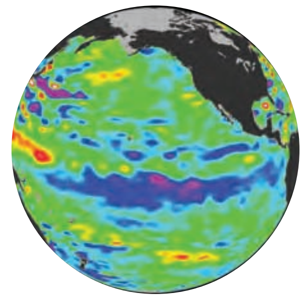
system (e.g., the Climate Research Committee and the Committee on the Human Dimensions of Global Change). CCSP will continue to rely on scientific advisory groups that support individual agencies, scientific steering groups organized to coordinate different CCSP research elements, and open dialog with the domestic and international scientific and user communities interested in global change issues.

CCSP Goals and Analysis of Progress Toward These Goals



The Climate Change Science Program focuses on five goals that address the full range of global change research, observations, and decision support. These goals address understanding the components of the Earth's varying environmental system, with a particular focus on climate; understanding how these components interact to determine present conditions; understanding what drives these components; understanding the history of global change and projecting future change; and understanding how knowledge about global environmental variability and change can be applied to present-day and future decisionmaking.

This section provides an overview of the progress made toward achieving these goals in the 12 to 18 months prior to the preparation of the FY 2009 edition of *Our Changing Planet*. Because of the breadth of climate research funded by the U.S. Government, this overview only provides a general summary of some of the many climate change research activities covered under the CCSP umbrella.

In the past decade, the primary focus of U.S. climate research has been on CCSP Goals 1, 2, and 3—emphasizing understanding the global climate system through observations, identifying the various components of the global climate system, understanding how

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.

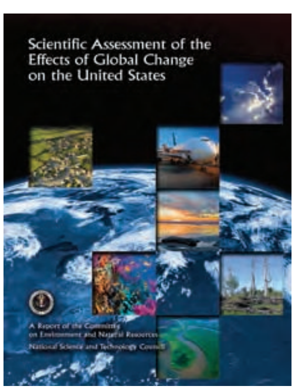
Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

the various components interact to drive the climate system, and working toward developing predictive tools that identify near- and long-term climate variability. As progress towards a better understanding of the global climate system continues to be made, Goals 4 and 5 are gaining additional attention.

The following are recent examples of progress contributing to each of these five goals, resulting from coordinated research activities in many disciplines conducted by or supported across the CCSP-participating agencies. In all of these areas, CCSP has functioned to facilitate interagency cooperation and coordination within the U.S. Government.

The FY 2009 edition of *Our Changing Planet* summarizes a massive array of scientific evidence that human activities are responsible for recent global warming. Recent studies have (1) documented and corrected errors in several previous studies that cast doubt on global warming, (2) reinforced the conclusion that solar forcing is not responsible for global warming for the past few decades, and (3) further documented ongoing global warming via observations of many different facets of the global climate system. Taken together, these recent reports provide unequivocal evidence that the planet is warming, and further research provides coherent evidence that it is very likely caused by human activities.[1] These conclusions by the Intergovernmental Panel on Climate Change (IPCC), made possible in part through CCSP research (see box on pages 11 and 12), emphasize CCSP's urgent mission of interagency cooperation and coordination. In order to continue to improve understanding of ongoing and future changes, in particular to provide information to support decisionmaking, the need for sustained satellite and *in situ* climate observations is underscored. These observational activities must be coupled with robust modeling and analysis, as well as research on impacts, adaptation, and vulnerability to global environmental variability and change.

CCSP's series of synthesis and assessment products, briefly described in this chapter, summarize the current state of interagency global change research within a multi-agency context. These products span all five CCSP goals. With their in-depth focus on North America, they provide an important complement to the IPCC reports.



In May 2008, CCSP released a report entitled *Scientific Assessment of the Effects of Global Change on the United States*, which draws from the IPCC reports and several of the synthesis and assessment products. The scientific assessment integrates, evaluates, and interprets the findings of CCSP and other scientific investigations of global change. It analyzes the trends and effects of global environmental changes, with a particular focus on climate change impacts on the United States. Together with CCSP's synthesis and assessment products and other major assessments, the report is an important tool for

EXAMPLES OF CCSP CONTRIBUTIONS TO THE IPCC FOURTH ASSESSMENT REPORT

CCSP scientists in cooperation with other international scientists contributed significantly to the Fourth Assessment Report of the IPCC, published in 2007. One of the highlights of this cooperation was the development of a large set of coupled atmosphere-ocean global climate model experiments for 20th and 21st century climate.[3] This effort, as well as the subsequent analysis phase, was organized through CCSP-sponsored cooperation with the World Climate Research Programme (WCRP) and its Climate Variability and Predictability (CLIVAR) project. The resulting data set is the largest and most comprehensive international global coupled climate model experiment and multi-model analysis effort ever attempted, and is openly available for analysis and academic applications. Over 200 journal articles, based in part on the data set, have been published or submitted for publication to date, and many more are being prepared. The ready access to the multi-model data set opens up these types of model analyses to researchers, including students and developing country scientists, who previously could not obtain state-of-the-art climate model output, and thus represents a new era in climate change research. As a direct consequence, these ongoing studies are increasing the body of knowledge regarding understanding of how the climate system currently works, and how it may change in the future.

With wide public acceptance of the IPCC Fourth Assessment Report findings, the climate science community is moving beyond simply running the basic scenarios to prove that climate change is occurring into new areas of focused climate change decision support. This will involve putting climate change in the context of the Earth's evolving environmental systems to assess the adaptation and mitigation implications of local, national, and international policies on emissions, energy use, and resource management. Providing climate knowledge support for society's decisionmakers will require developing an extremely accurate climate prediction capability to understand and accurately simulate Earth's complex energy-chemistry-climate system.

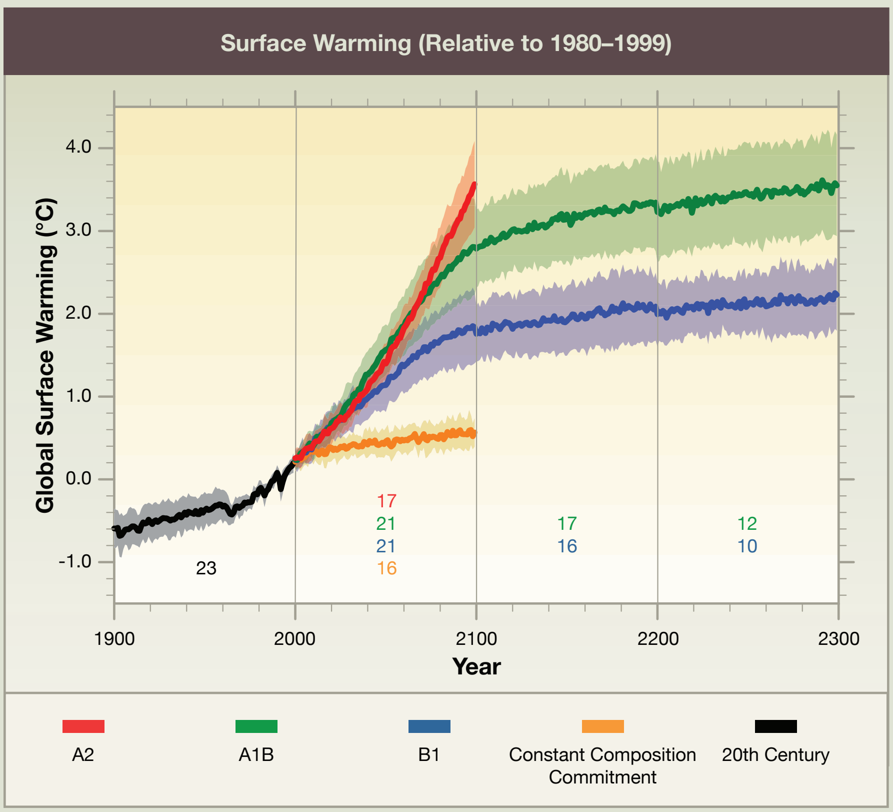


Figure 1: Surface Warming (Relative to 1980-1999). Surface warming (relative to 1980–1999) from the WCRP multi-model data set for the scenarios of high, medium, and low emissions (A2, A1B, and B1, respectively), shown as continuations of the 20th century simulations that included combinations of natural and anthropogenic forcings. Values beyond 2100 are for idealized stabilization where greenhouse gas concentrations were held fixed at year 2100 values and the models were run to the year 2300 to assess climate change commitment. Similarly, the "constant composition commitment" experiment is for idealized stabilization of all greenhouse gas concentrations at year 2000 values, with the model calculations projected through the year 2100. Lines show the multi-model means; shading denotes the ±1 standard deviation range of individual model annual means. Discontinuities between different periods have no physical meaning and are caused by the fact that the number of models that have run a given scenario is different for each period and scenario, as indicated by the colored numbers given for each period and scenario at the bottom of the panel. *Credit: G.A. Meehl, NCAR (reproduced from the* ***Bulletin of the American Meteorological Society*** *with permission from the American Meteorological Society).*

EXAMPLES OF CCSP CONTRIBUTIONS TO THE IPCC FOURTH ASSESSMENT REPORT [CONTINUED]

Figure 1 on the previous page summarizes the results from the IPCC Fourth Assessment Report experiments in terms of time series of globally averaged surface air temperatures from the different models for the various experiments. "Committed warming" is the term used to describe the lags between increases in concentrations of greenhouse gases and observed atmospheric temperature changes, caused by a number of factors including the thermal inertia of ocean and ice. Committed warming averages 0.1°C per decade for the first 2 decades of the 21st century. Across all scenarios, the average warming is 0.2°C per decade for that time period (the recent observed trend over roughly the last 2 decades is about 0.2°C per decade). Figure 2 shows that regional surface temperature changes are roughly double the globally averaged value, with the largest increases seen at high latitudes.

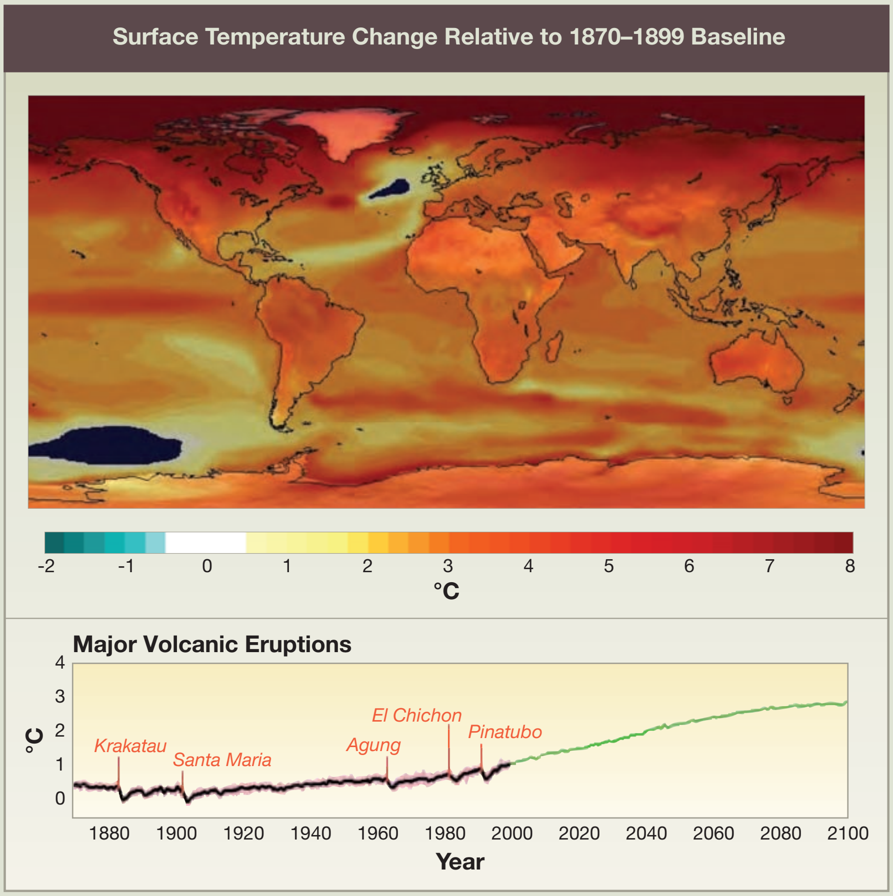


Figure 2: Surface Temperature Change Relative to 1870-1899 Baseline. The top panel shows that regional maximum surface temperature increases projected by the end of the 21st century are roughly double the globally averaged value, with the largest increases seen at high latitudes. Surface temperature increases in the tropics are much less, due to the more significant amounts of atmospheric water vapor, a very effective greenhouse gas.[4] The lower panel shows instances of dramatic global cooling resulting from large volcanic eruptions. Such eruptions—for example, Krakatau in 1883—can be seen a number of times in this run as sharp, 5-year cooling events. As there is no method for predicting the occurrence of volcanic eruptions in the future, the smooth temperature curve from 2000 to 2100 reflects the fact that such events are not included in the climate models after 2000.[5] *Credit: G. Strand, NCAR (adapted from the* **Journal of Climate** *with permission from the American Meteorological Society).*

decisionmakers to use when planning for the future. The scientific assessment addresses all areas required in Section 106 of the Global Change Research Act of 1990, including impacts on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity.

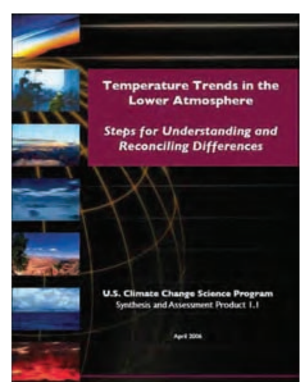
Examples of recent progress toward the five CCSP goals are briefly summarized below. Some of these examples were included in the Scientific Assessment.

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.

Over the past 30 years, a combination of ground and global satellite observations together with Earth system models conducted by the CCSP-participating agencies have resulted in remarkable progress in first documenting and subsequently understanding Earth system components of the global climate system and how these components interact. These multi-agency activities have resulted in basic information that has led to the formulation of numerical simulation models required to further understanding of Earth's climate system. Numerical climate simulation models using observed radiative forcing provide the means to anticipate future climate, manage future climate risks, and explore opportunities related to climate variability and change. Model simulations also identify shortcomings in the climate observations, thereby providing the feedback needed to improve the cycle of measurement and modeling.

In 2006, it was reported that the ocean cooled from 2003 to 2005.[6] This conclusion was inconsistent with a wide variety of numerical modeling results and direct measurements of surface and lower atmosphere warming. As a consequence of this reported cooling, some suggested that global warming was not occurring. This situation was resolved through a reanalysis of the ocean temperature data from the Argo float array: a serious error in these data was found to be due to a combination of measurement and analysis artifacts. The authors of the original study subsequently published a correction to their original work.[7]

Publication of the correction of the ocean temperature trend from 2003 to 2005 was subsequent to CCSP Synthesis and Assessment Product 1.1, *Temperature Trends in the Lower Atmosphere*, published in 2006.[8] This report corrected errors found in earlier analyses of atmospheric data from satellites and weather balloons. Corrections to the satellite data analyses and corrections to the weather balloon measurements showed globally averaged, mid-troposphere temperatures increased by 0.1 to 0.2°C per decade from the late 1970s to the present.[9,10] These corrections resulted in mid-troposphere temperature trends similar to measured surface air temperatures for the same time period. This synthesis and assessment product increased confidence in understanding of the causes of climate change.



CCSP agencies have been very active in observing the Arctic, an area where numerical climate models project the greatest increase in surface temperatures. Because of the direct consequences of warmer surface temperatures for sea ice, permafrost, and glacier recession in the Arctic and their feedbacks to climate, a wide range of studies have been and are being performed there. For example, a combination of laser altimetry, passive microwave, and synthetic aperture radar satellite data has documented the unprecedented late-summer decline of Arctic sea ice extent in 2007 to a record minimum 23% lower than the previous record minimum observed in September 2005.[11] This work is complemented by several other studies from the Arctic region. For example, gravity data from the Gravity Recovery and Climate Experiment (GRACE) satellite show that Greenland is losing ice mass at an increasing rate while documenting the month-to-month ice mass variations. In 2006, Greenland's ice mass suffered a net annual loss of approximately 110 km^3 yr^{-1} due to losses exceeding gains as stratified by altitude. At altitudes above 2000 m, Greenland's ice mass increased at a rate of 50 km^3 yr^{-1}, consistent with climate forcing producing a more active hydrological cycle (i.e., increased snowfall). For altitudes below 2000 m, the loss due to melting was found to be 160 km^3 yr^{-1}.[12]

The upcoming CCSP Synthesis and Assessment Product 1.2, *Past Climate Variability and Change in the Arctic and at High Latitudes*, provides an assessment of progress toward Goal 1, summarizing research on climate change in the Arctic. High latitudes are especially sensitive to global warming and provide early indications of climate change. Furthermore, new paleoclimate data from the Arctic will provide a long-term context for recent observed temperature increases there.

CCSP Synthesis and Assessment Product 1.3, *Reanalyses of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*, addresses understanding the magnitude of past climate variations. This is key to increasing present confidence in how and why climate has changed and why it may change in the future.

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

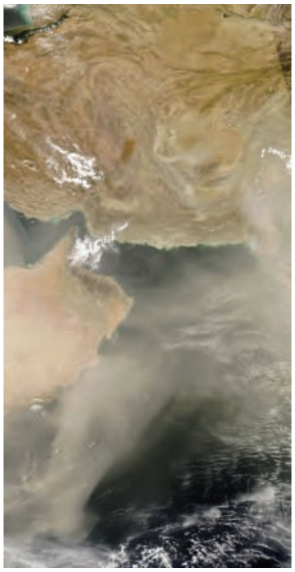
To understand the Earth's coupled ocean-atmosphere-land climate system, it is necessary to understand the abiotic and biotic processes that drive this system. These causes of climate change are called "forcing" factors and include greenhouse gases, land-cover change, volcanoes, air pollution and aerosols, and solar variability.

A 2007 report concluded that variations in the Sun are not responsible for recent global warming, either directly via increases in total solar irradiance or its ultraviolet spectral component, or through a decrease in the interaction between the solar wind and galactic cosmic rays.[13] This report is consistent with a significant body of literature on this topic, although it had been suggested that interaction between the variable solar wind and galactic cosmic rays influences climate forcing through variable cloud formation by some unknown mechanism.[14] Potential climate forcing by solar variability has been used to diminish human activities as a cause of global warming. While the authors of this report are European, they relied heavily upon NASA satellite data in their work.

CCSP agencies are making tremendous progress in understanding the role of aerosols in climate forcing. Aerosols are fine particles in the atmosphere that result from pollution, smoke, and dust. If they absorb light, they warm the atmosphere; if they reflect light, they cool it. The net forcing of aerosols is a key global warming uncertainty.

New Arctic research, much of it funded by CCSP agencies, has increased understanding of global climate change involving aerosols. A recent analysis of black carbon and non-sea salt sulfate aerosols from Greenland ice cores found a maximum black carbon net forcing of about 3 Wm^{-2} in the Arctic.[15] This maximum forcing occurred from 1906 to 1910 and was about eight times the pre-industrial forcing. Since the 1906 to 1910 period, the winter deposition of black carbon has gradually decreased while the summer deposition is highly variable, due to the variability of forest fires in North America. Non-sea salt sulfate aerosols, the product of fossil fuel combustion and a reflecting or "cooling" aerosol, increased strongly from the 1930s into the 1970s, after which they slowly declined until around 1992, and then plunged to pre-industrial levels by the early 2000s. Implementation of the Clean Air Act in the 1970s lowered U.S. sulfur emissions. Other countries followed with similar actions, explaining the dramatic reduction in non-sea salt sulfate aerosols since the 1970s.

CCSP work has shown how atmospheric composition, namely the gases and fine particles (aerosols) in the air, influence climate, the stratospheric ozone layer, and air quality. In the aerosol work, research has helped to better define the climate effects of

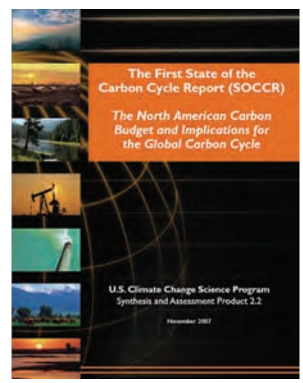


aerosols in large pollution plumes above regions of southern Asia (the "Asian brown cloud") using unmanned aerial vehicles, and in a variety of environments in the Arabian peninsula using a network of automated surface instruments.[16,17] Insights were also gathered regarding "Arctic haze," a widespread tropospheric haze or pollution cloud in the Arctic springtime. It was found that the Arctic haze resulted in an additional 2 to 3 Wm^{-2} of atmospheric warming during the haze maximum in mid-April.[18] The climate effects of this phenomenon will be further studied in 2008 using aircraft and ship platforms, as well as ground-stations. The connections between aerosols, clouds, and climate—one of the areas of largest uncertainty in current understanding of climate change—were the subject of CCSP research in field and modeling studies. Data from a field study showed that the chemical composition of the aerosol particles (specifically, the organic content) influences how effectively the aerosol activates the formation of cloud droplets.[19] Other research showed that the aerosol chemical composition affects the very structure of clouds, in a way that has dramatic implications for how the clouds reflect light and hence affect climate.[20] The knowledge gained through these CCSP studies will lead to advances in the ability to accurately represent aerosol-cloud-climate processes in models, ultimately contributing to the development of an improved predictive capability.

Researchers in CCSP have shown that atmospheric constituents other than carbon dioxide (CO_2), including water vapor and ozone, have implications for Earth's climate. Pollution was shown to interact with the nitrogen oxides formed during lightning strikes to cause increases in the summertime amounts of ozone (a greenhouse gas) in the upper troposphere above eastern North America during summer.[21] An 8-year record of surface measurements has shown how water vapor affects climate-related cloud properties.[22] The climate implications of cloud-water vapor-aerosol interactions were the focus of an intense field study in the tropical tropopause region near Costa Rica, a highly active region of the atmosphere that affects the transport of gases from the lower atmosphere to the stratosphere. Satellite observations of carbon monoxide (CO), a trace gas related to pollution, have elucidated the processes that transport pollution from source regions to areas where air quality is impacted.[23] Other work is looking at the effects of climate change on regional air quality in the United States.[24] CCSP researchers have developed an improved formulation for gauging the anticipated future effect of ozone-depleting substances (many of which are themselves greenhouse gases) on the recovery of the stratospheric ozone layer.[25]

Analysis of observations from aircraft, towers, and radar shows that land-use patterns have a strong influence on the horizontal distribution of heat exchange between the surface and atmosphere. Combined with land surface model runs, the data suggest that soil moisture influences the relative magnitude of the horizontal variation of this heat exchange.[26] This work provides additional support to the observation that a change in land cover from natural vegetation to managed uses not only affects the carbon cycle of the area in question, but also results in warmer surface temperatures.

CCSP research has investigated various carbon sequestration or carbon sink possibilities. On land, temperate and boreal forests in the Northern Hemisphere act as a substantial carbon sink, storing about 0.6 to 0.7 GtC per year. However, new results from the AmeriFlux research network show that forest disturbance from harvest and fire are responsible for much of the overall variability in forest carbon sequestration.[27] Forests are a carbon source to the atmosphere for as many as 20 years after these disturbance events, followed by a long period of carbon sequestration. After accounting for age and disturbance effects (e.g., wildfires, harvesting, infestations, etc.), low continuous levels of nitrogen deposition, largely the result of anthropogenic activities, appear to overwhelmingly account for additional carbon sequestration by these forests. This work is significant because it identifies the role of low-level nitrogen fertilization of Northern Hemisphere forests in the sequestration of carbon by terrestrial ecosystems.

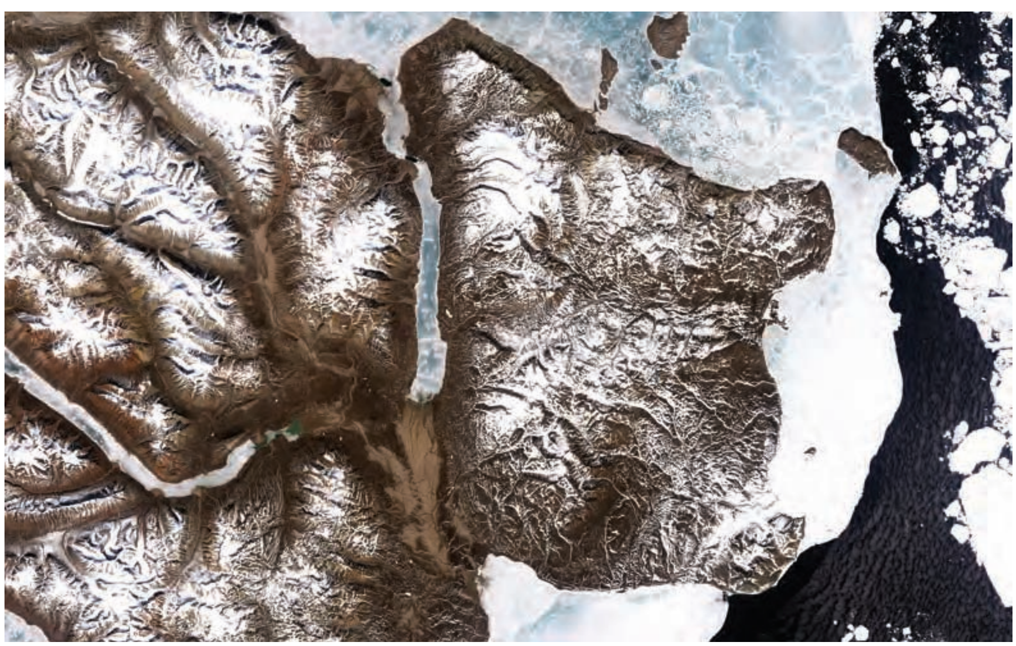


CCSP has produced two synthesis and assessment products and has two more in preparation that summarize progress towards meeting Goal 2 (see page 29 for the complete list of Goal 2 products). The most recently completed, *The North American Carbon Budget and Implications for the Global Carbon Cycle* (2.2), summarizes sources and sinks of carbon in North America.[28] Among the findings of this report is the expectation that the net release of carbon to the atmosphere will increase as North America's emissions continue to increase and its terrestrial carbon sinks, primarily in re-growing forests, decline. The report states that actions to address this imbalance in North America's carbon budget will likely require a mix of options that includes emissions reductions as well as sink enhancements. *Aerosol Properties and Their Impacts on Climate* (2.3) will address uncertainties about how different types of aerosols, both warming and cooling, may affect climate and thus how climate change might be affected by reductions in their emission rates. *Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure* (2.4) will provide an update on trends in stratospheric ozone, ozone-depleting gases, and ultraviolet radiation exposure; progress in improving model evaluations of the sensitivity of the ozone layer to changes in atmospheric composition and climate; and relevant implications for the United States.

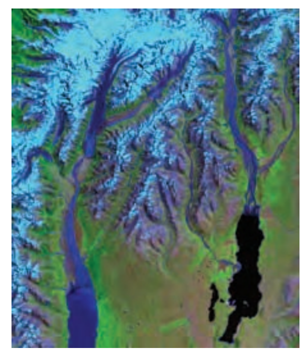
Goal 3. Reduce uncertainty in the projections of how the Earth's climate and related systems may change in the future.

CCSP research has led to significant improvements in the ability to produce estimates of future Earth climates on time scales of years to centuries, using numerical simulation models initialized with measured radiative forcing obtained from ground and satellite observations.

Key findings include making significant progress in understanding the response time of modern-day ice sheets to external temperature forcing. Previously, it was thought that the massive Greenland and Antarctic Ice Sheets took thousands of years to respond to increasing external temperatures. Recent work has measured major dynamical ice sheet changes likely related to warmer temperatures on a time scale of years.[29] This work stresses the importance of (1) improving large-scale models of ice sheet dynamics and their response to warmer temperatures, because current numerical models do not presently simulate the observed ice sheet dynamics; and (2) continuing the suite of satellite climate observations of ice sheets, such as laser altimetry, gravity field measurements, Landsat, Moderate Resolution Imaging Spectrometer (MODIS), passive microwave, and synthetic aperture radar. This ice sheet work has enormous implications for projecting sea-level rise with increasing surface temperature: Greenland contains a volume of ice that is the equivalent of about 7 m of global sea-level rise and Antarctica's ice sheet is the equivalent of about 57 m of global sea-level rise.



CCSP work has compared observations of Arctic sea ice with simulations of sea ice from more than a dozen models used in the IPCC Fourth Assessment Report. All models failed to produce the observed decreases in Arctic sea ice coverage, often substantially underestimating the decreases. This suggests that the Arctic could be seasonally free of sea ice earlier than IPCC projections.[11] A companion study considered factors that may contribute to declines in sea ice during the Arctic winter. The results show important regional differences in the processes leading to the changes, although the hemispheric-mean decline in winter ice extent appears primarily due to increasing sea surface temperatures in the Barents Sea and adjoining waters. These results emphasize the important roles of both atmospheric and oceanic processes in understanding and modeling the causes of rapid sea ice declines and demonstrate again that systematic climate observations are needed to understand the Earth's coupled land-atmosphere-ocean system.[30]



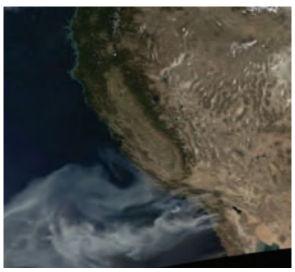
Important work on the relative contributions to sea-level rise from ice on land found that 60% of the sea-level rise was from ice loss from glaciers and ice caps and 40% was from the large ice sheets of Greenland and Antarctica.[31] All of these sources contribute less than the contribution to sea-level rise from the expansion of the oceans due to their warming.[1] If the loss of existing glacier ice from all sources occurs in proportion to projected increases in global temperature, sea level would rise about 0.5 to 1.4 m by 2100, which is greater than the estimate provided by IPCC (~0.2 to 0.6 m by 2100).[32] These studies stress the importance of climate change to sea-level rise through glacier recession and underscore many problems of human adaptation to sea-level rise.

CCSP Synthesis and Assessment Product 3.1, *Climate Models: An Assessment of Strengths and Limitations*, and Product 3.2, *Climate Projections Based on Emissions Scenarios for Long-Lived Radiatively Active Trace Gases and Future Climate Impacts of Short-Lived Radiatively Active Gases and Aerosols*, will constitute important steps toward reducing uncertainty in numerical model simulation of future climate conditions.

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

A key purpose of CCSP is to understand potential effects of changes in the Earth's climate system on natural ecosystems, managed ecosystems, and human systems through a coordinated program of ecological observations, experimental research, and numerical simulations made possible by advanced observations and experimentation being planned and implemented by CCSP. Not only does this goal address water, air quality, health, human infrastructure, and agriculture, it also addresses the effects of climate change on natural terrestrial and oceanic ecosystems. This integration is being compiled in a series of seven CCSP synthesis and assessment products.

Studies from the Arctic document significant temperature increases in the upper layers of permafrost (soil that is permanently frozen).[33,34] The circum-Arctic permafrost stability is now being studied, with special attention to the potential for large fluxes of CO_2 and methane following thawing of these areas. This is an area where CCSP has and continues to stress the importance of ongoing and sustained study.

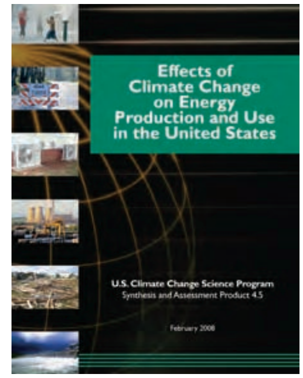


CCSP climate models projections for the 21st century for southwestern North America suggest much drier conditions, similar to the Dust Bowl of the 1930s.[35] This work indicates that storm tracks will shift northward, making the southwestern United States much drier and causing significant impacts on water resources, an increased frequency of forest fires, and potential economic destabilization. Snowmelt changes in mountains of the western United States have important implications on water availability in the southwestern regions.

CCSP-funded work has found that the ocean's ability to remove more CO_2 from the atmosphere will be impaired with warmer temperatures. The absorption of anthropogenic CO_2 and deposition of acid rain arising from fossil fuel and agricultural emissions can both contribute to the acidification of the ocean, reducing inorganic carbon storage. Additional impacts arise from atmospheric nitrogen deposition, leading to elevated primary production and biological drawdown of dissolved inorganic carbon that in some places reverses the sign of the surface acidity and air-sea CO_2 exchange. On a global scale, the alterations in surface water chemistry from anthropogenic deposition of reactive sulfur and nitrogen compounds are a few percent of the acidification, although the impacts are more substantial in coastal waters, where the ecosystem responses to ocean acidification could have the most severe implications for humanity.[36,37]

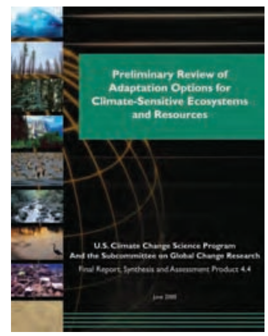
There has been substantial interagency cooperation over the past year in strengthening the capacity of the science community to incorporate an improved understanding of impacts and adaptation strategies in integrated assessments and in integrated modeling of the combined human and natural system behaviors, both in driving climate change and responding to climate change. During the past year, a major week-long session was held in Snowmass, Colorado, which brought together ecologists, Earth system modelers, economists, energy experts, health experts, social scientists, specialists in adaptation, and multiple agency representatives, all of whom had been important contributors to the recently published IPCC reports. The exchange of perspectives, review of IPCC results, and presentation of more recent research results have resulted in new collaborations being formed to investigate such issues as a more sophisticated integration of Earth system models; impact, adaptation, and vulnerability models; and integrated assessment models and an exploration of how the different research communities approach problems such as land-use and land-cover change, with the intent of developing more coordinated approaches.

Synthesis and Assessment Product 4.5, *Effects of Climate Change on Energy Production and Use in the United States*, was published in October 2007.[38] The report summarizes the current knowledge base concerning the possible effects of global change on energy production and use in the United States. The authors surveyed and assessed the available literature, paying attention to research findings on the implications of climate variability for energy production and use, and identified and considered relevant studies carried out in connection with CCSP, CCTP, and other programs of CCSP agencies. Significant attention was directed to consulting relevant stakeholders such as the electric utility and energy industries, environmental nongovernmental organizations, and the academic research community to determine what analyses had been conducted and what reports issued. Besides addressing questions of possible direct effects of climate change on energy consumption and production in the United States, the report also considered how climate change might affect various factors that indirectly shape energy production and consumption, such as energy technology choices, energy institutional structures, regional economic growth, energy prices, energy security, and greenhouse gas emissions.



The research evidence is relatively clear that climate warming will mean reductions in total U.S. heating requirements for buildings and increases in total cooling requirements. These changes will vary by region and by season, but they will affect household and business energy costs and their demands on energy supply institutions. In general, the changes imply increased demand for electricity, which supplies virtually all cooling energy services but only some heating services. Secondly, the effects of climate change on energy production are less strong than on energy consumption, but climate change could affect energy production and supply (a) if extreme weather events become more intense; (b) where regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies; (c) where temperature increases

decrease overall thermoelectric power generation efficiencies; and (d) where changed conditions affect facility site decisions. Most effects are likely to be modest except for possible regional effects of extreme weather events and water shortages. Thirdly, results for indirect effects ranged from abundant information about possible effects of climate change policies on energy technology choices to extremely limited information about such issues as effects on energy security. Based on this mixed evidence, it appears that climate change is likely to affect risk management in the investment behavior of some energy institutions, and it is very likely to have some effects on energy technology research and development investments and energy resource and technology choices. In addition, climate change can be expected to affect other countries in ways that in turn affect energy conditions in the United States through its participation in global and hemispheric energy markets, and climate change concerns could interact with some driving forces behind policies focused on U.S. energy security.



Four synthesis and assessment products address how changing climate affects natural and managed ecosystems (i.e., 4.1, 4.2, 4.4, and 4.6). See the table on page 29 for a complete list of the Goal 4 products.

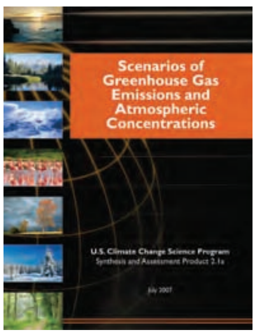
Goal 5. Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

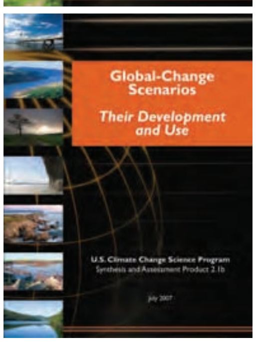
A critical responsibility for CCSP is to encourage the CCSP agencies to use scientific knowledge of climate and use of numerical simulation models to manage risks and identify opportunities related to climate variability and change.

One example of progress toward CCSP Goal 5 is a recent study of the water resource consequences of increasing tropical temperatures in the South American Andes, which will accelerate melting of tropical glaciers. This will affect the generation of hydroelectric power through diminished dry season river discharge, and directly affect the freshwater supply in many Andean communities.[39]

CCSP is generating three synthesis and assessment products under the Goal 5 rubric. Synthesis and Assessment Product 5.1, *Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions*, finds that there is a great need for producing regional climate information. Not only will this enable further evaluation of the reliability of current information, it is also crucial to developing new applications of climate data to aid in managing risks and opportunities. Synthesis and

Assessment Product 5.2, *Best-Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decisionmaking*, shows that improvements in how scientific uncertainty is evaluated and communicated are needed to reduce misunderstanding and misuse of this information. Synthesis and Assessment Product 5.3, *Decision Support Experiments and Evaluations Using Seasonal to Interannual Forecasts and Observational Data*, finds that climate variability is an important factor in resource planning and management at all levels of government, from the national level to the local level. Improved application of forecasts and data will benefit society in addressing climate change at all levels.





Other CCSP synthesis and assessment products are also of direct relevance to Goal 5. CCSP Synthesis and Assessment Product 2.1 consisted of two reports: *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations* (Part A) and *Global-Change Scenarios: Their Development and Use* (Part B).[40] Part A used several integrated assessment models as the foundation for a small group of new global emissions scenarios leading to long-term stabilization of greenhouse gas concentrations. One of the most important implications of the work reported in Part A was the primacy of technology in addressing climate change—not only in the near term, but also in the long term, where investments in basic science and technology can lay the foundations for deployment of dramatically improved technologies. Part B reviewed and evaluated how the science and stakeholder communities define, develop, implement, and communicate scenarios in the global climate change context, and how this process might be enhanced or improved. This included a review of past scenario development and application efforts. The report applies three integrated assessment climate models in a comparison of five different scenarios of greenhouse gas emissions under alternative assumptions regarding long-term global climate goals. The CCSP report is the first to use several alternative models to evaluate multiple stabilization scenarios in this way.

Pilot studies in the Gulf Coast region and the Chesapeake Bay were undertaken to test different approaches to assessing the flow and use of climate change science information in decisionmaking, the factors and institutions that affect its use, and the types and characteristics of decisions most sensitive to climate change and most in need of additional reevaluation and research in light of projected changes. Results from these studies are being used to determine the applicability of a decision assessment approach to the national level and to decisions related to water quality.

The Climate Impacts Group, a CCSP-supported Regional Integrated Sciences and Assessments (RISA) team, and King County, Washington's Climate Team created a guidebook on preparing for and adapting to climate change. *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* recommends a detailed, easy-to-understand process for climate change preparedness based on familiar resources and tools.[41] Local Governments for Sustainability contributed to the production and dissemination of the guidebook to make it accessible to local governments across the United States. The results of this guidebook will be used in future planning for sectoral work on urban issues.

CCSP FY 2009 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 2009 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, they are vital mechanisms through which CCSP will continue to integrate agency activities to create knowledge and products that are greater than the sum of the individual agency inputs. The development of CCSP interagency priorities is the result of a variety of planning processes, including planning processes within the 13 CCSP agencies (see Appendix A) and interagency planning conducted by the CCSP Interagency Committee (i.e., the Subcommittee on Global Change Research) and its subsidiary Interagency Working Groups. CCSP's interagency planning is informed by external advice from several NRC committees. CCSP's annual implementation priorities are logical evolutions of the program's interagency approaches to the priorities established in the CCSP Strategic Plan. The selection criteria for these activities require that they are founded upon a solid intellectual basis and are of high scientific quality; require coordination and/or integration across multiple CCSP agencies to create value-added products and services that cannot be created by any one agency alone; improve the characterization of key areas of scientific uncertainty and/or improve decision-support tools; provide a timely response to a particular need or leveraging opportunity; and are cost-effective.

The interagency implementation priorities generally represent only a fraction of CCSP's portfolio. The focus areas are listed here in an order similar to the research elements described in the CCSP Strategic Plan. However, due to their integrative nature they do not follow a one-to-one mapping to the research elements.