from this work show that forest carbon storage has been increasing in these ecosystems and is not in balance with the carbon lost by respiration and decay. This result is contrary to the contemporary concept of near balance of carbon sources and sinks in mature forests.[15] The gain in forest carbon is typical of findings from U.S.-based large-scale networks, as well as observations made in mature forests in China. Evidence is therefore mounting that these sinks for atmospheric CO_2 offer significant potential for modulating the rate of atmospheric CO_2 increase.[16]

In western states, large changes in land cover and land use have occurred over the past century, with rapidly expanding urbanization along the Pacific coast and extensive agricultural development inland. Researchers exploring the effects of urbanization and agriculture on regional climate have found that irrigated agriculture in California tended to lower average and maximum near-surface air temperatures, while conversion of natural vegetation to urban areas tended to increase near-surface air temperatures. The surface temperature changes and their associated effects on the atmosphere also caused changes in the regional airflow. Overall, it was found that conversion of natural vegetation to irrigated agriculture has likely had a larger effect on the climate of California than urban growth, but increased conversion of irrigated land to urban/suburban development could alter this conclusion.[17]

Scientists are concerned that increased permafrost thawing due to warming in Arctic regions could cause the release of substantial amounts of carbon long held in the frozen tundra. There appear to be two potential mechanisms for the carbon to reach the atmosphere: drainage of the carbon-rich river flow into the Arctic Ocean with subsequent emission, and direct respiration or recycling of the newly thawed carbon. Measurements made in the Yukon River basin in northern Canada have shown that the latter process predominates.[18]

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

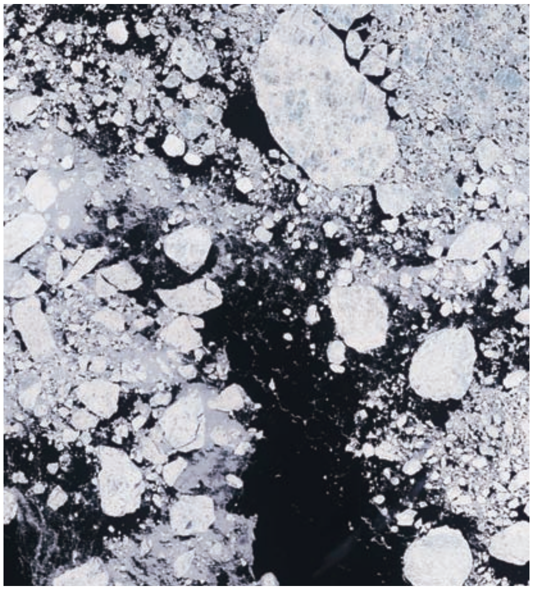
The accuracy of estimates of future Earth system conditions at time scales ranging from months to centuries and at spatial scales ranging from regional to global has been significantly improved by CCSP research. The primary tools for Earth system prediction and projection are computer models that reflect the best available knowledge of Earth system processes. The following examples demonstrate the integration of observations and modeling necessary to contribute to the progress being made in CCSP Goal 3.

For a model to produce a realistic climate projection, it must include realistic representations of physical processes such as cloudiness, precipitation, and solar energy. Recent innovative studies using newly developed, detailed models of cloud processes that are coupled with a global climate model provide results that are significantly more consistent with observations than traditional cloud modeling techniques.[19] The incorporation of improved cloud representation in climate models is expected to reduce the uncertainty in predictions of the global and regional water cycle and surface climate.

Energy from the sun not reflected back to space provides the driving energy to Earth's weather and climate systems. Clouds are a major component in the global reflectance of sunlight. Year-to-year variability in the global reflectance is dominated by the variability of cloudiness in the tropics.[20] On the other hand, scientists have recently found little change in the year-to-year variability of reflectance at middle and high latitudes despite decreases in the highly reflective snow and sea ice cover. This result appears to be due to the compensating increase in cloud cover balancing the decreasing surface-level reflectance. Clouds continue to provide the largest source of uncertainty in model estimates of climate sensitivity, although a recent study finds evidence that, in most climate models used in the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), clouds provide a positive feedback.[21]

Analyses of climate model simulations generated for the IPCC Fourth Assessment have identified several additional characteristics of climate change projections common to all of the models.[22] Examples of these robust model projections include strong subtropical drying, weakening of large-scale tropical atmospheric motions, and expansion of the poleward upper atmospheric wind pattern known as the Hadley circulation.

In another study, several models were used to investigate the effects of the freshwater input from melting ice and glaciers on the currents in the North Atlantic.[23] These currents are important due to their large-scale transport of heat. The study concluded that, in response to expected levels of freshwater input in the northern North Atlantic, the average modeled large-scale deep ocean current weakens by about 30% by the end of the century. All models simulate some weakening of this deep circulation, but no model simulates a complete shutdown of it.



CCSP researchers also use the geological record to test and apply climate models, particularly in cases where that knowledge has a bearing on climate change processes relevant to current society. One such analysis involves the largest known extinction in Earth's history, which took place approximately 250 million years ago at the Permian-Triassic boundary when approximately 95% of marine and 75% of terrestrial species were lost. In this study, a climate model simulation indicated that the elevated levels of CO_2 during this period led to climatic conditions inhospitable to both marine and terrestrial life.[24] It is hypothesized that a critical level of high-latitude warming was reached where the connection of oxygen-rich surface waters to the deep ocean was dramatically reduced—thus leading to a shutdown of marine biologic activity, which in turn led to increased atmospheric CO_2 and accelerated warming.

The historical record provides a broader set of observations to test and apply climate models to help reduce uncertainty in their future projections. A recent study used a simple model to attempt to reproduce paleoclimate reconstructions of Northern

Hemisphere temperature over the past seven centuries in response to estimated solar, volcanic, and greenhouse gas forcing during this period.[25] This study suggests that, for the current century, very high climate sensitivities predicted by some models for a doubling of atmospheric greenhouse gas concentrations are less likely than previously thought.

The projections made by CCSP research pertain not just to physical climate, but also to other components of the Earth system, including atmospheric chemistry. Continuing research has provided an estimate that the recovery of the Antarctic ozone hole will occur approximately 10 to 20 years later than the previous estimate of 2050.[26] As a result of the Montreal Protocol and its amendments, the use of ozone-depleting substances (ODS) has been greatly reduced. Improved understanding of atmospheric dynamics now gives 2001 as a better estimate of when the ODS peak occurred in the Antarctic stratosphere. This date is later than had been estimated previously and results in a longer projected time scale for recovery back to pre-1980 (unperturbed) levels of ODS.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Significant advances have been made in understanding the potential impacts of climate change. One of the characteristics of CCSP research is the use of many different sources of information, including analyses utilizing prehistoric information, direct observations, and model-based projections. Recent research also accounts for the dynamic nature of the response of human and natural systems to climate change. This research encompasses a wide range of potential impacts on societal needs such as water, health, and agriculture, as well as potential impacts on natural terrestrial and marine ecosystems. The integrated approach to developing the understanding sought in CCSP Goal 4 is illustrated in the following examples. This integration is occurring under several synthesis and assessment products (SAPs), particularly the seven products

under Goal 4. One example is the integration within SAP 4.1 that combines census population data, topographic elevation, shore protection, and land-use information to study the potential socioeconomic impact of various rates of sea-level rise.

Tools and research resulting from carbon cycle science are highly relevant to carbon management as demonstrated by a recent study that estimated the spatial variability of net primary production and potential biomass accumulation over the conterminous United States.[27] This study's model-based predictions indicate a potential to remove carbon from the atmosphere at a rate of 0.3 GtC per year through afforestation[c] of low-production crop and rangeland areas. This rate of carbon sequestration[d] would offset about one-fifth of the annual fossil fuel emissions of carbon in the United States.

The changing adaptability of coastal marshes is illustrated by the study of a coastal ecosystem. In a Chesapeake Bay marsh ecosystem, rising sea level, increasing CO_2, and high rainfall were shown to interact and improve the growth of a relatively tall bulrush at the expense of a hay-like cordgrass that grows in thick mats.[28] Such changes in species composition, caused by interacting global change factors, may influence the capacity of coastal marshes to rise in elevation at the pace required to keep abreast of sea-level rise because of species-specific differences in their ability to trap sediment and organic material.

Another example of the ecological consequences of climate change affecting adaptability involves the devastation of millions of acres of western U.S. and Canadian pines by bark beetles during the warmth and drought of 2000 to 2004. Recent modeling and observations revealed that beetles invading northernmost lodgepole pine trees are now only a few miles from previously pristine jack pine populations.[29] This may create a direct pathway of invasion to valued pine forests in the eastern United States and Canada.

CCSP's integrated approach to understanding the sensitivity and adaptability of natural ecosystems to climate change has also been applied in remote regions. The West Antarctic Peninsula is experiencing some of the largest, most rapid warming on Earth, which is causing loss of sea ice and increased snow precipitation. In turn, these changes are having major contrasting impacts on the adaptability of different penguin species. For example, in the vicinity of Anvers Island near the West Antarctic Peninsula during the last 3 decades, populations shifted south, so that local abundance of the ice-dependent and snow-intolerant Adelie penguins decreased by 65% (currently about

---

[c] Afforestation is the process of converting open land into forest by planting trees.

[d] Carbon sequestration is the process that removes carbon from the atmosphere, capturing and storing it by natural or artificial means.

5000), while the abundance of Chinstraps and Gentoos increased by 2,730% and 4,600% (currently about 300 and 650), respectively.[30] Climate warming in the Canadian Arctic has caused significant declines in total cover and thickness of sea ice and progressively earlier ice breakup in some areas. These changes affect the polar bear populations, causing them to extend their normal fast for longer periods during the open-water season.[31]

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

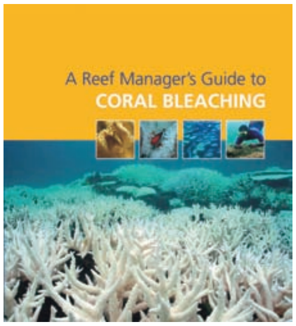
A substantial investment in basic research focused on global environmental variability and change has provided a significant set of opportunities for applying this knowledge in local, regional, and national planning. To explore and communicate the potential uses and limits of this knowledge, CCSP is using three approaches: developing scientific syntheses and assessments; exploring adaptive management and planning capabilities; and developing methods to support climate change policy inquiries. A few noteworthy examples of the progress made by CCSP in pursuing these approaches and actively working with the user community to apply this knowledge to manage risks and opportunities are described below.

CCSP scientists developed and documented a "water supply stress index" that calculates water shortage risks across the conterminous United States. The index is based on models and observations that integrate the effects of climate, land cover, and current water uses by municipalities and industries on water supply.[32] The water supply stress index and the methods associated with it will be used by local and regional decisionmakers to quantify the likelihood of future water shortages under changing climate, water, and land uses, for determining adaptation practices.

Incorporation of the subsurface water table into regional climate models is important, since land-cover changes produce significant effects on the water table and the hydrologic cycle. Shallow water tables can be either a sink or source of water to the surface soil depending on the relative balance of infiltration versus evaporation.[33] Recent studies using detailed observations and regional climate models have found that the fraction of rainfall that either recharges groundwater or ends up as streamflow tends to decrease when the fraction of land devoted to agriculture increases. This result suggests that intensive

agriculture can amplify surface water stresses, particularly during drought conditions.[34]

An example of regional decision support is the work carried out by the Consortium for Atlantic Regional Assessment (CARA), which is providing data and tools to help decisionmakers understand how outcomes of their decisions could be affected by potential changes in both climate and land use. On an interactive, user-friendly web site, CARA has organized data on climate (historical records and future projections from seven global climate models), land cover, and socioeconomic and environmental variables to help inform local and regional decisionmakers (see <www.cara.psu.edu>). The CARA tools and tutorials are designed to help decisionmakers understand the issues related to land-use and climate change by gathering, organizing, and presenting information for evaluating alternative mitigation strategies.



A Reef Manager's Guide to
CORAL BLEACHING

A workshop involving scientists and managers, co-led by several CCSP agencies under the auspices of the U.S. Coral Reef Task Force, resulted in the publication of *A Reef Manager's Guide to Coral Bleaching*.[35] The combined research results among state/territorial, Federal, academic, nongovernmental, and international scientists concluded that warming sea surface temperatures are a key factor in mass coral bleaching events. The *Guide* provides managers with strategies to support the natural resilience of coral reefs in the face of climatic change.

CCSP researchers have developed new metrics for estimating greenhouse gas emissions and carbon sequestration in the agricultural and forestry sectors.[36] These sectors can reduce atmospheric greenhouse gas concentrations by increasing carbon sequestration in biomass and soils, by reducing fossil fuel emissions through use of biomass fuels, and by substituting agricultural and forestry products that require less energy than other materials to produce. The DOE's National Greenhouse Gas Registry is using the new metrics as the basis for reporting greenhouse gas information from the agricultural and forestry sectors (see <www.eia.doe.gov/oiaf/1605/frntvrgg.html>).

CCSP FY 2008 KEY INTERAGENCY IMPLEMENTATION ACTIVITIES

The program's long-term vision, mission, goals, and objectives are described in the *CCSP Strategic Plan*. Implementation of this long-term plan occurs through agency activities that often benefit significantly from ongoing CCSP-facilitated coordination. CCSP has identified several key areas for FY 2008 that require particularly strong interagency coordination to achieve success; they cannot be adequately addressed by one agency alone. Although these priorities are only a small part of the overall program,