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.

CCSP research on the global carbon cycle in FY 2006 will continue to address questions of how large and variable the dynamic reservoirs and fluxes of carbon within the Earth system are, and how carbon cycling might change and be managed in future years, decades, and centuries. This research is needed to help human societies evaluate their options for managing carbon sources and sinks to achieve an appropriate balance of risk, cost, and benefit.

Over the past 2 centuries, fossil-fuel emissions, land-use change, and other human activities increased atmospheric carbon dioxide (CO_2) by 30% and methane (CH_4) by 150% to concentrations unprecedented over the past 420,000 years (the time span of the longest fully documented ice core record). Future atmospheric concentrations of these greenhouse gases will depend on trends and variability in natural and human-caused emissions and the capacity of terrestrial and marine sinks to absorb and retain carbon. Options available to societies for stabilizing or mitigating concentrations of greenhouse gases in the atmosphere through management of carbon in the environment involve: (1) reduction of carbon emissions at their source and/or (2) enhanced sequestration of carbon through biospheric storage or engineered approaches.

To address these and related research questions, the United States is focusing its carbon cycle science on targeted research areas that are ripe for scientific progress and that are most relevant to societal concerns. The agencies responsible for CCSP carbon cycle research have organized a coordinated, interagency, and multidisciplinary research strategy to bring together the broad range of infrastructure, resources, and expertise essential for providing this information. This approach involves investigators with atmospheric, oceanic, terrestrial, and human dimensions research expertise and observational, experimental, and modeling skills. These agencies also are establishing an ongoing dialog with stakeholders, including resource managers, policymakers, and other decisionmakers to ensure that information is provided in a useful form.

The North American Carbon Program (NACP), designed to address strategic research question 7.1 (see chapter banner), will continue to be a major priority. The NACP will quantify the magnitudes and distributions of terrestrial, freshwater, oceanic, and atmospheric carbon sources and sinks for North America and adjacent oceans; improve understanding of the processes controlling source and sink dynamics; and produce consistent analyses of North America's carbon budget that explain regional and sectoral contributions and year-to-year variability. The NACP is committed to reducing uncertainties related to the buildup of CO_2 and CH_4 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.

The first studies to address the objectives of CCSP's new Ocean Carbon and Climate Change (OCCC) program plan, designed to address strategic research question 7.2, will be initiated in FY 2006. The OCCC program is an integrated effort for oceanic monitoring and research aimed at determining how much CO_2 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. NACP and OCCC program interests and objectives converge in addressing carbon dynamics in the coastal oceans adjacent to North America and in the land-sea margins – diverse and variable areas where impacts of changes in the terrestrial environment and climate greatly complicate carbon cycle processes. New investigations of carbon dynamics in the coastal oceans adjacent to North America will address both OCCC and NACP objectives.

Other FY 2006 priorities, focused on reducing scientific uncertainties regarding carbon sources and sinks, are: (1) conducting and reporting on experimental studies to investigate the processes regulating carbon balance in terrestrial ecosystems, and (2) developing and improving global carbon cycle models and coupled carbon-climate models to aid in improving projections of atmospheric CO_2 concentrations and climate.

Highlights of Recent Research

AmeriFlux Network Measures Terrestrial Carbon Sinks and Sources and Identifies Biological Controls.[7,10,18] The AmeriFlux network of research sites measures terrestrial carbon sinks and sources and biological processes that regulate the net exchange of CO_2 between terrestrial ecosystems and the atmosphere [referred to as "net ecosystem exchange" (NEE)]. The measurements show that mature forests are important sinks for atmospheric CO_2 (Hollinger *et al.*, 2004). Disturbances that replace or remove forests can result in the land being a net source of CO_2 for a few years in mild climates or up to a decade in harsh climates while the forests are recovering (Law *et al.*, 2004), after which they may gradually revert to being a sink until the next disturbance. Moist tropical forests are not necessarily strong sinks because some of them have experienced recent mortality events that leave large amounts of decaying plant material that can release more CO_2 to the atmosphere than the forests remove [net source of about 1 tonne per hectare per year (Saleska *et al.*, 2003). Thus, the range of observed annual NEE of CO_2 ranges from a source of about 1 tonne per hectare to a net sink of 2 to 4 tonnes per hectare for forests and about 1 tonne or less per hectare for agricultural crops and grasslands. These results are expected to dramatically improve process depictions in carbon and climate models.

AmeriFlux Measurements Reveal Direct Influence of Volcanic Eruptions on Terrestrial Carbon Cycle.[1,5] The growth rate of atmospheric CO_2 concentration decreased after the explosive eruption of Mt. Pinatubo in the Philippines in June 1991. Scientists have been debating the cause of this atmospheric CO_2 decrease for many years. In a recent study by Gu *et al.* (2003), a group of AmeriFlux scientists found that aerosols (tiny particles suspended in the air) formed in the aftermath of the eruption altered the quantity and quality of solar radiation for vegetation, and this alteration significantly enhanced photosynthesis under cloudless conditions in a deciduous forest in the United States. These measurements indicate that increased CO_2 uptake by terrestrial vegetation caused by the effects of aerosols from the Pinatubo eruption on incident solar radiation were at least partly responsible for the sudden decline in the growth rate of atmospheric CO_2 concentration after the eruption. The study also indicates that anthropogenic aerosols, which can similarly change the quantity and quality of solar radiation for vegetation, may affect carbon cycling dynamics. A modeling study by Angert *et al*. (2004) suggests an alternate mechanism for the enhanced CO_2 sink in 1992-1993, due to a unique combination of an enhanced ocean CO_2 sink, reduced respiration driven by cooling and drying of the upper layers of the soil thereby reducing heterotrophic respiration, and reduced biomass burning. These studies illustrate the complexity of the global carbon cycle and underscore the crucial need for continued observations to resolve carbon cycle uncertainties.

Impact of Fires on Interannual Variability in Global Atmospheric Trace Gases.[20] Year-to-year changes in the atmospheric concentration of CO_2 and CH_4 are linked to fire activity associated with the El Niño/La Niña cycle. Information on vegetation, precipitation, surface air temperatures, and changes in Earth's radiation,

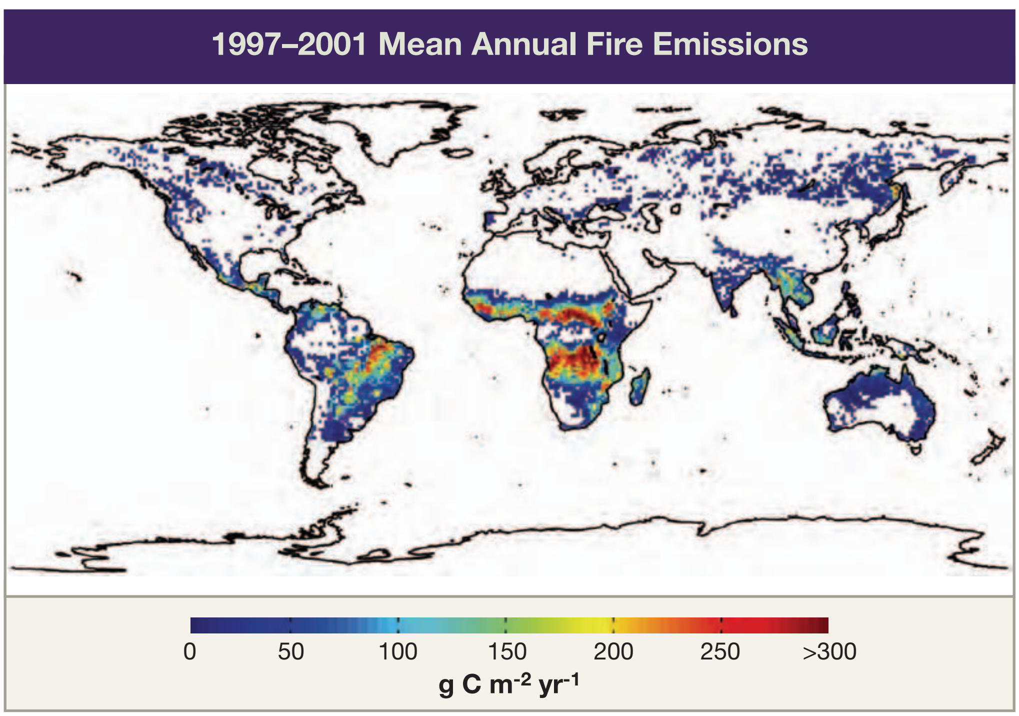


Figure 18: 1997–2001 Mean Annual Fire Emissions. Observations from the VIRS instrument on the Tropical Rainfall Measuring Mission satellite and MODIS instrument on Terra and Aqua satellites provide comprehensive information on the timing and locations of fires. Red to blue indicates high to low emissions of carbon from fires during 1997 to 2001, while white indicates no fires were observed during that period. *Credit: NASA/ Goddard Space Flight Center.*

derived from the Terra, Aqua, Tropical Rainfall Measuring Mission, and Active Cavity Radiometer Irradiance Monitor satellites, was used in modeling analyses of fire effects for 1997 to 2001. Researchers quantified the amount of CO_2 and CH_4 emitted by fires by combining the satellite data with *in situ* measurements of atmospheric gases. Emissions of greenhouse gases from fires increased across multiple continental regions in the El Niño year (1997-1998), including Southeast Asia (60% of the global increase), Central and South America (30%), and boreal forests of North America and Eurasia (10%). Vast areas of the tropics dry out and become vulnerable to fire during El Niño events, thus enabling humans to use fire more effectively as a tool for clearing land. Increases in fires and associated emissions of greenhouse gases are expected if El Niño events increase in frequency and/or intensity in the future.

Regionalization of Methane Emissions from the Amazon Basin.[13] The largest single source of CH_4 emissions to the atmosphere is natural wetlands, which account for between 20 and 40% of annual emissions; 60% of this is estimated to come from tropical wetlands, although there is large uncertainty regarding the magnitude and variability of that source. The Amazon Basin contains one of the largest areas of seasonally inundated tropical wetlands. Microwave remote-sensing techniques were used to measure wetland extent and seasonal variability, and the resulting data were combined with results from existing field studies of CH_4 flux in a model to extrapolate CH_4 flux across the entire Amazon Basin. Extrapolation to the Central Amazon Basin (1.77 million km^2 area) produces an estimated 6.8 TgC yr^{-1}, and extrapolation to the full Amazon River Basin below 500-m elevation (5.2 million km^2, of which 17% is wetland) produces an estimated 22 TgC yr^{-1} from CH_4 emissions. This estimate is lower than those previously reported for the region. The satellite data analyses indicate that past studies overestimated the length of time seasonal wetlands were flooded and therefore overestimated annual methane emissions.

Variability in Low Productivity Ocean Gyres.[12] The mid-ocean gyres are huge circulation cells within the major ocean basins. They are vast expanses of very low primary production and biomass. Their low productivity results from the physical dynamics of the circulation within the gyre, which depresses the depths at which significant nutrient concentrations (e.g., nitrate, phosphate, and silicate) required for photosynthesis occur. Global surface chlorophyll concentrations measured over seven years by the U.S. Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Japanese Ocean Color and Thermal Scanner (OCTS) satellite sensors were used to estimate

temporal changes in the size of each gyre. The analysis shows that these areas have a distinct seasonal cycle and that the overall area of the gyres in the North Pacific and North Atlantic expanded during 1996 to 2003, while there was little change in the area of the South Pacific, South Atlantic, and southern Indian Ocean gyres. The study did not attempt to explain why the Northern Hemisphere gyres are expanding and was too short to determine whether the trends will continue. This first-ever quantification of year-to-year variability across the global oceans has implications for carbon dynamics, and raises a concern about whether continued expansion of the low-productivity gyres would reduce the size of the ocean carbon sink. Continuing systematic satellite observations will be available to monitor future trends and address this concern.

Changing Carbon Dynamics in the Oceans.[4,17] The Repeat Hydrography CO_2/Tracer Program is a systematic and global re-measurement of select cross-sections of the ocean to quantify changes in storage and transport of heat, freshwater, CO_2, chlorofluorocarbon tracers, and related properties. For cruises in the North Pacific, difference plots for the 2004 Repeat Hydrography compared with the 1994 World Ocean Circulation Experiment quantitatively document significant changes. Increases in dissolved inorganic carbon (DIC) of up to 35 $\mu mol\ kg^{-1}$ were observed in surface waters and in intermediate depths ranging from 200 to 1000 m. On average, mixed layer DIC increases of $1.5 \pm 0.2\ \mu mol\ kg^{-1}\ yr^{-1}$ were observed in the subtropical waters of the North Pacific, indicating that over the past decade the oceanic uptake of CO_2 in this part of the global ocean has been faster than the rate of growth of CO_2 in the atmosphere. These results indicate that the rate of uptake of CO_2 may differ significantly in different regions of the global ocean.

Synthesis of Forest FACE Experiment Data.[8,21] Common data sets were assembled from four Free-Air CO_2 Enrichment (FACE) experiments being conducted in forest ecosystems. The ongoing, multi-year experiments were in established stands in North Carolina (loblolly pine) and Tennessee (sweetgum), and in young stands in Wisconsin (aspen-birch-maple) and Italy (poplar). Soil respiration increased in response to CO_2 enrichment, and the relative response was larger in the young stands. The temperature sensitivity of soil respiration was unaffected by CO_2 enrichment. No effects on soil nitrogen pools or processes were observed in the three forest FACE experiments in the United States, indicating that nitrogen limitations are unlikely to constrain increases in forest productivity at similar sites in the initial years following

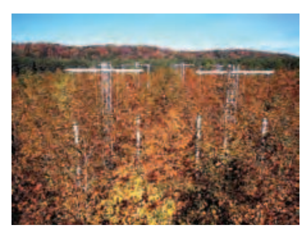


Figure 19: AmeriFlux Research Tower. Near Howland, Maine, a partnership between the University of Maine, USDA Forest Service, and Woods Hole Research Center provides a platform for studies of ecosystem-atmosphere CO_2 and energy exchange. Instruments visible on the tower include eddy flux instrumentation for measuring net CO_2 and energy exchange [supported by DOE's Office of Science/ Biological and Environmental Research (BER)], a dry deposition and meteorological package for studying air quality (supported by NOAA's Air Resources Laboratory), and a sun photometer for assessing atmospheric aerosols (supported by NASA's Aerosol Robotic Network). Recent results from this and a nearby companion tower have quantified flux measurement uncertainties needed for data-model fusion efforts under the North American Carbon Program (NACP), and have shown that this 140-year-old coniferous forest remains a strong sink for atmospheric CO_2. Researchers operate this site with support from DOE. *Credit: J. Lee, University of Maine*.

CO_2 enrichment. Continued study of these effects over longer time periods will be critical for our ability to predict long-term changes in soil nitrogen availability and the potential for sustained increases in productivity in a CO_2-enriched atmosphere.

Root Dynamics Control Forest Response to Atmospheric Carbon Dioxide.[11,14] Analysis of a nearly continuous 6-year record of fine root production and mortality in an experimental sweetgum forest revealed a large increase in root production and a significant change in the depth distribution of roots in forest plots exposed to a CO_2-enriched atmosphere. These responses, which were measured in a FACE experiment, have important implications for carbon sequestration and nitrogen and water uptake in this and other forest ecosystems. Allocation of carbon to fine roots reduces the potential for carbon sequestration in plant biomass, but increases the potential for carbon storage in soil. Comparison of the responses of the deciduous forest with those in a similar experiment in a pine forest suggests that root system dynamics can explain differences among ecosystems in their response to elevated atmospheric CO_2. These results indicate that accurate assessments of carbon flux and storage in forests must account for the responses of root systems.

Long-Term Forest Management Studies Inform Carbon Management Options.[15] The Long-Term Soil Productivity (LTSP) study seeks to understand how anthropogenic disturbances affect the land's capacity to store carbon through the conduct of a series of 62 long-term field experiments in major forest types of the United States and Canada. This unique study has been in place for more than a decade and is the largest and most extensive experiment of its type in the world. Results show differences in carbon and nutrient dynamics by soil type and climate regime and provide critical information for developing management systems that maintain and enhance productivity and carbon sequestration options. Findings from studies of alternative fuel treatments for reducing fire risk indicate no significant differences in CO_2 efflux following treatment and provide a basis for local communities to reduce fire risk and improve the health and vigor of forests without affecting greenhouse gas emissions.

Land Resource Management and Reclamation Activities have Significant Potential to Sequester Carbon.[2,3,9,16,19] As noted previously, changes in soil carbon can potentially change the concentrations of greenhouse gases in the atmosphere. If CO_2 from the atmosphere, captured through photosynthesis, is ultimately stored in the soil to a greater degree, the resulting soil carbon sequestration may help slow the rise of atmospheric CO_2. Studies of soil carbon dynamics and storage in a variety of managed systems in the United States and elsewhere have identified and quantified significant carbon sequestration potentials:

- *In situ* measurements and models have determined soil organic carbon (SOC) sequestration potentials for croplands, pastures and rangelands, disturbed lands such as mining areas, natural areas such as wetlands, land in the Conservation Reserve Program (CRP), and urban areas such as lawns, parks, and golf courses. With improved management practices, the potential average rates of SOC sequestration are approximately 70, 40, 60, and 13 Tg of organic carbon annually for cropland, grazing land, forests, and CRP soils, respectively (Lal *et al.*, 2003; USDA, 2004).
- Conversion of cropland to perennial systems in central Iowa increased the SOC content by an average of 11 tonnes per hectare in the upper 35 cm of soil (Cambardella *et al.*, 2004).
- For agroforestry systems in Costa Rica, increased biodiversity resulted in greater soil nutrient supply and carbon storage; plant roots were primarily responsible for soil carbon accrual in these systems. Root organic matter quality, and not the amount of root inputs, best explained effects of species diversity on soil carbon sequestration (Russell *et al.*, 2003).
- Restoration of semi-permanent wetlands in the prairie pothole region of the northern Great Plains increased carbon content in surface sediments (Euliss *et al.*, 2003).

These results are examples of findings that contribute new scientific knowledge about relationships of terrestrial ecosystem processes and management practices on carbon sequestration. Land and resource managers, agricultural consultants, and environmental organizations are using this new information to foster the development of agricultural and land management systems that mitigate greenhouse gas emissions, enhance soil fertility, and improve soil and water quality.

Climate-Induced Thawing of Permafrost and Implications for Soil Carbon Stocks.[6] The high-latitude regions of North America, including interior Alaska, are critical areas for research because thawing of permafrost within the soil zone can cause a release of carbon to the atmosphere. In the past 40 years, boreal North America has warmed by at least 2°C and has experienced pervasive drying of lakes and water tables. Landscapes with near-surface permafrost store greater than 60% of their carbon stocks in organic soils. While long-term records indicate net carbon storage on land, fires in recent decades have burned these landscapes in unexpected proportions. Trace gas studies at the Bonanza Creek Long-Term Ecological Research Station have revealed complex responses of permafrost landscapes to fire, with post-burn hydrological conditions and plant ecological processes determining the net balance between CH_4 and CO_2 emissions and carbon sequestration. Drought and fire induce complex responses (e.g., water table fluctuation, revegetation patterns) due in part to the discontinuous nature of the permafrost. These findings emphasize the importance of surface and subsurface hydrology for understanding the carbon dynamics of boreal and arctic regions and emphasize the need for baseline studies of carbon cycling on a variety of temporal and spatial scales.

Highlights of FY 2006 Plans

In FY 2006, continuing observations, field campaigns and experiments, and model development will be a priority under the NACP. Significant effort will be devoted to continuing the development, expansion, and optimization of observations and monitoring networks for North American, coastal, and global carbon sources and sinks. The Mid-Continent NACP Intensive Campaign will be completing its initial field phase. New ocean carbon research will be underway in support of the OCCC program, with early emphasis on studies of carbon dynamics in the coastal oceans adjacent to North America that also support NACP objectives. Data management plans and capabilities for NACP and OCCC will be implemented. New experimental studies will be conducted and the results of previous experimental studies will be synthesized to explain the processes regulating carbon dynamics in terrestrial ecosystems, including carbon sequestration. Modeling investigations will focus on improved coupling of carbon-climate models, carbon data assimilation, and better projections of CO_2 emissions and ecosystem responses for climate models. The first *State of the Carbon Cycle Report* is one of the CCSP synthesis and assessment products.

CCSP SYNTHESIS AND ASSESSMENT PRODUCT

The *CCSP Strategic Plan* identifies 21 planned synthesis and assessment products describing the current state of knowledge concerning many different aspects of climate and global change. One of these focuses on the carbon cycle.

North American Carbon Budget and Implications for the Global Carbon Cycle. Synthesis and Assessment Product 2.2 will provide a synthesis and integration of current knowledge of the North American carbon budget and its context within the global carbon cycle. In a format useful to decisionmakers, it will (1) summarize our knowledge of carbon cycle properties and changes relevant to the contributions of and impacts upon the United States and the rest of the world, and (2) provide scientific information for U.S. decision support focused on key issues for carbon management and policy. The report will address carbon emissions, natural reservoirs and sequestration, rates of transfer, the consequences of changes in carbon cycling on land and the ocean, effects of purposeful carbon management, and the socioeconomic drivers and consequences of changes in the carbon cycle. It will include an analysis of North America's carbon budget that will document the state of knowledge and quantify uncertainties. This analysis will provide a baseline against which future results from the North American Carbon Program (NACP) can be compared.

NACP: Measurements and Monitoring. In FY 2006, NACP will continue to assign high priority to global observations by enhancing observational capabilities and monitoring networks for carbon fluxes and stocks in North America and adjacent oceans. The following activities represent major commitments:

- *Regional Carbon Monitoring* – A carbon cycle atmospheric observing system is being built for deployment across the United States in support of research to reduce uncertainty in the North American carbon sink. Small aircraft flown from 24 U.S. sites will collect samples of carbon gases and other trace gases from the surface to about 8-km altitude on a weekly basis. In conjunction with this "vertical profiling," tall communications towers (~500 m) will sample CO_2 and other greenhouse gases continuously from about 12 U.S. sites. This system is expected to be fully implemented by 2007, contingent on availability of funding. The technique will provide critical data for analysis of regional carbon sources and sinks and useful decision-support information for carbon management.
- *Landscape-Scale Carbon Sources and Sinks in Forests* – Current forest monitoring capability lacks many of the observations needed for complete forest carbon accounting over large areas. An improved forest observation and monitoring system that integrates several existing programs is undergoing pilot testing at several forest sites in the United States. Standardized estimates of carbon stocks and flows will provide a strong scientific foundation for development and deployment of carbon sequestration technology to mitigate greenhouse gas emissions. Enhancing observations at experimental forests has additional benefits such as facilitating use of these sites for carbon management research and demonstration projects, and providing the basis for an "early warning" capability to detect the initial impacts of climate change.
- *Landscape-Scale Carbon Sources and Sinks on Department of the Interior Lands* – The recently developed National Carbon Map will be used to identify and quantify the

effects of fire, grazing, and other natural disturbances and human activities on the status and trends of carbon stocks and fluxes. The results will clarify the spatial and temporal dimensions of current U.S. carbon sources and sinks.

- *Measurement of Carbon Cycle Processes in Agricultural Ecosystems* – Process information, carbon flux data, and carbon inventories from agricultural ecosystems will be provided for the mid-continent region of North America. By expansion of the Greenhouse Gas Reduction through Agricultural Carbon Enhancement (GRACEnet) and Agriflux networks, this activity will systematically determine the effects of grazing and cropping on soil carbon and atmospheric CO_2 emissions.
- *Continental-Scale Satellite Data Time Series* – New and continuing investments will be made to produce continental-scale Earth Observing System (EOS) satellite data products for spatial extrapolation of carbon stock and flux estimates. Data products on primary productivity, land cover, and vegetation and phytoplankton properties of North American lands and adjacent oceans will be used to drive carbon and climate models.

- *Coastal Carbon Measurements and Process Studies* – New ocean margin studies will be initiated to determine rates of carbon burial and export to the open ocean, elucidation of factors controlling the efficiency of the solubility and biological pumps in coastal environments, quantification of the influence of coastal marine biogeochemical processes on the chemical composition of open ocean surface waters, and development of coupled physical-biogeochemical models for different types of continental margins

These activities will address Questions 7.1, 7.2, 7.3, and 7.6 of the CCSP Strategic Plan.

NACP: Field Studies. Intensive field campaigns and experimental studies under NACP will feature the following activities in FY 2006:

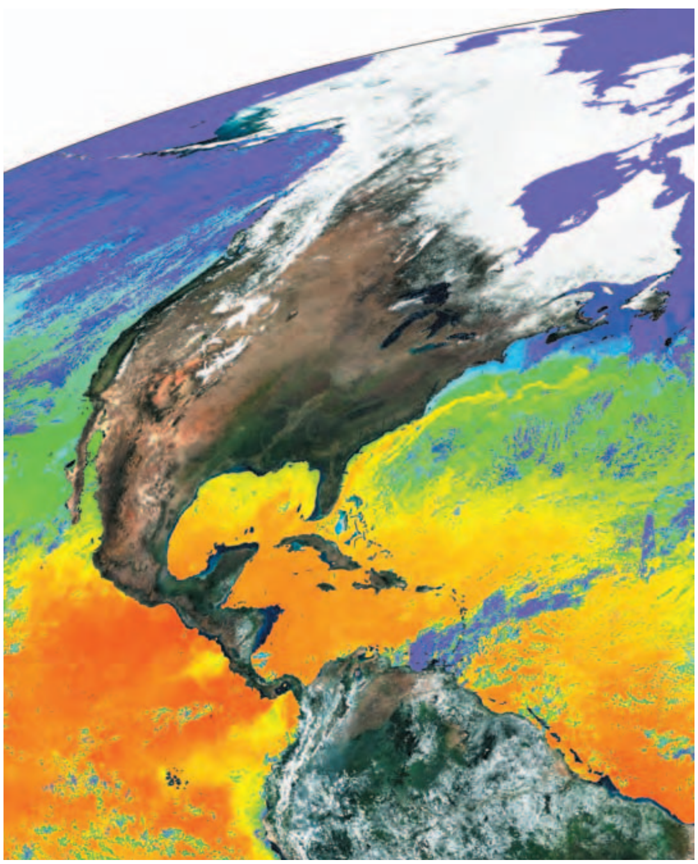
- *Mid-Continent NACP Intensive Campaign* – An intensive field investigation centered on the mid-continent region of North America will develop and test methods for regional and continental estimates of carbon sources and sinks. This study will evaluate and compare two independent approaches for estimating carbon fluxes at the regional scale: the "top-down" approach using atmospheric measurements and models, and the "bottom-up" approach using vegetation and soil carbon inventories, land cover, meteorological information, and models. This prototype study will integrate existing data on crop, forest, and soil carbon content with data from the AmeriFlux research network, airborne sensors, and satellites. Biological process information from current experiments, atmospheric profiling, and statistical databases of the mid-continent region will play key roles. Results will help in the design of more comprehensive research for quantifying and explaining variation of carbon sources and sinks across North America.

- *Tracing Soil Carbon Fluxes* – Research will continue on a unique experiment using radiocarbon to trace carbon flux within soils. The results will improve models of soil carbon processes and quantification of belowground carbon sequestration.

These activities will address Questions 7.1 and 7.3 of the CCSP Strategic Plan.

Ocean Carbon and Climate Change Research. New studies will be initiated to advance the goals of the OCCC science implementation strategy:

- *Ocean Repeat Hydrography and Carbon Measurements* – The Repeat Hydrography Program will continue measurements of key ocean properties along cross-sections of the North Pacific. The suite of measurements will include total carbon, partial pressure of CO_2, temperature, depth, salinity, oxygen, and nutrients.
- *Coastal CO_2 Measurement Platforms* – Prototype platforms will be sited off the U.S. East Coast to continuously measure ocean CO_2 partial pressure and atmospheric CO_2 concentrations. The measurements will improve information on atmosphere-ocean CO_2 exchange and atmospheric CO_2 at the continental boundary.
- *Satellite Data Analysis* – New studies will focus on using ocean color to characterize carbon dynamics globally and on using a variety of satellite and *in situ* data to quantify and understand the spatial variability of air-sea CO_2 flux in the oceans adjacent to North America. Other studies will focus on the development and analysis of remote-sensing data and products that facilitate understanding of the input and fate of non-CO_2, climate-relevant carbon compounds (e.g., dissolved organic matter, CH_4, carbon monoxide) to the aquatic environment.



These activities will address Questions 7.1, 7.2, and 7.4 of the CCSP Strategic Plan.

Study of Terrestrial Processes Regulating Carbon Balance. Long-term field experiments and major campaigns are identifying processes that are critical to reducing uncertainties in carbon budgets and improving model-based predictions of future terrestrial carbon dynamics. A variety of experimental studies will be continued and several scientific syntheses are anticipated in FY 2006; new studies to better understand climate-related ecosystem effects on carbon balance will be conducted:

- *Productivity at FACE Sites* – Net primary productivity (NPP) is an integrated measure of how ecosystems respond to atmospheric CO_2 enrichment. Data from four forest ecosystems that are being exposed to elevated atmospheric CO_2 in FACE experiments will be analyzed and synthesized to determine how NPP is affected by elevated atmospheric CO_2 and other environmental factors.
- *Acclimation to Enriched Carbon Dioxide* – Results of two studies investigating acclimation (adaptation to a new environmental condition; in these cases, enriched atmospheric CO_2) processes will be published in 2006. These results are expected to underscore the importance of acclimation processes for ecosystem- to global-scale modeling of carbon cycling.
- *Amazonian Carbon Balance* – Integrative research utilizing data from the Large Scale Biosphere-Atmosphere Experiment in Amazonia will document current understanding of carbon source and sink dynamics, the processes controlling them, and any remaining uncertainties for the Amazon region of South America. These results are expected to greatly reduce errors and uncertainties concerning the carbon balance of tropical forests.
- *Impacts of Invasive Species* – Research on the impacts of invasive species on terrestrial carbon cycling processes will continue by studying the responses of different types of invasive species (grasses vs. woody species) along a precipitation gradient. The research will provide information about invasive species impacts on ecosystem productivity to make global estimates of carbon cycling more accurate and reliable.
- *Climate-Induced Permafrost Thawing and Associated Drying and Forest Fires* – Research will continue to investigate the relationship between water-table fluctuations and associated changes in soil carbon in northern latitudes of Alaska. Investigations of lake drying at Yukon Flats Wildlife Refuge will be initiated, and post-fire regrowth will be monitored at study sites established after the pervasive 2004 wildfires.

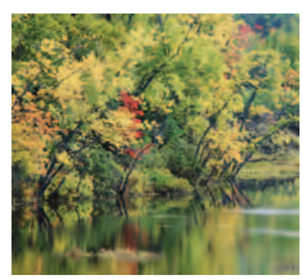
These activities will address Questions 7.1, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

Development of New Measurement and Analysis Methods. In FY 2006, the following work will be underway to develop new measurement and data analysis methodologies for carbon cycle science:

- *AmeriFlux Data Assimilation System* – An integrated framework for using AmeriFlux measurements and ecosystem models to understand terrestrial carbon cycling processes will be developed. This framework, which is called the AmeriFlux Data Assimilation System, takes advantage of diverse, continuous AmeriFlux measurements of CO_2 and energy exchanges and combines them with a detailed process-based ecosystem model. It will yield information on ecosystem states and carbon sinks in real time and will be an effective tool for scientists to investigate fundamental ecological processes that are difficult to observe directly.
- *New Remote-Sensing Measurements* – New remote-sensing research will be initiated to evaluate the technological capabilities for space-based measurement of: (1) vegetation three-dimensional structure and biomass; (2) phytoplankton and vegetation physiological properties and important plant functional types; and (3) the space-time variability of aquatic optical properties that may be translated into new ocean color observations of coastal particles and their abundance. All have direct relevance for quantifying global carbon sources and sinks.
- *Coastal Ocean Color Calibration* – Ocean color satellite calibration capabilities will be expanded to include observations of coastal zones. The objective will be to improve remote detection and quantification of optical, biological, and biogeochemical parameters in these regions. This research will improve our understanding of coastal biological and biogeochemical processes, improve coastal models, and eventually enable prediction of changes in processes such as offshore carbon fluxes.
- *Satellite Measurements of Atmospheric Carbon Dioxide* – Development of new remote-sensing capabilities for the measurement of atmospheric CO_2 will continue, and scientific research will be conducted to prepare for utilization of such data. Globally sampled measurements of atmospheric column CO_2 (i.e., column-integrated CO_2 dry air mole fraction) will increase by ~100 times the available measurements to drive inverse models and should enable regional resolution of carbon sources and sinks.

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

Improved Modeling for Projections of Carbon Dioxide and Climate. Continuing and new investments will be made in modeling studies to support NACP, the Mid-Continent NACP Intensive Campaign, the OCCC program, and activities on global carbon dynamics and climate change assessment.



- *Coupled Carbon-Climate Modeling* – Research will link terrestrial ecosystem models with climate simulation models to incorporate biogeochemical and physiological responses and feedbacks associated with climate change. Emphasis will be placed on developing new code for including these ecosystem-scale processes and responses in current representations of coupled climate-land surface models. Priorities are to model an empirically derived respiration acclimation feedback to climate perturbation and to include physiologically based mechanisms of ecosystem response to CO_2 using FACE experimental data.

- *Carbon Data Assimilation* – Research will be conducted to develop, test, and apply carbon data assimilation and data fusion schemes that incorporate *in situ* and remotely sensed data and focus on enabling forecasts of changes in atmospheric CO_2 and CH_4 concentrations on short or long time scales with estimates of uncertainty. Studies to explore assimilation of coastal or ocean margin carbon data into general circulation models will be initiated.
- *Model Comparisons* – The southern Great Plains of the United States will be the focus for a model-based comparison of "bottom-up" and "top-down" approaches to estimating ecosystem CO_2 fluxes at the regional scale. Predicted temporally and spatially resolved gross and net CO_2 fluxes will be made available to NACP researchers to help evaluate NACP-related results for regional CO_2 exchange, climate, and land use.

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

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