CHAPTER 7

WATER CYCLE

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 7
WATER CYCLE

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Question 1: To what extent does the water cycle vary and change with time, and what are the internal mechanisms and external forcing factors, including human activities, responsible for variability and change?

Question 2: How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

Question 3: What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

Question 4: How do the water cycle and its variability affect the availability and quality of water supplied for human consumption, economic activity, agriculture, and natural ecosystems; and how do its interactions and variability affect sediment and nutrient transports, and the movement of toxic chemicals and other biogeochemical substances?

Question 5: What are the consequences of global water cycle variability and change, at a range of temporal and spatial scales, for human societies and ecosystems? How can the results of global water cycle research be used to inform policy and water resource management decision processes?

Key Linkages

The global water cycle is an integral part of the Earth/climate system, manifesting itself through many processes and phenomena, such as clouds, precipitation, mountain snow packs, groundwater, droughts, and floods. The cycling of water exerts an important control on climate variability as a result of its complex feedbacks and interactions with other components of the climate system. Many of the uncertainties with respect to long-term changes in the climate system and their potential impacts, as described in Intergovernmental Panel on Climate Change (IPCC) reports, arise from our inadequate understanding of, and inability to model, water cycle processes as they feed back on the climate system. In particular, clouds, precipitation, and water vapor produce feedbacks that alter surface and atmospheric heating and cooling rates, and redistribution of the associated heat sources and sinks lead to adjustments in atmospheric circulation and precipitation patterns. The current inability to adequately represent these complex multiscale processes in climate models is a major source of uncertainty in long-term climate change projections and impacts, and seasonal to interannual climate forecasts.

The needs for adequate supplies of clean water and advance preparations for extreme hydrologic events, such as floods and droughts, pose major challenges to social and economic development and to the management of natural resources and ecosystems. Water supplies are subject to a range of stresses, such as population growth, pollution and industrial and urban development. These stresses are exacerbated by variations and changes in climate that alter the hydrologic cycle in ways that are currently unpredictable. These concerns are documented in a recent report on research needs and opportunities, *A Plan for a New Science Initiative on the Global Water Cycle* (Hornberger et al., 2001). This report identified questions and strategies for research on climate change and water cycle trends, prediction, and the linkages between water and nutrient cycles in terrestrial and freshwater ecosystems.

Advances in observing techniques, combined with increased computing power and improved numerical models, now provide new opportunities for significant scientific advances through a concerted, integrated Global Water Cycle research effort. Recently, reasonably accurate predictions of variations in the water cycle have been produced for some years in some regions. This new capability to produce credible predictions provides a basis for dialogue between the scientific community and water system and land managers. This dialogue is enabling the research community to understand decisionmakers' management processes and information needs. It will also identify opportunities for improving the adaptability of infrastructure and management practices to runoff variations, long-term changes and extremes.

To address the urgent need for better information on the water cycle, the Climate Change Science Program (CCSP) is planning its Global Water Cycle research program around two overarching questions, namely:

- **How do water cycle processes (including climate feedbacks) and human activities influence the distribution and quality of water within the Earth system, and to what extent are changes predictable? How are these processes and activities linked to the cycling of important chemicals, such as carbon, nitrogen, other nutrients, and toxic substances, and how do they affect human and ecosystem health?**
- **How will large-scale changes in climate, demographics, and land use (including changes in agricultural and land management practices), affect the capacity of societies to provide adequate supplies of clean water for human uses and ecosystems and respond to extreme hydrologic events?**

Question 1: To what extent does the water cycle vary and change with time, and what are the internal mechanisms and external forcing factors, including human activities, responsible for variability and change?

STATE OF KNOWLEDGE

Recent observations suggest that there have been notable changes in critical water variables: precipitation amounts, location, and type; surface and subsurface runoff; cloud cover, both amount and type; atmospheric water vapor; soil moisture; groundwater; etc. Although techniques for measuring many of these variables have improved, the number of observations is limited and, in some cases, new sensors are needed. Current models cannot properly simulate the global water cycle. Moreover, we cannot definitively attribute observed trends to human-induced climate changes as opposed to natural variability.

ILLUSTRATIVE RESEARCH QUESTIONS

- How have the characteristics of the water cycle changed in recent years, and are the changes due to natural variability or human induced causes?
- What are the key mechanisms and processes responsible for maintaining the global water cycle and its variability over those space and time scales relevant for climate?
- How are the rates of regional groundwater recharge, soil moisture availability, and runoff production affected by changing global precipitation patterns, vegetation distributions, and cryospheric processes (processes occurring in frozen regions)?
- How have changes in land use and water management infrastructure and practices affected trends in regional and global water cycles?

RESEARCH NEEDS

New observing capabilities, both satellite and *in situ*, will be critical to detecting patterns and quantifying fluxes, especially instruments for global measurement of terrestrial water cycle variables such as soil moisture. Existing *in situ* networks need to be maintained and enhanced, and data sets developed to ensure consistency between historical and new observations. Network enhancements and open data exchange are needed to address water quantity issues in critical areas such as high mountain areas and river deltas. Also needed are new data assimilation techniques that combine different kinds of data, and data with varying spatial and temporal characteristics, to produce consistent data products for research and process studies of key water cycle variables, such as clouds, precipitation, and soil moisture. Complementary research is planned under the Land Use/Land Cover Change program (Chapter 8).

PRODUCTS AND PAYOFFS

- Documentation of trends in key variables through data analysis and comparison with model-simulated trends to evaluate uncertainty in climate predictions for policy developers (2-5 years).

- Integrated long-term global and regional data sets of critical water cycle variables from satellite and *in situ* observations for monitoring climate trends and early detection of climate change (5-15 years).
- Improved regional water cycle process parameterizations based on process studies conducted over regional test beds to improve the reliability of climate change projections (5-15 years).

Question 2: How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

STATE OF KNOWLEDGE

As global temperatures warm, the atmosphere will hold more moisture. Given the same carbon dioxide (CO_2) increase, climate models produce different rates of warming and drastically different patterns of circulation, precipitation, and soil moisture depending on their parameterizations (simplified representations) of basic water cycle processes. This large discrepancy in model predictions indicates that the representation of key water cycle processes is rudimentary at best. A better understanding of these changes and the consequences of sub-grid processes (processes occurring at smaller scales than the model grid size) are needed to improve the reliability of climate projections. In particular, while some progress has been made in cloud parameterizations, the representation of clouds and cloud processes remains the greatest uncertainty in climate models. Further, cloud processes are inextricably linked to other critical water cycle processes.

ILLUSTRATIVE RESEARCH QUESTIONS

- What is the sign and magnitude of the net water vapor-cloud-radiation-climate feedback effect and how does it vary with latitude and season?
- How do changes in water vapor and water vapor gradients, from the stratosphere to the surface, affect climate variables such as radiation fluxes, surface radiation budgets, cloud formation and distribution, and precipitation patterns, globally and regionally?
- How do aerosols, their chemical composition, and distribution affect cloud formation and precipitation processes and patterns?
- How do freshwater fluxes to and from the ocean that affect the global ocean circulation and climate vary, and how may they be changing?
- How do changes in global and regional water cycles feed back on biogeochemical processes (e.g., vegetative growth and carbon sequestration), in cold regions where climate change is expected to have a substantial impact on permafrost melting, seasonal snow packs, and freeze/thaw cycles?
- How do changes in global and regional water cycles feed back on tropical and higher-latitude regions in the form of altered frequencies of droughts, floods, and storms, including hurricanes?

RESEARCH NEEDS

Model development will be accelerated by interdisciplinary field studies over regional test beds that provide much needed understanding of scaling effects. New parameterizations of water cycle/climate feedbacks (e.g., cloud-aerosol and land-atmosphere) and sub-grid scale processes (e.g., clouds, precipitation, evaporation, etc.) will have to be developed and validated, and the sensitivity of global models to these new parameterizations will have to be evaluated. Complementary research is planned under the Atmospheric Composition (Chapter 5) and Climate Variability and Change (Chapter 6) programs, and components of these programs, accelerated through the Climate Change Research Initiative (CCRI), are described in Chapter 2.

PRODUCTS AND PAYOFFS

- New parameterizations for water vapor, clouds, and precipitation processes for use in climate models, using new cloud-resolving models created in part as a result of field process studies (see Chapter 2) (2-5 years).
- Enhanced data sets for feedback studies including water cycle variables, aerosols, vegetation, and other related feedback variables generated from a combination of satellite and ground-based data to evaluate the role of human influences in climate change (5-15 years).
- New models capable of simulating the feedbacks between the water cycle and the climate system (including biogeochemical cycles) will support the development of carbon management strategies and resource management tools (5-15 years).

Question 3: What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

STATE OF KNOWLEDGE

Current global and regional models demonstrate limited skill in predicting precipitation, soil moisture, and runoff on time scales beyond a few days. One of the most critical deficiencies in climate change projections involves precipitation and soil moisture—essential parameters for assessments of the impacts of climate change and variability. While the large scale conditioning of the atmosphere by El Niño-Southern Oscillation (ENSO) events has been documented, memory effects of land conditions on the atmosphere are not fully quantified, and cloud and precipitation feedbacks and the interactions of the lower boundary layer (lower 500 meters of the atmosphere) with land and ocean surface conditions are not well understood. In addition, data sets are needed for the calibration of global coupled climate models and the development of regional downscaling and statistical forecasting techniques.

ILLUSTRATIVE RESEARCH QUESTIONS

- For different model resolutions, how can key water cycle processes be better simulated in current climate models, in order to enhance the capability of producing more accurate seasonal to interannual predictions of water cycle variables?
- How can the representation of water cycle processes in climate change models be improved to reduce uncertainties in climate change projections for hydrologic variables?
- What are the critical hydrological and atmospheric factors that are present in major flood and drought events that can be isolated, quantified, and incorporated into water cycle prediction methodologies?
- To what extent will the seasonality, intensity, and variability of high latitude freshwater fluxes (evapotranspiration, runoff) and stores (soil moisture, permafrost) change as a result of climate warming?
- How can we best characterize the uncertainty in the prediction of water cycle variables and effectively communicate this uncertainty to water resource managers?

RESEARCH NEEDS

Advances in prediction capabilities will depend on improvements in model structure and initialization, data assimilation, and parameter representations. Predictability studies will be required to determine the regions, seasons, lead times, and processes most likely to provide additional predictive skill. Better understanding and improved model representations of less-well-understood processes, such as the seasonal and longer-term interactions of mountains, vegetative cover, soils, oceans, and the cryosphere with the atmosphere are needed. In addition, model evaluation studies with enhanced data sets are needed to improve models and to characterize and reduce uncertainties. Complementary research is planned under the Climate Variability and Change (Chapter 6) and Carbon Cycle (Chapter 9) programs.

PRODUCTS AND PAYOFFS

- New drought monitoring and early warning tools based on improved measurements of precipitation, soil moisture, and runoff, and data assimilation techniques to inform the implementation of drought mitigation plans (2-5 years).
- Metrics (measures) for quantifying the uncertainty in predictions of water cycle variables, and progress in improving the accuracy of predictions and for making forecasts more useful in water resources management (2-5 years).
- Downscaling techniques, such as improved regional climate models, that bridge the disparate spatial and temporal scales between global model outputs and atmospheric, land surface, and river basin processes for improved evaluation of potential water resource impacts arising from climate change (5-15 years).

Question 4: How do the water cycle and its variability affect the availability and quality of water supplied for human consumption, economic activity, agriculture, and natural ecosystems; and how do its interactions and variability affect sediment and nutrient transports, and the movement of toxic chemicals and other biogeochemical substances?

STATE OF KNOWLEDGE

Our ability to quantify the role of flowing water as the primary agent for sediment transport that reshapes the Earth's surface, and for nutrient transport that feeds riparian habitats and degrades water bodies, is rudimentary. Currently, we do not have the monitoring framework needed to generate a database to support research on these processes. The priority challenges are to quantify water flow and the various transport rates, biochemical transformations, and constituent concentrations and feedbacks whereby the water cycle alters media and ecosystems. Furthermore, the consequences of variations in water availability and quality for agriculture, energy production and distribution, and urban and industrial uses need to be integrated into a common modeling framework.

ILLUSTRATIVE RESEARCH QUESTIONS

- How does the water cycle interact through physical, chemical, biophysical, and microbiological processes with other Earth system components at the watershed scale?
- How do changes in climate, land cover, and non-point waste discharges alter water availability, water quality, and the transport of sediments, nutrients, and other chemicals, and how do these changes affect human and ecosystem health?
- How do surface and subsurface processes change the quality of water available for human and environmental uses?

RESEARCH NEEDS

Overall, there is a basic need to develop an integrated research vision (complete with hypotheses) for addressing multiple-process (hydrological, physical, chemical, and ecological) interactions between water and other Earth systems. Techniques that scale up processes active at watershed and sub-watershed scales to the larger scales widely used in climate studies must be developed and tested. In addition, it is necessary to refine geophysical methods and the use of tracers, including isotopes, to determine subsurface paths, flow rates, and residence time, and to track pollution plumes. Complementary research is planned under the Land Use/Land Cover Change (Chapter 8), Carbon Cycle (Chapter 9), Ecosystems (Chapter 10), and Human Contributions and Responses to Environmental Change (Chapter 11) programs.

PRODUCTS AND PAYOFFS

- Reliable, commensurate data sets at the watershed scale that scientists from various disciplines will use to examine critical water-Earth interactions for improved integrated watershed management (2-5 years).
- Models that partition precipitation among surface and subsurface pathways, route flows, and quantify physical and chemical interactions for evaluating climate and pollution impacts (5-15 years).
- Development and application of more cost effective methods for monitoring subsurface waters for inventorying current and future water availability (5-15 years).

Question 5: What are the consequences of global water cycle variability and change, at a range of temporal and spatial scales, for human societies and ecosystems? How can the results of global water cycle research be used to inform policy and water resource management decision processes?

STATE OF KNOWLEDGE

Variability and changes in the water cycle have been shown to lead to profound impacts on human societies and ecosystems (including on human health), but many of the linkages between change and outcome are not yet understood in the detail needed for appropriate policy and management responses. Water management takes place within a set of constraints that include, among other things, stringent flood control standards, federal and state environmental regulations, hydropower production schedules, and increasing irrigation, urban, industrial, and recreational demands for water. There is evidence that the results of recent research on the water cycle can contribute to the decisionmaking capacities of policymakers and water managers who must operate within these constraints. However, advances in water cycle research have found little use in water management and decisionmaking. Factors such as regulatory inflexibility, institutional structures, and time pressures make it difficult to change established management and decision systems. In addition, there is a mismatch between research products and operational information needs. Efforts to eliminate the barriers between research and research users have been initiated and indicate that early collaboration and side-by-side demonstrations may be effective tools for speeding innovation.

ILLUSTRATIVE RESEARCH QUESTIONS

- How can water cycle research products, such as the hydroclimatological projections (predictions of future states of hydrologic components (e.g., runoff) of the climate system) and forecasts from global and regional climate models, remote sensing data streams, and snow pack information, be deployed to improve policy decisions and water resource management?
- What is the best means for transferring climate/water cycle variability and long-term change information into operational reservoir management and hydropower production, and the planning and design of water resources infrastructure?

- What are the gaps in current understanding of water cycle functions critical to US riparian (relating to rivers) and estuary environments and what research activities are needed to close those gaps?
- What are the implications of water cycle research for managing conflicting demands on transboundary waters?
- What are the current patterns of water consumption and how are they likely to change as a result of potential changes in temperature, land cover and land use, demographics, and water policies?
- What kinds of changes in institutional arrangements and management practices will be needed to respond to changes in water resource availability over a range of temporal and spatial scales?

RESEARCH NEEDS

In order to make rapid progress in projecting the consequences of variability and change it will be necessary to integrate data from a broad range of sources and disciplines. Basic needs to achieve this goal include frameworks for integration, such as improved mechanisms for integrating remote sensing, GIS capabilities, and existing databases in decision support tools for water managers. In order to determine patterns and trends, it will also be necessary to inventory existing data sources and regional and sectoral studies, especially for data for which regional, national, and global repositories are rare or non-existent, such as for water demand, diversion, use, and consumption. In order for scientific information to have an impact, it will have to rely on refined and extended research on the role, entry points, and types of water cycle knowledge required for water management and policy decisionmaking processes. Complementary research is planned under the Climate Variability and Change (Chapter 6), Land Use/Land Cover Change (Chapter 8), and Human Contributions and Responses to Environmental Change (Chapter 11) programs.

PRODUCTS AND PAYOFFS

- Technology transfer and enhanced capability to produce operational streamflow forecasts over a range of spatial and temporal scales (days, weeks, months, and seasons), for more effective water management decisions (2-5 years).
- Decision support tools integrating historic climate variability, water cycle predictions, and socio-economic analyses to produce planning and management tools that include these major decision factors (2-15 years).
- Observing system simulation and forecast demonstrations using advanced watershed and river system management models and decision support systems, to facilitate acceptance and utilization of these advanced technologies for improved hydropower production and river system management (5-15 years).
- Integrated models of total water consumption for incorporation into decision support tools that identify water-scarce regions and efficient water use strategies (5-15 years).

Key Linkages

A strong Global Water Cycle research program is essential for, and will derive critical inputs from, the following CCSP elements: Climate Variability and Change, Carbon Cycle, Land Use/Land Cover Change, Ecosystems, Atmospheric Composition, and Human Contributions and Responses to Environmental Change. In particular, the modes of water cycle variability arising from ocean sea surface temperatures will be addressed by the Climate Variability and Change element. Furthermore, to carry out this ambitious Global Water Cycle program, support will be required in the areas of Climate Quality Observations (Chapter 3) and in Decision Support Resources (Chapter 4). In addition, there will be a need to work closely with the Decision Support Resources activity to ensure that Water Cycle research is more effectively used in policy development and decisionmaking. Finally, sustained progress toward answering the questions addressed by the Global Water Cycle research program will depend on development of the modeling, observations, and information systems described in Chapter 12.

There are strong international linkages between the Global Water Cycle program and the World Climate Research Programme's (WCRP) Global Energy and Water Cycle Experiment (GEWEX). Other connections to international programs occur in the observational area with Integrated Global Observing Strategy (IGOS) Partners in terms of its emerging Water Cycle theme as well as the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS). In addition, the water cycle program will collaborate with a number of international programs concerned with water cycle research, water resources, and climate. These include the WCRP, International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme (IHDP), and Diversitas Joint Water Project; the World Meteorological Organization's Hydrology and Water Resources Programme; and United Nations Educational, Scientific and Cultural Organization's International Hydrology Program and Hydrology for Environment, Life and Policy (HELP), as well as the Dialogue on Water and the 3rd World Water Forum. Also, the Global Water Cycle program will contribute to work through bilateral treaties, particularly with countries like Japan, that have placed a priority on water cycle research.

References:

Hornberger et al., 2001. Hornberger et al., *A Plan for a New Science Initiative on the Global Water Cycle* (Washington, D.C., US Global Change Research Program).

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