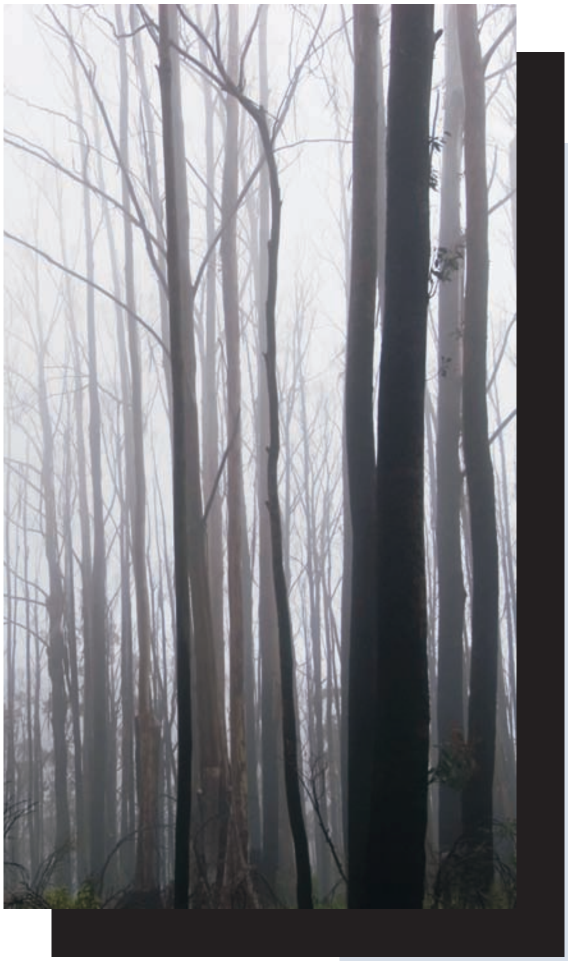


5 | Global Carbon Cycle

Strategic Research Questions

7.1 What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.2 What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.3 What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?

7.4 How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

7.5 What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?

7.6 How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

See Chapter 7 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The U.S. Carbon Cycle Science Program is clarifying the changes, magnitudes, and distributions of carbon sources and sinks; the fluxes between the major terrestrial, oceanic, and atmospheric carbon reservoirs; and the underlying mechanisms involved including human activities, fossil-fuel emissions, land use, and climate. Program scientists are now beginning to reveal and quantify some of the intricate complexities of and interactions between the Earth's carbon reservoirs and climate.

The Carbon Cycle Science Program engages many science disciplines and extends over a broad range of spatial and temporal scales. Many Federal agencies coordinate and support the activities included under the North American Carbon Program (NACP) and the Ocean Carbon and Climate Change (OCCC) program. In FY 2008, the integration of the terrestrial, oceanic, and atmospheric investigations will be critical and will continue as a priority of the U.S. Carbon Cycle Science Program. Assimilation of carbon data into models is developing at scales from regional to global as an important means of incorporating observations into carbon cycle analyses. The goal is to develop increasingly realistic, fully coupled carbon cycle-climate models to provide insight into potential feedbacks between and drivers of these major Earth systems.

THE NORTH AMERICAN CARBON PROGRAM

The North American Carbon Program (NACP) is designed to address Strategic Research Question 7.1 in Chapter 7 of the *CCSP Strategic Plan*. It will quantify the magnitudes and distributions of terrestrial, freshwater, oceanic, and atmospheric carbon sources and sinks for North America and adjacent oceans; enhance understanding of the processes controlling source and sink dynamics; and produce consistent analyses of North America's carbon budget that explain regional and continental contributions and year-to-year variability. This program is committed to reducing uncertainties related to the increase of carbon dioxide and methane in the atmosphere and the amount of carbon—including the fraction of fossil-fuel carbon—being taken up by North America's ecosystems and adjacent oceans.

A major accomplishment for this research element involves publication of *The First State of the Carbon Cycle Report on the North American Carbon Budget and Implications for the Global Carbon Cycle* (CCSP Synthesis and Assessment Product 2.2). It synthesizes current knowledge and uncertainties about carbon in North America relevant to the United States and the rest of the world, and provides baseline information to support decisionmaking on key issues related to U.S. carbon management and policy. In FY 2008, the NACP will address key gaps and uncertainties identified in the synthesis. Other planned activities will focus on integrating carbon cycle research,

THE OCEAN CARBON AND CLIMATE CHANGE PROGRAM

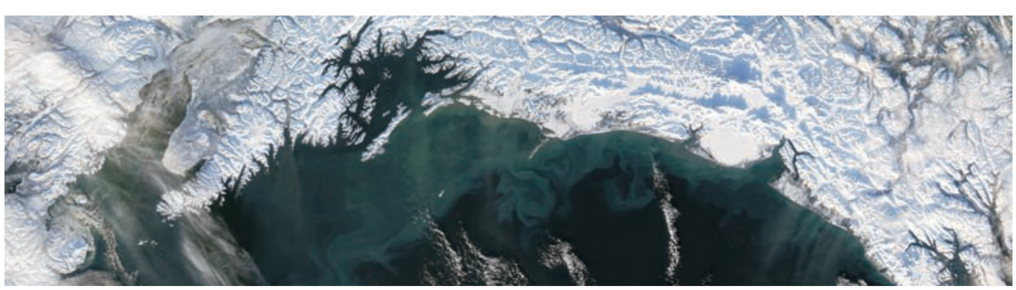
The Ocean Carbon and Climate Change (OCCC) program is designed to address Strategic Research Question 7.2 in Chapter 7 of the *CCSP Strategic Plan*. It will focus on oceanic monitoring and research aimed at determining how much atmospheric carbon dioxide is being taken up by the ocean at the present time and how climate change will affect the future behavior of the oceanic carbon sink. The terrestrial and ocean carbon programs are synergistic, integrating program activities in addressing carbon dynamics on the coastal shelves adjacent to North America, where carbon changes in the terrestrial system greatly influence carbon processes in the coastal ocean.

increasing observational and network capabilities, measuring carbon fluxes and stocks, conducting manipulative experiments, modeling the carbon cycle for predictive analyses, and coupling carbon models with other Earth component models for Earth system analyses. Successful completion will provide, and be measured by, integrated and accessible observational databases, quantified carbon budgets, more precise estimates of changes occurring or likely to occur, and more accurate carbon sink and source estimates.

U.S. CARBON CYCLE SCIENCE PROGRAM

The U.S. Carbon Cycle Science Program contributes to all CCSP goals, focusing particularly on Goal 2: *Improved quantification of the forces bringing about changes in the Earth's climate and related systems*. It addresses directly the six carbon cycle questions of Chapter 7 of the *CCSP Strategic Plan*. The research element is synergistic with the Ecosystems, Global Water Cycle, Climate Variability and Change, Atmospheric Composition, Land-Use/Land-Cover Change, and Human Contributions and Responses research elements. The agencies responsible for carbon cycle research are DOE, NASA, NOAA, NSF, USDA, and USGS. Together, they have planned and are coordinating a multidisciplinary research strategy to integrate the broad range of needed infrastructure and resources, scientific expertise, and stakeholder input essential for program success and improved decision processes.

Looking beyond FY 2008, the research element will extend its observation and network systems to high latitudes and other undersampled regions of the world. The anticipated emphasis on high-latitude research will provide critical scientific information on the carbon dynamics of the undersampled regions of North America and adjacent oceans, Antarctica, and the Southern Ocean as high-latitude warming changes system dynamics. Collaborations with Canada and Mexico under the Joint NACP (Canada, Mexico, and the United States) cooperative will be well underway. Efforts are also underway to initiate stronger international collaborations with the European Union and its research program under the CarboEurope and CarboOcean Programs. Other international initiatives and collaborations are also expected to address regional to global issues, interactions between carbon cycle dynamics and global climate change, linkages between and feedbacks within Earth systems, and the uncertainties associated with continental and oceanic carbon sources and sinks.



Highlights of Recent Research

The research highlights that follow are derived from carbon cycle science programs spanning terrestrial, oceanic, and atmospheric reservoirs and the complex interactions that link these reservoirs within the global carbon cycle.

Climate Forcing

Atmospheric carbon dioxide (CO_2) and methane (CH_4) are significant forcing agents of Earth's climate and have been increasing over the past 2 centuries as a result of human activities. Approximately 85 to 90% of today's anthropogenic emissions are attributed to fossil-fuel combustion with land-use change accounting for most of the rest. Future concentrations of carbon dioxide and methane in the atmosphere will depend on the long-term trends and variability in natural and anthropogenic emissions and the capacity of natural and managed sinks in the carbon cycle.

Distinguishing Fossil Fuel Emissions from Biological CO_2 Cycling.[1] Measurements of atmospheric $^{14}CO_2$, carbon monoxide (CO), and sulfur hexafluoride (SF_6) as tracers of fossil-fuel CO_2 emissions show that $^{14}CO_2$ provides accurate quantification of fossil-fuel CO_2. Issues remain concerning the distributions of SF_6 and CO emissions relative to CO_2 that may bias regional estimates. This research focused mainly on winter and spring data from two different regions, Colorado and New England, to test the approach under widely different conditions. The effort as a whole, however, extends to much of the atmospheric research network and is anticipated to be enhanced to produce viable regional estimates of fossil-fuel contributions to atmospheric CO_2 and CH_4 concentrations, thus allowing more accurate estimates of biological contributions to the atmospheric carbon budget.

Forest Fire Impacts on Climate Change.[2] Contemporary wisdom supports the concept that increases in temperature would lengthen the growing season in boreal ecosystems and increase the probability of fire, leading to a positive feedback between warming, fires, carbon loss, and future climate change. However, a new multi-factor analysis of the long-term effects of a well-characterized boreal forest fire indicates that the net radiative forcing may be negative. During the first year after the fire, all factors combined to increase radiative forcing (34 ± 31 Wm^{-2} of burned area), but when averaged over an 80-year fire cycle the net effect was to decrease radiative forcing (-2.3 ± 2.2 Wm^{-2}). The reason is that multidecadal increases in surface reflectance had a larger impact than the fire-emitted greenhouse gases. This study illustrates the importance of interdisciplinary, multi-factor analysis and the need to examine effects over decades to centuries in order to fully understand the impacts of disturbance and the feedbacks between Earth's physical and biogeochemical systems.

Changes in Forest and Soil Carbon.[3,4] A 13-year study of carbon flux measurements at the Harvard Forest clearly shows that the uptake of atmospheric CO_2 has been increasing in this ecosystem; mean carbon gain for the 1992 to 2004 period was 2.4 metric tons of carbon ha^{-1} yr^{-1}, and carbon uptake has been increasing at the rate of 0.15 metric ton of carbon ha^{-1} yr^{-1}. This magnitude of forest carbon gain is typical of other findings from the AmeriFlux observation network. In the top 20-cm soil layer in preserved old-growth forests in southern China, a study shows that soils accumulated atmospheric carbon at an unexpectedly high rate from 1979 to 2003. These long-term observations show that the rate of photosynthetic carbon assimilation can exceed ecosystem carbon loss by respiration. Such studies demonstrate the significant potential for terrestrial sources and sinks to affect atmospheric CO_2 increases.

Terrestrial Carbon Cycle

The terrestrial carbon cycle is composed of a complex set of interactive biological, chemical, and physical processes that transfer carbon between land, oceans, and the atmosphere. Collectively, these processes influence atmospheric CO_2 and CH_4 concentrations. Improving the scientific understanding of the role of these reservoirs and links in the carbon cycle reduces the uncertainty about the factors influencing greenhouse gas increases and provides a stronger basis for climate change decision support, in particular for carbon management to mitigate CO_2 and CH_4 increases.

Carbon Storage in Forested Ecosystems.[5,6,7] Forested ecosystems in the United States have a major impact on regional and global sources of CO_2—taking up 25 to 50% of CO_2 emitted annually from fossil-fuel combustion in the United States, a significant amount since the United States accounts for about 20% of global emissions. The CO_2 Boundary-Layer and Regional Airborne (COBRA) study developed model-data fusion methods to determine accurate regional- and continental-scale carbon budgets and to attribute carbon fluxes to

specific causes and processes. Model predictions for the 1990s, with and without contributions from CO_2 fertilization, are within the range of uncertainties; but, in the absence of CO_2 fertilization, the carbon sink in forests will approach zero by 2050, as the effects of forest harvesting offset those of agricultural land abandonment. Long-term measurements, such as those undertaken by AmeriFlux and tall-tower networks, are critical for detecting the signatures of processes that give rise to long-term uptake of atmospheric CO_2 by major ecosystems of North America.

Seasonality of Amazonian Forests.[8] Measurements of vegetation "greenness" from the Moderate Resolution Imaging Spectrometer (MODIS) on the Terra and Aqua satellites revealed an increase in greenness across Amazonian forests during the dry season, a pattern opposite to what had been previously thought and portrayed in models (see Figure 8). Researchers explained that the deep-rooted forests are able to access deep soil water and take advantage of the increased sunlight in the dry season. In contrast, areas converted to pastures, with more shallowly rooted plants, show the expected decline in greenness during the dry season. With this knowledge, scientists can refine models used to represent the tropical biosphere and how it exchanges carbon with the atmosphere, thus improving long-term carbon cycle and climate models.

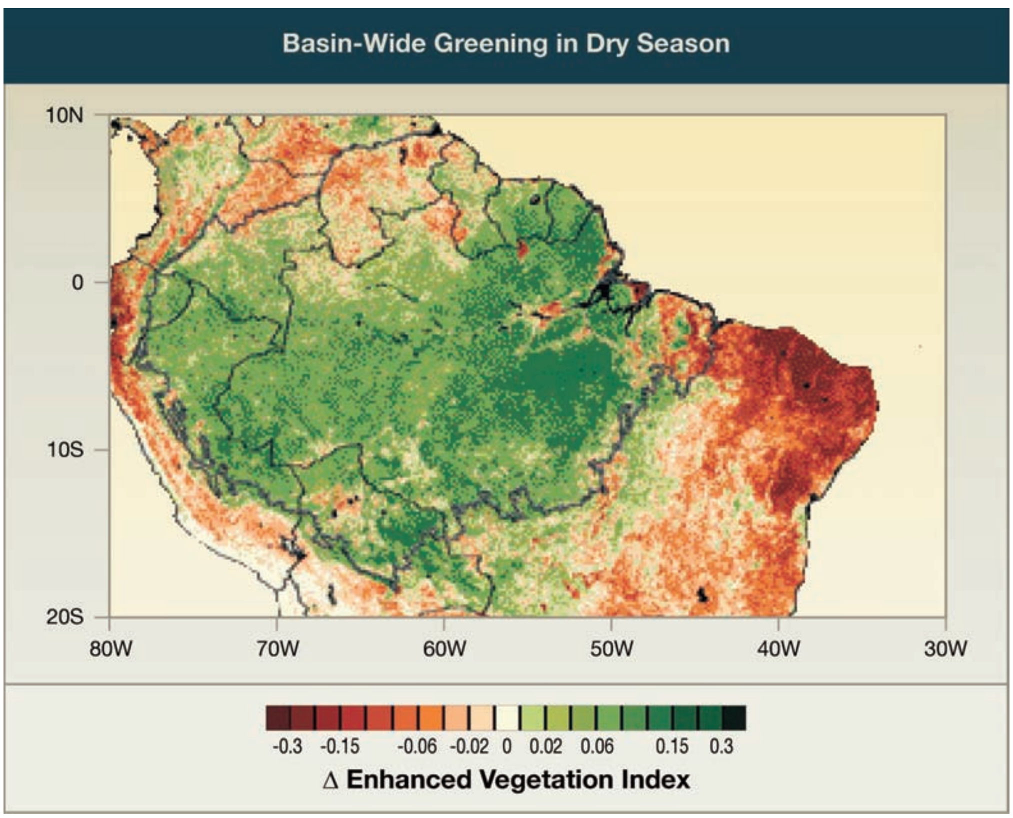
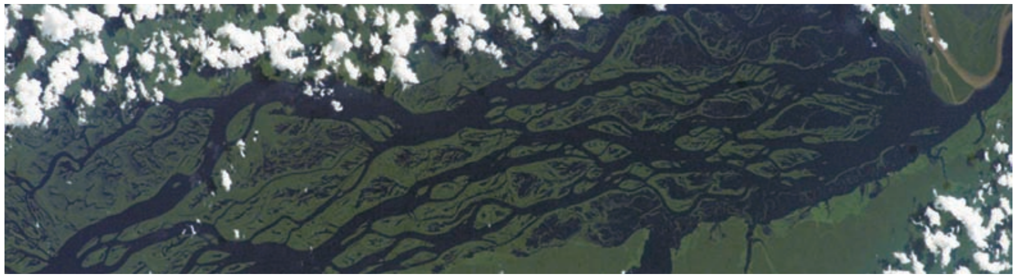
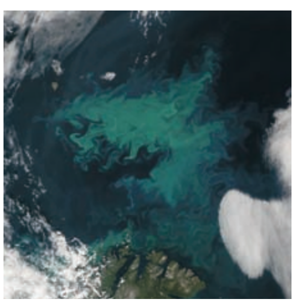


Figure 8: Basin-Wide Greening in Dry Season. Amazon rainforest basin-wide image of average (2000-2005) Enhanced Vegetation Index (EVI) change between the wet (October) and dry (June) seasons. Green colors depict "greening" and red colors depict "browning" in the dry season. *Credit: A.R. Huete, K. Didan, P. Ratana, and S.R. Seleska, University of Arizona; Y.E. Shimabukuro, Instituto Nacional de Pesquisas Espaciais, Brazil; L.R. Hutyra, Harvard University; W. Yang and R. Myneni, Boston University; and R.R. Nemani, NASA / Ames Research Center (reproduced from* **Geophysical Research Letters** *with permission from the American Geophysical Union).*



Carbon Storage in Forest Soils.[9] A novel approach was developed to monitor carbon sequestration in aggregates of small particles that has profound implications for carbon protection in soil. The approach is based on ultra-small angle X-ray scattering of synchrotron X-rays that indicates the tendency of soil containing organic carbon to become more stable as a greater proportion of the soil micropores become filled. This mechanism suggests that the potential for organic matter storage in soil is larger than generally thought because it is neither limited by the surface area of minerals nor dependent on strong sorption by these surfaces. Another critical implication is that agricultural management and land use, particularly as they affect the stability of a microporous soil structure, can significantly alter the extent of carbon sequestration via both positive and negative feedbacks.



Oceanic Carbon Cycle

The global ocean carbon sink is an important component of the climate system that regulates the uptake, storage, and release of CO_2 and other climate-relevant chemical species to the atmosphere. The future behavior of this carbon sink is quite uncertain because of the potential impacts of climate change on many ocean processes.

Ocean Carbon Dynamics.[10] The air-sea exchange and storage of CO_2 in the tropical and extra-tropical North Pacific Ocean play a key role in the global carbon cycle. Upwelling in the equatorial Pacific brings high carbon content water to the surface, generating the ocean's largest natural source of CO_2 to the atmosphere. The tropical Pacific outgassing is well known to respond very sensitively to climatic fluctuations, particularly the El Niño Southern Oscillation (ENSO), with outgassing nearly vanishing during a fully developed El Niño. Modeling studies have suggested that fluctuations in the tropical Pacific dominate the global air-sea CO_2 flux variability on interannual time scales. The most important results on surface ocean CO_2 partial pressure (pCO_2) and air-sea CO_2 flux variability in the North Pacific to date are summarized in Figure 9. The small plots in each of the regions illustrate the observed trends in surface ocean pCO_2 over the last 2 decades. Most regions show a steady increase at rates roughly the

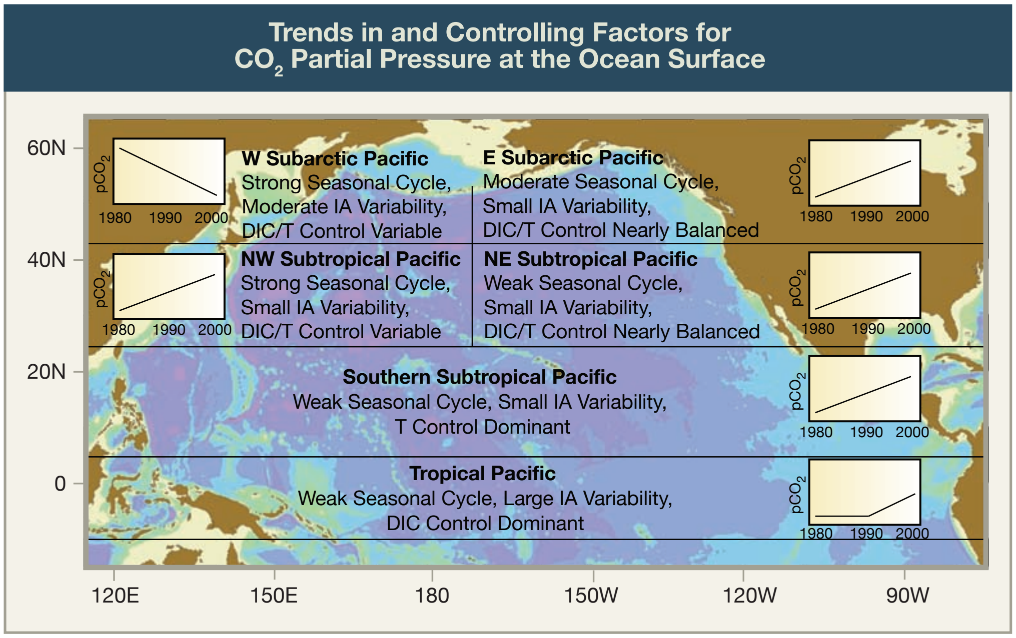


Figure 9: Trends in and Controlling Factors for CO_2 Partial Pressure at the Ocean Surface. This illustration provides a summary of trends in CO_2 partial pressure (pCO_2) at the ocean surface and controls in the North Pacific. Increasing trends in the subplots indicate that ocean CO_2 is increasing with the atmospheric concentration as expected. Flat or decreasing trends indicate that other processes are working to counteract the natural CO_2 increase. The text in the figure identifies the observed variability and primary controls on the observed trends. IA, DIC, and T stand for interannual variability, dissolved inorganic carbon, and temperature, respectively. *Credit: C. Sabine, NOAA / Pacific Marine Environmental Laboratory and N. Gruber, University of California - Los Angeles (reproduced from the* **Journal of Geophysical Research** *with permission from the American Geophysical Union).*

same as that of atmospheric pCO_2 over the same time period. The two notable exceptions are the far western subarctic region where surface water pCO_2 has decreased with time, and the equatorial Pacific which shows a rate of pCO_2 increase akin to that of atmospheric CO_2 only after 1990, while oceanic pCO_2 remained nearly constant before. The reasons behind these different trends are still under investigation, but they highlight the need for continuing observations of the oceanic carbon system.

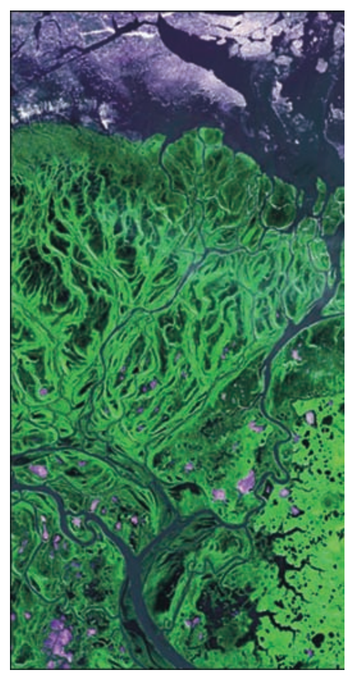
Coastal Carbon Storage.[11,12] Recent research on carbon storage in intertidal and subtidal estuarine ecosystems in the northeastern United States shows that these systems store more organic carbon to a depth of 1 m than forest soils in the adjacent uplands. The reason for this observation is that subtidal and intertidal soils are generally located on stable landforms and are accumulating organic carbon annually as sea level rises. Contrary to the common assumption that the carbon being stored in these ecosystems is from terrestrial vegetation, the majority of the organic carbon found was fixed by benthic algae. These results indicate the importance of including subtidal and intertidal estuarine ecosystems in global carbon models.

High-Latitude Systems

High-latitude systems are becoming increasingly important sources of CO_2 and CH_4 in the atmosphere as regional warming changes carbon dynamics in the cold regions. Understanding carbon dynamics in high-latitude systems and the factors that may lead to changes in those dynamics are crucial elements of global carbon modeling and essential for understanding the linkages and feedbacks between carbon, ecosystems and land cover, hydrology, and climate variability and change.

Arctic Ocean Sensitivity to Climate Change.[13] The Arctic Ocean and adjacent continental shelf seas are particularly sensitive to long-term changes and low-frequency modes of atmosphere-ocean-sea ice forcing arising from climate change. The cold, low-salinity surface waters of the Canadian Basin of the Arctic Ocean are undersaturated with respect to CO_2 in the atmosphere and thus the region has the potential to take up atmospheric CO_2, although presently covered over by sea ice. Undersaturated CO_2 conditions in the Arctic Ocean are maintained by export of water with low dissolved inorganic carbon content and modified by intense seasonal shelf primary production. Sea ice extent and volume in the Arctic Ocean have decreased over the last few decades, and researchers have estimated that the Arctic Ocean sink for CO_2 has nearly tripled over the last three decades (24 to 66 million metric tons of carbon per year) due to sea ice retreat with future sea ice melting projected to enhance air-to-sea CO_2 flux by about 28% per decade.

Carbon Export from Permafrost Ecosystems.[14,15] The Yukon River discharges almost 7.8 million metric tons of carbon to the Bering Sea annually, of which about 30% is organic. With permafrost thawing throughout the Yukon basin, scientists are concerned about a potentially large release of bio-available dissolved and particulate organic carbon to the Arctic Ocean. Radiocarbon analysis of the discharged carbon indicates that most of the dissolved organic carbon is modern, but that particulate carbon has a large component that is thousands of years old. This is consistent with most particulate organic carbon originating from erosion of riverbanks and most dissolved organic carbon originating from surface runoff—not from thawed permafrost. Earlier work suggests that this pattern may continue if newly thawed dissolved organic carbon is respired rather than exported downstream.



Methane Release from Thawed Permafrost Lowlands.[16] Global warming is causing permafrost to thaw in areas of Alaska, Canada, and Siberia. When permafrost thaws, localized areas in a landscape may collapse and flood, forming wetlands where there were once forests. According to recent research, these wetlands release large amounts of CH_4 to the atmosphere compared to the surrounding forests. Wetlands in interior Alaska formed from permafrost thaw released up to 35 times more CH_4 per unit area than the surrounding forest soils over 1 year. If widespread wetland formation occurs across areas of thawing permafrost, the increase in CH_4 release could have significant impacts on global climate change because it is a strong greenhouse gas.

Fire Disturbance and Permafrost Degradation in Boreal Regions.[17,18] Fire regimes and permafrost degradation, which are closely linked through organic soil (ground fuel) in boreal regions, have the potential to shift in response to changes in climate. Over the past few decades, fire disturbance maintained the heterogeneous patterns of both permafrost and vegetation in boreal forests, mainly through the regulation of soil temperature by organic soil thickness. More severe burns such as occurred in 2004 and 2005, however, may promote a vastly different landscape depending in part on how much post-fire organic soil is retained. In all boreal landscapes, whether burned or not, ecosystem response to climate as well as associated carbon and energy exchanges depend largely on whether thaw-water is pooled on or drained from the landscape. Over the next several years, investigations will focus on detecting and studying the fate of both surface water and ecosystem carbon under various thaw regimes in the Alaskan interior.

Carbon Management and Decision Support

Carbon cycle research provides scientific input to policy and resource management decisions for carbon management and mitigation of climate change. The results of research supported by the carbon cycle research element of the CCSP are informing carbon management, as described in the research highlights below, and their impact is expected to increase over the course of this program.

The First State of the Carbon Cycle Report: CCSP Synthesis and Assessment Product 2.2.[19] This report finds that in 2003, North American terrestrial carbon sinks removed approximately 520 million metric tons of carbon per year (±50% with 95% confidence) from the atmosphere, which is equivalent to approximately 30% of North American fossil-fuel emissions in 2003. Approximately 50% of the sink is due to the regrowth of forests in the United States on former agricultural land and on forested land recovering from harvest. This sink is expected to decline. As forests mature they grow more slowly and take up less carbon from the atmosphere. The current source to sink imbalance of more than 3 to 1 (ratio of fossil-fuel emissions to net terrestrial carbon uptake) and the potential trend of increasing sources and decreasing sinks suggest that addressing imbalances in the North American carbon budget will likely require actions focused on reducing fossil-fuel emissions. Options focused on enhancing carbon sinks in soils and vegetation can contribute as well, but their potential is far from sufficient to offset current fossil-fuel emissions.

Carbon Sequestration in Low-Production Lands.[20] Sequestering carbon through afforestation on low-production cropland and rangeland may be a means of reducing net carbon emissions from the United States and a process worth monitoring for carbon management. Information on the potential for such sequestration was derived through application of an ecosystem carbon model using a "greenness" product obtained from the Advanced Very High-Resolution Radiometer (AVHRR)—a space-borne instrument. The model results, at 8-km resolution, show the spatial variability in monthly net primary production (NPP) and accumulation rates of biomass (i.e., carbon storage) in low-production cropland and rangelands (see Figure 10). The model predictions indicate potential carbon sequestration rates of 300 million metric tons per year—the equivalent of 20% of the current U.S. carbon emissions from fossil-fuel combustion.

Forest Management.[21] Healthy, productive forests constitute an important terrestrial buffer against rising atmospheric CO_2, a major driver of climate change. A team of American and Brazilian scientists, using extensive high-resolution multi-satellite analyses, concluded that forest harvests in the Brazilian Amazon are dominated by practices that leave forests more susceptible to drought and fire and threaten their long-term health and productivity. At the same time, they found that recently logged forests have a high probability of being cleared for farming and settlements, further reducing the potential of this land for carbon storage. Recently, the Brazilian Government enacted legislation to regulate forest lands and the timber industry, and this new policy has the potential to maintain forests under long-term timber management.

Landowners' Greenhouse Gas Reporting Tools.[22,23,24] A new set of tools have been developed for the agricultural and forestry sectors to enable farmers and landowners to estimate carbon sequestration and greenhouse gas emissions. These sectors can reduce atmospheric concentrations of greenhouse gases by increasing carbon sequestration in biomass and soils, by reducing fossil-fuel emissions through use of climate-neutral fuels, and by substituting agricultural and forestry products that

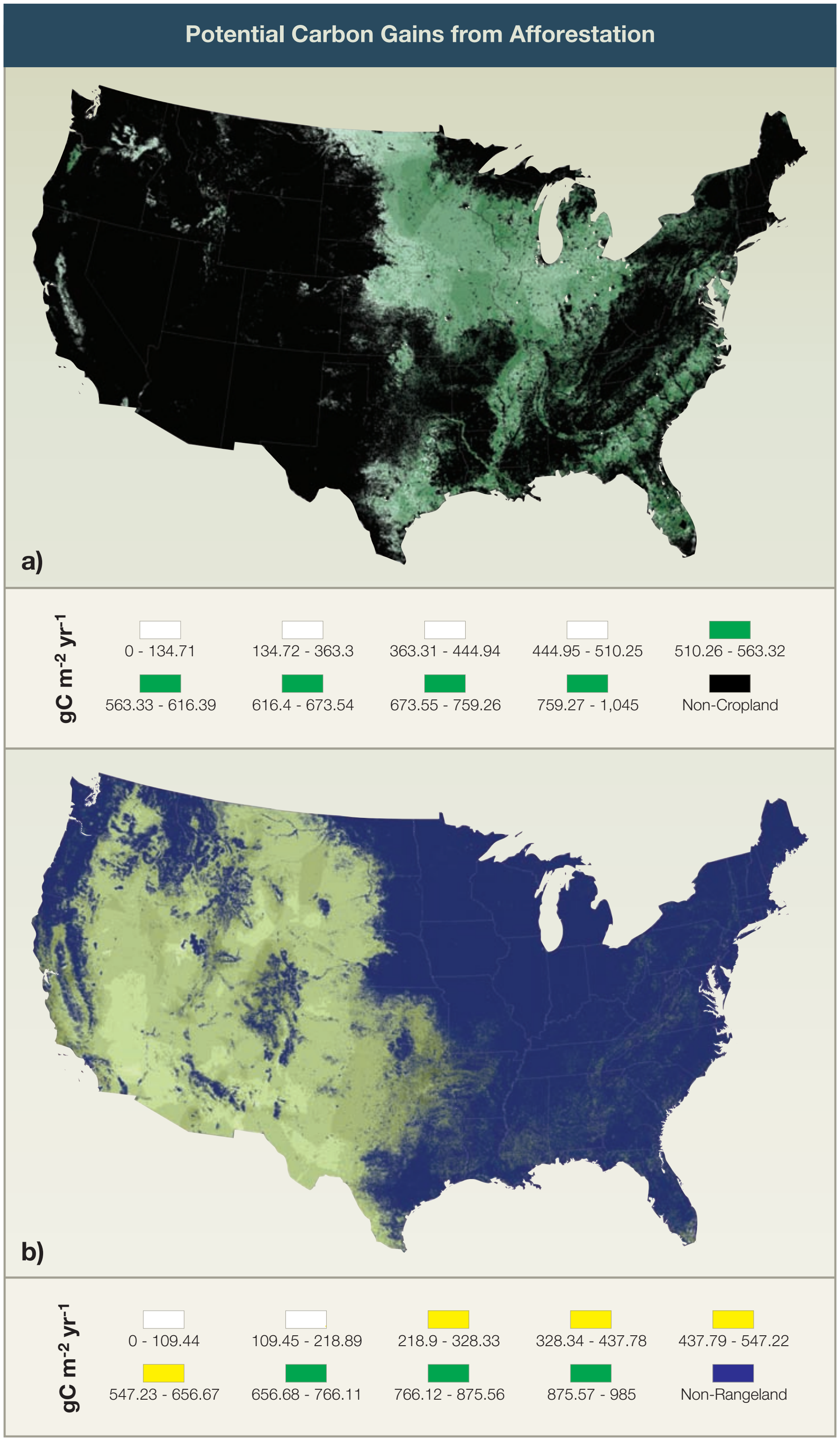


Figure 10: Potential Carbon Gains from Afforestation. Potential afforestation carbon gains in (a) relatively low-production crop areas, and (b) relatively low-production rangelands. Both panels are mapped to show predicted gross carbon sink flux per year at 1-km resolution. Corrections for probable net primary productivity loss over time due to decomposition, disturbance, and aging in predicted forest stands are not included. *Credit: C. Potter and M. Fladeland, NASA / Ames Research Center; S. Klooster and V. Genovese, California State University – Monterey Bay; and S. Hiatt, San Jose State University and Education Associates (reproduced from* ***Climatic Change*** *with permission from Springer Netherlands).*

require less energy than other materials to produce. The tools have been adopted by DOE for use in the National Voluntary Greenhouse Gas Reporting Registry. The tools could also be adopted for use in state or regional registries and for use by voluntary greenhouse gas markets, opening new opportunities to reward landowners for reducing atmospheric greenhouse gases, enabling industry to meet global environmental goals at lower costs, and strengthening rural economies while protecting the environment.

Societally Useful Measure of Greenhouse Gas Forcing.[25] The challenge of effectively informing society led scientists to develop a simple way to express greenhouse gas forcing for decisionmakers and the public. The perturbation to radiative climate forcing that has the largest magnitude and smallest scientific uncertainty is the forcing related to changes in long-lived and well-mixed greenhouse gases—in particular CO_2, CH_4, nitrous oxide (N_2O) and halocarbons. The change in annual total radiative forcing by these gases since the pre-industrial era (1750) is used to define the Annual Greenhouse Gas Index (AGGI), which is normalized to radiative forcing in 1990. The AGGI shows that between 1990 and 2006 there was a 23% increase in radiative forcing due to long-lived greenhouse gases. This index is designed to help bridge the technical gap between scientists and decisionmakers and is now used and disseminated by the World Meteorological Organization.

Highlights of Plans for FY 2008

Continuing integration within the NACP and the OCCC program will provide better estimates of the North American carbon budget including the roles of adjacent ocean basins. More comprehensive global and regional models and analyses, driven by improved *in situ* measurements and experiments, reservoir inventories, and remote sensing will provide better forecasts and understanding of critical carbon cycle dynamics.

Advanced Carbon Models. Research will continue to develop carbon cycle and coupled carbon-climate models that are more comprehensive in their treatment of significant carbon dynamics and drivers, including those involving or stemming from human activities. These advanced models will incorporate multiple, interacting factors, address time scales of decades to centuries, and integrate across spatial scales. Carbon data assimilation at both regional and continental scales will continue to integrate multiple data streams including fluxes by eddy-covariance methods, atmospheric CO_2 and CH_4 concentrations using tower-based instruments, and aircraft and satellite remote-sensing observations. An important aspect of these integrated investigations is the potential to reveal expected drivers within the carbon cycle and climate system,

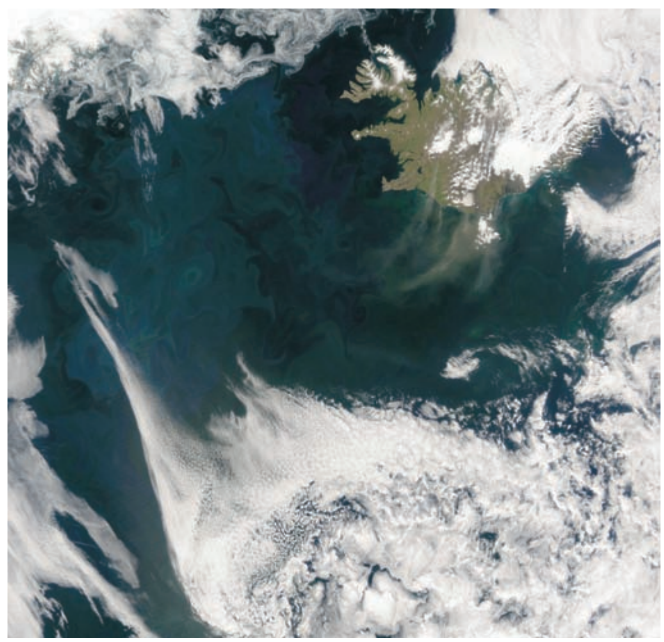
and especially in those systems where sensitivities of carbon processes and stocks to climate change are high (e.g., Arctic and boreal systems). Modeling research focusing on the Southern Ocean and Antarctica will capitalize on existing and impending remote and *in situ* observations and will include synthesized data sets, existing models, and data assimilation techniques to advance the ability to quantify southern high-latitude sensitivities and variability. Significant advances are expected in regional and global carbon cycle modeling.

These activities will address Goals 2, 3, and 5 and Questions 7.1, 7.2, 7.4, and 7.5 of the CCSP Strategic Plan.

Atmospheric Monitoring. Measurements of radiative trace species (including CO_2 and CH_4), started six years ago at Summit, Greenland, will continue, and measurements will be expanded to include tracers of carbon sources (e.g., hydrofluorocarbons) with new instrumentation. Weekly carbon cycle flask measurements will continue across Arctic areas in Canada, Norway, Iceland, Finland, the North Atlantic, and Alaska. A collaborative effort of U.S. agencies in the Yukon will install instrumentation for continuous, vertical sampling within a 300-m boundary layer. Aircraft sampling for carbon cycle gases will be expanded to sites in Saskatchewan, Canada and Poker Flats, Alaska. If funding permits, aircraft sampling will be added over Churchill on Hudson Bay, Manitoba, and several other sites. International cooperation continues with Russia at the Baseline Observatory on the central Siberian Arctic Ocean coast where carbon gas measurements will be conducted, particularly the measurements of CH_4 that could be released from wetlands as the northern high latitudes continue to warm. In the Antarctic, flask gas sampling will continue at the South Pole Station, and at Halley, Syowa, and Palmer on the Antarctic coast. Carbon flask sampling will continue across the Drake Passage and around Antarctica on the support ship from Ushuaia to Palmer and the annual Chinese cruise, respectively.

These activities will address Goals 2, 3, and 4 and Questions 7.1, 7.2, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

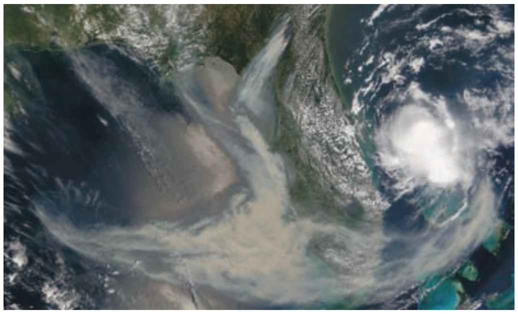
Global Ocean Carbon. Ongoing and new studies will continue to address understanding of the ocean carbon cycle and its effects on ocean carbon dynamics. Of particular interest are the feedbacks and drivers of ocean chemistry and biology, the biotic and abiotic partitioning of carbon, and constraints on ocean carbon sequestration. An interagency field study of air-sea CO_2 flux and remotely sensed data in the high-latitude Southern Ocean during the 2007-2008 austral summer will focus on understanding both (a) the kinetics of gas exchange and the factors controlling it, and (b) the physical and biogeochemical factors controlling the exchange of CO_2 across the air-sea interface, in the context of developing parameterizations for those factors that can ultimately be remotely sensed to determine regional and global air-sea CO_2 fluxes. The Southern Ocean Gas Exchange Experiment (SO GasEx) will be conducted in the Atlantic sector of the Southern Ocean. Shipboard studies will include physical, chemical, biological, and meteorological measurements.



These activities will address Goals 2 and 3 and Questions 7.2, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

Satellite Remote Sensing. A new satellite will be launched with the Orbiting Carbon Observatory (OCO) to provide, for the first time, consistent atmospheric carbon observations globally from space. Measurements made from the observatory will permit carbon data assimilation systems to derive estimates of carbon sources and sinks with far higher spatial and temporal resolutions.

This activity will address Goals 2 and 3 and Questions 7.1, 7.2, 7.4, and 7.5 of the CCSP Strategic Plan.



Carbon Management and Decision Support. New projects are underway that will allow government agencies, industry associations, and private landowners to include carbon management information derived from data, ecosystem models, and on-line tools (products of carbon cycle science research) into near- and long-term resource management decisions and policies. These projects are having a particular impact on forest management and agricultural practices. Projects will continue beyond the fiscal year to evaluate the utility of new observations of carbon in the atmosphere (e.g., from OCO to monitor and manage carbon sources and sinks) and to identify key carbon management questions that will benefit from a high-latitude priority planned for FY 2009.

These activities will address Goals 2 and 4 and Questions 7.3, 7.4, and 7.6 of the CCSP Strategic Plan.

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