Carbon Cycle Science Working Group Recommendations Summary

U.S. Carbon Cycle Science Plan for 2010 to 2020

Summary

The global carbon cycle is changing rapidly as a result of human actions, altering Earth's climate. A decade ago, the 1999 U.S. Carbon Cycle Science Plan identified research priorities and many of these remain important today, including: improved measurement, increased observations, and long-term monitoring of the carbon cycle; experiments that manipulate the carbon cycle on land and in the oceans; and observation and modeling studies of processes that control the current and future carbon balance. However, additional new priorities for carbon cycle research are vitally important for the coming decade. The proposed focus for the upcoming decades centers on (i) understanding how natural processes and human actions affect the carbon cycle, on land, in the atmosphere, and in the oceans, (ii) determining how policy and management decisions affect the levels of the primary carbon containing gases, carbon dioxide and methane, in the atmosphere, and (iii) diagnosing how ecosystems, species, and natural resources are impacted by increasing greenhouse gas concentrations, the associated changes in climate, and by carbon management decisions. These priorities reflect an expanded focus on the effects of human activities on carbon cycling, the vulnerability and resilience of ecosystems to changes in carbon cycling and associated changes in climate, and the efficacy and environmental consequences of carbon management policies, strategies, and technologies. Additional research is also needed to evaluate uncertainties in carbon cycling and to coordinate researchers from different scientific disciplines to address common carbon cycle questions. We must continue to pursue key research priorities identified in the 1999 plan and incorporate these new priorities focused on human activity and ecosystem vulnerability within the scope of carbon cycle research. In so doing, we can make progress in the basic science and provide stronger scientific input to decision makers for carbon cycle management.

Introduction

Research on the cycling of carbon, including where the carbon comes from and where it ultimately goes, is central to addressing the climate change problem. Sustained atmospheric measurements of carbon dioxide started in the 1950s and continue today as a coordinated global monitoring network. From these and other observations, atmospheric carbon dioxide and methane concentrations are clearly increasing, driven largely by the burning of fossil fuels and the loss of carbon from forests, terrestrial soils, and melting permafrost. Process-based understanding of the global carbon cycle is needed to determine how that cycle is being modified by people and to develop sound climate change mitigation and adaptation strategies, including ways to reduce adverse impacts on the Earth's climate and ecosystems.

In 1998-1999, a Working Group of 16 carbon-cycle researchers prepared a science plan to focus and coordinate carbon-cycle research conducted in the United States. The intent was "to develop a strategic and optimal mix of essential components, which include sustained observations, modeling, and innovative process studies, coordinated to make the whole greater than the sum of its parts" (J.L. Sarmiento and S.C. Wofsy, *A U.S. Carbon Cycle Science Plan*, University

Corporation for Atmospheric Research, Washington, D. C., 1999). In the decade since the first Science Plan was published, carbon-cycle researchers have worked to improve carbon-observing networks and to coordinate research projects addressing the goals of the plan. Much progress has been made over the past decade, but funding constraints have prevented many aspects of the original plan from being fully realized. Furthermore, carbon-cycle research over the last decade has identified new issues that were not highlighted in the original plan. Now is the time for the research community to update the original plan for the coming decade, re-examining research and policy needs, outlining the funding necessary to meet those needs, and prioritizing current and future research directions.

Under the auspices of the United States Carbon Cycle Science Program's Science Steering Group, a working group of 27 scientists was formed in 2008 to review the 1999 Plan and to develop an updated strategy for research on the global carbon cycle to be conducted by U.S. researchers for the period from 2010 to 2020. A comprehensive review was conducted with wide input from the research and stakeholder communities. This report summarizes the proposed U.S. strategy for carbon cycle science over the next decade. The strategies described here align well with independent recommendations in the National Academy of Sciences' report, "Restructuring Federal Climate Research to Meet the Challenges of Climate Change" (National Research Council, Washington, D.C., 2009).

Approach

In outlining a research agenda for the next decade we have chosen to preserve the hierarchal structure adopted in the 1999 Carbon Cycle Science Plan. That is, we have articulated three overriding questions that guide the research agenda. Within this research agenda we have identified seven goals that define what we plan to accomplish over the next decade and beyond, and we have listed the primary research elements that we believe will have to be pursued to achieve the stated goals. The research elements are presented here in a matrix format because individual research elements can contribute to multiple goals and because achieving most goals will require contributions from multiple research elements. The research elements are the backbone of observations and analyses needed for all of the research science. While we can list the primary elements individually, their composite will determine success in reaching the stated Program goals.

The Fundamental Science Questions

The three fundamental science questions that form the basis of the Plan for the next decade are:

- **Q1 How do natural processes and human actions affect the carbon cycle, on land, in the atmosphere, and in the oceans?**
- **Q2 How do policy and management decisions affect the levels of the primary carbon containing gases, carbon dioxide and methane, in the atmosphere?**
- **Q3 How are ecosystems, species, and natural resources impacted by increasing greenhouse gas concentrations, the associated changes in climate, and by carbon management decisions?**

These three questions are, as elaborated elsewhere in this report, extensions from the two Fundamental Science Questions posed in the 1999 Plan. They reflect increased concern with the impact of human activities – both inadvertent and planned – on the global carbon cycle, increased appreciation that policy and management decisions are likely to be made in a specific effort to manage human impacts on the climate system, and increased recognition that carbon dioxide emissions have important direct and interactive impacts other than through their effect on climate. These considerations are included in the fundamental research questions, acknowledging that there are still important questions of basic science about the "natural" cycling of carbon that remain unanswered or inadequately answered.

GOALS for the Carbon Cycle Science Program:

Seven proposed goals provide concrete milestones for carbon cycle science for the upcoming decade. The goals are listed here, and the primary questions addressed are given in brackets after each goal.

G1 Provide clear and timely explanation of past and current variations observed in atmospheric CO_2 and CH_4 - and the uncertainties surrounding them. (Q1, Q2) To address this goal, we need to develop the capability to estimate variability in carbon sources and sinks, as well as the processes controlling that variability. This goal also provides a link to the human dimensions of the carbon cycle, because understanding the economic and policy effects on anthropogenic emissions and sequestration efforts is essential for understanding variations in atmospheric CO_2 and CH_4.

G2 Quantify and verify anthropogenic carbon emissions and sequestration using methods that are transparent and relevant to policymakers. (Q1, Q2) Human activities are currently driving the increase in atmospheric CO_2. This goal involves the development of a framework for verifying emissions and sequestration through a combination of "bottom up" (e.g. inventory) and "top down" (e.g. atmospheric observation based) methods. The goal is focused on accurately determining the magnitude of the fluxes, their response to mitigation efforts, and the monitoring and verification of mitigation agreements and activities.

G3 Determine and evaluate the carbon stocks and flows that are most vulnerable to climate change and land–use change, emphasizing potential positive feedbacks to sources or sinks that make climate stabilization more critical or more difficult. (Q1, Q2, Q3) All carbon reservoirs and carbon processes are not equally vulnerable to change, resilient to stress, responsive to management, and susceptible to unintended consequences of management decisions. We need to be able to identify the signs of change, the symptoms of trouble, and the opportunities for management wherever they occur in the Earth's ecosystems.

G4 Predict how ecosystems, biodiversity, and natural resources will change under different CO_2 and climate change scenarios. (Q3) Even in the absence of climate change, rising atmospheric CO_2 alters ecological factors such as the chemistry of surface waters and the biodiversity of terrestrial ecosystems. For instance, changes in water chemistry have been shown to have important but still poorly understood consequences for coral reefs and other marine organisms with carbonate shells. This goal assesses the impacts of increased atmospheric CO_2 on ecosystem form and function.

G5 Determine the likelihood of success and the potential for unintended consequences of carbon-management pathways that might be undertaken to achieve a low carbon future. (Q1, Q2, Q3) The global carbon cycle is complex and closely linked to the energy, water, and nutrient cycles on Earth as well as to demographic and economic systems globally. Ethical and equity issues are central to what actions might be taken, who takes them, and what consequences result. This goal aims to understand interlinked natural and managed systems well enough for individuals, corporations, and governments to be able to make rational and well-informed decisions on how to best reduce their environmental footprint.

G6 Understand decision-maker needs for current and future carbon-cycle information and provide data and projections that are relevant, credible, and legitimate for their decisions. (Q1, Q2, Q3) Useful science involves both asking the right questions and making the results available in a useful way. A goal of carbon cycle research is to interact with decision makers in an on-going dialogue so that socially relevant questions are addressed and that research results are accessible where and when needed. Decision makers need a sound understanding of what is happening now and sound projections of what can be expected in the future. We also recognize the importance of curiosity-driven research that will provide the basic understanding needed to address questions not yet asked by decision makers.

G7 Establish baseline data sets and monitoring systems for key carbon system variables and begin developing long-term records to detect change. In support of all of the other goals, we need an optimally designed and integrated long-term monitoring system of essential atmospheric, oceanic, biologic, demographic, and socioeconomic data to establish baselines, evaluate change, understand processes, and monitor mitigation actions. With this goal comes a commitment to data management and rapid data access.

The primary ELEMENTS of carbon cycle research in the U.S. for the next decade

Note that all four of the primary elements defined here are needed to address each of the goals outlined in the last section.

E1 Global and regional observational networks

- Earth observing satellites for carbon and related parameters.
- Integrated tower and aircraft sampling of atmospheric carbon and related species.
- Coordinated global ocean carbon and ocean acidification observing networks.
- Global networks of terrestrial inventories and fluxes, including soils.
- Monitoring and assessment of human systems, including mitigation and adaptation strategies and associated impacts.

	Program Elements			
Goals	Sustained observations	Process studies and	Modeling, prediction,	Communication dissemination

		experiments	synthesis	
Explain observed variations	X	X	X	X
Quantify anthropogenic emissions	X	X	X	X
Evaluate vulnerable stocks and flows	X	X	X	X
Ecosystem impacts	X	X	X	X
Evaluate carbon management options	X	X	X	X
Decision support and information management	X	X	X	X

E2 Global, regional, urban, and ecosystem scale process studies of system dynamics and function

- Experiments to distinguish natural variability from anthropogenic changes.
- Intensives studies to understand physical and socioeconomic processes responsible for controlling carbon emissions, uptake, and storage as well as how they might change in the future.
- Manipulative laboratory and field studies to elucidate the response of representative land and marine ecosystems to climate and biogeochemical change.

E3 Data assimilation, modeling, prediction, synthesis, and uncertainty quantification

- Coupled physical and socio-economic components of existing climate system and integrated assessment models to produce first-generation integrated Earth System models.
- Synthesis of observations, experimental results, and models to reduce uncertainty in model predictions and to increase model skill.
- Data assimilation methods for optimally integrating atmospheric observations, including land, ocean, and fossil fuel fluxes, and coupling those observations with atmospheric transport models to quantify and reduce uncertainty in carbon cycle estimates.

E4 Communications across Traditional Disciplines

- Regular, two-way communication between the carbon science community and the public, including seeking out critical decision-maker and public information needs.
- Tools to translate results from scientific synthesis and prediction into quantitative, understandable products for policy and management professionals.
- Approaches for communicating the level of certainty that scientists have in various components of the carbon budget to managers, decision-makers, and the general public.
- Regional analyses to determine how management options are being evaluated and how the carbon science community can help inform that process.