CHAPTER TWO

RESEARCH FOCUSED ON KEY CLIMATE CHANGE UNCERTAINTIES

from the

Strategic Plan
for the
Climate Change Science Program

By the agencies and staff of the
US Climate Change Science Program

Review draft dated 11 November 2002

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11 November 2002

Dear Colleague,

The Climate Change Science Program will hold the U.S. Climate Change Science Program Planning Workshop for Scientists and Stakeholders at the Marriott Wardman Park Hotel in Washington, D.C., from 3-5 December 2002. The purpose of the Workshop is to provide a comprehensive review of the discussion draft of the Strategic Plan for U.S. climate change and global change research. This Workshop will offer extensive opportunities for the scientific and stakeholder communities to provide comment and input to the Climate Change Science Program Strategic Plan. When finalized by April 2003, the Strategic Plan will provide the principal guidance for U.S. climate change and global change research during the next several years, subject to revisions as appropriate to respond to newly developed information and decision support tools.

We are writing to request your comments on the discussion draft of the Climate Change Science Program Strategic Plan. Comments on all elements of the plan from all communities are essential in order to improve the plan and identify gaps. In your review, we ask you to provide a perspective on the content, implications, and challenges outlined in the plan as well as suggestions for any alternate approaches you wish to have considered, and the types of climate and global change information required by policy makers and resource managers. We also ask that you comment on any inconsistencies within or across chapters, and omissions of important topics. For any shortcomings that you note in the draft, please propose specific remedies. To participate in the review it is not necessary that you review the entire plan.

We ask that comments be submitted by E-mail to <comments@climatescience.gov>. All comments submitted by 13 January 2003 will be posted on the <http://www.climatescience.gov> website for public review. While we are unable to promised detailed responses to individual comments, we confirm that all submitted comments will be given consideration during the development of the final version of the Strategic Plan.

Attached to this letter are instructions and format guidelines for submitting review comments. Following the instructions will ensure that your comments are properly processed and given appropriate consideration. If you wish to distribute copies of the plan to colleagues to participate in the review, please provide them with a copy of this letter as well as the attached instructions and format guidelines. We have posted the plan on the workshop website at <http://www.climatescience.gov>. PDF files for individual chapters of the plan can be downloaded from this site. If you have any questions, please contact: Sandy MacCracken at 1-202-419-3483 (voice), 1-202-223-3065 (fax), or via the address in the footer below.

We appreciate your contribution of time and expertise to this review, and look forward to your response.

Sincerely,

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, U.S. Climate Change Science Program

Instructions For Submission of Strategic Plan Review Comments

Thank you for participating in the review process. Please follow the instructions for preparing and submitting your review. Using the format guidance described below will facilitate our processing of reviewer comments and assure that your comments are given appropriate consideration. An example of the format is also provided. Comments are due by **13 January, 2003**.

- Select the chapter(s) or sections of chapters which you wish to review. It is not necessary that you review the entire plan. In your comments, please consider the following issues:
  - **Overview**: overview on the content, implications, and challenges outlined in the plan;
  - **Agreement/Disagreement**: areas of agreement and disagreement, as appropriate;
  - **Suggestions**: suggestions for alternative approaches, if appropriate;
  - **Inconsistencies**: inconsistencies within or across chapters;
  - **Omissions**: omissions of important topics;
  - **Remedies**: specific remedies for identified shortcomings of the draft plan;
  - **Stakeholder climate information**: type of climate and global change information required by representative groups;
  - **Other:** other comments not covered above.
- Please do not comment on grammar, spelling, or punctuation. Professional copy editing will correct deficiencies in these areas for the final draft.
- Use the format guidance that follows for organizing your comments.
- Submit your comments by email to <comments@climatescience.gov> by 13 January, 2003.

Format Guidance for Comments

Please provide background information about yourself on the first page of your comments: your name(s), organization(s), area of expertise(s), mailing address(es), telephone and fax numbers, and email address(es).

- Overview comments on the chapter should follow your background information and should be numbered.
- Comments that are specific to particular pages, paragraphs or lines of the chapter should follow your overview comments and should identify the page and line numbers to which they apply.
- Comments that refer to a table or figure should identify the table or figure number. In the case of tables, please also identify the row and column to which the comment refers.
- Order your comments sequentially by page and line number.
- At the end of each comment, please insert your name and affiliation.

Format Example for Comments

I. Background Information

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II. Overview Comments on Chapter 5: Atmospheric Composition

First Overview Comment: (Comment)
Reviewer's name, affiliation: John Doe, University College

Second Overview Comment: (Comment)
Reviewer's name, affiliation: John Doe, University College

III. Specific Comments on Chapter 5: Atmospheric Composition

Page 57, Line 5: (Comment)
John Doe, University College

Page 58, Line 32 - Page 59, Line 5: (Comment)
John Doe, University College

Table 1-4, Row 3, Column 6: (Comment)
John Doe, University College

Please send comments by email to <comments@climatescience.gov>

Foreword

In February 2002 President George W. Bush announced the formation of a new management structure, the Climate Change Science Program (CCSP), to coordinate and direct the US research efforts in the areas of climate and global change. These research efforts include the US Global Change Research Program (USGCRP) authorized by the Global Change Research Act of 1990, and the Climate Change Research Initiative (CCRI) launched by the President in June 2001 to reduce significant uncertainties in climate science, improve global climate observing systems, and develop resources to support policymaking and resource management.

The President's Climate Change Research Initiative was launched to provide a distinct focus to the 13-year old Global Change Research Program. The CCRI focus is defined by a group of uncertainties about the global climate system that have been identified by policymakers and analyzed by the National Research Council in a 2001 report requested by the Administration.

The Climate Change Science Program aims to balance the near-term (2- to 4-year) focus of the CCRI with the breadth of the USGCRP, pursuing accelerated development of answers to the scientific aspects of key climate policy issues while continuing to seek advances in the knowledge of the physical, biological and chemical processes that influence the Earth system.

This *discussion draft* strategic plan has been prepared by the thirteen federal agencies participating in the CCSP, with input from a large number of scientific steering groups and coordination by the CCSP staff under the leadership of Dr. Richard H. Moss, to provide a vehicle to facilitate comments and suggestions by the scientific and stakeholder communities interested in climate and global change issues.

We welcome comments on this draft plan by all interested persons. Comments may be provided during the US Climate Change Science Program Planning Workshop for Scientists and Stakeholders being held in Washington, DC on December 3 – 5, 2002, and during a subsequent public comment period extending to January 13, 2003. Information about the Workshop and the written comment opportunities is available on the web site www.climatescience.gov. A specially formed committee of the National Research Council is also reviewing this draft plan, and will provide its analysis of the plan, the workshop and the written comments received after the workshop. A final version of the strategic plan, setting a path for the next few years of research under the CCSP, will be published by April 2003. We appreciate your assistance with this important process.

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, Climate Change Science Program

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of the
Strategic Plan for the Climate Change Science Program

CHAPTER 2

RESEARCH FOCUSED ON KEY CLIMATE CHANGE UNCERTAINTIES

This chapter's contents…

1. What aerosols are contributing factors to climate change and what is their relative contribution to climate change?
2. What are the magnitudes and distributions of North American carbon sources and sinks, and what are the processes controlling their dynamics?
3. How much of the expected climate change is the consequence of feedback processes?

The Climate Change Research Initiative (CCRI) will address key and emerging climate change science areas that offer the prospect of significant improvement in understanding of climate change phenomena, and where accelerated development of decision support information is possible. The purpose of CCRI accelerated science activities is to enhance the ongoing US Global Change Research Program (USGCRP) elements described in Part II where focused effort would rapidly lead to critical decision support information. At the request of the President, the National Research Council (NRC) identified "the areas in the science of climate change where there are the greatest certainties and uncertainties," (NRC, 2001a). This section outlines three key areas where the CCRI will address the specific uncertainties identified by the NRC, including: atmospheric concentrations of aerosols (see also Chapter 5); North American carbon sources and sinks (see also Chapter 9); and climate feedbacks and climate system sensitivities (see also Chapters 5, 6, and 7).

1. What aerosols are contributing factors to climate change and what is their relative contribution to climate change?

Aerosols play a unique role in the Earth's radiation (energy) budget, and scientists believe they play a large part in global and regional climate changes. However, because aerosols have a relatively short atmospheric residence time, have a spatially and temporally heterogeneous (non-uniform) distribution, and include a complex mixture of substances from numerous sources (e.g., black carbon, sulfate), there are substantial uncertainties in quantifying their role.

The Climate Change Science Program (CCSP) plan in Chapter 5 and the National Aerosol-Climate Interactions Program plan (NACIP, 2002) emphasize the importance of characterizing the distribution of all major aerosol species and their spatial and temporal variability, the separate contributions of aerosols from various anthropogenic activities and natural sources, and the processes by which the separate sources are linked to the global distribution of aerosols and their radiative characteristics.

Enhanced aerosol-climate research is needed to deliver focused information within 2-4 years that would be helpful in quantifying the role of aerosols in regional and global climate change in decision-relevant terms. The following research emphases will allow more meaningful assessments and projections, with a focus on decision-relevant products by 2006.

RESEARCH NEEDS

- Strongly intensity efforts to determine the composition of organic aerosols and develop simpler instruments for measurement of carbon-associated aerosols by class.
- Establish realistic aerosol and precursor source-strength estimates for specific aerosol compositions for the industrial era.
- Enhance field and laboratory studies of the processes that influence aerosol distributions and characteristics, including those involved in indirect (e.g., cloud) effects.
- Develop aerosol chemistry/transport models and carry out simulations for aerosol source-strength scenarios.
- Compare simulations of past aerosol compositions to records such as ice, bog, and lake core data.
- Focus on comparing the geographic and height dependence of simulated aerosol distributions and radiative characteristics against field and composition-specific (e.g., polarimetric) satellite data, with an emphasis on regions that can best test the reliability of current model simulations (e.g., using the extensive North American emission data base).
- Emphasize comprehensive climate-response simulations including the direct and indirect effects of aerosols, with an emphasis on placing bounds on the indirect effects and on the degree to which simulations of past conditions match observations.

PRODUCTS AND PAYOFFS

- Improved global aerosol climatology, including regional distribution by major aerosol type (e.g., black carbon) and radiative properties, which will provide updated and more reliable input to climate models.
- Empirically validated assessment of the capabilities of current models to link emissions of aerosols and their precursors to aerosol distributions and the warming/cooling properties of aerosols, which will help quantify the uncertainties in simulating the response of radiative forcing to potential emission changes.
- Improved assessment and attribution of observed climate changes, with better quantitative links between climate change and strong regional forcing, such as aerosols and tropospheric ozone.

- Improved overall assessment of the climate effects of aerosols and clouds, compared to the benchmark of the Intergovernmental Panel on Climate Change (IPCC) *Third Assessment Report* (IPCC, 2001).
- Vital quantitative support for the suite of CCRI "If…, then…" climate scenarios and options that are planned as decision support tools, including better estimates of the uncertainties associated with the scenarios.
- Information on potential options for obtaining changes in climate forcing via changes in the aerosol forcing, which, similar to those for tropospheric ozone, might be achieved more rapidly than by changing carbon dioxide (CO_2) forcing because aerosols have a shorter residence time in the atmosphere.
- Quantitative information on how changes in aerosol-related emissions associated with air quality decisions have and/or will impact the radiative forcing of climate change, thereby allowing multiple issues to be more effectively addressed.

2. What are the magnitudes and distributions of North American carbon sources and sinks, and what are the processes controlling their dynamics?

Intensive research to quantify and explain the processes controlling North America's carbon sources and sinks is a near-term priority. Accelerated research within the overall framework of the North American Carbon Program (NACP) will address fundamental questions relating to the buildup of CO_2 and methane (CH_4) in the atmosphere, and the fraction of fossil-fuel carbon being taken up by North America's ecosystems and coastal oceans.

Investments over the past decade have resulted in an unprecedented opportunity to study the carbon cycle over a scale not previously attempted—that of continents and ocean basins. Observational capabilities such as the US forest and soil inventories, flux and tall tower networks, Atlantic and Pacific ocean time series and ships of opportunity, and vegetation and ocean color remote sensing have all contributed to a better understanding of components of the carbon cycle for North America and adjacent ocean basins. Current estimates of regional distributions of carbon sources and sinks derived from atmospheric and oceanic data and models differ from forest inventory and terrestrial ecosystem model estimates. Scientific understanding has now progressed to the point where targeted investments can yield major returns within five years. The CCRI will accelerate the observational, experimental, analytical, and data management activities needed to address uncertainties, reduce errors, and produce a consistent analysis of carbon sources and sinks for North America.

RESEARCH NEEDS

The integrated NACP requires enhanced observational networks and improved monitoring techniques; studies of key controlling processes and resource management regimes that regulate carbon storage and fluxes; modeling that integrates among atmospheric, land, ocean, and human systems; and periodic reporting. Priorities for an accelerated initial phase are:

- Strengthening existing carbon measurement networks; including augmenting flux and biometric measurements at existing agriculture, rangeland, and forest sites and adding new coastal ocean carbon surveys;
- Developing and improving *in situ* carbon measurement sensors;
- Developing innovative diagnostic modeling frameworks and model-data fusion approaches to assure that data are analyzed promptly and efficiently;
- Optimizing national inventories for carbon accounting;
- Improving databases of fossil fuel use, land use and land cover, and land management; and
- Developing remote sensing technologies for measuring atmospheric CO_2, CH_4, and carbon monoxide and aboveground biomass.

An intensive regional-scale field program is needed and could begin as early as 2004. It will require *in situ* observations and process studies, intensive aircraft and remote sensing surveys, enhanced inventories, and modeling. It is also needed as a test bed for subsequent continent-wide implementation of the NACP. The NACP will leverage existing agency research activities and observational programs, but will require additional targeted investments to achieve the desired near-term results.

PRODUCTS AND PAYOFFS

- A quantitative analysis of North American carbon sources and sinks, describing land, ocean, atmosphere, and human systems, will be delivered. Uncertainties in estimates of carbon sink capacity and longevity will be reduced.
- A prototype *State of North American Carbon Report* will be produced based on a synthesis using existing data and models (2 years); a more comprehensive report, including results from an accelerated field program and integrated carbon models, will also be produced (4 years).
- Demonstration and evaluation of measurement approaches for carbon accounting.

Accelerated research within the NACP will provide near-term information for decision support, scenario analysis, and carbon management. Results of this research will also establish the scientific underpinning needed to evaluate carbon management in US croplands, forests, rangelands, soils, and coastal systems and to support analyses of greenhouse gas trends and net emissions intensity. These results will contribute to decision analysis of the impacts of various resource management policies.

3. How much of the expected climate change is the consequence of feedback processes?

WHAT IS THE CONTRIBUTION OF CLOUDS AND WATER VAPOR FEEDBACKS?

Water plays a key role in the radiative balance of the atmosphere: water vapor is the most important of the greenhouse gases, and clouds (whether liquid or ice) affect both vertical heating profiles and geographic heating patterns. In addition, results from climate models suggest there will be an overall increase in water vapor as the climate warms.

Predictions of climate change vary in large part because of differences in the way that the various feedback processes are represented in the models. The greatest differences are those associated with water vapor and cloud processes. For example, scientists do not know how the amount and distribution of clouds will change, both vertically and horizontally, as the water vapor in the atmosphere changes. More importantly, they do not know how the associated changes in radiative forcing and precipitation will affect climate. The feedback to the Earth's radiative balance and cloud structure from increased upper tropospheric water vapor is potentially quite large and could be positive or negative.

Basic understanding of the processes that control the atmospheric water vapor and clouds must be improved and incorporated into models. Better representation of the distribution of water vapor is critical given its contribution to temperature increases as an active radiative gas, as well as its role in cloud formation. Because the physical processes responsible for the horizontal and vertical transport of water vapor and cloud formation occur at scales that are not resolved by climate models, they must be parameterized (simplified for incorporation in the models). New, integrated, three-dimensional data sets of cloud properties and water vapor will be produced to reduce uncertainties due to the representation of clouds and water vapor in climate models. A combination of these data sets, new observations, and targeted process studies will be developed with a focus on model improvements.

RESEARCH NEEDS

- Combined *in situ* and remotely-sensed measurements of water vapor and radiative properties for process studies of water vapor transport into the upper atmosphere by convection, with emphasis on the tropics.
- Analysis of three-dimensional data on cloud properties and dynamics, cloud radiation, and precipitation processes using a combination of ground-based measurements and satellite remote sensing.
- Tests of cloud parameterizations for General Circulation Models (GCMs) using process-resolving models.

- Tests of cloud parameterizations against observations in the framework of operational regional or global atmospheric circulation models.
- Tests of climate model sensitivity to three-dimensional cloud representation employing cloud-resolving models.

While the studies described here will substantially improve understanding of feedbacks, other studies proposed as part of *A Plan for a New Science Initiative on the Global Water Cycle* (Hornberger et al., 2001) and the CCSP Strategic Plan (see Chapter 7) will be critical to predicting the impact of climate change on precipitation and water availability, for example, determining long-term trends in the global water cycle including the character of hydrologic events and their causes; developing the ability to bridge climate and weather modeling; and determining the relationship between the water cycle and biogeochemical/ecological processes.

PRODUCTS AND PAYOFFS

- Improved estimates of global radiative energy losses arising from water vapor variability in the upper troposphere.
- New, observationally tested cloud parameterizations for GCMs that can help to reduce uncertainties in predictions of climate change related to clouds and water vapor transport.

HOW DO FEEDBACKS IN THE POLAR REGIONS AFFECT CLIMATE CHANGE?

The polar regions, particularly the Arctic, are especially sensitive to changes in climate, and models consistently predict future warming to be much more significant in these regions than elsewhere. This sensitivity arises primarily from the positive albedo (how much radiation is reflected by the surface) feedbacks associated with melting of snow and ice that blanket most of the region, which can as much as triple the amount of absorbed solar radiation. Compounding this sensitivity is the fact that sea ice cover modulates the exchange of heat and moisture between the ocean and atmosphere. The disappearance of insulating sea ice increases the transfer of energy and water vapor from the ocean to the atmosphere, enhancing atmospheric warming. Furthermore, Arctic soils serve as significant reservoirs of CO_2 and CH_4, and warming of the region could result in increased emission of these greenhouse gases, contributing to the carbon cycle in ways that are not yet clear.

In addition to high-latitude precipitation, and freshwater discharge from melting snow and ice, sea ice cover plays a major role in the Atlantic thermohaline circulation (controlled by temperature and salinity variations) in the Arctic, and the formation of Antarctic bottom water in the Southern Hemisphere. These are two dominant factors in ocean circulation that directly influence climate throughout the world. It is unclear how future polar climate changes, in particular changes in sea ice cover, will affect these oceanic drivers of the global climate system. In the case of the Arctic, for example, it is possible that increased surface freshening (reduced salinity) associated with enhanced melting and precipitation may suppress the overturning in the North Atlantic Ocean, which may lead to major abrupt changes in climate, such as has been observed in paleoclimatic data.

Ice on land is of critical importance for climate and sea level. The Greenland and Antarctic ice sheets contain enough ice to raise sea level by more than 70 meters (230 feet). The smaller glaciers and ice caps contain the equivalent of only about 0.5 meters (1.6 feet) of sea level rise, but they are far more susceptible to near-term changes and are disappearing rapidly. While global sea level is currently estimated to be rising at a rate of nearly 2 millimeters (0.08 inches) per year, there is evidence that in the past sea level has risen by as much as 50 millimeters (2 inches) per year in some locations. Such rapid rises, consistent with recently discovered abrupt climate changes, can only be attributed to changes in the Earth's larger ice masses. Given the potential economic consequences of sea level rise, there is a pressing need to understand changes in the amount of ice stored on land, and the mechanisms that drive these changes.

Representation of polar climate in climate models is not as advanced as that of the lower latitudes. This arises in part because of the limited data available for model development, refinement, and validation, and a limited understanding of the processes at work. An enhanced observation system and the use of existing and future satellite data sets should improve the representation of these areas in climate models, which is necessary to accurately predict future climate changes and assess the potential for these changes to be abrupt.

Warming temperatures may also affect Arctic land areas. If continuous permafrost areas become discontinuous and discontinuous areas experience complete summer thawing, the hydrology of northern land areas would be substantially altered. Many of the wetlands, marshes, and perched lakes in the Arctic are underlain by permanent ice. The reduction of this ice would lead to the infiltration of the water into the soil and widespread changes in vegetation patterns. The release of greenhouse gases such as CH_4 associated with wetlands would expand in areas where melt water resulting from deeper and longer thaw periods does not have a natural drainage path to the ocean.

Warming could also lead to changes in the water cycle in polar regions. Reducing the uncertainties in current understanding of the relationships between climate change and Arctic hydrology is critical for evaluating the potential impacts of climate change on Arctic communities and their infrastructure. Further, a better understanding of these relationships may allow the development of monitoring procedures that use changes in the Arctic as a signal of the progress of global climate warming.

RESEARCH NEEDS

- Determination of basin-wide Arctic sea ice thickness, particularly in the marginal seas, for a period sufficient to determine if observed historic changes are present across the basin.
- Modeling of observed sea ice changes to determine the relative role of transport versus net loss.

- Establishing the mass balance and ice dynamic regime of the Thwaites/Pine Island drainage system of the West Antarctic Ice Sheet and assessing its stability through observationally constrained models.
- Assessment of the mass balance of the Greenland ice sheet, its variability, and its potential contributions to near-term sea level rise.
- Measurement of permafrost temperatures and thaw patterns for five years in sufficient detail to establish regional thaw patterns.

PRODUCTS AND PAYOFFS

- Reduced uncertainty in estimates of the future state of the Arctic Ocean, its impact on global climate, and its navigability for strategic and commercial purposes.
- Ability to measure sea surface salinity from space in order to detect equatorward transport of fresh water from the melting of sea ice and its impact on thermohaline circulation.
- Initial assessments of the likelihood of polar changes to contribute to abrupt climate change in the near future.
- More reliable assessment of future sea level changes and the potential for rapid sea level rise (>10 mm/yr), and reduction in the uncertainty of sea level rise estimates for the 21st century.
- Quantification of permafrost contributions to the carbon budget and climate warming.

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- IPCC, 2001d. *Synthesis Report*. A Contribution of Working Groups I, II, and III

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