3 | Global Carbon Cycle

The USGCRP budget includes $252 million in FY 2003 for research and observations related primarily to the Global Carbon Cycle. The USGCRP Global Carbon Cycle program endeavors to identify 1) the size and variability of the dynamic reservoirs and fluxes of carbon within the Earth system and how carbon cycling might change and be changed in the future, and 2) provide the scientific underpinning for evaluating options being considered by society for managing carbon sources and sinks to achieve an appropriate balance of risk, costs, and benefits. This research requires an interdisciplinary approach, bringing together investigators from a multitude of disciplines spanning the atmospheric, oceanic, terrestrial, and human dimensions of the carbon cycle.

We are entering an era in which reducing uncertainties about the carbon cycle will be central to answering questions of future climate change and its consequences for humans. Such questions include: What will be the future atmospheric concentrations of carbon dioxide and methane resulting from environmental changes, human actions, and past and future emissions? To what extent can forest and agriculture management be used to effectively offset emissions of carbon from fossil fuel combustion, regionally, nationally, and globally? How will the natural processes that store carbon in the oceans and on land change in the future? What are the prospects for feedbacks within the climate system, especially those that might prompt large increases in carbon emissions from the land and oceans? Will food security increase or decrease as the composition of the atmosphere continues to change? How do the prospects for carbon storage through increasing the growth of trees and plants compare to and interact with the prospects for storing carbon in the deep oceans and in geological formations?

To answer these and related questions, the USGCRP has initiated an integrated carbon cycle science program, focusing on targeted research areas that are ripe for scientific progress, and that are the most relevant to pressing societal concerns. Key research challenges include quantifying North American carbon sources and sinks and the processes controlling their dynamics; quantifying the oceanic carbon sink and the processes controlling its dynamics; periodically reporting the "state of the global carbon cycle;" evaluating the impact of land-use change and terrestrial and marine resource management practices on carbon sources and sinks; projecting future atmospheric carbon dioxide (CO_2) and methane (CH_4) concentrations and changes in terrestrial and marine carbon sinks; and providing the scientific underpinning, and evaluations from specific test cases, for enhancing management of carbon in the environment.

In FY 2003, the program has chosen to focus its priority efforts on a targeted, integrated program over North America and the adjacent ocean basins. The North American Carbon Program plans to focus intensively on carbon sources and sinks on the land and in the ocean basins adjacent to North America. Research will be conducted over the next 5-10 years to improve monitoring techniques, reconcile approaches for quantifying carbon storage, and elucidate key controlling processes and land management practices regulating carbon fluxes between the atmosphere and the land and ocean. The North American Carbon Program calls for expansion of the AmeriFlux network, vertical atmospheric profiling over North America, the development of automated carbon dioxide sensors, improvements in ground-based measurements and inventories of forest and agricultural lands, empirical and process modeling, continued remote-sensing observational platforms, and new remote-sensing measurement techniques. It will be implemented in three phases: (1) 2002-2004 – development of new instrumentation and initial modeling capabilities; (2) 2005-2007 – testing and implementing a new observational network and intensive field observations and process studies; (3) beyond 2008 – operational phase, when a legacy of optimized networks and model-data fusion capabilities will provide regular and reliable estimates of net sources and sinks for CO_2, CH_4, and carbon monoxide (CO) for North America and its adjacent ocean basins. Useful data products and assessments of results are planned for as early as 2005 and will continue throughout the study. These results will provide information that could inform future decisions on policies to (1) reduce net emissions of CO_2 and CH_4 and (2) enhance sequestration of carbon through active carbon management.

In addition, research into the ocean carbon sink will continue in FY 2003 with ship-based surveys of carbon and analyses of more comprehensive satellite ocean color data sets. New results will become available on the effects of land use and land management on carbon sources and sinks, on deliberate management practices for carbon sequestration in forest biomass and agricultural lands, and on the effects of large-scale biomass burning and industrial emissions on regional carbon balances.

HIGHLIGHTS OF RECENT RESEARCH

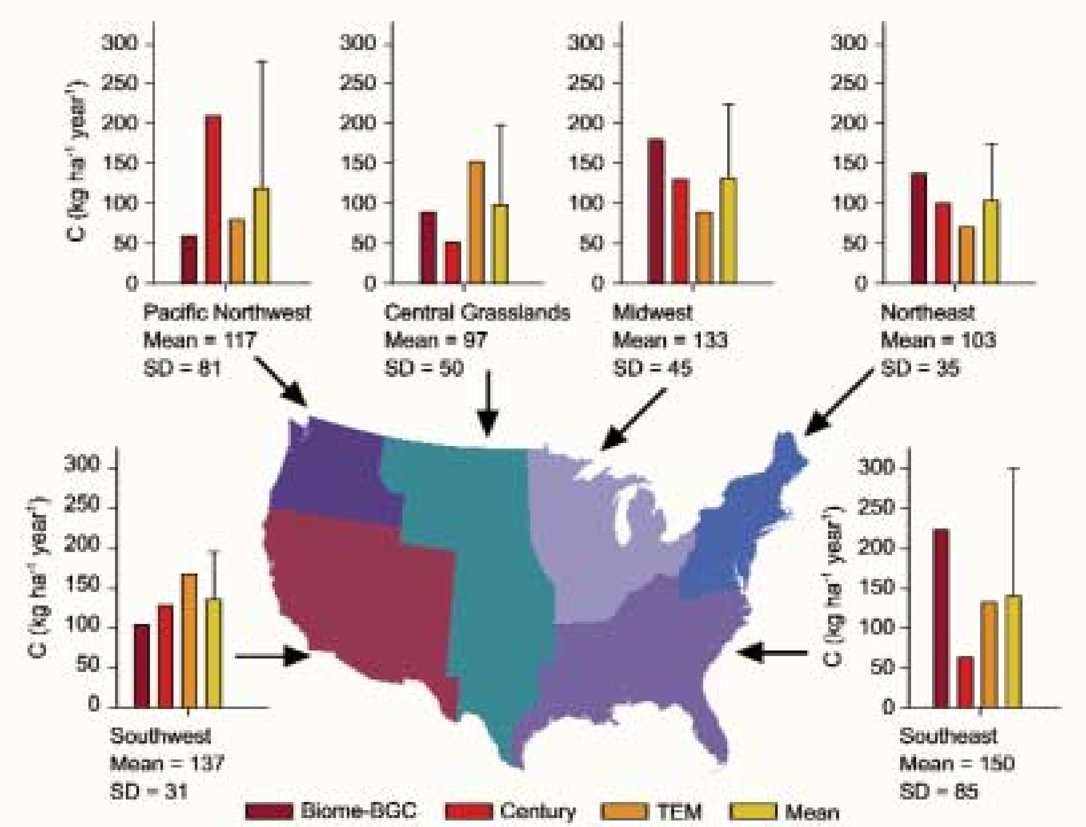
Reconciled North American Carbon Sink Estimates: For the first time, estimates of the carbon sink over North America were reconciled for a given time period (in this case, 1980-1989) using two distinct methods. In the past, atmospheric-based

Figure 4.1
Estimates from three biogeochemical models of net carbon storage for different bioclimatic regions of the United States, for the period 1980-1993. The effects of increasing carbon dioxide and changes in climate on net carbon storage in terrestrial ecosystems of the conterminous United States were modeled using new, detailed historical climate information from the NOAA Historical Climate Network database. For the period 1980-1993, results from an ensemble of three models agree within 25 percent, simulating a land carbon sink of 80 million metric tons of carbon per year.

Credit: Schimel, et al., Science, March 17, 2000

For additional information see Appendix B.

NORTH AMERICAN TERRESTRIAL CARBON SINK: CONTRIBUTION OF INCREASING CO_2 AND CLIMATE TO CARBON STORAGE BY ECOSYSTEMS IN THE UNITED STATES



methods and land surveying methods did not give statistically similar estimates of the U.S. carbon sink. The methods and data sets used in this recent study pave the way for developing the capability to routinely quantify sources and sinks across North America and understand the underlying mechanisms. Enhancing our ability to estimate the quantity of CO_2 absorbed by North American ecosystems will help hone estimates of atmospheric CO_2 concentrations in future years.

A Large Carbon Sink in Northern Forests: Significant biomass carbon gains in Eurasian and North American temperate forests and losses in some Canadian boreal forests have been revealed from analysis of two decades of AVHRR satellite data in combination with forest inventories. Increases in forest growth have been attributed to fire suppression and forest re-growth in the U.S. and declining harvests in Russia. Decreases in growth in Canada have been attributed to fires and infestations. This research suggests the possibility of surveying forests from space and will help in locating and characterizing the dynamics of terrestrial sinks and their role in sequestering carbon, and the impact of climate change on terrestrial ecosystems. We are now better able to track changes in global-scale terrestrial productivity, which is important for identifying where the carbon is being stored and where it is likely to continue to be stored.

Agreement of Methodologies for Carbon Uptake Measurement: AmeriFlux research quantified net carbon uptake by a forest ecosystem using two independent measures. Over a 10-year period at the same site at the Harvard Forest, estimates of carbon uptake from both flux tower measurements and intensive forest inventory measurements and biometry were found to be statistically similar. Close agreement of the measures builds confidence in the use of the two different methods for more accurately estimating net ecosystem production and terrestrial carbon sinks.

Insight into Carbon Exchange Using Oxygen Isotope: Researchers have developed a model that simulates the flow of the oxygen-18 isotope in CO_2 and water between plants, soil, and canopy water vapor. The oxygen-18 isotope acts as a tracer that allows scientists to partition the sources of CO_2 and water, thus providing significant insight into the properties governing the carbon exchange between ecosystems and the atmosphere. The model has been incorporated into the NCAR Community Climate System Model (CCSM)—a linked land-surface model. This modification provides a new and powerful tool for providing information on carbon fluxes in the plant and soil components of ecosystems. This research is necessary for understanding and interpreting larger-scale regional and continental fluxes, and for understanding and predicting the behavior of terrestrial carbon sinks.

Identification of Carbon Management Options: At the Forestry and Agriculture Greenhouse Gas Modeling Forum in 2001, two USGCRP agencies convened leading researchers to compare potential greenhouse gas mitigation options in the agriculture and forestry sectors. At this first of what is intended to be a series of annual workshops, attendees compiled and compared North American agriculture and forestry emission-reduction estimates across selected global and national models that link economic and biophysical analyses and identified promising directions for future research to inform decisionmaking about management options.

Synthesis and Collaboration of Carbon Knowledge: The Forest Service led an international, multiagency meeting on carbon dynamics in urban, rangeland, forest, agricultural and wetland ecosystems. The proceedings (published in a special issue of the *Journal of Environmental Pollution*) summarized current understanding of carbon stocks and carbon dynamics in terrestrial systems. The proceedings included numerous papers that emphasized the importance of understanding the roles of disturbances (such as fire), climate, basic ecological processes, and management practices to accurately model and project carbon sequestration potential in different regions and ecosystems. This knowledge synthesis documents the “state-of-the-science” to support: (1) increasing carbon sequestration; (2) monitoring and verifying changes in carbon sequestration; and (3) developing accounting rules and guidelines for potential decisionmaking on reporting and trading of future carbon credits.

Estimation of Anthropogenic CO_2 Uptake in Pacific Ocean: The first comprehensive ocean inventories of anthropogenic carbon storage are nearing completion in the Pacific and Atlantic Oceans. Using database methods, the Pacific Ocean was found to carry a burden of anthropogenic carbon that is approximately 45 billion tons greater than in preindustrial times, in agreement with ocean modeling simulations. This represents about 20 percent of the total fossil fuel emissions over the period. A complete synthesis of ocean inventories based upon direct measurements has recently been published. These basin-wide inventories have contributed to our understanding of how much carbon emitted by humans is absorbed by the ocean, as well as how anthropogenic carbon is transported and distributed among the Earth’s major ocean basins.

Air-Sea CO_2 Exchange: The first study of direct air-sea exchange of carbon dioxide in the equatorial Pacific Ocean was completed in 2001. This region is the largest natural oceanic source of carbon dioxide to the atmosphere. The kinetics of gas exchange

Figure 4.2
Carbon dioxide measurements and experiments — (a) AmeriFlux tower; (b) Free Air CO_2 Enrichment (FACE); (c) Elevated CO_2 concentration experiment

Credits: AmeriFlux – Oak Ridge National Laboratory; FACE – Brookhaven National Laboratory; Smithsonian Environmental Research Center

For additional information see Appendix B.

(a) AmeriFlux: The AmeriFlux network, established in 1996, includes more than 40 funded sites operating across North, Central, and South America. AmeriFlux sites constitute an infrastructure for making long-term measurements of CO_2, water, and energy exchanges from a variety of ecosystems.

(b) FACE: FACE facilities can tell us how the structuring and functioning of terrestrial ecosystems will be affected by increasing atmospheric CO_2, including their ability and capacity to take up and sequester CO_2 emitted to the atmosphere from human activities. FACE provides a technology by which the microclimate around growing plants may be modified to simulate climate change conditions.

(c) The **Smithsonian Environmental Research Center** (SERC) is conducting a series of experiments that expose portions of salt marsh and forest ecosystems to elevated CO_2 concentrations in outdoor chambers.

between the air and sea is currently a major source of uncertaintity in quantifying ocean uptake at regional scales. Direct measurements of air-sea CO_2 exchange were accurately obtained using three distinct methodologies. These data will be incorporated into algorithms to improve estimates of ocean uptake of fossil-fuel-derived carbon dioxide.

Interannual and Climate-Driven Variation in Ocean Biomass Observed: Based on three years of data from the SeaWiFS ocean color satellite instrument, the first continuous global estimates of ocean plant biomass and terrestrial plant photosynthesis that accurately track and characterize seasonal and interannual variability were documented. Strong El Niño/La Niña-related differences were observed, especially in the tropical oceans where significant increases in ocean plant biomass were observed. In addition, the first successful cross-calibration of two ocean-color data sets—from SeaWiFS and Japan's Ocean Color and Temperature Scanner (OCTS)—was completed, initiating a long-term, highly calibrated ocean color time series for the global ocean. The ability to quantify annual and interannual changes in ocean and land plant productivity will enhance our ability to forecast ecological responses to changes in climate.

HIGHLIGHTS OF FY 2003 PLANS

The USGCRP will continue to focus on understanding and quantifying global carbon sources and sinks, with a particular emphasis on North America and adjacent oceans for the near term, and on filling critical gaps in understanding of the causes of carbon sinks on land as well as processes controlling the uptake and storage of carbon in the oceans. Key research plans for FY 2003 include:

North American Carbon Program: Conduct a range of preparatory activities for the North American Carbon Program (NACP), including detailed implementation planning for observational networks and intensive field campaigns, calls for proposals, establishment of a Science Team, deployment of new observational sites, and development and/or integration of inventory databases and new land-cover data sets. DOE, NOAA, NSF, and USDA have requested funding in FY 2003 as part of the Climate Change Research Initiative to begin implementing parts of the NACP.

Carbon Sequestration Potential in Agriculture: Complete an economic analysis of carbon sequestration potential associated with land-use change and land management activities in the U.S. agriculture sector. Building upon prior biophysical research on technical feasibility, this research on economic feasibility will explore the

Table 5
GLOBAL CARBON CYCLE
FY 2003 BUDGET BY AGENCY

(Discretionary budget authority in $millions)

Scientific Research	
NASA	40
NSF	24
USDA	15
DOE	14
NOAA	9
USGS	4
SI	<1
Scientific Research Subtotal	106
NASA Space-Based Observations	146
Global Carbon Cycle Total	252

(*Amounts are rounded to the nearest $million)

economic cost of achieving different levels of net carbon emission reduction in the agriculture sector, and the implications for net emissions, other environmental outcomes, commodity prices and output, and farm income of different levels of financial incentives for sequestration. The research, which will be reported during FY 2003, will provide information to support potential decisionmaking about alternative mitigation strategies.

Forest Carbon Estimates: Initiate development of improved estimates of carbon stored in forest biomass, forest soils, and wood products across the United States. The research, planned to be ongoing, will improve forest carbon measurement and estimation methodology. The results will provide a stronger scientific basis for international and domestic discussions about cost-effective ways to mitigate greenhouse gas emissions through forestry management practices. This work will build on existing expertise in carbon accounting and projection and will utilize U.S. Forest Service Forest Inventory and Analysis (FIA) data.

Carbon Exchange in U.S. Terrestrial Ecosystems: Over the next five years, carbon exchange results from the Ameriflux network of sites will provide more comprehensive estimates of carbon gain or loss by terrestrial ecosystems in the United

States. Additional analyses comparing net ecosystem carbon exchange (based on eddy covariance) with biometric and forest inventory methods will be conducted to identify requirements and protocols needed for accurate and reliable measurement of the terrestrial carbon cycle, and for achieving the goal of quantifying carbon storage in different ecosystems and landscapes. Legacies of prior disturbance and management, especially stand age and composition, will also be evaluated. Data from about five Ameriflux sites and a carbon cycle model analysis of net CO_2 exchange for a given vegetation type or a specified region will be reported in FY 2003.

Measurement of Air-Sea Carbon Fluxes: Instrument additional ships of opportunity with sensors that measure the partial pressure of CO_2 (pCO_2) at the ocean's surface, with the highest priority in undersampled regions in the North Atlantic and North Pacific oceans. The ultimate goal of this effort is to enable quantification of global-scale air-sea fluxes by combining remote-sensing and pCO_2 measurements. To accomplish this goal the variability of mechanisms controlling pCO_2 on short time and space scales must be determined. These data will be important in constraining estimates of the North American carbon budget as part of the developing North American Carbon Program.

Ocean Carbon Inventory: Repeat ocean inventories of carbon measurements, to better understand interannual and decadal variability, which is currently not well-understood. These measurements are part of the global climate observing system. One major goal is to assess changes in decadal inventories of anthropogenic CO_2 in response to increasing atmospheric concentrations of anthropogenic CO_2 as well as climate variability. These constraints will ultimately be used to better predict the behavior of the global oceanic carbon sink in response to further climate perturbations.