Atmospheric Composition

The USGCRP budget includes $310 million in FY 2002 for research and observations related to improving understanding of ongoing changes in atmospheric composition. The atmosphere links the other components of the Earth system—including the oceans, land, terrestrial and marine biosphere, and the frozen regions. Because of these linkages, the atmosphere is a conduit of change. For example, natural events and human activities can change atmospheric composition in ways that alter the Earth's radiative (energy) balance. Associated responses involving the climate system and the stratospheric ozone layer influence the well-being of human and natural systems.

Because the atmosphere is the "fast mixer" in the Earth system, changes in the composition and chemistry of the atmosphere spread over very large areas very quickly. As a result, observations of changes in the atmosphere are among the very earliest harbingers of changes in the global environment. The very long atmospheric residence times of some chemical species cause changes in their concentrations to be virtually irreversible for decades, centuries, and millennia—thereby affecting all countries and populations, not just the emitters. The improving capability for modeling the composition of the global atmosphere as a whole is enabling quantification of the linkages between continental air quality and climate change, which were once considered separately and independently.

Future research will build upon recent scientific accomplishments. In one of the extraordinary success stories of global change research, scientific understanding has led to measures that have reversed the decades-long growth in atmospheric concentrations of the substances responsible for depleting the stratospheric ozone layer. The steps agreed to in the 1987 Montreal Protocol on the ozone layer (and subsequent amendments) are beginning to produce the intended results. For example, the tropospheric concentration of chlorine peaked in 1994—thereby building public confidence in science-based governmental and industrial decisionmaking.

Recent Accomplishments

- Observations from the Upper Atmosphere Research Satellite (UARS) show a decline in the total abundance of chlorine compounds in the stratosphere. This result adds credence to the model calculations used to project future changes in atmospheric chemistry and validates the basic strategy that was embarked on with the Montreal Protocol. This evidence of a stratospheric peaking of chlorine compounds follows a similar pattern observed five years ago in the troposphere, demonstrating consistency in our understanding of the transport of chemicals between the troposphere and the stratosphere and of atmospheric chlorine chemistry.
- Recent data from the Total Ozone Mapping Spectrometer (TOMS) demonstrate how short-term variability in global climate can combine with fires originating in connection with forest-clearing activity to produce massive air pollution over a wide area. These results describe a buildup of pollution in Southeast Asia during the last El Niño event, in September 1997. Ozone column measurements document an intensely polluted air mass covering densely populated areas around Singapore and Indonesia. These high pollution levels resulted from an unprecedented incidence of fires occur-

ring on the island of Borneo (Kalimantan). This analysis built on a decade of research that has led to an increasingly precise description of tropospheric ozone.

- A synthesis of results from meteorological data and satellite measurements shows a strong historical relationship between late-wintertime minimum temperatures and stratospheric ozone depletion in the Arctic region—colder temperatures are associated with greater ozone depletion.
- Recent measurements add support to the hypothesis that the Arctic springtime will show individual years of substantial depletion of the ozone layer, even as the trend of increasing atmospheric concentrations of chlorine is reversed. Concentrations of reactive nitrogen and chlorine during the coldest Arctic winters of the 1990s are similar to the levels observed in the Antarctic. This finding illustrates the importance of the linkage between atmospheric chemistry and temperature, and suggests that the future health of the ozone layer in the Northern hemisphere will be linked to future changes in stratospheric temperature caused by rising concentrations of greenhouse gases.
- With multiagency support, the Aerosol Characterization Experiment-Asia (ACE-Asia) was completed successfully in spring 2001. Newly developed instrumentation, including improved airborne sampling techniques, was used to characterize the distribution of aerosols in the region of outflow of air masses in Northeast Asia. NSF, Navy, and NOAA aircraft-based observing instruments were complemented by ground-based and satellite observations to measure a complex mixture of pollution-derived and natural aerosols, including mineral dust.
- Improved atmospheric transport and chemistry models have been developed that assimilate satellite observations in real time and include descriptions of atmospheric aerosols and their transport. Information on distributions and chemical nature of aerosols is needed in order to determine their radiative impact. Aerosol models with predictive capabilities have been developed and used successfully in several field campaigns to guide the deployment of research aircraft.
- The relative importance of seasonally and geographically varying processes that affect the production and fate of oxidants has been evaluated quantitatively for several metropolitan areas in the United States, providing vital information on the likely success of various possible control strategies for tropospheric ozone.

Table 4
Atmospheric Composition

FY 2002 Budget by Agency
(Discretionary budget authority in $millions)

Scientific Research	
DOC/NOAA	7.8
DOE	12.6
NASA	54.1
NSF	16.9
Smithsonian	0.3
USDA	18.0
Scientific Research Subtotal	**109.7**
NASA Space-Based Observations	199.1
NOAA Surface-Based Observations	1.0
Observations Subtotal	**200.1**
Atmospheric Composition Total	**309.8**

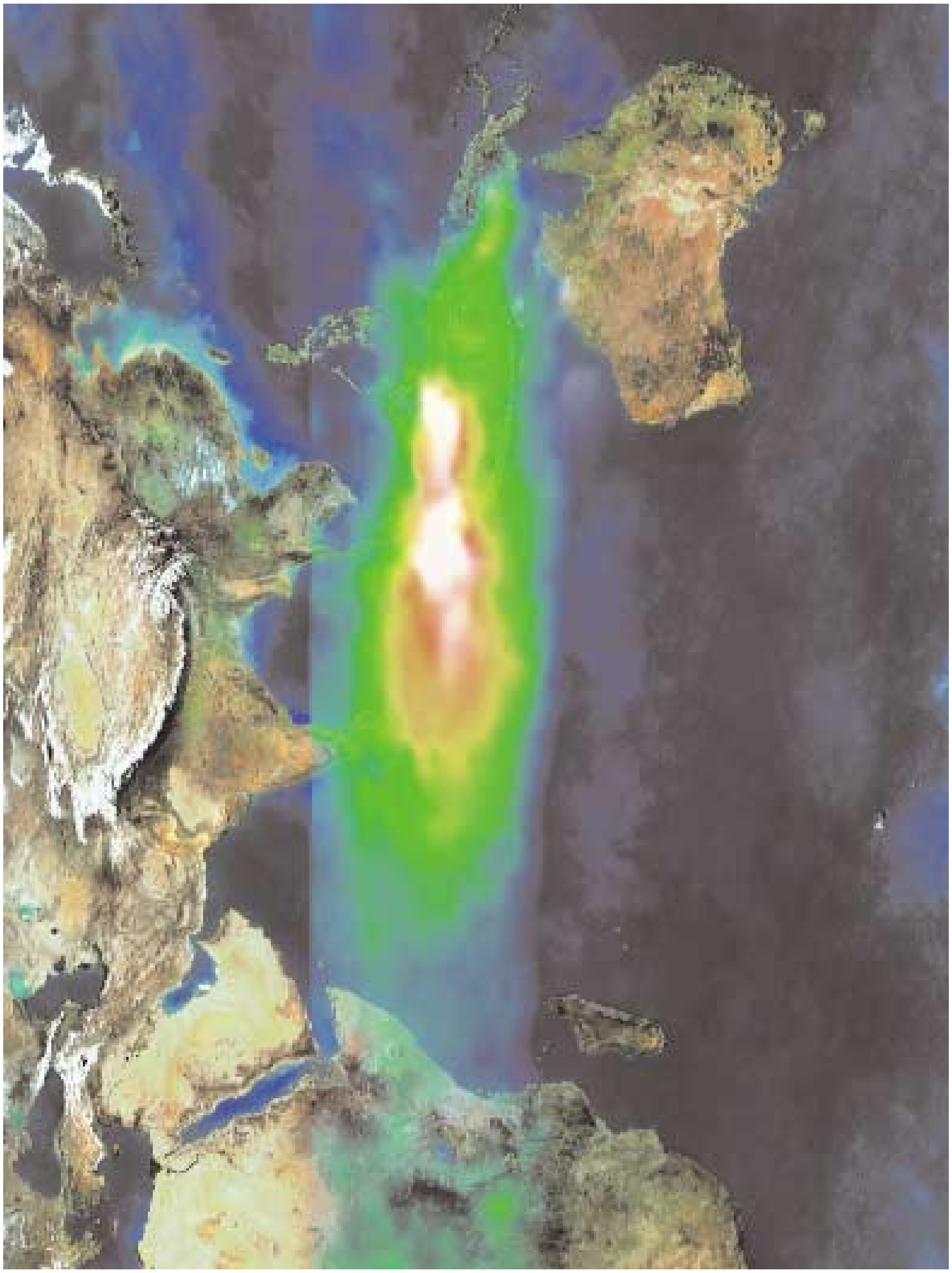

Figure 3. Large-Scale Atmospheric Pollution in Southeast Asia During the Last El Niño Event

The Total Ozone Mapping Spectrometer (TOMS) shows a heavily polluted air mass covering much of Southeast Asia during the last El Niño event (October 1997), an illustration of how short-term variations in global climate and land-use practices can lead to unhealthy levels of large-scale pollution.

Source: NASA. See Appendix B for additional information.

FY 2002 Plans

The USGCRP will continue to gather and analyze information through measurement, modeling, and assessment studies to enhance understanding of atmospheric composition and of the processes affecting stratospheric and tropospheric chemistry. Key research goals for FY 2002 include:

- Quantify interannual variations in global emissions of carbon monoxide and methane using measurements obtained from the EOS Terra satellite and data on forest fires taken over North America using airborne instruments, in association with simulations using atmospheric chemical transport models. The results will enable a more accurate evaluation of the contribution of fires and fossil-fuel combustion to global concentrations of these gases, and of the sources of methane and its potential to change atmospheric composition and climate.
- Initiate a study to characterize the magnitude and chemistry of the atmospheric plume from East Asia and assess its contribution to regional and global atmospheric chemical composition. The study will use data gathered by the Transport of Chemical Evolution over the Pacific (TRACE-P) airborne mission, satellite data, and atmospheric models. During FY 2002, in the first of the Intercontinental Transport and Chemical Transformation experiments, airborne and shipborne measurements will be taken of gases and aerosol chemical composition that are key to the photochemistry of the eastern Pacific Ocean, and results will be analyzed. This research will enable a better quantification of the relationship between changes in regional air quality and changes in global atmospheric composition, processes, and radiation balance, as well as an indication of the impact of air pollution from Asia on North America.
- Improve radiative transfer and chemical transport models using the comprehensive data set obtained by the Aerosol Characterization Experiment-Asia (ACE-Asia). This experiment was designed to increase understanding of how atmospheric aerosol particles affect the Earth's climate system. Detailed analysis of the data on chemical, physical, and optical properties of the aerosols, as well as radiation measurements, will be used to determine the radiative impact of aerosols in the region of outflow of air masses in Northeast Asia.
- Launch the SAGE III satellite to continue the long-term (multidecade) record of the evolution and interannual variability of high-latitude ozone, aerosol, and polar stratospheric cloud profiles. Data obtained by SAGE III will be combined with data obtained from previous instruments as a step toward improving estimates of the contribution of ozone changes to climate change. In addition, these analyses will improve understanding of the response of ozone, aerosol, and polar stratospheric cloud concentrations to climate variation.
- USGCRP-supported scientists play a major role in leading and preparing an updated international scientific assessment of stratospheric ozone depletion—the next in a series that has provided the scientific underpinning for decisions made under the Montreal Protocol on protection of the ozone layer. Particular attention will be devoted to interpreting the observed downward trends in ozone-depleting gases in terms of the reported emissions; characterizing the impacts on the ozone layer of new, very-short-lived chemicals; examining the latest information on trends in stratospheric ozone; and evaluating the role of climate change in the recovery of the ozone layer.

- Conduct field, laboratory, and modeling studies to improve understanding of the fundamental atmospheric processes associated with energy-related emissions and their effects on air quality and climate, and of the fundamental processes that control transport of energy-related pollutants out of the near-surface and transition boundary layers up to levels where they can be dispersed globally.

Global Carbon Cycle

The USGCRP budget includes $221 million in FY 2002 for research and observations related to understanding the global carbon cycle. Carbon is important as the basis for the food and fiber that sustain human populations, as the primary energy source that fuels human economies, and as a major contributor to the planetary greenhouse effect and the potential for climate change. Carbon dioxide (CO_2) and methane (CH_4) concentrations have been increasing in the atmosphere, primarily as a result of human use of fossil fuels and land clearing, and are now higher than they have been for at least 400,000 years.

Of the CO_2 emitted to the atmosphere, about half is currently taken up as part of the natural cycling of carbon into the ocean, and into land plants and soils. These reservoirs of carbon are known as carbon "sinks." Changes in land management practices and the addition of CO_2 and nutrients are known to have the potential to enhance significantly the uptake of carbon, particularly by forests and croplands. Options for enhancing carbon sequestration in the oceans are also being considered. Uncertainties remain, however, about how much additional carbon storage can be achieved through improved management of ecosystems and other approaches, for how long the enhanced storage could be sustained, and just how vulnerable or resilient the natural carbon cycle is to manipulation of sources and sinks.

Successful carbon management strategies will need to be based on solid scientific information on the basic processes affecting the global carbon cycle, an understanding of long-term interactions of carbon dynamics with other aspects of the Earth system (such as climate variability and change and the global water cycle) and other environmental changes (such as nitrogen deposition), assessment of how management for maximizing carbon storage affects other uses of ecosystems, and the vulnerability of stored carbon to disturbance. In addition, knowledge of the carbon cycle, especially biological productivity, is essential for effective natural resource management and for maintaining the long-term sustainability of ecological goods and services.

The research community has developed a plan for enhancing understanding of the global carbon balance. Research progress is being stimulated by breakthroughs in the development of techniques for observing and modeling the atmospheric, terrestrial, and oceanic components of the carbon cycle. A concerted research effort is planned to identify, characterize, quantify, and project the major regional sources and sinks of CO_2. Key research topics will include the Northern Hemisphere terrestrial carbon sink; the oceanic carbon sink; the global distribution of carbon sources and sinks and their temporal dynamics; the effects of land use and land management on carbon sources and sinks; projecting future atmospheric CO_2 and related greenhouse gas concentrations; and scientific issues of carbon management.

Recent Accomplishments

- In 2001,the SeaWiFS satellite instrument marked its third anniversary of uninterrupted remote-sensing data set on ocean color. An instrument aboard the EOS Terra satellite also began producing a wide array of data products on marine ecosystems. Ocean color measurements can be converted into estimates of phytoplankton (or "plant") biomass in the ocean surface layer, and can indicate the presence of certain species. Phytoplankton are important to measure because they process carbon in the upper ocean, transforming carbon from dissolved form to particulate, and are therefore essential components of the ocean carbon cycle. Without phytoplankton living in the ocean's surface layer, atmospheric carbon dioxide levels would be many times higher than they are today.
- Uptake of carbon in North America and European ecosystems was demonstrated across a wide range of latitude locations. The rates of carbon storage range from near zero at high latitudes to 7.5 tonnes of carbon gain per hectare at southern latitudes in North America. Differences in the data between North American and European sites suggest that, at a given latitude, higher temperatures promote greater carbon uptake.
- Preliminary results from the ongoing Large-Scale Biosphere-Atmosphere Experiment in Amazonia have led to new insights into the complexity of carbon cycling in Amazonia, with significant implications for quantifying the global carbon budget and for how processes known to affect the cycling of carbon are represented in biogeochemical cycling models.

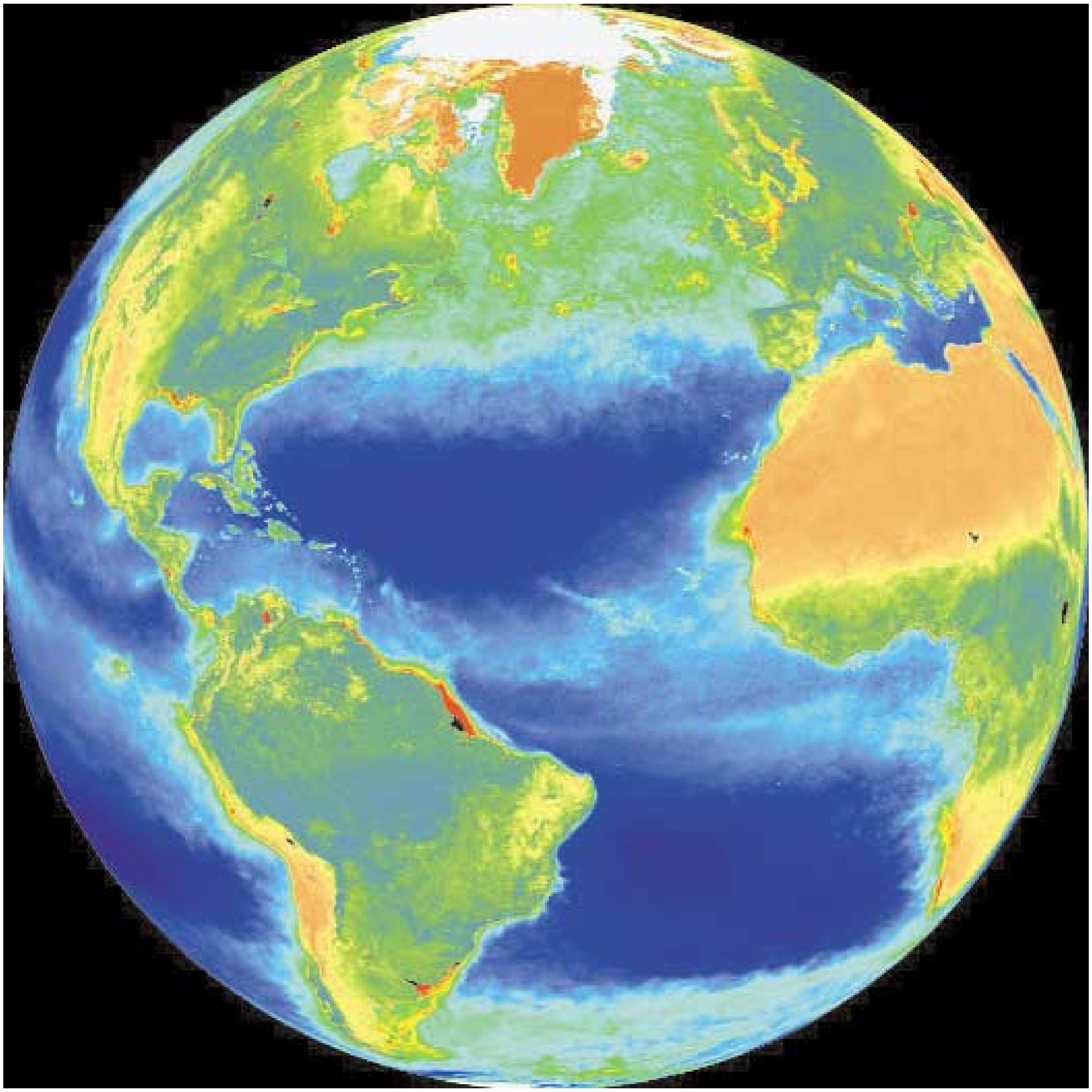

Figure 4. Plant Life on Earth as Observed From Space

False-color image of plant life on Earth as observed from space with the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). On land, greens indicate abundant vegetation, and tans show relatively sparse plant cover. In the oceans, blue areas are the least biologically productive, whereas green, yellow, and red areas represent progressively greater productivity.

Source: SeaWiFS Project, NASA Goddard Space Flight Center and ORBIMAGE. See Appendix B for additional information.

Table 5
Global Carbon Cycle

FY 2002 Budget by Agency
(Discretionary budget authority in $millions)

Scientific Research	
DOC/NOAA	4.8
DOE	13.7
DOI/USGS	3.0
NASA	47.2
NSF	21.5
Smithsonian	0.3
USDA	14.8
Scientific Research Subtotal	**105.3**
NASA Space-Based Observations	111.6
NOAA Surface-Based Observations	4.2
Observations Subtotal	**115.8**
Global Carbon Cycle Total	**221.1**

FY 2002 Plans

The USGCRP will continue to focus on understanding and quantifying carbon sources and sinks, particularly in North America, and on filling critical gaps in understanding of the causes of carbon sinks on land as well as processes controlling the uptake and storage of carbon in the ocean. Key research goals for FY 2002 include:

- Quantify the amounts and changes in carbon storage in crop land and grazing land soils, as affected by management practices such as tillage, crop rotation, irrigation, and animal feeding, by expanding studies to agricultural systems used throughout the United States, as part of a five-year research effort. Because the values from individual practices are not simply additive, agricultural “systems” will be studied, in controlled experiments and on farms and ranches. The studies will lead to the development of decision-support tools and models that can enable land managers to project the amounts and changes in carbon storage in crop and grazing lands under different management practices, at spatial scales ranging from individual fields to large regions.
- Improve quantification of terrestrial biosphere carbon exchanges with the atmosphere and of global and regional carbon budgets, using ongoing acquisition of near-daily global measurements of the terrestrial biosphere from instruments on EOS

Terra (enhanced by new data from EOS Aqua after launch). The unprecedented calibration of EOS sensors and new, refined and validated algorithms will make improved quantification of productivity possible. These same data will make possible new, quantitative analyses of agricultural and forest productivity and enable early warning of regional food shortages and certain disease and pest outbreaks. Provision of timely data to U.S. and U.N. operational famine early warning programs focused on Africa and Latin America will yield more accurate forecasts of food shortages and disease/pest outbreaks. Early in FY 2002, "science quality" data will be released and end users, such as the U.N. Food and Agriculture Organization, will be able for the first time to integrate high-quality data from the MODIS instrument into their operational analyses.

- Complete an intercomparison of atmospheric transport models used to estimate carbon sources and sinks on a global scale. Transport models are a large source of uncertainty in locating and quantifying sources and sinks. Improvements in these models also will enable more accurate forecasts of weather and climate variability.
- Initiate a major ocean experiment and observations in the Southern Ocean around the Antarctic Polar Front Zone. This experiment will involve scientists from across the country in investigating: (1) the role of iron in the biological pump of carbon in silicate-rich versus silicate-poor High-Nutrient-Low Chlorophyll (HNLC) waters; (2) the ways in which iron mediates the differential drawdown of major nutrients; (3) iron limitation of carbon fixation and export from surface waters; (4) the biophysical response of primary producers to added iron; and (5) the potential effect of iron-induced carbon export on mid-water remineralization and denitrification processes. This effort will begin to provide a stronger scientific basis for discussions of the efficacy and efficiency of using the oceans to draw down atmospheric CO_2.
- Complete the field analysis phase of a unique collaborative study of gas exchange in the equatorial Pacific—the ocean's largest natural source region of CO_2. Preliminary results suggest that CO_2 fluxes across the sea-air interface are highly dependent upon the near-surface winds and local mixing processes in the top few meters of the water column. This study is contributing to our understanding of processes that control gas exchange at the surface of the ocean and will ultimately lead to an improved ability to parameterize gas exchange using remote sensing. Understanding gas exchange is essential for being able to estimate the amount of CO_2 that the ocean absorbs from or releases to the atmosphere.

Global Water Cycle

The USGCRP budget includes $309 million in FY 2002 for research and observations related to understanding the global water cycle. Providing adequate supplies of clean water and coping with extreme hydrologic events, such as floods and droughts, pose major obstacles to achieving social and economic goals, to sustaining essential ecosystems, and to managing natural resources effectively. During the 20th century, water systems and infrastructure were developed to reduce floods and store water for future distribution. Nonetheless, floods and water shortages still cause significant property damage, public health risks, loss of life, and impairment of agricultural, commercial, industrial, and recreational activities.

Complex scientific questions arise in efforts to understand the relationships between climate processes and the water cycle, as do questions about how societies and water management systems should respond to the impacts of natural climate variability and human-induced change. Reliable seasonal forecasts and longer-range projections of precipitation, evaporation, and water flow and quality are needed to optimize the use of water over seasonal, and annual to decadal planning cycles.

Study of the water cycle requires systematic, high-resolution observations of atmospheric, hydrologic, land surface/vegetation and other climate system variables using existing (operational) and new satellite and in-situ systems. In addition, models are required for data assimilation as well as for simulation and predictability studies. Research activities are directed toward enhancing capabilities to quantify and predict, on seasonal and longer timescales, trends in the global water cycle and the regional availability of fresh water resources. Emphasis is being placed on the interaction between the water cycle and the carbon, nitrogen, and nutrient cycles, as well as the effort to achieve a better understanding of the role of water management institutions and other human activities in the distribution and quality of available water resources. Each year, a combination of observational programs and modeling, analysis, and process studies addressing a range of spatial and temporal scales, contribute to improving the quantification and prediction of changes in the water cycle at global and regional scales, and of the impacts of these changes.

The Global Water Cycle Study Panel, established by the USGCRP and made up of leading representatives of the research community, completed development of a Global Water Cycle Science Plan, which was published in May 2001. Using this plan as a framework, the USGCRP Interagency Working Group on the Global Water Cycle developed a long-term strategy for implementation.

Recent Accomplishments

- Completed almost four years of rainfall measurements by the Tropical Rainfall Measuring Mission (TRMM), which, combined with other satellite and surface-based observations, has provided a greatly improved global tropical rainfall climatology. TRMM also has provided the data for preparation of accurate maps of the diurnal cycle of precipitation, contributing to a new benchmark for documenting tropical precipitation. In parallel, TRMM data provide a more accurate basis for verifying global precipitation weather forecasts, a goal of the U.S. Weather Research Program.
- Completed the first year of analysis of global measurements of the radiative properties of clouds and aerosols taken by EOS Terra. These observations, together with those of EOS Aqua (launch scheduled for late 2001/early 2002) will reduce uncertainty in the determination of cloud/aerosol radiative forcing and feedback processes involved in the heating and cooling of the Earth's surface and atmosphere.
- Developed improved representations for modeling of the land surface, including topographic variability, soil physics, and snowpack physics. These improvements will contribute to more accurate seasonal predictions of changes in weather patterns associated with El Niño cycles, and resulting changes in land surface hydrology.
- Completed the second precisely controlled mapping of most of Antarctica in a mode

that will enable the calculation of surface flow rates. High-resolution data from LANDSAT-7 and EOS Terra showed the early beginnings of a crack in an Antarctic ice flow. The crack, found to be 25 km long and 400-500 meters wide in January 2001, was growing at about 13 meters a day. This is the first observation of the beginning of the formation of massive icebergs.

- Provided the means for accurate, continuous measurements of water vapor vertical profiles from field campaigns at one of the Atmospheric Radiation Measurement (ARM) program sites. These new measurements provide an improved understanding of the variability of atmospheric water vapor at all altitudes of interest to climate and weather-prediction modelers.
- Differentiated the chemical characteristics in spring snow melt between cool morning periods and warmer periods later in the day. Increased understanding of these processes will improve estimates of the impacts of global change on water quality in streams and rivers carrying snowmelt water.
- Analyses of data acquired with commercial aircraft have demonstrated the ubiquity, globally and throughout the year, of air that circulates widely in relatively thin layers in the troposphere (present in layers averaging about 1 km thick at altitudes from 2 to 12 km). The existence of these layers, which can be characterized by their water vapor and ozone content, has important implications for understanding the large-scale atmospheric circulation when the radiative properties of these layers are taken into account.

Table 6
Global Water Cycle

FY 2002 Budget by Agency
(Discretionary budget authority in $millions)

Scientific Research	
DOC/NOAA	5.7
NASA	56.6
NSF	12.7
USDA	2.8
Scientific Research Subtotal	**77.8**
NASA Space-Based Observations	231.6
Global Water Cycle Total	**309.4**

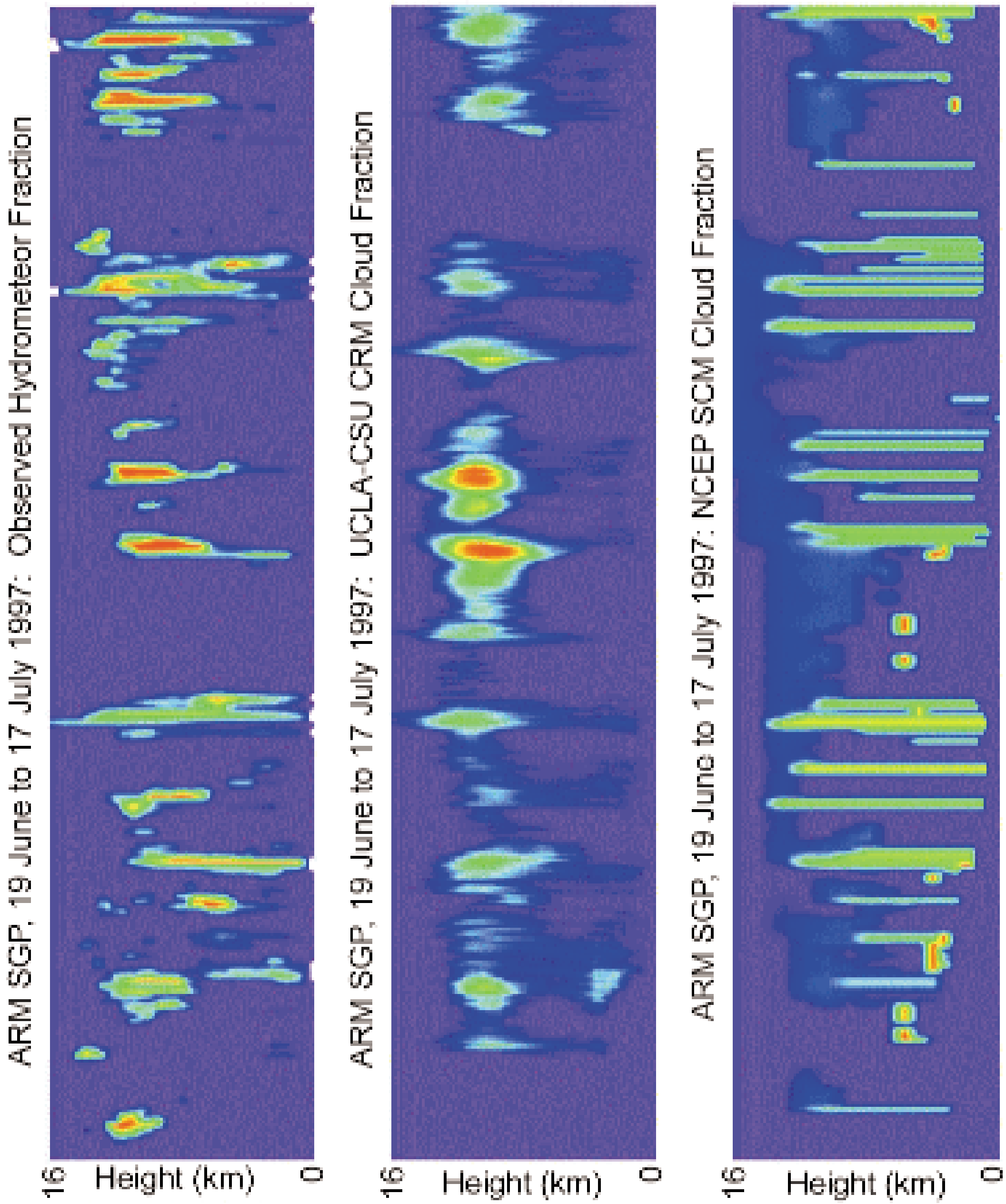

Figure 5. Modeling Clouds

Predicted vs. observed time-height cloud fraction at the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains site from 19 June to 17 July 1997. Left panel: Cloud fraction observed by cloud radar. Center and right

panels: Cloud fraction predicted by models. Color indicates cloud fraction, which ranges from 0 (violet) to 1 (red). Developing the capability to account for cloud water distribution will lead to improved climate simulation models and will support efforts to predict precipitation.

Source: DOE ARM Program. See Appendix B for additional information.

FY 2002 Plans

The USGCRP will continue to improve the capabilities for measuring important aspects of the global water cycle and will conduct a number of important research and analysis projects. Key research goals for FY 2002 include:

- Analyze data from the first year of the EOS-Aqua satellite, which is scheduled for launch in late 2001/early 2002. These results should complement measurements from EOS-Terra of clouds, aerosols, radiation budget parameters, land surface characteristics, vegetation cover, snow cover, sea surface temperature, sea ice, atmospheric temperature and water vapor, and other critical parameters. Together, these data sets will enable a more accurate quantification of the water cycle at global and regional scales.
- Launch the EOS/ Earth System Science Pathfinder Gravity Recovery and Climate Experiment (GRACE) (November 2001) to improve measurement of the mass balance of ice sheets, and changes in storage of water/snow on continents. Launch ICESat (December 2001), the first mission to use precision altimetry to measure changes in the topography and mass balance of polar ice sheets. Conduct elevation-change surveys of areas in Greenland that show the most dramatic thinning of the ice sheet, to determine if the thinning is constant, accelerating, or decelerating. Produce high-resolution (10 m) maps for parts of Antarctica, to provide a basis for detecting changes in ice sheets.
- Reduce uncertainty (by 3-7 percent in monthly mean) in the current International Satellite Cloud Climatology Project dataset of globally observed cloud characteristics, particularly in the polar regions, by comparing it with new satellite datasets (that include new constraints on the derived quantities), and with in situ ground-based and airborne measurements.
- Demonstrate over a variety of landscapes the capability to measure and diagnose soil moisture from airborne platforms.
- Demonstrate the impact of assimilating rainfall data from the Tropical Rainfall Measuring Mission on forecasting the track and intensity of tropical storms.
- Improve quantification of land-surface hydrology and the ability of models to simulate climate at regional (large watershed) scales, through the development and demonstration of improved methods to quantify components of the water budget. In an experiment in the Walnut River watershed, winter and summer storm events will be studied in conjunction with ongoing ARM carbon flux and meteorological measurements. A prototype water isotope measurement and modeling program will be implemented.
- Investigate the exchanges of water, energy, and carbon nutrients at selected experimental basins. The processes that control these exchanges are critical to understanding snowpack chemistry, surface hydrology, and climate response.