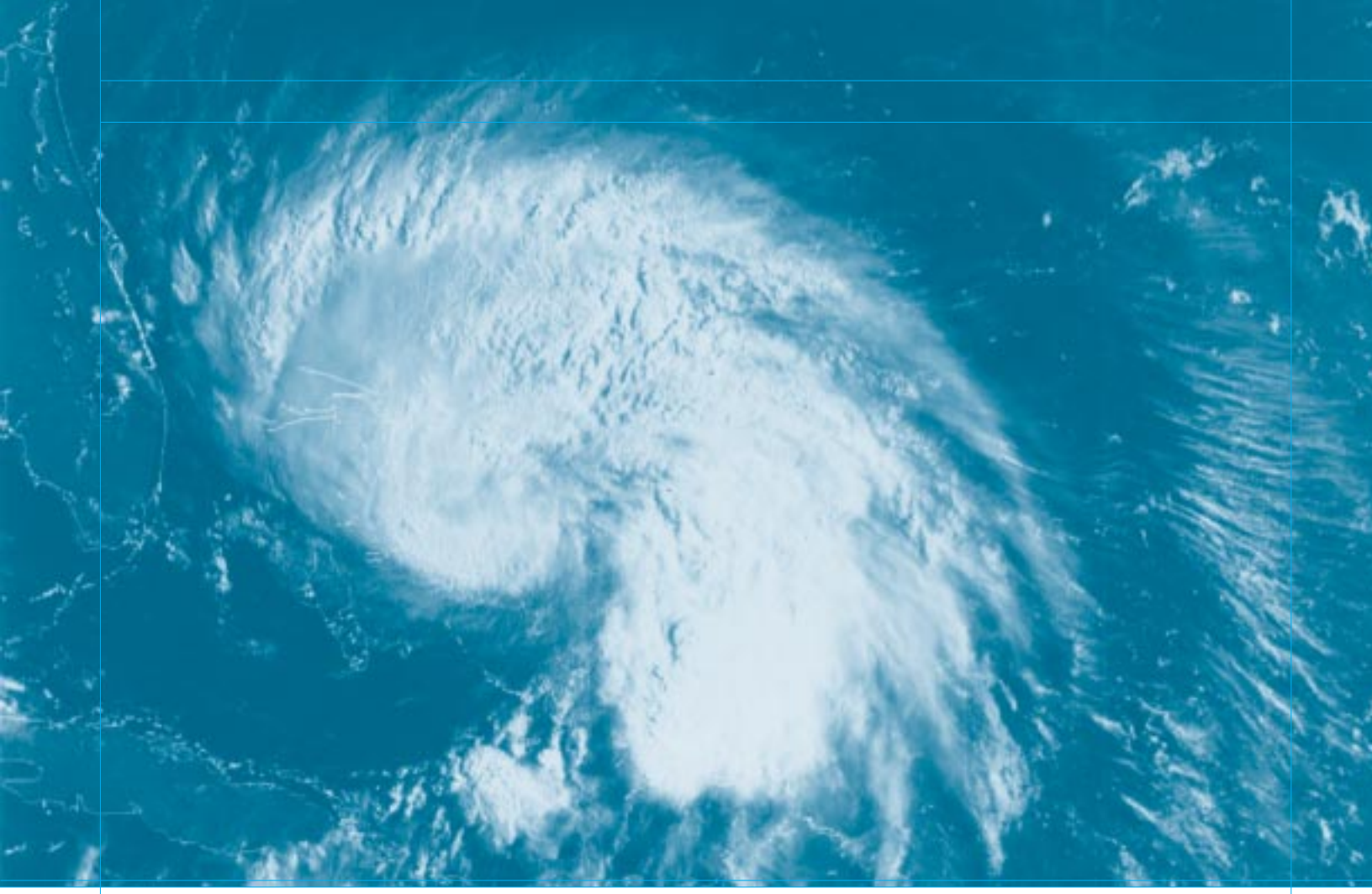


# Chapter 8
# Research and Systematic Observation

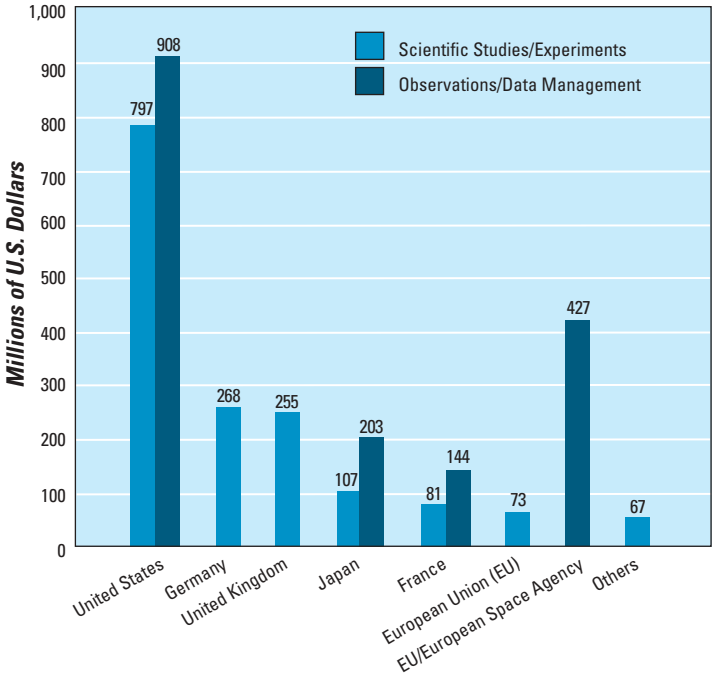
The United States leads the world in research on climate and other global environmental changes, spending approximately $1.7 billion annually on its focused climate change research programs. This contribution is roughly half of the world's focused climate change research expenditures, three times more than the next largest contributor, and larger than the combined contributions of Japan and all 15 nations of the European Union (Figure 8-1).

Most of this research is coordinated through the U.S. Global Change Research Program (USGCRP). Definition of the program began in the late 1980s, and Congress codified the program in the Global Change Research Act of 1990. The USGCRP was created as a high-priority, national research program to:

- address key uncertainties about changes in the Earth's global environment, both natural and human-induced;

## FIGURE 8-1 Research Expenditures by Country: 1999-2000

The United States is responsible for roughly half of the world's focused climate change research expenditures—three times more than the next-largest contributor, and larger than the contributions of Japan and all 15 nations of the European Union combined.




Note: Contributions by the United Kingdom and Germany to the European Space Agency (ESA) are included in the ESA observations total. No data are included from Australia, Brazil, India, Indonesia, Italy, Korea, Mexico, the People's Republic of China, Poland, Russia, Spain, Taiwan, and the Nordic Council. Inclusion of these could raise the totals by 10-20 percent.

Source: IGFA 2000.

- monitor, understand, and predict global change; and
- provide a sound scientific basis for national and international decision making.

The program builds on research undertaken over previous decades by independent researchers and programs. Today the USGCRP facilitates coordination across eleven federal departments and agencies with active global change programs. This distributed structure enables the program to draw on the missions, resources, and expertise of both research and mission-oriented agencies as it works to reduce uncertainties and develop useful applications of global change research. Participants include the Departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Defense, Energy, Health and Human Services (National Institutes of Health), Interior (U.S. Geological Survey), and Transportation; the U.S. Environmental Protection Agency; the National Aeronautics and Space Administration; the National Science Foundation; and the Smithsonian Institution. The Office of Science and Technology Policy and the Office of Management and Budget provide oversight on behalf of the Executive Office of the President.

Despite the intensive U.S. investment in climate change science over the past decade, numerous gaps remain in our understanding. President Bush directed a Cabinet-level review of climate policy, including the state of science. As an input to this review, the U.S. National Academy of Sciences (NAS) prepared a report on *Climate Change Science: An Analysis of Some Key Questions* (NRC 2001a). This report was released in June 2001 and reached a number of findings regarding uncertainties and gaps in our knowledge that impede policymaking.[1] The report states:

> *Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments (either upward or downward). Reducing the wide range of uncertainty inherent in current model predictions of global climate change will require major advances in understanding and modeling of both (1) the factors that determine atmospheric concentrations of greenhouse gases and aerosols, and (2) the so-called "feedbacks" that determine the sensitivity of the climate system to a prescribed increase in greenhouse gases. There is also a pressing need for a global system designed for monitoring climate.*

With respect to specific areas of knowledge, the NAS report concluded that greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise (see Appendix D). The changes observed over the last several decades are likely to result mostly from human activities, but some significant part of these changes is also a reflection of natural variability. Human-induced warming and associated sea level rise are expected to continue through the 21st century. Computer model simulations and basic physical reasoning suggest secondary effects, including potential changes in rainfall rates and in the susceptibility of semi-arid regions to drought. The impacts of

[1] The National Academy of Science report (NRC 2001a) generally agreed with the assessment of human-caused climate change presented in the recent IPCC Working Group I scientific report (IPCC 2001d), but sought to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them (see Appendix D).

these changes will be critically dependent on the magnitude of the effect, the rate at which it occurs, secular trends in technology that affect society's adaptability and vulnerability, and specific measures taken to adapt to or reduce vulnerability to climate change.

Accordingly, the NAS found that reducing the wide range of uncertainty inherent in current approaches to projecting global climate change and its effects on human beings and ecosystems will require major advances in understanding and modeling. To ensure that policies are informed by the best science, the United States is working aggressively to advance the science of climate and global change. In June 2001, President Bush announced the U.S. Climate Change Research Initiative, which is focused on reducing key areas of uncertainty in climate change science.

## RESEARCH

U.S. research focuses on the full range of global change issues. The U.S. Congress, in the Global Change Research Act of 1990 (Public Law 101-606), directs the implementation of a program aimed at "understanding and responding to global change, including cumulative effects of human activities and natural processes on the environment." The Act defines global change as "changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life." This perspective recognizes the profound socioeconomic and ecological implications of global environmental change.

The USGCRP focuses on sets of interacting changes in the coupled human–environment system, which is undergoing change at a pace unprecedented in human history. These changes are occurring on many time and spatial scales, and many feedbacks and interdependencies link them. These numerous and various forces complicate efforts to understand the interactions of human and natural systems and how they may affect the capacity of the Earth to sustain life over the long term. Indeed, the interactions between changes in external (solar) forcing, human activities, and the intrinsic variability of the Earth's atmosphere, hydrosphere, and biosphere make understanding and projecting atmospheric and oceanic circulation, global energy and water cycles, and biogeochemical cycling among the most demanding scientific challenges.

### U.S. Climate Change Research Initiative

On June 11, 2001, President Bush announced the establishment of the U.S. Climate Change Research Initiative to study areas of uncertainty and identify priority areas for investment in climate change science. He directed the Secretary of Commerce to work with other agencies to set priorities for additional investments in climate change research and to fully fund high-priority research areas that are underfunded or need to be accelerated. The definition of this new initiative is underway. It will improve the integration of scientific knowledge, including measures of uncertainty, into effective decision support systems.

### Ongoing Broader Agenda for U.S. Research

The Climate Change Research Initiative will take place in the context of the broader global change research program that is ongoing in federal agencies. The USGCRP provides a framework and coordination mechanism for the continuing study of all of the complex, interrelated global change aspects in the NAS recommendations that are not addressed by the initiative.

The USGCRP is engaged in a continuing process to review its objectives and structure so that it can help government, the private sector, and communities to make informed management decisions regarding global environmental changes in light of persistent uncertainties. This will require the program to continue fundamental research to address crucial uncertainties about how human activities are changing the Earth's climate and environment. This program will need to continue developing increasingly detailed projections of how natural variability and human-induced environmental change interact and affect conditions on global to regional scales, and how we can manage natural resources in the future. Scientific understanding and data will need to be applied to tools useful for reducing risks and seizing opportunities resulting from global change.

The program will build on decades of scientific progress and will take advantage of the development of powerful advances in computing, remote sensing, environmental monitoring, and data and information technologies. Through additional focused investment in observations, scientific studies, and modeling, the USGCRP will seek to reduce uncertainties in the understanding of some of the most basic questions. The science needed to accomplish this ambitious objective is organized into the six research elements presented in Table 8-1, each of which focuses on topics crucial to projecting change and understanding its potential importance.

The USGCRP will also work with its partners to transition scientific knowledge to applications in resource management, disaster preparedness, planning for growth and infrastructure, and environmental and health assessment, among other areas. Partnerships among research programs, operational entities, and actors in the private sector and in federal, state, and local governments will be essential for the success of this effort. It will also require significant levels of cooperation and new management techniques to permit co-production of knowledge and deliverables across agencies and stakeholders.

### National Climate Change Technology Initiative

The United States is further committed to improving climate change technology research and development, enhancing basic research, strengthening applied research through public–private partnerships, developing

## TABLE 8-1 Fundamental Climate Change Research Needs

To support informed decision making, the U.S. Global Change Research Program is addressing uncertainties about how human activities are changing the Earth's climate and environment. The six research elements in this table focus on topics essential to projecting climate change and understanding its potential importance:

| Research Uncertainty | USGCRP Research Focus |
|---|---|
| **Atmospheric Composition**<br>• How do human activities and natural phenomena change the composition of the global atmosphere?<br>• How do these changes influence climate, ozone, ultraviolet radiation, pollutant exposure, ecosystems, and human health? | • Processes affecting the recovery of the stratospheric ozone layer.<br>• Properties and distribution of greenhouse gases and aerosols.<br>• Long-range transport of pollutants and implications for air quality.<br>• Integrated assessments of the effects of these changes for the nation and the world. |
| **Climate Variability and Change**<br>• How do changes in the Earth system that result from natural processes and human activities affect the climate elements that are important to human and natural systems, especially temperature, precipitation, clouds, winds, and extreme events? | • Predictions of seasonal-to-decadal climate variations (e.g., the El Niño–Southern Oscillation).<br>• Detection and attribution of human-induced change.<br>• Projections of long-term climate change.<br>• Potential for changes in extreme events at regional-to-local scales.<br>• Possibility of abrupt climate change.<br>• How to improve the effectiveness of interactions between producers and users of climate forecast information. |
| **Carbon Cycle**<br>• How large and variable are the reservoirs and transfers of carbon within the Earth system?<br>• How might carbon sources and sinks change and be managed in the future? | • North American and ocean carbon sources and sinks.<br>• Impacts of land-use changes and resource management practices on carbon sources and sinks.<br>• Future atmospheric carbon dioxide and methane concentrations and changes in land-based and marine carbon sinks.<br>• Periodic reporting (starting in 2010) on the global distribution of carbon sources and sinks and how they are changing. |
| **Global Water Cycle**<br>• How do human activities and natural processes that affect climate variability influence the distribution and quality of water within the Earth system?<br>• To what extent are these changes predictable?<br>• How will these changes affect climate, the cycling of carbon and other nutrients, and other environmental properties? | • Trends in the intensity of the water cycle and the causes of these changes (including feedback effects of clouds on the water and energy budgets, as well as the global climate system).<br>• Predictions of precipitation and evaporation on time scales of months to years and longer.<br>• Models of physical and biological processes and human demands and institutional processes, to facilitate efficient management of water resources.<br>• Research supporting reports on the state of the global water cycle and national water resources. |
| **Terrestrial and Marine Ecosystems**<br>• How do natural and human-induced changes in the environment interact to affect ecosystems (from natural to intensively managed), their ability to provide natural resources and commodities, and their influence on regional and global climate? | • Structure and function of ecosystems, including cycling of nutrients and how they interact with the carbon cycle.<br>• Key processes that link ecosystems with climate.<br>• Vulnerability of ecosystems to global change.<br>• Options for enhancing resilience and sustaining ecosystem goods and services.<br>• Scientific underpinning for improved interactions with resource managers. |
| **Changes in Land Use and Land Cover**<br>• What processes determine land cover and land use at local, regional, and global scales?<br>• How will land use and land cover evolve over time scales of 10–50 years? | • Identifying the human drivers of changes in land use and cover.<br>• Monitoring, measuring, and mapping land use and land cover and managing data systems.<br>• Developing projections of land-cover and land-use changes under various assumptions about climate, demographic, economic, and technological trends.<br>• Integrating information about land use, land management, and land cover into other research elements. |

improved technologies for measuring and monitoring gross and net greenhouse gas emissions, and supporting demonstration projects for new technologies.

### *Enhanced Carbon Technologies*

The United States has committed to a number of projects to develop enhanced carbon technologies for capturing, storing, and sequestering carbon. Two contracts signed on July 11, 2001, solidified partnerships with The Nature Conservancy and with an international team of energy companies.

**The Nature Conservancy Project.** The Department of Energy will work in partnership with The Nature Conservancy and such companies as General Motors Corporation and American Electric Power to study how carbon dioxide can be stored more effectively by changing land-use practices and by investing in forestry projects. Using newly developed aerial and satellite-based technology, researchers will study forestry projects in Brazil and Belize to determine their carbon sequestration potential. Researchers will also test new software models that predict how carbon is sequestered by soil and vegetation at sites in the United States and abroad. The United States will provide $1.7 million of the $2 million cost of the three-year project.

**International Team of Energy Companies.** The Department of Energy will also collaborate with nine energy companies from four nations to develop breakthrough technologies to reduce the cost of capturing carbon dioxide from fossil fuel combustion and safely storing it underground. The nine energy companies are: BP–Amoco, Shell, Chevron, Texaco, Pan Canadian (Canada), Suncor Energy (Canada), ENI (Italy), Statoil Forskningssenter (Norway), and Norsk Hydro ASA (Norway). The U.S. government's contribution of $5 million will leverage an international commitment that will total more than $25 million over the next three years, including funding from the European Union, Norway's Klimatek Program, and the nine industry partners.

## Human Effects on and Responses to Environmental Changes

In an effort to identify strategies to enhance the resilience of human systems to climate change, the U.S. Global Change Research Program continues to support research both on human activities that influence environmental change from local and regional to global scales and on how human systems prepare for and respond to environmental changes. An expanding research area will focus on analyses of the regional impacts of climate change on human systems and how improved information about climate change impacts can help decision makers in the public and private sectors.

### *Recent Accomplishments*

Following are some recent USGCRP accomplishments in human dimensions and socioeconomic analyses:

- The U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) have established ongoing regional research and assessment projects in six U.S. regions to study the effects of climate variability and change on natural and human systems. These projects have been highly successful in analyzing the regional context of global change impacts, fostering relationships between scientists and stakeholders in the regions, and determining how research can meet stakeholders' needs for water-resource planning, fisheries management, ranching, and other climate-sensitive resource management issues.
- The U.S. Department of Transportation (DOT) established a center to identify effective ways to reduce the transportation sector's emissions and to help prepare the nation for the impacts of climate change. As part of its research efforts, the center will investigate how climate change could affect transportation infrastructure.
- Interdisciplinary investigations of human responses to seasonal and yearly swings in climate are highlighting the effects of market forces, access to resources, institutional flexibility, impacts across state boundaries, and the role of local culture and experience on the likelihood that individuals and institutions will use improved scientific information.

## International Research Cooperation

The Working Group on International Research and Cooperation provides international affairs support for the USGCRP. The working group has representatives from interested government agencies and departments and acts as a forum to keep them informed on international global change research and funding issues. It addresses interagency support for international global change research programs and coordination, and infrastructure funding for such organizations as the Asia–Pacific Network for Global Change Research, the Inter-American Institute for Global Change Research, the International Human Dimensions Programme, the International Geosphere-Biosphere Programme, the World Climate Research Programme, and the Global Change System for Analysis, Research, and Training. The working group also addresses concerns raised by international nongovernmental global change organizations, such as free and open data exchange. These organizations include the International Group of Funding Agencies for Global Change Research and the Arctic Ocean Sciences Board.

The USGCRP contributes to and benefits from international research efforts to improve understanding of climate change on regional and global scales. USGCRP-supported scientists coordinate many of their programs with those of their counterparts in other countries, providing essential inputs to the increasingly complex models that enable scientists to improve analysis and prediction of climate change. Following are some examples of recent, ongoing, and planned climate change research and related activities in which USGCRP-supported scientists are

heavily involved and for which international cooperation, participation, and support are especially important.

### U.S.–Japan Cooperation in Global Change Research

During 2000, the United States and Japan co-sponsored a series of scientific workshops to identify important climate change research problems of mutual interest and to recommend how scientists from the two countries might constructively address them. Conducted under the auspices of the U.S.–Japan Agreement on Cooperation in Research and Development in Science and Technology, these workshops are managed on the U.S. side by the Working Group on International Research and Cooperation of the federal interagency Subcommittee on Global Change

The workshops developed recommendations to study the health impacts of climate change, in particular the impacts of greater and longer-lasting exposures to higher temperatures interacting with different air pollutants. A workshop on monsoon systems identified a number of cooperative bilateral and multilateral activities for the two countries to undertake. In 2001, Japan hosted the ninth workshop in this series, entitled Carbon Cycle Management in Terrestrial Ecosystems. The workshops have stimulated cooperation between Japanese and U.S. scientists and have led to numerous follow-up activities, including more focused planning workshops, data exchanges, and collaborative projects.

### Climate and Societal Interactions

NOAA's Climate and Societal Interactions Program supports Regional Climate Outlook Fora, pilot application projects, workshops, training sessions, capacity building, and technical assistance for better understanding of climate variability and extreme events and for improving prediction and forecasting capability and data management, in Africa, Latin America, the Caribbean, Southeast Asia, and the Pacific. The Climate Information Project is developing a new program—Radio and Internet for the Communication of Hydro-Meteorological and Climate Information—to provide training to meteorological services worldwide on the use and production of radio and multimedia content in conjunction with digital satellite communication. This effort is being led by NOAA and involves a number of international partners, including the U.S. Agency for International Development; the World Bank; the World Meteorological Organization; the Inter-American Institute for Global Change Research; the Global Change System for Analysis, Research, and Training; and the Asia–Pacific Network for Global Change Research.

### Eastern Pacific Investigation of Climate Processes

The Department of Commerce, through NOAA, and the National Science Foundation are bringing together more than 100 scientists from the United States, Mexico, Chile, and Peru to cooperate in the Eastern Pacific Investigation of Climate (EPIC). EPIC's scientific objectives are to observe and understand: (1) ocean–atmosphere processes in the equatorial and northeastern Pacific portions of the Inter-Tropical Convergence Zone (ITCZ); and (2) the properties of cloud decks in the trade wind and cross-equatorial flow regime and their interactions with the ocean below.

The project will study stratus cloud decks located off the west coast of South America, a region of cool sea-surface temperatures located along the equator in the eastern Pacific Ocean, and a region of intense precipitation located in the eastern Pacific north of the equator. All three of these phenomena interact to control the climate of the Southwest United States and Central and South America.

### Studies of Global Ocean Ecosystem (GLOBEC) Dynamics

Scientists and research vessels from Germany, the United Kingdom, and the United States are conducting a closely coordinated major GLOBEC field study on krill near the West Antarctic Peninsula. Krill are an essential component of the Southern Ocean food web and a commercially important species. Their predators—including sea birds, seals, and whales—depend on this food resource for survival. Sea ice plays an essential role as a habitat for krill (which feed beneath the ice) and their predators. Since evidence suggests that interannual variation in the extent of sea ice affects the abundance of krill, improving understanding of the role of climate factors affecting sea ice will comprise a critical component of the Southern Ocean GLOBEC program.

### IGBP Open Science Conference

The International Geosphere–Biosphere Programme (IGBP) convened an open science conference in July 2001 in Amsterdam. A major objective of this conference was to present the latest results of climate change research at a series of levels: research conducted through the individual IGBP core projects and research integrated across these projects; research that has been integrated between the IGBP and the World Climate Research Programme, the International Human Dimensions Programme, Diversitas, and the Global Change System for Analysis, Research and Training, and other regional programs; and individual research projects on which these integrated efforts are based. The conference also identified new approaches to the study of the complex planetary system in which human activities are closely linked to natural processes.

### International Group of Funding Agencies

The International Group of Funding Agencies (IGFA) is a forum through which national agencies that fund research on global change identify issues of mutual interest and ways to address them through coordinated national and, when appropriate, international actions. IGFA's focus is not on the funding of single projects, which is still a matter of national procedures; instead, it coordinates the support for the programs

## Climate, Ecosystems, and Infectious Disease: Key Findings

The USGCRP, six federal agencies, and the Electric Power Research Institute sponsored a study completed in 2001 by the U.S. National Research Council's Committee on Climate, Ecosystems, Infectious Disease, and Human Health, entitled *Under the Weather: Climate, Ecosystems, and Infectious Disease* (NRC 2001b). Following are the Committee's key findings related to linkages between climate and infectious diseases.

**Weather fluctuations and seasonal-to-interannual climate variability influence many infectious diseases.** The characteristic geographic distributions and seasonal variations of many infectious diseases are *prima facie* evidence of linkages to weather and climate. Studies have shown that such factors as temperature, precipitation, and humidity affect the life cycles of many disease pathogens and vectors (both directly, and indirectly through ecological changes) and thus can affect the timing and intensity of disease outbreaks. However, disease incidence is also affected by such factors as sanitation and public health services, population density and demographics, land-use changes, and travel patterns. The importance of climate relative to these other variables must be evaluated in the context of each situation.

**Observational and modeling studies must be interpreted cautiously.** Although numerous studies have shown an association between climatic variations and disease incidence, they are not able to fully account for the complex web of causation that underlies disease dynamics. Thus, they may not be reliable indicators of future changes. Likewise, a variety of models have been developed to simulate the effects of climatic changes on the incidence of such diseases as malaria, dengue, and cholera. While these models are useful heuristic tools for testing hypotheses and carrying out sensitivity analyses, they are not necessarily intended to serve as predictive tools, and often do not include such processes as physical/biological feedbacks and human adaptation. Thus, caution must be exercised in using these models to create scenarios of future disease incidence and to provide a basis for early warnings and policy decisions.

**The potential disease impacts of global climate change remain highly uncertain.** Changes in regional climate patterns caused by long-term global warming could affect the potential geographic range of many infectious diseases. However, if the climate of some regions becomes more suitable for transmission of disease agents, human behavioral adaptations and public health interventions could serve to mitigate many adverse impacts. Basic public health protections, such as adequate housing and sanitation, as well as new vaccines and drugs, may limit the future distribution and impact of some infectious diseases, regardless of climate-associated changes. These protections, however, depend upon maintaining strong public health programs and ensuring vaccine and drug access in the poorer countries of the world.

**Climate change may affect the evolution and emergence of infectious diseases.** The potential impacts of climate change on the evolution and emergence of infectious disease agents create another important but highly uncertain risk. Ecosystem instabilities brought about by climate change and concurrent stresses, such as land-use changes, species dislocation, and increasing global travel, potentially influence the genetics of pathogenic microbes through mutation and horizontal gene transfer, and could give rise to new interactions among hosts and disease agents.

**There are potential pitfalls in extrapolating climate and disease relationships from one spatial/temporal scale to another.** The relationships between climate and infectious disease are often highly dependent upon local-scale parameters, and it is not always possible to extrapolate these relationships meaningfully to broader spatial scales. Likewise, disease impacts of seasonal-to-interannual climate variability may not always provide a useful analog for the impacts of long-term climate change. Ecological responses on the time scale of an El Niño event, for example, may be significantly different from the ecological responses and social adaptation expected under long-term climate change. Also, long-term climate change may influence regional climate variability patterns, hence limiting the predictive power of current observations.

**Recent technological advances will aid efforts to improve modeling of infectious disease epidemiology.** Rapid advances being made in several disparate scientific disciplines may spawn radically new techniques for modeling infectious disease epidemiology. These include advances in sequencing of microbial genes, satellite-based remote sensing of ecological conditions, the development of geographic information system (GIS) analytical techniques, and increases in inexpensive computational power. Such techniques will make it possible to analyze the evolution and distribution of microbes and their relationship to different ecological niches, and may dramatically improve our abilities to quantify the disease impacts of climatic and ecological changes.

themselves (Secretariats, International Project Offices, etc.). IGFA facilitates international climate change research by bringing the perspective of national funding agencies to strategic research planning and implementation. At its October 2000 meeting, most IGFA member nations reported increases in funding for climate change research, initiation and deployment of new national programs, and establishment of some new research centers.

### *Diversitas*

Diversitas was established in 1991 as an umbrella program to coordinate a broad research effort in the biodiversity sciences at the global level. The program has played an important role at the interface between science and policy by building a partnership with the Convention on Biological Diversity. Diversitas has signed a Memorandum of Understanding with the Secretariat of the Convention and has provided input to its Subsidiary Body on Scientific, Technical and Technological Advice. Among the issues that IGFA considered at its 2001 plenary meeting in Stockholm was the development of a new implementation strategy for Diversitas. Countries, via IGFA, have committed funds to help strengthen the international infrastructure for biodiversity research through Diversitas according to the model of the other partner global change programs.

### *International Paleoclimate Research*

An international team of researchers from the United States, Germany, and Russia is investigating El'gygytgyn Lake in northeastern Siberia, just north of the Arctic Circle. This crater was formed 3.6 million years ago by a meteorite impact. Its sediments hold the promise of revealing the evolution of Arctic climate a full one million years before the first major glaciation of the Northern Hemisphere. In addition, through an international consortium of researchers, the Nyanza Project team, involving scientists from the United States, Europe, and four countries in Africa, is studying climate variability, as well as environmental and

ecological change, through the entire episode of human evolution. As part of this project, a unique 2,000-year-old annually resolved record of atmospheric circulation and dynamics, revealing El Niño–Southern Oscillation and solar cycles, has been recovered from sediments in Lake Tanganyika, the second deepest lake on the planet.

## SYSTEMATIC OBSERVATION

Long-term, high-quality observations of the global environmental system are essential for defining the current state of the Earth's system, and its history and variability. This task requires both space- and surface-based observation systems. The term "climate observations" can encompass a broad range of environmental observations, including:

- routine weather observations, which, collected over a long enough period, can be used to help describe a region's climatology;
- observations collected as part of research investigations to elucidate chemical, dynamic, biological, or radiative processes that contribute to maintaining climate patterns or to their variability;
- highly precise, continuous observations of climate system variables collected for the express purpose of documenting long-term (decadal-to-centennial) change; and
- observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time to provide information on climate change for millennial and longer time scales.

The various federal agencies involved in observing climate through space-based and ground-based activities provide many long-term observations. Space-based systems have the unique advantage of obtaining global spatial coverage, particularly over the vast expanses of the oceans, sparsely populated land areas (e.g., deserts, mountains, forests, and polar regions), and the mid and upper troposphere and stratosphere. They provide unique measurements of solar output; the Earth's radiation budget; vegetation cover; ocean biomass productivity; atmospheric ozone; stratospheric water vapor and aerosols; greenhouse gas distributions; sea level and ocean interior; ocean surface conditions; winds, weather, and tropical precipitation; and other variables.

Satellite observations alone are not sufficient. *In-situ* observations are required for the measurement of parameters that cannot be estimated from space platforms (e.g., biodiversity, ground water, carbon sequestration at the root zone, and subsurface ocean parameters). *In-situ* observations also provide long time-series of observations required for the detection and diagnosis of global change, such as surface temperature, precipitation and water resources, weather and other natural hazards, the emission or discharge of pollutants, and the impacts of multiple stresses on the environment due to human and natural causes. To meet the need for the documentation of global changes on a long-term basis, the United States integrates observations from both research and operational systems. The goal of the U.S. observation and monitoring program is to ensure a long-term, high-quality record of the state of the Earth system, its natural variability, and changes that occur.

Since 1998, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have noted with concern the mounting evidence of a decline in the global observing capability and have urged Parties to undertake programs of systematic observations and to strengthen the collection, exchange, and use of environmental data and information. It has long been recognized that the range of global observations needed to understand and monitor Earth processes contributing to climate and to assess the impact of human activities cannot be satisfied by a single program, agency, or country. The United States supports the need to improve global observing systems for climate and to exchange information on national plans and programs that contribute to the global capacity in this area.

## Documentation of U.S. Climate Observations

As part of its continuing contributions to systematic observations in support of climate monitoring, the United States forwarded *The U.S. Detailed National Report on Systematic Observations for Climate* to the UNFCCC Secretariat on September 6, 2001 (U.S. DOC/NOAA 2001c). Because this was the U.S. government's first attempt to document all U.S. contributions to global climate observations, a wide net was cast to include information on observations that fell into each of the following categories: (1) *in-situ* atmospheric observations; (2) *in-situ* oceanographic observations; (3) *in-situ* terrestrial observations; (4) satellite-based observations, which by their nature cut across the atmospheric, oceanographic, and terrestrial domains; and (5) data and information management related to systematic observations. The report attempted to cover all relevant observation systems and is representative of the larger U.S. effort to collect environmental data.

Material for the report was developed by a U.S. interagency Global Climate Observing System (GCOS) coordination group comprised of representatives from the following federal agencies: (1) the U.S. Department of Agriculture's Natural Resources Conservation Service and U.S. Forest Service; (2) three line offices of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration; (3) the U.S. Department of Energy's Office of Science; (4) the U.S. Environmental Protection Agency; (5) the U.S. Department of the Interior's U.S. Geological Survey; (6) the National Aeronautics and Space Administration; (7) the U.S. Department of Transportation's Federal Aviation Administration; (8) the National Science Foundation; (9) the U.S. Naval Oceanographic Office; (10) the U.S. Army Corps of Engineers; and (11) the U.S. Air Force. The report was coordinated with the U.S. Global Change Research Program.

## *In-situ* Climate Observation

The United States supports a broad network of global atmospheric, ocean, and terrestrial observation systems.

### *Atmospheric Observation*

The United States supports 75 stations in the GCOS Surface Network (GSN), 20 stations in the GCOS Upper Air Network (GUAN), and 4 stations in the Global Atmospheric Watch (GAW). These stations are distributed geographically as prescribed in the GCOS and GAW network designs. The data (metadata and observations) from these stations are shared according to GCOS and GAW protocols. The GSN and GUAN stations are part of a larger network, which was developed for purposes other than climate monitoring. Nonetheless, the stations fully meet the GCOS requirements.

The United States has no comprehensive system designed to observe climate change and climate variability. Basically, U.S. sustained observing systems provide data principally for nonclimatic purposes, such as predicting weather, advising the public, and managing resources. In addition, U.S. research-observing systems collect data for climate purposes, but are often oriented toward gathering data for climate process studies or other research programs, rather than climate monitoring. They are usually limited in their spatial and temporal extent. Because the U.S. climate record is based upon a combination of existing operational and research programs, it may not be "ideal" from a long-term climate monitoring perspective. Nevertheless, these observing systems collectively provide voluminous and significant information about the spatial and temporal variability of U.S. climate and contribute to the international climate observing effort as well. The atmospheric section in the main body of the detailed national report examines *in-situ* climate monitoring involving systems from the surface, upper air, and atmospheric deposition domains (U.S. DOC/NOAA 2001c).

### *Ocean Observation*

The Global Ocean Observing System (GOOS) requirements are the same as the GCOS requirements. Both are based on the Ocean Observing System Development Panel Report (OOSDP 1995). Like GCOS, the GOOS is based on a number of *in-situ* and space-based observing components. The United States supports the Integrated Global Ocean Observing System's surface and marine observations through a variety of components, including fixed and surface-drifting buoys, subsurface floats, and volunteer observing ships. It also supports the Global Sea Level Observing System through a network of sea-level tidal gauges. The United States currently provides satellite coverage of the global oceans for sea-surface temperatures, surface elevation, ocean surface winds, sea ice, ocean color, and other climate variables. These satellite activities are coordinated internationally through the Committee on Earth Observation Satellites.

### *Terrestrial Observation*

For terrestrial observations, the requirements for climate observations were developed jointly between GCOS and the Global Terrestrial Observing System (GTOS) through the Terrestrial Observations Panel for Climate (WMO 1997). GCOS and GTOS have identified permafrost thermal state and permafrost active layer as key variables for monitoring the state of the cryosphere. GCOS approved the development of a globally comprehensive permafrost-monitoring network to detect temporal changes in the solid earth component of the cryosphere. As such, the Global Terrestrial Network for Permafrost (GTN-P) is quite new and still very much in the developmental stage. The International Permafrost Association has the responsibility for managing and implementing the GTN-P.

U.S. contributions to the GTN-P network are provided by the Department of the Interior and the National Science Foundation, through grants to various universities. All the U.S. GTN-P stations are located in Alaska. The active layer thickness is currently being monitored at 27 sites. Forty-eight bore holes exist in Alaska where permafrost thermal state can be determined. Of these, 4 are classified as *surface* (0–10 m) sites, 1 is *shallow* (10–25 m), 22 are *intermediate depth* (25–125 m), and 21 are *deep bore holes* (>125 m). The U.S. contribution to the GTN-P network comes from short-term (three- to five-year) research projects.

The United States operates a long-term "benchmark" glacier program to intensively monitor climate, glacier motion, glacier mass balance, glacier geometry, and stream runoff at a few select sites. The data collected are used to understand glacier-related hydrologic processes and improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change.

The approach has been to establish long-term, mass-balance monitoring programs at three widely spaced U.S. glacier basins that clearly sample different climate-glacier-runoff regimes. The three glacier basins are South Cascade Glacier in Washington State, and Gulkana and Wolverine Glaciers in Alaska. Mass-balance data are available beginning in 1959 for the South Cascade Glacier, and beginning in 1966 for the Gulkana and Wolverine Glaciers.

The AmeriFLUX network endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of $CO_2$, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global $CO_2$ budget, enable improved projections of future concentrations of atmospheric $CO_2$, and enhance the understanding of carbon fluxes, net ecosystem production, and carbon sequestration in the terrestrial biosphere.

The terrestrial section of the detailed U.S. report examines *in-situ* climate monitoring and discusses, in addition to the GTN-P, the Global Terrestrial Network for Glaciers (GTN-G), and the

AmeriFLUX programs, stream-flow and surface-water gauging, ground-water monitoring, snow and soil monitoring, the U.S. paleoclimatology program, ecological observation networks, fire-weather observation stations, as well as global, national, and regional land cover characterization. The United States contributes to all of these activities.

## Satellite Observation Programs

Space-based, remote-sensing observations of the atmosphere–ocean–land system have evolved substantially since the early 1970s, when the first operational weather satellite systems were launched. Over the last decade satellites have proven their capability to accurately monitor nearly all aspects of the total Earth system on a global basis—a capability unmatched by ground-based systems, which are limited to land areas and cover only about 30 percent of the planetary surface.

Currently, satellite systems monitor the evolution and impacts of El Niño, weather phenomena, natural hazards, and extreme events, such as floods and droughts; vegetation cycles; the ozone hole; solar fluctuations; changes in snow cover, sea ice and ice sheets, ocean surface temperatures, and biological activity; coastal zones and algal blooms; deforestation and forest fires; urban development; volcanic activity; tectonic plate motions; and other climate-related information. These various observations are used extensively in real-time decision making and in the strategic planning and management of industrial, economic, and natural resources. Examples include weather and climate forecasting, agriculture, transportation, energy and water resource management, urban planning, forestry, fisheries, and early warning systems for natural disasters and human health impacts.

The GCOS planning process addressed satellite requirements for climate. In so doing, it identified an extensive suite of variables that should be observed and monitored from space (WMO 1995). In addition, GCOS plans specified that instrument calibration and validation be performed to ensure that the resulting space-based observations meet climate requirements for accuracy, continuity, and low bias.

The current generation of U.S. research satellite instruments exceeds the GCOS requirements for the absolute calibration of sensors—something that was lacking in the early satellite platforms used for real-time operational purposes. Several of the historical data series from operational satellites have been reprocessed using substantially improved retrieval algorithms to provide good-quality global data products for use in climate change research and applications.

### NPOESS Program

Improving the on-board capabilities for calibration on operational satellites will be one of the objectives in the development of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Prior to the launch of NPOESS in 2008, an NPOESS Preparatory Project (NPP) satellite will be launched in the 2005 time frame as a bridge mission between the NASA Earth Observing Satellites (EOS) program and NPOESS.

The mission of NPP is to demonstrate advanced technology for atmospheric sounding, and to provide ongoing observations after EOS-Terra and EOS-Aqua. It will supply data on atmospheric and sea-surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. NPP will also provide early instrument and system-level testing and early user evaluation of NPOESS data products, such as algorithms, and will identify opportunities for instrument calibration. The information and lessons learned from NPP will help reduce instrument risk and will enable design modifications in time to ensure NPOESS launch readiness.

### U.S. Environmental Satellite Program

A number of U.S. satellite operational and research missions form the basis of a robust national remote-sensing program that fully supports the requirements of GCOS (U.S. DOC/NOAA 2001c). These include instruments on the Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), the series of Earth Observing Satellites (EOS), the Landsats 5 and 7, the Total Ozone Mapping Spectrometer satellite, and the TOPEX/Poseidon satellite measuring sea-surface height, winds, and waves. Additional satellite missions in support of GCOS include (1) the Active Cavity Radiometer Irradiance Monitor for measuring solar irradiance; (2) EOS-Terra; (3) QuickSCAT; (4) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean productivity; (5) the Shuttle Radar Topography Mission; and (6) the Tropical Rainfall Measuring Mission for measuring rainfall, clouds, sea-surface temperature, radiation, and lightning.

### Defense Meteorological Satellite Program

The Defense Meteorological Satellite Program (DMSP) is a Department of Defense program run by the Air Force Space and Missile Systems Center. The program designs, builds, launches, and maintains several near-polar-orbiting, sun-synchronous satellites, which monitor the meteorological, oceanographic, and solar–terrestrial physics environments. DMSP satellites are in a near-polar, sun-synchronous orbit. Each satellite crosses any point on the Earth up to two times a day, thus providing nearly complete global coverage of clouds approximately every six hours.

### Integrated Global Observing Strategy

The United States cooperates on an international basis with a number of coordinating bodies. The Integrated Global Observing Strategy (IGOS) is a strategic planning process covering major satellite- and surface-based systems for global environmental observations of the atmosphere, oceans, and land, that provides a framework for decisions and resource allocations by

individual funding agencies. IGOS assesses Earth-observing requirements, evaluates capabilities of current and planned observing systems, and has begun (at least among the space agencies) to obtain commitments to address these gaps.

An IGOS Ocean Theme is in the implementation phase under leadership from GOOS. An analysis of requirements, gaps, and recommendations for priority observations is underway for integrated global carbon observations as well as integrated global atmospheric chemistry observations. Similar analyses, recommendations, and commitments are also being explored for geological and geophysical hazards, coasts and coral reefs, and the global water cycle.

### *Operational Weather Satellites*

Operational weather satellites are internationally coordinated through the Coordination Group for Meteorological Satellites, of which the World Meteorological Organization is a member and major beneficiary, along with five other satellite agency members. The primary body for policy and technical issues of common interest related to the whole spectrum of Earth observation satellite missions is the Committee on Earth Observation Satellites (CEOS). CEOS has 22 space agency members, including both research and operational satellite agencies, with funding and program responsibilities for a satellite Earth observation program currently operating or in the later stages of system development. CEOS encourages compatibility among space-borne Earth-observing systems through coordination in mission planning; promotion of full and nondiscriminatory data access; setting of data product standards; and development of data products, services, applications, and policies.

## Global Change Data and Information System

Global environmental concerns are an overriding justification for the unrestricted international exchange of GCOS data and products for peaceful, noncommercial, global scientific, and applications purposes. As such, GCOS developed an overarching data policy that endorses the full and open sharing and exchange of GCOS-relevant data and products for all GCOS users at the lowest possible cost. The United States recognizes and subscribes to this data policy.

Achieving the goals of the U.S. climate observing program requires multidisciplinary analysis of data and information to an extent never before attempted. This includes the analysis of interlinked environmental changes that occur on multiple temporal and spatial scales, which is very challenging both technically and intellectually. For example, many types of satellite and *in-situ* observations at multiple scales need to be integrated with models, and the results need to be presented in understandable ways to all levels of the research community, decision makers, and the public. Additionally, very large volumes of data from a wide variety of sources and results from many different investigations need to be readily accessible to scientists and other stakeholders in usable forms that can be integrated.

Various U.S. agencies have engaged in extensive development of interagency data and information processes to foster better integration and accessibility of data- and discipline-specific information. The Global Change Data and Information System (GCDIS) has been developed to facilitate this goal. GCDIS currently provides a gateway for access to more than 70 federally funded sources of data, both governmental and academic. During the last decade, significant strides have been made in creating seamless connections between diverse data sets and sources, as well as enhancing its ability to search across the full complement of data sources. While the Internet has facilitated this effort, the provision of data and information in forms needed for cross-disciplinary analyses remains a challenge.

The U.S. government's position (as evidenced by its support of the "10 Principles of Climate Observations" and of the U.S. climate research community [NRC 1999]) is that high standards must be met for a particular set of observations to serve the purpose of monitoring the climate system to detect long-term change. In general, the observing programs and resulting data sets described here have not yet fully met these principles. This shortfall stems from two main factors: (1) the principles were articulated only within the past decade (Karl et al. 1995), long after the initiation of most of our long-term observing systems; and (2) more recent observing programs typically do not have climate monitoring as their prime function.

The U.S. systematic climate observing effort will continue to improve and enhance understanding of the climate system. A full copy of the *The U.S. Detailed National Report on Systematic Observations for Climate* (U.S. DOC/NOAA 2001c) can be found at http://www.eis.noaa.gov/gcos/soc_long.pdf.