Analysis of Progress Toward Goals

The CCSP has five overarching goals that cut across the program's research elements, providing an integrated analytical framework. These five goals span the full range of climate-related issues, including natural climate conditions and variability; forces that influence climate, including cycles and processes that affect atmospheric concentrations of greenhouse gases and aerosols; climate responses; consequences for ecosystems, society, and the economy; and application of knowledge to decisionmaking. These

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.

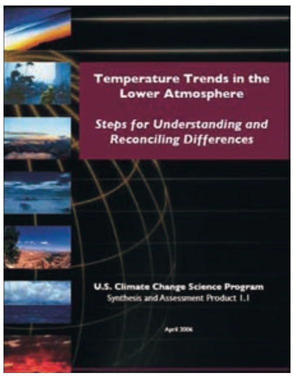
overarching goals are complemented by the detailed objectives, milestones, products, and payoffs articulated in the *CCSP Strategic Plan*.

This section of *Our Changing Planet*, which is new this year, provides an overview of progress made toward the program's goals since the release of the *CCSP Strategic Plan* in 2003. Because of the program's breadth and wide-ranging progress, this overview cannot address all advances. 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. See pages 157 to 163 for a description of the 21 CCSP synthesis and assessment products.

U.S. climate research has historically focused 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 has matured and its societal utility has become more evident, the importance of Goals 4 and 5 has become magnified. The examples of progress provided below are often the result of activities that integrate research from many disciplines conducted or supported across the participating 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.

The program's research is built upon a solid foundation of observationally based analyses, which are used to improve understanding of Earth system processes, to test and improve models, and to determine the extent of climate variations. These analyses span all aspects of the climate system. In the past few years, these analyses have enabled several important advances in understanding the nature and variability of the Earth system.



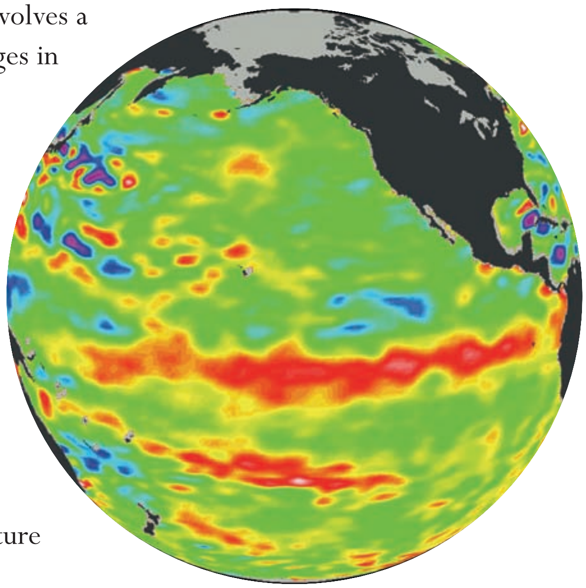
A key example is the analytical work reported in the CCSP synthesis and assessment report *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences* (CCSP, 2006). Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human-induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite and radiosonde data showed little or no warming above the surface. This significant discrepancy no longer exists because errors in the satellite and radiosonde data have been identified and corrected. New data sets have also been developed that do not show such discrepancies.

The synthesis and assessment report is an important revision to the conclusions of earlier reports from the NRC (2000) and the Intergovernmental Panel on Climate Change (IPCC, 2001). For recent decades, all current atmospheric data sets now show global-average warming that is similar to the surface warming. While these data are consistent with the results from climate models at the global scale, discrepancies in the tropics remain to be resolved. Nevertheless, the most recent observational and model evidence has increased confidence in our understanding of observed climatic changes and their causes.

While temperature has traditionally been a leading measure of climate variability and change, CCSP's work on other climate system parameters has significantly advanced understanding of variations that have important connections to societal well-being. Prime illustrations of this work are recent wide-ranging analyses of the terrestrial and oceanic water cycle. For example, observations in the western United States indicate that the annual peak in spring river runoff is occurring earlier in the season and is supplying less water during the growing season (Mote *et al.*, 2005). New satellite-based observations of the polar regions indicate significant reductions in the volume of the Greenland Ice Sheet (Velicogna and Wahr, 2005), declining Arctic sea-ice cover, and loss of ice mass in Antarctica despite no measurable change in snowfall over the last 50 years (Velicogna and Wahr, 2006; Managhan *et al.*, 2006). Observations of global sea-level increases are consistent with the declining volume of land ice as well as observations of ocean warming, which contributes to sea-level rise by expanding ocean volume. Observations of the North Atlantic indicate a reduction in salinity (Curry and Mauritzen, 2005), which climate system models indicate may lead to a slowdown of the large-scale ocean circulation that transports heat to high-latitude regions (Stouffer *et al.*, 2006a). Global-scale observations of ocean temperature indicate a pattern of warming that is generally consistent with climate model projections of greenhouse warming (Barnett *et al.*, 2005a). Although significant uncertainty remains, a pattern of climatic change is emerging that appears to be the likely result of a human imprint upon a complex background of natural climate system variability (Barnett *et al.*, 2005b; NRC, 2001).

Although it is scientifically critical to observe and understand variations in the average state of particular climate parameters, it is perhaps even more important for society to understand changes in the frequency or intensity of relatively uncommon phenomena (extreme events). One example of research on this topic indicates that recent U.S. droughts are relatively minor in comparison to naturally occurring droughts over the past millennium as shown by proxy records derived from tree rings and sediment cores (Cook *et al.*, 2004). Other examples of research on extreme events are observational analyses suggesting that the occurrence of severe hurricanes is increasing (Emanuel, 2005; Webster *et al.*, 2005) and opposing analyses suggesting that the apparent trends may be the result of flaws in the observational data (Landsea *et al.*, 2006). Interpreting changes in the characteristics of extreme events remains one of CCSP's ongoing research frontiers.

Under Goal 1, CCSP has made important progress in understanding the climate system's natural recurrent patterns of variability. The most prominent is El Niño, which recurs on a time scale of approximately 2 to 7 years and involves a warming of the eastern tropical Pacific in combination with changes in atmospheric circulation. Recent research links decadal changes in this pattern to droughts and wet conditions over North America and suggests that a portion of such decadal changes may be predictable (Seager *et al.*, 2005). Other important sets of recurrent patterns of variability include the so-called Annular Modes, which are concentric patterns of high and low pressure centered on the North and South Poles. Recent research has made significant advances in explaining the nature of these patterns and their effect on mid-latitude climate (Thompson and Wallace, 2000). Using this improved understanding of natural climate variability to improve predictions of the occurrence of specific climate variations from 2 weeks to several years in the future remains a major challenge.



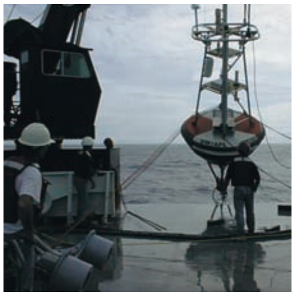
Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

An understanding of the factors responsible for global environmental change is necessary to make long-term climate projections. These forcing factors include greenhouse gases, tiny airborne particles (aerosols), land cover, and solar variability.

The greenhouse gas that plays the largest role in causing climate change is carbon dioxide (CO_2). An understanding of the sources and sinks of CO_2 and of carbon cycle dynamics is required for developing scenarios of future atmospheric CO_2 concentration and for developing effective strategies to manage carbon cycle processes that affect the concentration of atmospheric CO_2.

Climate and the global carbon cycle are a tightly coupled system where changes in climate affect the transfer of atmospheric CO_2 to the terrestrial biosphere and the ocean, and *vice versa*. An important conclusion of recent carbon cycle research is that future warming is likely to lead to a further decrease in the efficiencies of land and ocean in absorbing excess CO_2 (i.e., a positive feedback) (Fung *et al.*, 2005). This assessment is based on advances in U.S. and global carbon observations and improvements in carbon cycle models. Controlled experiments on carbon uptake and release in ecosystems are one means of improving our understanding of carbon cycle dynamics, which can contribute to corresponding carbon cycle model improvements. For example, Free-Air Carbon Dioxide Enrichment experiments, in which CO_2 is purposely injected into the air around a small plot of land, have led to the conclusion that the mass of carbon in ecosystems initially tends to increase when exposed to increased levels of CO_2 (Norby *et al.*, 2005; Jastrow *et al.*, 2005). This increase may be limited by the availability of nutrients, although a comprehensive meta-analysis indicates that nitrogen supply generally keeps pace with plant demands in natural systems (Luo *et al.*, 2006). Other controlled experiments in which ecosystems are purposely warmed generally indicate greater ecosystem CO_2 release with higher temperatures. However, there are still significant uncertainties associated with the biospheric response to climate change, particularly with respect to the complex and dynamic nature of ecosystems and their interactions with climate and the hydrologic cycle.

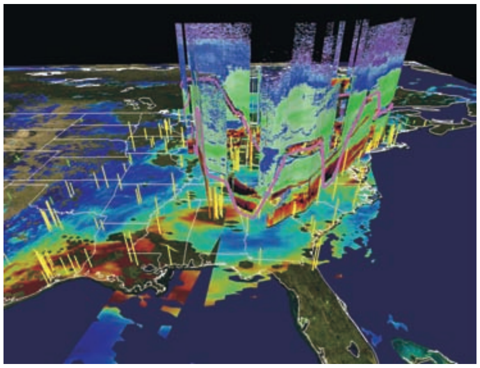
Another important recent advance is improved estimates of the amount of carbon being sequestered in North America and globally, and in particular, how the rate of carbon uptake is changing in all ecosystems. These estimates are made through the innovative combination of carbon cycle models and observations of carbon concentrations and isotopes (Fung *et al.*, 2005). A key goal of the North American Carbon Program is to further improve estimates of carbon sources and sinks. Work of this nature is vital for assessing the efficacy of natural carbon uptake, as well as the potential for purposeful carbon capture in managed ecosystems.



Observations of ocean carbon are important for addressing uncertainties associated with the global carbon budget. New global-scale ocean carbon analyses indicate increasing carbon concentrations in ocean water. In addition to confirming the oceans as a significant carbon sink, this information is also being used to estimate the increase in ocean acidity caused by increasing amounts of dissolved CO_2, and the potentially deleterious consequences for marine ecosystems (Orr *et al.*, 2005). Recent measurements of carbon sedimentation along continental shelves have shown these regions to be responsible for a significant fraction of oceanic carbon uptake (Muller-Karger *et al.*, 2005).

CCSP has made significant advances in understanding the processes responsible for the production and destruction of other greenhouse gases, including methane and nitrous oxide. For example, recent analyses estimate that approximately 60% of all methane emissions from wetlands occur in the tropics (Melack *et al.*, 2004). In polar regions, recent studies have elucidated processes by which carbon, currently trapped either as organic matter or methane hydrates in the permafrost (frozen soil), is released to the atmosphere (Zimov *et al.*, 2006). Warming increases these releases and can create an amplifying feedback loop. Another example of progress on non-carbon greenhouse gases is the work that has improved understanding of interactions between climate variability and near-surface ozone, which is a health hazard.

One of the largest uncertainties in projections of potential future climate change is the role of aerosols. Recent research has reduced some of this uncertainty, in part through efforts made possible by the CCRI. In the first phase of preparing the synthesis and assessment report that deals with aerosol properties and their impacts on climate, a comprehensive paper has been published that reviews recent progress in characterizing aerosols and assessing the direct effect of aerosols on climate change (Yu *et al.*, 2006). This work will serve as a major resource in the preparation of the IPCC Fourth Assessment Report. One study cited in the review paper, for example, concluded from



observational evidence that enhanced aerosol concentrations increase the amount of thermal energy emitted by Arctic clouds to the surface, which could augment surface warming caused by greenhouse gases (Lubin and Vogelmann, 2006).

Examples of other areas in which the program has made significant advances in understanding include the potential effects of land-use change on climate, the recovery of the ozone layer and its interactions with climate change, and the magnitude of variations in solar output and their potential effects on climate (Feddema *et al.*, 2005; Reinsel *et al.*, 2005; Lean *et al.*, 2005; Meehl *et al.*; 2004a).

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

CCSP has significantly advanced the ability to estimate future Earth system conditions at time scales ranging from months to centuries and at spatial scales ranging from regional to global. The primary tools for Earth system prediction and projection are computer models that reflect the best available knowledge of Earth system processes. Recent model simulations of the climate of the past 100 years have been compared to observations. The results generally indicate improvements over previous generations of models, including the ability to represent weather systems, climate variability (e.g., monsoons, El Niño), ocean processes (e.g., the Gulf Stream), surface hydrology, and other Earth system processes, components, and dynamics (Collins *et al.*, 2006; Schmidt *et al.*, 2006). One of the ways in which these models have advanced is through improvements in the representation of the processes responsible for key Earth system feedbacks such as those associated with water vapor, clouds, sea ice, and the carbon cycle (Delworth *et al.*, 2006; Gnanadesikan *et al.*, 2006; Wittenberg *et al.*, 2006).

The magnitude of future warming will be strongly influenced by the extent to which atmospheric water vapor concentration increases in response to an initial warming caused by increases in CO_2 and other greenhouse gases. An accurate representation of this feedback in climate models is critical for making long-term climate projections. Recent innovative analyses have shown that water vapor increases in the upper atmosphere measured by satellites and balloon-borne sensors are generally consistent with state-of-the-art climate model simulations, lending credence to the ability of current models to represent the water vapor feedback (Soden *et al.*, 2005; Cess, 2005).

New cloud simulation modules that have been developed and incorporated into climate system models indicate improved performance when compared to the ability of earlier cloud modules to represent day-to-day and seasonal cloud

variability (Khairoutdinov *et al.*, 2005). Advances have also been made in understanding the effects of aerosols on cloud formation and precipitation, although significant uncertainties remain (Lohmann and Feicher, 2005). Other types of important cloud processes that require further work are those associated with deep convection (thunderstorms), low-level ocean stratus cloud formation, and the very fine-scale effects of cloud properties on the Earth's energy balance (Stephens, 2005). A priority for the program is to continue to improve understanding of these and other cloud processes and to incorporate these improvements into climate models.

The CCSP modeling strategy utilizes a multi-tiered approach in which new and improved Earth system sub-models (e.g., clouds, ecosystem dynamics, sea ice) are developed and tested by individual researchers or small research teams. When significant improvements in these sub-models arise, they are integrated as appropriate into high-end Earth system models. A result of these ongoing efforts is a set of U.S. models that expand beyond earlier atmosphere-ocean models to include relatively sophisticated representations of land-surface hydrology, sea ice, ecosystems, and atmospheric chemistry. Several U.S. Earth system modeling centers have used variations of these models to produce ensembles of projections that are providing important new perspectives on potential future climate system change (Meehl *et al.*, 2004a; Stouffer *et al.*, 2006b). These ensembles are also being used to characterize the intrinsic uncertainty associated with potential future climate change.

A set of new high-resolution climate model simulations has been completed for North America that provides information at a scale finer than 100 km x 100 km (Leung *et al.*, 2004; Han and Roads, 2004; Mason, 2004; Wood *et al.*, 2004). The ability of these regional-scale models to represent climate processes is being assessed (see <www.narccap.ucar.edu>). These regional and global simulations, based on models developed at U.S. institutions, are contributing to the IPCC Fourth Assessment Report.

Because Earth system models are extremely complex and benefit greatly from input and evaluation by multiple research teams, several new efforts have been initiated to enable sharing, testing, and improvement of these models by diverse groups of researchers (Meehl *et al.*, 2004b, 2005). Many of the recent model simulations referred to above are now widely available through a new capability for data archiving and dissemination developed by the Program for Climate Model Data and Intercomparison (see <www-pcmdi.llnl.gov>). Large strides have been made in creating climate model code according to a set of standards that facilitate exchange of sub-models (e.g., the Earth System Model Framework), which enables researchers to readily trace the source of differences between various models and between models and observations. The U.S. Climate Variability and Predictability Program (CLIVAR) is exploring a new approach for bringing together observers, theorists, and high-end modelers to improve key model deficiencies (Bretherton *et al.*, 2004; USCLIVAR, 2002). This approach is attempting to significantly reduce the time lags that often exist between the observation of key climate processes and the integration of these processes into more comprehensive Earth system models. Several high-end Earth system modeling efforts in the United States, which involve many different, independent research teams, are using these types of new collaborative approaches and tools to evaluate, improve, and integrate model components.

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

CCSP has made significant advances in understanding the potential impacts of climate change. One of the hallmarks of CCSP research is the use of many different sources of information, including analyses using prehistoric information, direct observations, and model-based projections. Recent research has also begun to account for the dynamic nature of the response of human and natural systems to climate change (Lucier *et al.*, 2006). 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.

One example of this type of work addresses the potential impacts of variations in water availability in the western United States (Barnett *et al.*, 2004). As mentioned previously, paleoclimatic research indicates that decades-long droughts have occurred many times over the past millennium. This information, in combination with climate model projections of potential reductions in future water availability due to increases in greenhouse gases, suggests that current water management systems in the West (e.g., California) may be insufficient to respond to future climate conditions (VanRheenen *et al.*, 2004; Dettinger *et al.*, 2004). Other research indicates that multi-decadal climate variability in the western United States may have significant impacts on ecosystems, mountain glaciers, tourism, and fire frequency (Christensen *et al.*, 2004; Brown *et al.*, 2004).

Another example of CCSP research related to Goal 4 is analyses of the potential implications of climate variability and change on river and marine ecosystems. For example, measurements of salmon populations originating in Alaskan and Pacific Northwest coastal rivers indicate large fluctuations in abundance in recent decades, resulting in significant economic and social costs and ecological impacts in riverine and coastal marine communities. In addition to impacts from loss of habitat, river obstructions, harvest, and competition from hatcheries there is some evidence that salmon abundance is linked to large-scale climate fluctuations, but details of the processes involved are poorly understood due to the complexity of the food chain upon which the salmon depend (Pierce, 2004; Farley *et al.*, 2006; Ruggerone *et al.*, 2005). Fisheries research has made important strides in understanding the interplay of factors responsible for variations in harvests of many different species, including the effects of water temperature, changing fishing practices, and management of fish hatcheries and migration routes. Another example of multi-factorial coastal research in CCSP is work on coral systems, which has found that human disturbance and coral disease, coupled with ocean warming events, are contributing to coral bleaching (West and Salm, 2003). Research into the potential implications of sea-level rise also points to the need to account for a wide variety of factors when assessing future impacts. For example, some measures to protect coastlines may carry negative side effects, such as the potential for wetlands loss when inland barriers are constructed, preventing the wetlands from migrating inland in response to rising sea level (Cahoon *et al.*, 2006).

Components of CCSP research funded in part through the U.S. Joint Global Ocean Flux Study Program have explored ecosystem impacts in the open ocean resulting from climate variability and change as well as from changes in ocean chemistry and thermal structure. An example of a chemical impact is the chain of events causing the oceans to become more acidic due to chemical changes resulting from the absorption of increasing concentrations of atmospheric CO_2 (Orr *et al.*, 2005). Ocean warming tends to increase vertical stratification (layering) and thus slow the overturning of nutrient-rich deep-ocean waters (Schmittner, 2005). Recent model projections suggest that increased ocean acidification and increased layering of the upper ocean due to warming are likely to reduce plankton production. These model results are supported by satellite observations indicating significant changes in photosynthetic plankton concentrations, including declines in the North Atlantic and Pacific and increases in the Indian Ocean (Gregg *et al.*, 2003).

Observational and modeling studies of terrestrial ecosystems indicate a wide variety of changes in which it appears that climate variations play a significant role. For example,

recent evidence indicates a northward expansion of the ranges of many bird and butterfly species in the United States corresponding to warming in the region (Sekercioglu *et al.*, 2004). Declines in Arctic sea ice, observed both *in situ* and by satellites, have been linked to increasing vulnerability of polar bear populations (ACIA, 2005). Satellite and *in situ* observations also indicate a trend toward earlier growth of spring vegetation (Angert *et al.*, 2005). In addition to temperature and hydrologic changes, the increasing level of atmospheric CO_2 is thought to play a role in changing ecosystem distributions and characteristics due to its fertilizing effect. Agricultural yield models account for this effect, and project a range of agricultural impacts depending on the magnitude and nature of future climate change, crop types, and the types of adaptive measures that are adopted. Recent research indicates that different strategies may be required to manage insects, weeds, and diseases in agricultural systems (Ziska and Runion, 2006).

In addition to managed ecosystems, CCSP research has expanded understanding of the sensitivity and adaptability of a variety of other societal sectors. One of these is human health, which may be affected directly by changes in temperature and storm intensity, or indirectly through changes in distributions of insects that carry pathogens. An example of research in this area is the effects of climate change on heat waves. As described in the Climate Variability and Change chapter, recent observational and modeling work suggests that the probability of heat waves such as the one that occurred in Europe in 2003 has increased significantly, and that future warming may make heat waves of similar magnitude a normal summer occurrence within several decades (Meehl and Tebaldi, 2004). Recent research on the societal dimensions of climate variations has shown that physical climate analyses, such as the aforementioned study of heat waves, must be assessed within a complex fabric of other social and environmental factors (Poumadere *et al.*, 2005). An example is the general increase in financial losses due to hurricanes over the past century, which is probably attributable more to expanding coastal development than to any changes in hurricane characteristics (Pielke *et al.*, 2005). In regions such as

central Africa, where the capacity to adapt to environmental variations is often relatively low, recent research has shown strong correlations between year-to-year climate variations and malaria outbreaks (Thomson *et al.*, 2006).

These are a few examples of CCSP's research examining the sensitivity and adaptability of human and natural systems to climate variability and change. It is clear from this work that climate variations can have both beneficial and adverse effects on environmental and socioeconomic systems. However, future projections indicate that the larger the magnitude and rate of climate change, the more likely it is that adverse effects will dominate (NRC, 2002).

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

The Nation's basic research on global environmental variability and change has pointed toward a large set of important opportunities for applying the knowledge that is being developed. CCSP is taking three main approaches for exploring and communicating the potential uses and limits of this knowledge, namely the development of scientific syntheses and assessments; adaptive management and planning capabilities; and methods to support climate change policy inquiries.

One key focus of the program's synthesis and assessment activities is its current suite of 21 Synthesis and Assessment (S&A) products, which are intended to provide current evaluations of the science foundation that can be used for informing public debate, policy, and operational decisions, and for defining and setting the future direction and priorities of the program. The Decision Support chapter of this report describes the S&A products more fully, including the first completed product—the report on temperature trends at the surface and in the atmosphere referred to earlier. Another important focus for the program's synthesis and assessment activities is its involvement in the IPCC. The IPCC's major activity is to prepare at regular intervals comprehensive assessments of policy-relevant scientific, technical, and socioeconomic information appropriate to the understanding of human-induced climate change, potential impacts of climate change, and options for mitigation and adaptation. Approximately 120 U.S. scientists are IPCC authors and 15 are Review Editors. The United States co-chairs and hosts IPCC Working Group I, which primarily addresses physical science aspects of climate change. The United States has also played significant roles in the World Meteorological Organization (WMO) / United Nations Environment Programme (UNEP) ozone assessments (WMO, 2003), the Arctic Climate Impact Assessment (ACIA, 2005), and the Millennium Ecosystem Assessment (MEA, 2005), among others.

The second of CCSP's decision-support approaches is the exploration of adaptive management strategies. Activities under this approach develop and evaluate options for adjusting to variability and change in climate and other conditions through "learning by doing" and integrating knowledge with practice. This area of work grows out of the insight that a key to assessment and decision support is close and ongoing interaction between users and producers of information. Many adaptive management projects in the United States are extensions of the first U.S. National Assessment's stakeholder-driven and interdisciplinary collaborations (NAST, 2001).

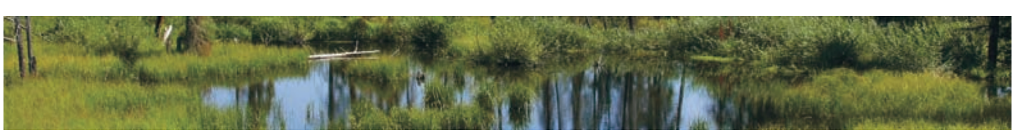
One example of this work is an ongoing project that brings together researchers who study climate processes and their effects on the U.S. Southwest with individuals and organizations that need climate information to make informed decisions (Jacobs *et al.*, 2005). Numerous tangible benefits from this project have helped a wide variety of decisionmakers, from State and local water planners to farmers to public health officials. For example, the project developed a suite of products that make predictions of water availability months in advance, allowing water managers to adjust reservoir levels accordingly to meet the competing demands for this scarce resource.

Another example is the combined use of satellite-based observations of fires and moisture conditions together with seasonal climate forecasts to provide information to fire managers to help them make early and effective decisions about the resources they will need to cope with emerging fires and fire-season dangers. One way in which this information is communicated is through annual workshops targeted separately at eastern and western U.S. fire hazards, which bring together climate scientists and forecasters with fire managers to produce seasonal fire outlooks (see <www.ispe.arizona.edu/climas/conferences/NSAW>). There are many other examples of the exploratory use of seasonal-to-interannual climate information for decisionmaking both domestically and internationally.

In addition to CCSP's work on adaptive management at seasonal-to-interannual time scales, the program is also developing valuable information for long-term (decades to centuries) adaptation issues. One example is the program's analyses of ways in which agricultural practices might be adjusted to take advantage of rising CO_2 levels and to cope with potentially warmer temperatures and decreased moisture availability (Boote *et al.*, 2005). Recent work has shown that sufficient variability exists within some crop species to begin selecting for crop varieties that could maintain or increase yields in a future enhanced-CO_2 environment.

CCSP's third decision-support approach is to help inform inquiries related to climate change policy, in part by using comparative analyses of climate change scenarios. One example is a collaboration between climate scientists and New York City water infrastructure planners that is using regional-scale hydrologic scenarios to inform the long-lasting investments that are being considered in the modernization of the city's water supply system (see <www.ccsr.columbia.edu/cig/taskforce>). Another example is the application of carbon cycle research to assess the potential feasibility, magnitude, and permanence of a variety of different carbon sequestration options (Sarmiento *et al.*, 1999). An initial result from this line of work is the preliminary conclusion that the restoration of inland wetlands could be a particularly efficient means for sequestering carbon in North American prairie lands (Euliss *et al.*, 2006).

Another important way in which CCSP is helping to inform climate change policy inquiries is through integrated assessment modeling, which considers the social and economic factors that may lead to climate change (e.g., greenhouse gas emissions) and the resultant effects of those activities on the Earth system and human welfare. These models are useful for considering the costs and effects of various policy options. One important result of this work suggests that reducing emissions of greenhouse gases other than CO_2 could be an economically efficient first step in reducing the overall atmospheric burden of greenhouse gases (Hansen and Sato, 2004). Another important new set of analyses assesses various policy options while accounting for inherent scientific and economic uncertainty (Webster *et al.*, 2003).



The U.S. Climate Change Science Program for FY 2007

The preceding descriptions provide a thumbnail sketch of the progress CCSP has made toward its goals. However, an important body of work remains within each of these goals that still must be tackled if this Nation is to be fully equipped to wisely address the challenges posed by global environmental variability and change. The *CCSP Strategic Plan* articulates this research agenda, and the research element chapters of this report outline specific examples of work proposed for FY 2007. The research element chapters also include updates on CCSP research-product preparation, milestones, and activities, with reference to the research focus areas for each goal.