



The National Climate Program: Early Achievements and Future Directions (1986)

Pages
66

Size
5 x 9

ISBN
0309321646

Board on Atmospheric Sciences and Climate;
Commission on Physical Sciences, Mathematics, and
Resources; National Research Council

 [Find Similar Titles](#)

 [More Information](#)

Visit the National Academies Press online and register for...

✓ Instant access to free PDF downloads of titles from the

- NATIONAL ACADEMY OF SCIENCES
- NATIONAL ACADEMY OF ENGINEERING
- INSTITUTE OF MEDICINE
- NATIONAL RESEARCH COUNCIL

✓ 10% off print titles

✓ Custom notification of new releases in your field of interest

✓ Special offers and discounts

Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press. Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.

To request permission to reprint or otherwise distribute portions of this publication contact our Customer Service Department at 800-624-6242.

Copyright © National Academy of Sciences. All rights reserved.



**THE NATIONAL CLIMATE PROGRAM:
EARLY ACHIEVEMENTS AND FUTURE DIRECTIONS**

**Report of the Woods Hole Workshop
July 15-19, 1985**

**Board on Atmospheric Sciences and Climate
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council**

Order from
National Technical
Information Service,
Springfield, Va.
22161
Order No. PB 86-48975

**NATIONAL ACADEMY PRESS
Washington, D.C. 1986**

**NAS-NAE
MAY 1 1986
LIBRARY**

QC
989
.N95
1986
C.1

NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This material is based on work supported jointly by the National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the Department of Agriculture, the Department of Defense, the Department of Energy, the Department of the Interior, the Department of Transportation, the Environmental Protection Agency, and the National Climate Program Office under Contract Number NA79RAC000104.

Available from the
Board on Atmospheric Sciences and Climate
2101 Constitution Avenue
Washington, D.C. 20418

BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE

**Charles L. Hosler, Jr., Pennsylvania State University,
Chairman**

Louis J. Battan, University of Arizona

Kirk Bryan, Princeton University

**William C. Clark, International Institute for Applied
Systems Analysis**

Robert A. Duce, University of Rhode Island

John A. Eddy, National Center for Atmospheric Research

John Gerber, University of Florida, Gainesville

**John B. Hovermale, Naval Environmental Prediction
Research Facility**

Francis S. Johnson, University of Texas, Dallas

Michael B. McElroy, Harvard University

Volker A. Mohnen, State University of New York, Albany

Andrew F. Nagy, University of Michigan

Julia M. Paegle, University of Utah

Roger R. Revelle, University of California, San Diego

Juan G. Roederer, University of Alaska

**Warren Washington, National Center for Atmospheric
Research**

Ex-Officio Members

Werner A. Baum, Florida State University

Devrie Intriligator, Carmel Research Center

Joseph Smagorinsky, Princeton University

Verner E. Suomi, University of Wisconsin, Madison

Staff

John S. Perry, Staff Director

Fred D. White, Staff Officer

Thomas O'Neill, Staff Officer

**COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND
RESOURCES**

Herbert Friedman, National Research Council, Chairman
Clarence R. Allen, California Institute of Technology
Thomas Barrow, Standard Oil Company
Elkan R. Blout, Harvard Medical School
Bernard F. Burke, Massachusetts Institute of Technology
George F. Carrier, Harvard University
Herman Chernoff, Massachusetts Institute of Technology
Charles L. Drake, Dartmouth College
Mildred S. Dresselhaus, Massachusetts Institute of
Technology
Joseph L. Fisher, Office of the Governor, Commonwealth of
Virginia
James C. Fletcher, University of Pittsburgh
William A. Fowler, California Institute of Technology
Gerhart Friedlander, Brookhaven National Laboratory
Edward D. Goldberg, University of California, San Diego
Mary L. Good, Signal Research Center, Inc.
J. Ross MacDonald, University of North Carolina
Thomas F. Malone, Saint Joseph College
Charles J. Mankin, Oklahoma Geological Survey
Perry L. McCarty, Stanford University
William D. Phillips, Mallinckrodt, Inc.
Robert E. Sievers, University of Colorado
John D. Spengler, Harvard School of Public Health
George W. Wetherill, Carnegie Institution of Washington
Irving Wladawsky-Berger, IBM Corporation

Raphael G. Kasper, Executive Director
Lawrence E. McCray, Associate Executive Director

LIST OF PARTICIPANTS

Charles L. Hosler, Pennsylvania State University, Chairman
Jesse H. Ausubel, National Academy of Engineering
Tim P. Barnett, Scripps Institution of Oceanography
Werner A. Baum, Florida State University
Eugene W. Bierly, National Science Foundation
Mark A. Cane, Lamont-Doherty Geological Observatory
Stanley A. Changnon, Jr., Illinois State Water Survey
Curt Collins, National Science Foundation
Margaret Courain, National Oceanic and Atmospheric
Administration
Thomas Crowley, National Science Foundation
Bernard Dethier, Cornell University
John Diamante, National Oceanic and Atmospheric
Administration
Robert E. Dickinson, National Center for Atmospheric
Research
Joseph O. Fletcher, National Oceanic and Atmospheric
Administration
Kenneth D. Hadeen, National Climatic Data Center
J. Michael Hall, National Oceanic and Atmospheric
Administration
Richard E. Hallgren, National Weather Service
Bruce B. Hanshaw, U.S. Geological Survey
Edward J. Harrison, Jr., Department of Defense
Alan D. Hecht, National Climate Program Office
Isaac M. Held, National Oceanic and Atmospheric
Administration
Wilnot N. Hess, National Center for Atmospheric Research
Howard Hill, National Climate Program Office
John Hoffman, Environmental Protection Agency
Ray Hoxit, Climatological Consulting Corporation
Kenneth G. Hubbard, University of Nebraska and American
Association of State Climatologists

Paul Janota, The Analytic Sciences Corporation
Roy L. Jenne, National Center for Atmospheric Research
Robert W. Kates, Clark University
Frederick A. Koomanoff, Department of Energy
Helmut E. Landsberg, University of Maryland
Thomas McKee, Colorado State University
Robert E. Palmer, U.S. House of Representatives
Ronald G. Prinn, Massachusetts Institute of Technology
**Eugene M. Rasmusson, National Oceanic and Atmospheric
Administration**
William Riebsame, University of Colorado
**David R. Rodenhuis, National Oceanic and Atmospheric
Administration**
Claes H. Rooth, National Climate Program Office
Norman J. Rosenberg, University of Nebraska
Brian Rothschild, University of Maryland
**The Honorable James H. Scheuer, U.S. House of
Representatives**
**Robert A. Schiffer, National Aeronautics and Space
Administration**
**Stephen H. Schneider, National Center for Atmospheric
Research**
Gunter Seckel, Monterey, California
Joseph Smagorinsky, Princeton University
William Sprigg, National Climate Program Office
Norton D. Strommen, Department of Agriculture
Eric T. Sundquist, U.S. Geological Survey
Verner E. Suomi, University of Wisconsin
Otto Thiele, National Aeronautics and Space Administration
**Shelby G. Tilford, National Aeronautics and Space
Administration**
Joseph A. Warburton, Desert Research Institute
Robert M. White, National Academy of Engineering
Herbert L. Wiser, Environmental Protection Agency
Carl I. Wunsch, Massachusetts Institute of Technology

Staff

Wendy McGhee Graham, National Climate Program Office
Judy Marshall, National Research Council
John S. Perry, National Research Council
Fred D. White, National Research Council

FOREWORD

More than any other aspect of the natural environment, climate has shaped the way mankind lives on this small planet. Sometimes modern man is inclined to consider earth as an unchanging element of geography. Although geologists and paleontologists told exciting tales about ice ages of the distant past, contemporary climate was left to the statisticians toiling in dusty archives.

Although a few individuals had been studying climatic change for many decades, a renewed sense of awareness emerged in the 1960s. Research revealed fascinating and puzzling details about climate variability on all time scales. There had been a Little Ice Age. Would there be another one? Interglacial periods such as ours seemed to be about 10,000 years long. Was a return of ice just around the corner? Measurements showed that we were changing our atmosphere, and models predicted disturbing effects on climate. Was a hothouse earth in our future? A series of climate-related disturbances afflicted countries around the earth. Were long-term climate changes already under way?

These factors converged to prompt the development of organized national and international programs to improve our understanding of climate and our ability to use that knowledge. Internationally, the World Climate Conference of 1979 led to development of a World Climate Program under the auspices of the World Meteorological Organization and other international bodies. In our own country, a complex series of initiatives led to the enactment of the National Climate Program Act of 1978. This innovative "experiment in public administration," as it was termed by Congressman George Brown, called for establishment of an interagency National Climate Program that would be guided by periodically updated Five-Year Plans.

The first version of this plan was powerfully shaped by two major workshops organized by the Climate Research Board, a predecessor of the current Board on Atmospheric Sciences and Climate, in the summers of 1978 and 1979. The resulting plan served well, but no vehicle as dynamic as the National Climate Program can travel indefinitely on the static tracks of an aging document. An updated plan was urgently needed, and indeed was mandated by the legislation. The National Research Council was again requested to provide guidance to the National Climate Program Office for the development of a new plan. Again a workshop was convened at the Study Center of the National Academy of Sciences in Woods Hole, Massachusetts, on July 15-19, 1985. The participants were charged with reviewing the current federal efforts in climate, and developing concepts and recommendations that might assist the federal agencies and the National Climate Program Office in the development of an updated plan for this important national endeavor. The meeting was well-attended, the discussions were animated and constructive, and the work sessions were intense and fruitful. It was clear that the National Climate Program, with many significant achievements already to its credit, faces a promising future in robust health.

Charles L. Hosler, Chairman
Board on Atmospheric Sciences
and Climate

EXECUTIVE SUMMARY

OVERVIEW

Since its passage in 1978, the National Climate Program Act has provided both a focus and an incentive for research and improvement of services in climate prediction and the utilization of our knowledge of climate. The National Climate Program (NCP) has begun to show accomplishments in areas identified by the act: greater use and availability of climate data, increased coordination of climate research activities, increased emphasis on climate prediction, and coordination of U.S. participation in international climate activities. The accomplishments to date provide a base for future work aimed at meeting the goals set by the act.

Climate and society interact in numerous and complex ways; thus climate and public policy are inextricably intertwined. Coordination of the climate-related activities and interests of the various federal agencies involved is fundamental for program success.

Legislation to amend the National Climate Program Act continues to be essential. Amendments to the National Climate Program Act that will make explicit the functions of the National Climate Program Office (NCPO) and strengthen the interagency program coordination have been proposed and should be promptly enacted. (See Section 2.1.2)

Experience in the NCP over the past five years has shown that many users need a continuum of weather and climate data. New data storage and processing technologies are making possible systems that allow access to data more rapidly and more efficiently. A major goal of the NCP should be to provide ready access to weather and climate data from observations to archives, and particu-

larly those data in near real time that are not now readily available.

The rapidly growing body of research knowledge on climate impact assessment methodology should be aggressively transferred to the planning efforts of federal, state, and international agencies. The potential for significantly increased skills in monthly, seasonal, and interannual climate prediction may be on the horizon, and an understanding of the possible economic and social implications of such capabilities is needed.

Among the specific climate-related problems that the program might address, drought undoubtedly has high priority. State and regional drought response plans should be fostered, and coordinated national research, monitoring, impact assessment, and relief programs should be developed. Indeed, enhanced efforts to integrate our growing understanding of climate variability and impacts into national water resource planning and management at all levels should be fostered by the program.

Another problem that remains to be addressed is the development of management strategies to deal with socioeconomic consequences of climate variation. These strategies are virtually unknown as yet, except as concepts, and their development will involve participation from several disciplines.

Climate knows no borders; thus the international dimension of climate is inherent and inescapable. The World Climate Program (WCP) being carried out through the World Meteorological Organization (WMO) continues to merit strong support and vigorous participation by the United States. Also, the potential of international climate-related research and services to support U.S. national interests in the world community merits closer attention.

CLIMATE SYSTEM RESEARCH

The statistical characteristics and time-dependent variations of climate depend on the behavior of the global climate system. The quest for better understanding of this system and improved capabilities to predict its behavior received a solid head start through the Global Atmospheric Research Program (GARP). Continued research is producing significant advances under the aegis of the World Climate Research Program (WCRP). A strategy is now being developed for organizing climate research efforts

with emphasis on ocean-atmosphere-land interactions, and a theoretical basis for climate prediction is emerging. Major accomplishments since 1978 include the following:

- improved understanding of the interannual variability of the tropical ocean and the global atmosphere, through studies of the El Niño/Southern Oscillation (ENSO) phenomenon, and development of the international Tropical Ocean and Global Atmosphere (TOGA) program to address these problems.
- initial success in simulation of climatic variability on monthly time scales.
- progress toward development of long-range prediction models by both dynamical and statistical methods.
- development of methods for measuring and modeling the ocean and its interaction with the atmosphere.
- increased understanding of past climatic regimes and of the accompanying changes in atmospheric composition.
- measurements of trends in trace atmospheric constituents potentially influencing climate.
- research on variability of energy inputs and outflows to and from the climate system, through such studies as the Earth Radiation Budget Experiment (ERBE) and the International Satellite Cloud Climatology Project (ISCCP).

Research over the next five years, and indeed through the remainder of this century, should continue this momentum, constructively coordinated through the NCP and the WCRP. Within this broad spectrum of endeavors, a number of research areas may be identified that are logical extensions of existing programs or that address gaps that now exist. These include, not in priority order, the following:

- continued study of atmospheric trace constituents and biosphere interaction.
- the role of polar processes in climate variation and the response of polar ice masses to climate variations.
- the causes and prediction of drought and desertification, a concern heightened by the continuing African drought.

- the dynamics of cloud-radiation interactions, which are important for reducing uncertainty in climate forecasting.
- the global ocean circulation, a topic being imaginatively addressed through the World Ocean Circulation Experiment (WOCE).
- long-range weather prediction through statistical and dynamical methods, where atmospheric states potentially predictable over weeks to seasons may be identifiable.
- tropical ocean and global atmosphere interactions, where significant potential for prediction of tropical, subtropical, and even mid-latitude climate anomalies exists, and where a well-focused research program--TOGA--merits continued strong support.
- paleoclimatology, where research has yielded promising new techniques and intriguing new knowledge, permitting highly useful interaction with climate modeling.

The effectiveness of climate research will depend upon continued cooperative support by the federal agencies within the context of the NCP, with the Department of Energy (DOE), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA) playing particularly important roles. Federal efforts will be especially needed in ensuring the homogeneity and continuity of significant data sets by maintaining conventional land, satellite, ocean, and trace species observing programs. In particular, the integrity of the operational and research satellite programs must be maintained. Moreover, improvements are required in the area of satellite data management to improve the timely availability and direct access while lowering costs.

CLIMATE IMPACTS

A start has been made in understanding the societal impacts of climate variability and change. The community of researchers addressing this area has grown and strengthened, and methodology for the study of impacts has been greatly advanced and systematized. The Environmental Protection Agency (EPA) has undertaken initial impact studies of sea level change and changes in water resources in the western United States that are

likely to result from climate change due to warming of the atmosphere. Other efforts such as the Climate Impacts Perception and Adjustment Experiment (CLIMPAX) demonstrate concrete progress. International studies are moving ahead within the context of the World Climate Impacts Program (WCIP) (under the United Nations Environment Program (UNEP)) and the International Institute for Applied Systems Analysis (IIASA).

Priority themes for study over the next few years have been identified as follows:

- study of extremes of climate variability over the range of different time scales and the changes in extreme characteristics that might accompany man-made or natural climate change.
- the influences of climate variations on water resources and their implications for long-range planning.
- drought, with special emphasis on long-range implications for Africa.
- agricultural management and research, with a view to achieving more efficient production management through better adaptation to climatic variations in agricultural planning and practice.
- CO₂ and trace gas impacts.

A number of specific initiatives should be given high priority:

- A new Climatic Atlas is needed to provide a comprehensive updated climatology of the United States, and as a related effort to the World Climate Impacts Program. The atlas would emphasize climate-society interactions and provide practical information needed for planning by federal, state, and local agencies and for commercial and business uses. The atlas should be developed in coordination with the 1990 census and should have the same population reference base.
- Studies of the utility of climate predictions should be undertaken. Significantly enhanced capabilities seem on the horizon, societal and economic implications may be great, and present understanding of the impact of operational predictions is lacking.
- Empirical studies of the impacts of actually experienced climatic variations should be expanded beyond the current CLIMPAX project; scenarios of likely future climate changes should be incorporated into long-term water resource and environmental planning.

In addition, work is needed to improve dissemination of impact assessment methods, coordination and verification of climate impact models in various sectoral areas, studies of the social costs of adjustment to climate variations, and more realistic projection of CO₂ and trace gas trends.

The NCPO should play an increasingly important catalytic and coordinating role in climate impacts research. The demonstrated progress and clear potential of the field merits increased support and active participation by a broader range of federal and state agencies. Internationally, the WCIP shows increasingly positive results and merits continuing support, guidance, and involvement.

CLIMATIC DATA, INFORMATION, AND SERVICES

Climate services are the ultimate product of the NCP, and the program's early efforts have yielded significant improvements important to government, industry, and individual citizens. Technological advances in computers and communications have greatly increased the potential for improved services, while decision-makers have come to demand ever more comprehensive and timely information.

Traditionally, "weather" data concerns current atmospheric conditions, while "climate" data refers to statistics of fairly lengthy past time periods. In fact, however, it is obvious that weather and climate form a continuum. Indeed, there is an emerging and largely growing demand for near-real-time information. Agriculture and agribusiness decision makers, in particular, are major users of near-real-time information, in addition to their traditional use of conventional climate and weather information.¹ Future directions point to a merging of the use of weather and climate data, and suggest that new institutional arrangements be considered by NOAA to better coordinate weather and climate services and to achieve the data in a format that is convenient and relatively inexpensive to the user.

¹Lamb, P.J., S.T. Sonka, and S.A. Changnon, Jr., Use of Climate Information by U.S. Agribusiness. Illinois Water Survey (submitted for publication); and Dale, (ed.) (1985). Workshop on Weather and Climate Research Needs for Agriculture in the Nineties, University of Missouri.

Since initiation of the NCP, important advances in climate products and services have been realized:

- an interim climate data inventory has been developed.
- a computer-based Climate Anomaly Monitoring System (CAMS) provides a mechanism for monitoring anomalies in real time.
- the Monthly Climate Diagnostics Bulletin has been enhanced.
- global crop conditions are being monitored through the Joint Agricultural Weather Facility (JAWF) of NOAA and the Department of Agriculture (USDA).
- a National Environmental Data Referral Service (NEDRES) has been implemented.
- the National Climatic Data Center (NCDC) has been strengthened.
- two regional climate centers have been established and are demonstrating methods for federal-state cooperation in climate services and management.
- a promising demonstration project in automated weather monitoring has been developed and extended to a regional drought-monitoring program.

Further development of climate services might be guided by the recommendations of earlier reports of the National Research Council (NRC), many of which have not yet been addressed effectively. Maintenance of an adequate surface observing network is particularly essential. The cooperative climatological observing network, the solar and terrestrial radiation network, and the Reference Climatological Station network should be strengthened. The goals of the Intergovernmental Climate Program provisions of the National Climate Program Act should be pursued under the leadership of the NCPO by involving existing state and regional climate programs and by encouraging further development of such programs.

Continued problems in providing services stem from several causes: expansion and dispersion of basic data sets, the lack of timely data inventories, slow progress by states in funding and in providing climate data and related information to users, and caution in the private sector in developing and marketing specialized climate services.

Despite the development of two regional climate centers, the lack of dependable federal funding has led to fragmented and idiosyncratic capabilities. The United

States still lacks a nationwide system of climate services. NOAA could advance the development of such a system by implementing the existing NCPO plans for a coordinated nationwide system of climate services, which include increasing operational support for existing regional centers and establishing new regional centers to complete a nationwide system.

Technological advances in observation, communications, data processing, storage, and dissemination of climate information provide a foundation for development of an effective national climate services program. The development of high-speed weather/climate data transmission systems and the development of systems and standards to deliver near-real-time products to meet state, regional, and national needs are essential. The National Weather Service (NWS) modernization program will provide a flood of new data. Corresponding improvements in data management are essential. The timeliness of data and information is a key issue. New technology will provide unprecedented opportunities for rapid and cost-effective data dissemination.

Since establishment of the NCP, private sector weather and climate activities have grown to serve thousands of clients. The private sector should be taken into account in the planning of future weather/climate services, should be provided unrestricted access to publicly collected data at fair prices, and should be allowed to compete for provision of services to both private and public customers.

INTRODUCTION

No single feature of the environment may be more universally tied to human existence and activity than is climate. Climate has shaped our anatomy, body functions, sweat glands, cold sensors, and pigmentation; it determines our food supply and diet; and it is the principal motivator for our dress and habitation. Minor changes in climate can render man's works, developed over centuries, inappropriate and incompatible with man's needs. Climate changes can be cataclysmic or so gradual that we are unaware of them until some threshold is passed that limits food production or transport: a bay or river freezes or the water supply fails, early or late frost limits a crop range, or an essential component in the food chain disappears. Just as the daily weather forecast can guide man's activities to minimize weather-related losses and take advantage of favorable weather, knowledge or warning of climate change can guide those who are responsible for longer range plans and contingencies. At the same time, the persistence of climate permits past experience, manifested in climate data, to guide current planning and design of man-made systems.

Since the NCP was organized in 1978,^{1, 2} a focus of effort toward climate prediction and utilization of climate data has been achieved that did not exist before. The National Climate Program Office (NCPO) has served to inform and, with the National Climate Program Policy

¹Public Law 95-367 (September 1978) The National Climate Program Act.

²National Research Council (1979) Toward a U.S. Climate Program Plan. Washington, D.C.: National Academy Press.

Board (NCPBB), has helped coordinate agency efforts across the government. NCPO has proved to be a positive force in the coordination of some states' activities. Experimental forecast centers, supplemented by the work of individual researchers, have been a focus of predictive experiments and have resulted in progress in improving prediction. Observational networks have shed much light on the trends of greenhouse gases (CO₂, CH₄, N₂O, CH₃Cl, etc.). It is now accepted that trace gases could soon have an equal impact with CO₂ in terms of changes in the radiation budget. The ENSO of 1982-1983 was well documented, and atmospheric and oceanic models using real data have begun to reveal the physical basis for the evolution of this phenomenon. Confidence is building that early signs of the next event may help in predicting anomalies for a year or more in advance. The importance of long records of physical parameters in the atmosphere and oceans has been underlined. The need for understanding anthropogenic, biological, and geological forcing and feedbacks has become more obvious than ever. Global change,³ global habitability,⁴ and International Geosphere-Biosphere Program⁵ are emerging concepts largely stimulated by a greater awareness of climate complexity, variability, and impacts. Such programs seek to enhance our ability to unify and understand the global system and make predictive models possible.

Technological advances provide a potential for improvements in the quantity, quality, and timeliness of climate data. Many states have installed automated weather stations to meet research and operational needs. A few states have been linked into a network. Increasingly, computer and communications technology are used in combination to provide climate data in near real time. This has helped create opportunities for new uses of climate data.

³Malone, T.F., and J.G. Roederer (1984) ICSU Symposium on Global Change. New York: Cambridge University Press.

⁴Goody, R.M. (1982) Global Change: Impact on Habitability. Jet Propulsion Laboratory (JPL D-95), California Institute of Technology, Pasadena, Calif.

⁵National Research Council (1986) Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP. Washington, D.C.: National Academy Press.

These beginnings of understanding have been built upon 200 years of data stemming from the understanding that Washington, Jefferson, and Franklin had of the importance of climate as a resource and the necessity to inventory, monitor, and understand it for the continued development and guidance of society. Future productivity and the quality of life will depend upon enlarging our understanding and predictive capabilities. They also will depend on using the historical data and predictions to make our systems more resilient and responsive to change and to guide our actions in a way that will not induce undesirable or costly change.

Climate is at the same time a global resource, a problem, and a concern. The physical connection between events occurring in any part of the globe and the rest of the world, telegraphed by the oceans and atmospheres, can be communicated into man's activities that are further connected economically, politically, and sociologically. Global understanding of climate can occur only through global cooperation in science. The quality of life for all mankind can be assured only if there is global utilization of our knowledge to minimize suffering and loss, to maximize productivity, and to minimize adverse impacts on oceans and atmosphere through man's activity.

CLIMATE PROGRAM POLICY ISSUES

Because climate and society interact in complex ways and because the National Climate Program (NCP) is an inter-agency, intergovernmental effort, questions of public policy pervade the program. Many of these questions have been and are continually being addressed by the National Climate Program Policy Board (NCPFB), which is made up of senior agency officials. This forum provides a mechanism for coordinating key elements of the program and for establishing agency commitments to national and international projects. The board addresses key policy issues raised by our growing understanding of climate, its impacts on society, and the emerging technologies of data management and climate prediction. A limited number of these issues that deserve consideration in the NCP planning process are addressed here.

2.1 The National Climate Program Act and Its Provisions

2.1.1 Interagency Coordination

At the core of national climate policy is the act itself and its key provision for the coordination and enhancement of agency efforts in the climate area. The development of a five-year plan is in itself a mechanism through which interagency coordination and commitments are developed. The main responsibility of the NCPO is to ensure that the agreed program is adequately coordinated and that the planning process is updated annually. A key function of the NCPFB is to foster interagency coordination and to identify areas where such coordination is needed. The NCPO and the NCPFB also should reach out to user agencies to encourage their greater participation in the program.

2.1.2 Climate Act Amendments

Over the last five years, several efforts have been made to amend and clarify the National Climate Program Act of 1978. Congressional hearings have been held and a revised bill was enacted by both the House of Representatives and the Senate in December 1984. Unfortunately the bill was not signed into law because of problems with other legislative matters incorporated in the bill. These amendments are being considered by the current Congress. Among their provisions are the removal of the requirement for an advisory committee of users and producers of climate data and information; the creation of a charter for the existing interagency Climate Program Policy Board, together with an outline of its responsibilities; elimination of the requirement for a formal Intergovernmental Climate Program; changes in the frequency for revising the Five-Year Plan from biennially to at least once each four years; and better definition of the duties of the NCPO and its Director. (Note: the latest version of the amended act passed the House in December 1985 and is currently being considered by the Senate.)

2.1.3 Gap-Filling Role of NCPO

Greater flexibility is needed by the NCPO to provide support of "as needed" efforts to fill gaps in the NCP not addressed adequately by individual agencies and to support one-time efforts such as the recent review of nuclear winter, and drought planning. This funding leverage is critical to the development of a comprehensive climate program. Funding to fill critical gaps should not distract the NCPO from its core coordination mission, but must nevertheless be adequate to produce high-quality studies and assessments of emerging issues.

2.2 Climate Data Management

The nation's system for collection, archiving, and disseminating climate data is far from optimum. State programs are of uneven quality. The regional climate center concept has not yet fulfilled its potential to integrate data gathering and management. Furthermore, distinctions between weather and climate information in terms of data communication and management have been

largely outdated by technological developments in the past five to ten years. Communications and micro-processing technologies make it easier to access all types of geophysical data in near real time. Indeed, experience has shown that many users need access to a continuum of weather and climate data.

This blurring of the distinction between weather and climate data offers a good opportunity to coordinate atmospheric data management among various levels of government and the private sector. This will be discussed in Chapter 5. The NCP can provide a framework and impetus for taking advantage of this opportunity to solve a critical problem in weather and climate research and services.

2.3 Drought Policy

It is time to institute a coordinated interagency and intergovernmental effort to reduce our vulnerability to drought (including shortages in agricultural, urban, and industrial water supplies). Policy planning analyses of governmental drought response in the 1970s^{1, 2} point to the poorly coordinated reaction to, and inefficient monitoring and assessment of drought.

The development of several state drought plans (e.g., Colorado, South Dakota, Nebraska, and New York³) speaks to a recognized need to have in place mechanisms for detecting, assessing, and mitigating drought impacts. The creeping, large-scale nature of drought makes it particularly difficult to manage without broad

¹General Accounting Office (1979) Federal Response to the 1976-1977 Drought: What Should be Done Next. Report to the Comptroller General. Washington, D.C. 29 pp.

²Wilhite, D.A., N.J. Rosenberg, and M.H. Glantz (1984) Government Response to Drought in the United States: Lessons from the Mid-1970s, Part 1, Executive Summary. Progress Report 84-1, Center for Agricultural Meteorology and Climatology, University of Nebraska, Lincoln.

³Wilhite, D.A., N.J. Rosenberg, and M.H. Glantz (1984) Government Response to Drought in the United States: Lessons from the Mid-1970s, Part 1, Executive Summary. Progress Report 84-1, Center for Agricultural Meteorology and Climatology, University of Nebraska, Lincoln.

coordination of information and responses. The apparent lack of drought planning at the federal level suggests that the next major U.S. drought will again evoke an inefficient and poorly coordinated response as did the droughts of the 1970s.

The NCPO is in a unique position to initiate planning of efforts to improve our scientific understanding of droughts as a basis for development of more effective tactics and strategies for water and land management. The effort should include the following:

- improved definition of drought, with enough detail so that response mechanisms can be tailored to drought extent and magnitude.
- better monitoring of key physical and social variables, and data analysis that feeds into preexisting drought assessment schemes.
- better local, state, and federal communication and coordination as drought develops.
- better determination of drought response relief responsibilities. A coordinated drought contingency plan should also provide for predrought and postdrought mitigation that encourages adjustment in drought-vulnerable areas and activities while the experience is still fresh.

An integrated drought policy must include the planning and participation of all levels of government and private sectors sensitive to water shortages.

Drought is a global problem posing challenging scientific questions and involving difficult humanitarian and economic issues. Specific further comments on some of these questions are given in Section 4.2.3.

2.4 Application of Impact Assessment Methods

A process of evaluation, innovation, and integration during the last five years has yielded a better integrated body of climate impact assessment methodology than was previously available.⁴ Articulated chiefly within the academic community, it is prudent to suggest that

⁴Kates, R.W., J.H. Ausubel, and M. Berberian (1985) Climate Impact Assessment. SCOPE 27, Wiley, Chichester.

the methods be transferred, where appropriate, to governmental operation impact assessment efforts. The NCPO should continue to promote the application of climate impact assessments by federal agencies.

2.5 The Social and Institutional Implications of Climate Forecasting

Research developments may portend increased skill in long-range (e.g., monthly and beyond) climate forecasts. Studies of the El Niño/Southern Oscillation (ENSO), oceanic circulation, and the meshing of statistical and dynamical approaches promise improved accuracy and lead time. This raises a host of policy questions centering on the social and institutional implications of such forecasts, both nationally and internationally. Among these concerns are problems stemming from uneven forecast quality from different sources, possible premature reliance on climate forecasts, and potential economic, legal, international, and ethical questions surrounding forecast dissemination and use.

The Experimental Forecast Program, mandated by the NCP Act, includes a caution against premature reliance on long-range forecasts. But recent events (e.g., burgeoning sensitivity to issues of liability in government-generated forecasts, and international concerns over earthquake predictions and their economic impacts) suggest that this caution be widened to include review of the full range of social implications of emerging long-range forecast capabilities.

During the next five years the NCPO should initiate and support a forum for alerting the climate community to the possible social and institutional issues raised by climate forecasts and their uncertainty, format, dissemination, and source. The goal of this forum should be broadly exploratory, in an attempt to identify possible problems before they become critical. Simultaneously, the effort might be used to identify useful applications for long-range forecasts that might not yet be apparent.

2.6 Water Resources and Climate

The emerging nationwide problem of water supply and quality may not have been accorded timely and adequate attention by the NCP. Key agencies with water resources

responsibilities (e.g., the U.S. Geological Survey (USGS), Bureau of Reclamation, Soil Conservation Service, and the Army Corps of Engineers) have not been integrated adequately into the program. Yet water issues raise serious public policy concerns for the near future. The National Climate Program Policy Board should make a concerted effort to see that understanding of climate and its impacts is more fully considered in water planning and management. The effort, through increased interaction of the relevant agencies and water-related professions in workshops, data sharing, and research, should be aimed at anticipating the water problems likely to be associated with future climate fluctuations.

2.7. International Cooperation

The central international effort in the arena of climate is the World Climate Program (WCP), an enterprise of the World Meteorological Organization (WMO). The WCP has four major subprograms:

1. The World Climate Research Program (WCRP)⁵ is sponsored by WMO and the International Council of Scientific Unions (ICSU). It is directed by a Joint Scientific Committee (JSC) and carried out by a Joint Planning Staff. The WCRP seeks to develop the scientific understanding necessary for prediction of climate fluctuations and assessment of the sensitivity of climate to human influences.
2. The World Climate Impacts Program (WCIP), led by the United Nations Environment Program (UNEP), seeks to develop and apply methods for assessing the effects of climate variation and change on human society.
3. The World Climate Applications Program (WCAP), conducted by WMO, seeks to develop and disseminate techniques for applying our knowledge of climate to practical applications in problem areas such as food, water, and energy. For example, a Climate Applications Referral System (CARS) has been developed.

⁵International Council of Scientific Unions and World Meteorological Organization (1985). First Implementation Plan for the World Climate Research Programme (WCRP No. 5).

4. The World Climate Data Program (WCDP), also conducted by the WMO, seeks to improve the availability of climate data required by the other components of the program.

The United States has been a major contributor to the development of the WCP and will be a major beneficiary. As the program evolves to maturity, its worldwide support has strengthened steadily. The inherently global nature of many of the most important climate-related scientific and societal problems demands a coherent and stable international framework. Therefore, it is recommended that the United States maintain its long-standing endorsement of the program as a whole and take part actively in its component subprograms.

In the next five years, the WMO will ask member nations to make national commitments to programs of the WCP. An informal commitments meeting for the WCRP is already planned for May 1986. The NCPO has the responsibility for coordinating the development of a national position for commitment meetings as they arise. The NCP Policy Board is the appropriate forum for negotiating agency commitments to the WCP and for developing national positions.

Other forms of international cooperation (e.g., bilateral agreements with the Soviet Union and the People's Republic of China, and the recently signed Memorandum of Understanding with the Canadian Climate Program) are to be encouraged, as are collaborative research, data, and services activities.

CLIMATE SYSTEM RESEARCH

The second objective of the Global Atmospheric Research Program (GARP) was to undertake research that would lead to a better understanding of the physical basis of climate. Considerable progress has been made in advancing our ability to model the climate system to the point where many of its gross characteristics, and even some of its nuances, can be simulated and verified. As a result of this substantial headstart, climate system research has gone beyond merely accounting for the large-scale structure of the average or "equilibrium" climate. We are beginning to be able to deal with climate variability on several different time scales.

Some of the time scales of climate variability are forced by external influences, such as by seasonal variations of the solar declination or by much longer-term orbital variations of the planet (20,000-100,000 years). Others are related to changes in the composition of the atmosphere or in the nature of its lower boundary--problems with time scales of years, decades, and centuries. Compositional changes could be anthropogenic or natural in origin--CO₂ being a notable example. The same is true in the case of the lower boundary influences--deforestation and overgrazing providing good illustrations of human influences. Considerable research is being supported in anticipating the response of climate to such forcing factors.

The climate system comprises the atmosphere, the oceans, the land surfaces, the biosphere, and the cryosphere (that is, the snow and ice cover). This system is extremely complicated. Its components have widely differing thermal and dynamical response times. Furthermore, the total system has built into it feedback mechanisms, some of which accentuate interactions and

some of which moderate them. Several of these feedback mechanisms already have been identified and modeled. Such feedbacks complicate the nature and the sensitivity of response of climate to such influences as a CO₂ increase.

Nevertheless, feedbacks also complicate the natural variability of climate, which would occur even if man did not tamper with the atmosphere's composition or with the characteristics of the lower boundary. In fact, it is now thought that certain characteristics of this natural variability might be predictable, at least in some of its significant statistical properties. The most prominent example is variability on seasonal and interannual time scales, including such phenomena as El Niño, drought, and other short-term extremes of climate.

In looking back, it is evident that some progress already has been made in understanding the workings of the climate machine, but as our ability to provide answers improves, we inexorably ask more difficult and more detailed questions. It is this chain of challenges that drives the quest for the ingredients of a more intimate understanding of nature.

3.1 Progress (1978-1985)

Research in climate has progressed on a variety of fronts since 1978. Some of the most important advances include the following:

- greatly increased understanding of atmosphere-ocean interaction including the ENSO phenomenon.
- a new appreciation of the distinct structures of atmospheric variability on time scales of weeks to months.
- improvements in both statistical and dynamical long-range forecasting.
- breakthroughs in satellite technology that, together with new knowledge of transient tracer distributions in the oceans, have opened new possibilities for oceanic modeling.
- the first measurements in ice core bubbles of the CO₂ concentration from glacial times to the present.
- the measurement of significant upward trends in greenhouse trace gases, as well as new data and models for tropospheric ozone and stratospheric aerosols.
- the development of the Earth Radiation Budget Experiment (ERBE) satellite and the International Satellite Cloud Climatology Project (ISCCP).

3.1.1 Interannual Variability of the Tropical Ocean and the Global Atmosphere (TOGA)

Within the past 20 years, scientists have recognized that the oceanographic El Niño phenomenon and the atmospheric Southern Oscillation are intimately related parts of a single phenomenon, ENSO. Understanding of the two-way interaction between the tropical ocean and atmosphere responsible for ENSO has progressed rapidly since 1978 following the establishment of Equatorial Pacific Ocean Climate Studies (EPOCS). Meteorologists have learned to recognize the patterns of global atmospheric circulation anomalies that arise in response to El Niño sea surface temperature anomalies. Oceanographers have gained an understanding of the response of tropical oceans to wind anomalies. Coupled atmosphere/ocean models have been developed that simulate some features of the ENSO events. Recent statistical and dynamical modeling suggests that ENSO events, including atmospheric manifestations such as drought in India and Indonesia, flooding in Peru and Ecuador, and cold winters in the southeastern United States, may be predictable with varying degrees of skill a year or more in advance.

3.1.2 Low-Frequency Variability

Observational and theoretical studies have dramatically increased our understanding of the structure of atmospheric variability on time scales of weeks to months. These structures include mid-latitude blocking and wavelike teleconnection patterns, and the 30- to 50-day oscillation in the tropics that is intimately related to the "active-break" cycle in the Indian summer monsoon. This work has provided a new conceptual framework within which one can analyze the success or failure of long-range forecasts. Increasing computer power also has permitted the analysis of the natural variability of atmospheric general circulation models on these time scales. The spontaneous generation of all of the above-mentioned structures has been observed in the models, generating a variety of new avenues for research.

3.1.3 Long-Range Prediction

Important advances have been made in both dynamical and statistical prediction on time scales of weeks to

months. Sophisticated statistical methods have been developed that leave no doubt that objective statistical forecasts of monthly and seasonal mean temperature do have significant skill. Dynamical predictions with general circulation models of time-averaged properties also have shown very promising skill in certain instances. Analysis of the time evolution of systematic errors in numerical weather forecasts has developed into an important technique for isolating sources of bias in atmospheric circulation models. The combination of results from observational studies, dynamical models, and statistical prediction has set the stage for advances in forecasting ability on these time scales.

3.1.4 Ocean Circulation

Marked progress took place in the period since 1978 in the ability to observe and understand the ocean circulation on climatologically important space and time scales. 1978 was the year of the SEASAT spacecraft mission, which lasted long enough to demonstrate the capability of measuring global surface winds and the altimetric determination of sea surface topography. Many other major technological developments of the mid-1970s to the present occurred in in situ instruments, such as neutrally buoyant floats, and in acoustic and other instruments capable of large-scale deployments.

New analytical techniques have made it practical to utilize a number of man-made trace substances, particularly freons and the isotope pair H^3/He^3 , for the study of decadal time scale exchange between atmosphere and ocean, and the related oceanic transport processes as well as rates of water mass modifications. Equally important progress was made in computing power and model development so that it now is apparent that eddy resolving, thermodynamically active basin, and larger-scale ocean circulation models are becoming available.

The prospects for availability of substantial data sets have encouraged increasing effort to develop diagnostic techniques and to test the performance of numerical ocean circulation models in prediction of transient tracer field evolutions. Model performance in this respect is important for problems like the oceanic CO_2 uptake as well as for studies of heat transport transients and of biogeochemical fluxes of potential climatic significance. A technological revolution

analogous to that which led to the Global Weather Experiment (also known as FGGE, the First GARP Global Experiment) is, for the first time, possible for oceanic observation and understanding.

3.1.5 Paleoclimatology

Paleoclimatology continues to provide valuable insights into climate dynamics and sensitivity. Recent measurements of the composition of air bubbles in Greenland and Antarctic ice cores have demonstrated that the CO₂ concentration in the atmosphere at the peak of the last ice age was only about 200 ppm (compares to about 260 ppm in 1850 and 340 ppm now). Ice core measurements have also provided new estimates of the pre-Industrial CO₂ concentration. It is also now apparent from detailed ice core studies that the changes in atmospheric CO₂ measured from ice cores and temperature changes derived from oxygen isotopic analyses are remarkably coincident, thus obscuring any direct causal relationship.

Simulation of the ice age climate and climates of the early Holocene with general circulation models (GCMs) has indicated that reconstructions of these paleoclimates are invaluable in testing the models' sensitivity. New information on the evolution of oceanic circulations from glacial to postglacial times promises to provide very useful tests of oceanic models. The case has been strengthened that the glacial and interglacial fluctuations of the last million years are controlled by changes in the earth's orbital parameters (the Milankovitch theory), challenging the climate modelers to explain how these perturbations can produce such large fluctuations.

3.1.6 Minor Atmospheric Constituents

Trace Gas Trends. Recent evidence (measurements and model results) suggests that the cumulative effects of increasing concentrations of radiatively active trace gases in the atmosphere (e.g., N₂O, CH₄, O₃, CFC₁₃, and CF₂Cl₂) could have an overall greenhouse effect comparable to that of CO₂. Since accumulation rates of some species are growing at a rate greater than the accumulation rate of CO₂, a suitable monitoring program is warranted as a basis for projecting future concentrations.

Tropospheric Ozone. Measurements have shown that tropospheric ozone has increased in northern middle latitudes by about 7 percent during the past decade. The cause of this increase is unknown. This is of particular concern because of its dual effect as a greenhouse gas and as a troublesome pollutant.

Stratospheric Aerosols. Recent studies of stratospheric aerosols injected by volcanic eruptions, e.g., El Chichon, have provided much insight into the effects of aerosols on atmospheric radiation and climate. In general, the impact of stratospheric aerosols is opposite to that of infrared absorbing gases such as CO₂¹ in that they tend to produce a heating of the stratosphere and a tropospheric cooling. On the basis of comparison of El Chichon with other volcanic eruptions (e.g., Mt. St. Helens, Agung), it was concluded further that the critical factor is not so much the explosive power of the eruption as the quantity of sulfur compounds injected into the stratosphere. Variations in the stratospheric aerosol loading will complicate attempts to isolate the predicted warming due to greenhouse gases.

3.1.7 Radiation and Clouds

Building on experience gained from experiments flown during the 1970s as part of the initial Nimbus program, the NASA Earth Radiation Budget Experiments (ERBE) program was developed to provide improved broad-band, top-of-the-atmosphere flux measurements crucial for understanding and modeling the energy balance of the earth. The first two satellites in the three-satellite program were launched in 1984.

The International Satellite Cloud Climatology Project (ISCCP) began its operational data collection phase in 1983. The objective is to produce a five-year radiance and cloud data set, the most important characteristic being globally uniform coverage of various indices of cloud cover and radiative properties. The difficulty of

¹World Meteorological Organization (1985) Conference Statement on International Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts.

modeling clouds in climate models is the main impediment to improving estimates of climatic sensitivity. The global ISCCP data set represents a step in the attack on this very tough problem.

3.2 Priorities for the Future

In assessing the progress made in climate system research since the NCP began, the importance of institutional flexibility becomes obvious. Although many of the research gaps and opportunities identified in 1978 retained their importance or urgency, some problems had not been anticipated at all or at least their importance had not been fully appreciated. Yet the federal system of research support was flexible enough to respond to changing needs. Such flexibility is essential for the continued success of any national climate research program.

The climate research program is broadly interdisciplinary with subprograms that often are basic to several different objectives. Furthermore, some programs have become timely because an opportunity has attained maturity, sometimes unexpectedly. Others are timely because of a critical need to fill some important gaps. Some subprograms are critically in need of a few good ideas that may turn out to be inexpensive to implement. Others may be unavoidably expensive, particularly observing systems. Some efforts may require protracted attention, while others may promise a relatively short-term payoff.

It would be misleading to assign relative priorities based on oversimplified indices of judgment. What follows is a list of eight subprogram areas of widely different type, dimension, and disciplinary content that have been identified for sponsoring agencies. These are logical next steps in an overall strategy to understand and predict climate variations. There is no significance to the order in which they are listed. Clearly, the responsive flexibility demonstrated by mission agencies will continue to be required to fund and implement the overall program.

3.2.1 Minor Atmospheric Constituents

Radiatively and photochemically active trace gases and aerosols in the atmosphere influence the earth's climate

to an extent far greater than their concentration suggests at first glance. The recent discovery that the combined effects of a number of trace gases (nitrous oxide, methane, fluorocarbons) are likely to produce climate impacts comparable to those of the expected CO₂ rise over the next 50 years warrants significant attention to the monitoring of and research on trace gases. Recent studies indicate that the chemistry and radiative effects of volcanic aerosols and their residence times in the stratosphere may mask and obscure the greenhouse effect of the trace gases. Accordingly, a continuing research program should be maintained.

To accompany monitoring of trace gas concentrations, research on biogeochemical cycles should address the question of sources, both natural and man-made, and sinks of these potentially important constituents.

3.2.2 Polar Processes

Climate variability results from changes of the global atmospheric circulation that are forced by the global pattern of heat gain and loss. The time variability of the global pattern of thermal forcing is central to understanding climate variations.

It is of fundamental importance to delineate the time variability of the intensity of the two polar heat sinks, especially Antarctica. Priority should be given to temporal variability over the last century, a period for which instrumental observations permit reconstruction of the structure of climate variations over much of the planet. It is also important to delineate coherent spatial variability over Antarctica by reconstructing temperature histories from a network of shallow cores from the high ice plateau (20-m depth is adequate for most locations).

It is also important to determine the physical processes and factors responsible for interannual and decadal variability of the Antarctic heat sink. This requires measurement over time of all components of the surface atmospheric and oceanic heat budgets at selected stations that are representative of large regions.²

²National Research Council (1984) *The Polar Regions and Climate Change*. Washington, D.C.: National Academy Press.

Model results indicate that the greenhouse warming will be largest in polar regions. This polar amplification is sensitive to the details of the sea ice model. Field programs designed to improve our ability to model sea ice, ice shelves, and marine-based ice sheets should be given high priority. The formation of deep and intermediate waters at high latitudes is of particular importance.

3.2.3 Drought

The topic of drought is both a gap in the climate program and a special opportunity to advance our understanding of climate variability and climate change. Drought research also includes the more general problem of water resource availability, especially since one cannot understand or define a drought without considering the periods of normal or surplus precipitation. Worldwide attention on the drought in Africa makes it more likely that intellectual and financial resources can be marshalled to provide the most complete description of global meteorological and other climatic variables associated with this tragic phenomenon. Such a set of empirical studies is a precondition for advances in theory and modeling.

The study of low-latitude rainfall variability requires an extension of the knowledge of ocean-atmosphere coupling accumulating under the TOGA rubric to a related but more complex situation in land surface processes. The relation of drought episodes of a few years duration to the longer term process of desertification should be investigated. Longer term is used here to mean several decades, but it should be noted that the drying up of the Sahara has been taking place for thousands of years.

Recurrent droughts in regions of the continental United States are an obvious concern of the National Climate Program. It would be valuable to study them in parallel with droughts in tropical and subtropical regions because the contrasts and similarities between droughts in the two regions should provide broader insight into the general problem of drought.

High priority should be given to focused study of the climatic aspects of drought within the context of the national and world climate programs. The project might include the following components:

- reconstruction of long time series of African climatic data to improve our understanding of the natural variability of rainfall and paleoclimatic reconstructions of past wet and dry periods.
- a study of the older droughts in the United States, such as those in the 1930s. Meteorological data in addition to precipitation data are required.
- TOGA-related research bearing on the genesis and predictability of low-latitude rainfall.
- model studies of the relationships between land surface changes and climate, notably including efforts to incorporate more realistic ground hydrology into GCMs.

Changes in land use and vegetation (e.g., large irrigated areas, deforestation, and overgrazing) have important feedbacks on climate. For example, there is some evidence that summer irrigation in the U.S. western Great Plains is associated with increased precipitation in that season.

3.2.4 Cloud-Radiation Interaction

A major deficiency exists in the parameterization of clouds and their radiative effects in climate models. Changes in cloud cover statistics over a large area will alter, after a period of time, the basic state of the atmosphere and oceans, and thus will constitute a potentially important feedback mechanism with respect to climate change. This is of particular concern in efforts to evaluate climate response to CO₂ and trace gas increase.

Increasing the cloud cover at the same altitude, in general, will reduce the solar energy absorbed by the earth-atmosphere system and, at the same time, reduce the thermal radiation loss to space. The extent to which these effects tend to balance in some overall sense has been a subject of great controversy over the past decade. In principle, it is possible to compute the radiation fluxes when the cloud distribution and physical structure are known accurately. Nevertheless, the problem of predicting the cloud fields in the required detail is far more formidable and is as yet unresolved. Particular problems relate to the prediction of extended multilayer clouds, marine boundary layer stratus clouds, and cirrus.

Ultimately, to be useful for climate studies, parameterizations will have to be such that statistical

properties of cloud fields will have to be related to the large-scale parameters of the climate system. Steps to achieving a satisfactory scheme are as follows:

- develop a global climatology of important cloud cover parameters and exploit these data in the study of cloud/climate feedback.
- develop cloud dynamic models in which the turbulent, thermodynamic, and microphysical processes that contribute to the generation, maintenance, and dissipation of clouds are incorporated.
- develop and test methods of parameterizing clouds in a hierarchy of climate models including GCMS, statistical-dynamical models, and energy-balanced models. Parameterizations must cover the radiative and dynamical processes.

These three steps involve a wide range of research activities including satellite observations, data set development, theoretical studies, and model developments. The first step is addressed by the ISCCP, the second and third by the First ISCCP Research Experiment (FIRE).

3.2.5 World Ocean Circulation Experiment (WOCE)

As soon as time scales of interest in climate exceed a few weeks, understanding the role of the ocean as an active participant becomes essential. The development of oceanic models of the sophistication necessary to understand climate will flounder if the ability to observe the ocean on global scales does not improve dramatically.

At the present time, there are almost no continuing observations of the ocean other than marine surface meteorological observations. The technical revolution described in Section 3.1 has made it possible to construct a plan for observing the ocean for the first time on the requisite global scale. This plan, WOCE,³ will provide a global-scale observation and modeling program directed squarely at climate issues. (WOCE also is a major element of the World Climate Research Program.)

³Woods, J.D. (1985). The World Ocean Circulation Experiment. *Nature* 314:501-511.

For WOCE to proceed there must be commitments in the very near term for the long-lead-time satellite elements that are crucial to its success, Ocean Topography Experiment (TOPEX) and Navy Remote Ocean Sensing System (NROSS). In order to realize the full benefit of these new satellite observing systems, it also is necessary to put in place certain ground-based observing systems such as an expanded and modernized global sea level observing network. Chemical transients (especially fluorocarbons, tritium, and helium-3) must be observed on a global scale beginning immediately, before the major benefits of being able to observe them are lost. Modeling resources necessary to cope with the anticipated data sets must become available.

3.2.6 Long-Range Weather Prediction (weeks to months)

Through development of statistical and dynamical methods, there has been an improvement in our ability to prepare monthly and seasonal forecasts. For example, experiments in recent years with general circulation models have suggested that the persistence of a blocking episode for as long as a month may be predictable in some cases. The potential of a still broader class of predictable states in the weeks to seasonal time range needs to be explored aggressively. If such states can be isolated, and understood, then the prediction of extreme anomalies of precipitation and temperature can be exploited for decision making for weather-sensitive socioeconomic activities. Furthermore, research on extended range prediction promises to be invaluable in isolating biases in models now used both for extended prediction (i.e., 10 days or less) and for climate sensitivity studies.

It is through the experimental climate forecast centers that university scientists, working with government operational programs, can initiate, develop, and test new prediction ideas. Such university-based basic research needs to be expanded.

3.2.7 Tropical Ocean/Global Atmosphere (TOGA)

The TOGA program, especially in its ENSO-related element, offers great prospects for a payoff in the future. It appears that a satisfactory theoretical framework for the ENSO cycle will be firmly established within the next five years.

Progress in understanding the coupled ocean-atmosphere system in the tropical Pacific and its relation to global atmospheric fluctuations can be expected to lead to new insights into other phenomena that depend on a coupling between the tropical oceans and the global atmosphere. Climate variations in countries surrounding the tropical Atlantic and fluctuations in the Indian monsoon are likely examples. In addition, this improved understanding and modeling capability strongly suggests that significant predictive skill for El Niño and related global climate fluctuations in both tropics and mid-latitudes (i.e., the Southern Oscillation pattern) will be attained within the next five years. Prospects for success for this forecasting activity can be enhanced substantially by providing the proper support--observational monitoring, data collection and analysis, and model development.

3.2.8 Paleoclimatology

Definitive estimates of climatic sensitivity remain elusive, primarily because of uncertainty in the cloud feedback. New methods of estimating sensitivity and of testing climate models must be pursued vigorously. The most promising of these involve paleoclimatology. Paleoclimatology, paleoecology, and paleochemistry are the backdrops against which human modifications must be scaled.

The accurate reconstruction of past climates has taken on a new urgency with the recent discovery in ice cores of low atmospheric CO₂ concentrations during the last glacial maximum, raising the possibility that information on sensitivity to CO₂ can be extracted from such reconstructions. The ice core work itself must be given the highest priority. Research aimed at improving the paleoclimatic record over the time interval for which CO₂ information is available is also of central importance. Of particular concern are ice age climates in the tropics (both over land and over oceans) and in the Southern Hemisphere. For example, there is substantial disagreement between the Climate/Long-range Investigation, Mapping and Prediction (CLIMAP) reconstruction and current climate models in the tropics. On the other hand, models suggest that it is in the Southern Hemisphere that the CO₂ signal in the paleoclimatic record is most easily isolated. Paleoclimatology thus continues to provide valuable tests of our understanding of climate.

Adequate support for a well-rounded program on a variety of time scales is highly desirable.

3.3 Observational Systems

By its very nature, climate research is global and requires adequate global observing systems. It is multidisciplinary and requires commitment of resources over long periods of time. The problems of global observing systems, climate monitoring, and data analysis are not glamorous, but are the foundations for improvements in climate research.

Data required for research are often provided as a by-product of operational services and by dedicated research-oriented programs. Thus NOAA's operational programs, while primarily justified for routine weather prediction, form an indispensable base for climate research.

Development of satellite-based observing systems and prototype data systems by NASA and NOAA has contributed greatly to climate research. Continuing and stable commitment of resources to research satellite systems; satellite data analysis together with associated diagnostic efforts; enhanced computer resources, particularly at the National Meteorological Center (NMC); and data management facilities will be essential in the future for the orderly development of the climate research program.

With respect to specific observation and data needs, the following goals are offered for consideration:

(a) Homogeneity and continuity in climatically significant data sets.

- Maintain, at all costs, current operational satellite capabilities, including geostationary and polar-orbiting satellites. In view of the importance of wind stress both for mechanical forcing and as a major influence on trace substance transfer at the ocean surface, measurement of surface wind stress from future operational satellite systems is of major concern.

- Develop a regular ocean observation system and improvements in the existing global sea level network particularly to meet the needs of the TOGA program. The Integrated Global Ocean Services System (IGOSS), while valuable, does not ensure a regular flow of observations.

- Implement future research satellite missions that will measure ocean topography, atmospheric trace gases, and land surface processes important for climate and precipitation.

- Extend atmospheric trace species monitoring by both direct sampling and satellite remote sensing techniques.

(b) Institutional arrangements for data management to ensure continuing improvements in data availability, access, and cost.

- Insist that data implications be considered in the planning process for each major research initiative. This is sometimes done (as for FGGE, ERBE, TOGA, etc.), but it must be a necessity in the planning of future programs.

- Facilitate access to recent (near real time) data streams for some research concerns (as for selected aspects of TOGA).

- Undertake selected data rescue efforts.

- Maintain a relatively small but continuing effort in data referral. This includes the need for summarized information in addition to extensive data listings.

- Continue to pursue technological developments that can permit a reduction in the purchase and processing costs of large volume data sets that now impede their use for important climate research.

CLIMATE IMPACTS

The imperative to understand the actual and potential impacts of climatic variability and change has intensified in the years since the NCP was established. The world has experienced another El Niño and observed a continued African drought. Evidence has accumulated that mankind may bring about a long-term global warming while major increases in volcanism could produce an opposite effect. Nuclear war could also produce a severe transient global cooling. Translating our understanding of climatic variation into responses by the environment and society, and into sound plans and policies for living with climate variability and change remains a major challenge.

At the same time, the development of the impacts aspects of the NCP has been gratifying. The community of researchers concerned with the impact of climate variation on the environment and society has been strengthened, domestically and internationally. A directory recently published by the Environmental and Societal Impacts Group at the National Center for Atmospheric Research (NCAR) listed some 25 groups now active in the United States.¹ Methods of studying relationships of climate to society have been clarified and improved,² and several useful pieces of work have been completed, ranging from examinations of drought impacts to assessments of

¹Environmental and Societal Impacts Group (1985) Institutional Director. Workshop on Climate-Related Impacts. National Center for Atmospheric Research, Boulder.

²Kates, R.W., J.H. Ausubel, and M. Berberian (1985) Climate Impact Assessment. SCOPE 27, Wiley, Chichester.

consequences of a human-induced greenhouse warming. These studies have been carried out by both the academic research community and researchers in government agencies.

A second generation of climate impact studies is now under way, based on clearer problem definitions and better appreciation of appropriate techniques and available data. Among these might be mentioned the IIASA/UNEP studies on climate change and cold and semi-arid agricultural margins,³ studies on the environmental consequences of nuclear winter,⁴ and the Climate Impacts, Perception, and Adjustment Experiment (CLIMPAX), discussed below. While the NCP has not been central to the conduct of these efforts, the existence of the program has bolstered greatly the ability of the U.S. community to focus and work together. The existence of the program has helped facilitate access to useful data, for example, at the Climate Analysis Center and the National Climatic Data Center (NCDC).

When the NCP began, the principal support for impacts work was coming from the DOE, in connection with the identification of areas of socioeconomic impact from a potential CO₂-induced climatic change. The DOE support for impact studies diminished, and their support was concentrated instead on questions of physiological impacts of CO₂ increase on plants. In the last year or so, the DOE again has begun to support climate impacts work, largely within the DOE national laboratories. Meanwhile, the NSF has emerged as the principal source of support for independent workers in the impacts area. Agencies, of course, have continued to perform impacts work in support of their specific missions. For example, the USDA and NOAA have developed diagnostic bulletins on climate and agriculture. EPA has performed several assessments pertinent to environmental quality.

During the next five years, a number of impact areas can be identified easily as logical extensions of current work. Obviously, the program must be open to fresh ideas, opportunities, and needs that cannot be anticipated at present. Also, different areas may

³Parry, M.L., ed. (1985) Climatic Change 7. (Special Issue on Climate Impacts.)

⁴Harwell, M.H. (1984) Nuclear Winter: The Human and Environmental Consequences of Nuclear War. New York: Springer-Verlag.

require very different levels of commitments of resource and effort by the NCP. These areas include the following:

- **Extremes.** There is a need for greater attention to the study of extremes of climate variability and excursions that might cause a change in the central tendency of climate. This might occur as a result of increases in the atmospheric concentration of greenhouse gases. Almost all attempts to study impacts of greenhouse gases have focused on changes in average climate characteristics. Nevertheless, many scientists believe that society perceives, responds to, and is affected primarily by extreme events. Close interaction between natural scientists and workers in impacts areas will be required in this regard.⁵

- **Climate and Water.** While communities explicitly concerned with climate in relation to agriculture and energy and some other sectors have emerged over the first phase of the NCP, a similar group has not developed to a great extent in the water area. This is probably because many climate-water problems have been solved or it is perceived that they have been solved. Nevertheless, there may be several areas where important issues remain. Among potential problem areas are the relation of climate variability to water quality, optimization of water use efficiency under various climatic conditions, and the impact of a potential long-term climatic change (beyond design values) on water supply systems. As noted in Section 2.6 above, the NCPO should explore the usefulness of an enhanced program related to climate and water with the USGS, the Bureau of Reclamation, the Army Corps of Engineers, the Soil Conservation Service, other government units, and professional groups concerned with water. A workshop would be a suitable way to identify needs and future activities.

- **Drought, with Special Emphasis on Africa.** While drought is likely to continue in Africa for some time, it remains unclear what major contributions might be made in this regard by the impacts program. The climate research program can help expand what we know about African climate and whether human activities have contributed to the apparently changing behavior of the climate. Program

⁵Wigley, T.M.L. (1985) Impact of extreme events. Nature 315:106-107.

options range from research on tropical droughts (as in Brazil and India, for example) to comparative studies of drought response among areas. Agricultural development programs supported by U.S. AID and other international sponsors can be improved greatly by the inclusion of climatological information in their planning. Agro-meteorologists can assist in tailoring agronomic systems to local conditions so as to minimize climate stresses and make best use of available sunshine and precipitation. Specifically, crop scheduling to avoid premature germination of seeds, use of windbreaks, intercropping, relay cropping, irrigation scheduling, and other techniques depend on the proper use of climatic and meteorological information.

Large amounts of funds and numbers of researchers, advisors, and consultants are engaged in applications of climate information, such as those listed above, and in developing new applications. This research, technology transfer, and use of the results of climate impact assessments should continue.

The interdisciplinary requirement is especially important and underlies all successful climate impact assessments. In the case of African drought studies, for instance, the participation of physical geographers and agricultural scientists is needed to describe expected changes in land use and ecological systems for use as assumptions in simulations of future African drought. Then, should simulations produce meaningful results from a societal point of view, experts from the social and behavioral sciences should be involved to help interpret their significance. As regional agro-ecological systems begin to be understood and mapped, this information should be disseminated widely and problems identified for follow-up action or further research.

- Carbon Dioxide and Other Trace Gases. Steadily increasing atmospheric concentrations of CO₂ and other radiatively active trace gases are expected to produce significant changes in global climate. Many important decisions in water resource development and utilization, large-scale engineering projects, energy planning, and so on are being made on the assumption that the climate of the future will be the same as that of the recent past. Moreover, changes in the greenhouse gases arise from a complex of human activities--population growth, industrialization, energy production, and land-use changes--that are in turn linked with other environmental problems such as acid deposition. Research is thus required not

only on the impact of long-term climatic change but also in the analysis of policy and economic options to deal with this interlinked network of issues. Such studies should be carried out through active collaboration between scientists and policy makers and may require the development of innovative methodology.

4.1 Areas for Specific Initiatives

Of the following seven opportunities for impacts project initiatives, the top three represent a priority group. The additional four are recommended as resources permit or as needs arise for informational analysis relating to specific problems.

4.1.1 Development of a New Climatic Atlas

A new climatic atlas designed to elucidate in a systematic way the interaction of climate, environment, and society can both advance the state-of-the-art and serve many concerned groups and individuals. Published and available in both hard copy and digital formats, it would contain maps and charts of, for example, the following:

- productive potential of agricultural regions as a function of climate;
- variability of crop production attributable to climate;
- diffusion of crop varieties relative to climate;
- water supply in various regions given a changed climatic regime;
- migration of people versus climatic zones;
- costs of climatic adjustment in different regions;
- frequency and distribution of climatic hazards;
- sustained climatic anomalies; and
- distribution of population and property at land elevations that would be affected by sea level rise, increased storm surge, and coastal erosion.

A U.S. climate atlas should be considered as a contribution to the World Climate Impacts Program and might serve as an example to be emulated by other countries. While some products might begin to appear quite soon, the long-term and continuing nature of this venture should be emphasized. One strategy that would

increase the quality and amplify the utility of the atlas would be to link certain aspects of it to data obtained from the 1990 Population Census to be performed by the Bureau of the Census of the Department of Commerce.

In view of the many potential practical and intellectual benefits from the endeavor to design and produce the atlas, high priority should be given to this task. A leadership role by the NCPO is integral to the success of the project.

4.1.2 Utility of Prediction

It is likely that within five years or so, climate forecasts will have sufficient skill to be of interest to a considerably larger number of users beyond the research community (see Chapter 3). Among the several styles of prediction now being explored, it is reasonable to expect that some might have greater application potential to a full range of users from government and private organizations to individuals, both in the United States and abroad. During the past seven years, little attention has been given to questions of the value and policy implications of the availability and use of long-range forecasting. While a few researchers have pursued questions in this area, it now appears timely to support a broader effort, linked to the emerging capabilities for climate forecasting.

The NCPO is moving in this direction, with the scheduling of a seminar in March 1986 on political and economic aspects of improved climate forecasting. This symposium will be used to identify policy issues that may require further study by agencies in the NCP. The next few years, while climate forecasting is in its early stages, are the time for research on the utility and value of climate prediction. At this stage, feedback between researchers examining the physical system and those concerned with social and behavioral aspects can be especially fruitful.

Agencies supporting research on long-range forecasting, especially NOAA and NSF, should support and help catalyze sound proposals in this area.

4.1.3 Empirical Studies of Comparative Impacts of Actually Experienced Climatic Variations

Several methods have been identified for assessing sectoral impacts of climate. The opportunity now exists to apply these methods, especially as the historic climatic data base is growing and is more easily accessed and utilized. While there are several operational efforts to issue timely estimates of costs of climatic variations, little work is done that carefully goes back over well-documented episodes and assesses impacts in a way that is consistent with measurement of impacts of other episodes.

One opportunity to achieve results along these lines is the Climate Impacts, Adjustment, and Perception Experiment (CLIMPAX), which will evaluate the effects of precisely defined, sustained (10-20 year) excursions from climatic means on water supplies, energy demand, agricultural yields, and so forth for selected regions in the United States. Such efforts to achieve a much more reliable set of comparable analyses should be encouraged. Efforts like CLIMPAX provide good opportunities for contributions to the NCP by a range of agencies and for partnership among the federal agencies, state groups, and researchers in universities.

4.1.4 Dissemination of Methods

Progress has been made, as noted above, in a number of areas of impact assessment. This progress is likely to diffuse rapidly in the academic research community. Normal processes may not work as rapidly in federal and state agencies that make operational assessments and among individuals whose focus is not on climate but on the climate-related activity. It may be possible for the NCPO to take advantage of such activities as meetings of state climatologists, professional societies, and regional groups to organize sessions on recent progress in climate impact assessment.

4.1.5 Coordination and Verification of Models

Models connecting climate variations with crops, fish stocks, forestry, and a variety of other sectors have been or can be developed. A desirable goal is to have available tested models, which might be employed in given

situations and which are widely conceded to be the most suitable for the given question. To reach such a situation, it is necessary for a critical dialogue to develop around climate impact models. The NCPO should take the lead in engaging concerned federal agencies in such a dialogue. For example, a workshop on intercomparison and applications of crop-climate models or fisheries-climate models might be useful.

A good example of the type of modeling to be achieved is in the area of fisheries. While it is well known that climate variability affects the abundance of fish stocks, the intensity of driving forces, which also are variable, is not known. The atmosphere and the ocean generate variability in ocean temperature, in motion, and in the distribution of irradiance. The variability in these physical variables generates in turn variability in the production of phytoplankton and the organisms that depend in various ways on phytoplankton, zooplankton, fish and oceanic minerals, and sea birds. Thus, the problem is not only one of fish variability but also of biological oceanography--how the ocean-atmosphere coupling affects living plants and animals of the sea and how fish production relates to the general biological productivity.

Despite its importance, there are few dynamic models of the system. In fact, it might be said that the climate/ocean/fish resource system is among the most poorly understood components of the earth's natural resource system. This is but one example of climate resource interactions for which realistic models are needed. But, modeling is a dynamic activity, and models change over time. The NCP emphasis must be on encouraging development and ongoing critical dialogue and quality control within relevant modeling communities.

4.1.6 Social Costs of Adjustment

While there are projects under way that will clarify and compare a range of first- and second-order impacts, the largest single impact of climate may be the human effort expended to adjust or adapt to seasonal changes and expected variability of climate. There have been few systematic studies of the extent of such adjustments. In practice, low residual losses or damages may be a sign of relative insensitivity to climate or, conversely, of very great sensitivity accompanied by effective, successful, albeit costly human adaptation. This topic may provide a

largely untapped research area of great potential interest.

4.1.7 Projecting Trace Gas Emissions from Human Activities

The future evolution of climate will be greatly influenced by changes in the composition of trace gases in the atmosphere. Projections are thus needed of what emissions will result from industrial and agricultural activity. The best information available from experts in industrial processes and products, agricultural trends and development, geography, economics, and so forth should be employed in generating these projections. Such projections are of importance to many agencies involved in the NCP, including NOAA, NASA, DOE, EPA, NSF, and USDA. These agencies should carefully coordinate efforts to obtain sound and defensible forecasts of future emissions and not simply employ projections that extrapolate casually from recent records.

4.2 Institutional Issues

The NCPO should play an important role in regard to climate impacts, primarily as a catalyst. Projects such as the preparation of the new climatic atlas are of the type where NCPO can play an important role.

While considerable progress has been made in impacts research, this research area needs strengthening. In carrying out their mission, it is recommended that agencies such as DOE and EPA make investments in such a way that a lasting national capability is created. The distribution of expertise in academia, government agencies, nonprofit research institutes, and for-profit consulting firms needs to be kept in mind. Emphasis on achieving short-term results or reports is not likely to produce either a credible finding or a capability to do better in the future.

Internationally, there have been positive results from the World Climate Impacts Program. Three of the principal projects supported--the Scientific Committee on Problems of the Environment (SCOPE) project on impact assessment methods, the International Institute for Applied Systems Analysis (IIASA) project on climate impacts on cold and semiarid agricultural margins, and the International

Meteorological Institute (IMI) project on CO₂-induced climate change, emphasizing effects on northern ecosystems--are all bearing fruit. Some other projects, for example, on climate and food systems in Mexico and India and on identification of climate-sensitive sectors, have been less successful. While overall results of these projects have been good, the management of the program has been somewhat weak. A stronger Scientific Advisory Committee for the WCIP is highly desirable.

CLIMATIC DATA, INFORMATION, AND SERVICES

The need for climate data and information is expanding rapidly worldwide. User needs have increased in parallel with technological advances in computers, communications, and data storage media. As a result, there has been increasing recognition of the value and utility of climate information throughout our society. Human activities have placed increasing demands on the environment, necessitating further monitoring and understanding of the earth's climate. Climate services are the ultimate product of the NCP. They sustain the application of current knowledge and information for government, industry, and individuals.

The first years of the NCP (1978-1985) have produced modest achievements in the processing of data, information exchange, and the provision of climatic services to the public. Experiences gained have also brought a number of problems into clearer focus. Now it is time to deal with these problems. All climate services are intensely dependent on data and dissemination capabilities. Advances in technology have transformed the time scale and structure of climate services. In fact, the past decade has brought together two streams, one technological and one behavioral, to change climate services. The technological change has been the development of inexpensive computers and communication systems that greatly increase the capability to handle data needed for climate services. The full benefit of this change awaits advances in data storage, a limitation in the past that is being removed rapidly. The cultural change is that individuals charged with decision-making responsibilities are expecting, even demanding, to have accurate up-to-date information to use in decision making. At the same time, there is a continuing need for the traditional long-term climate data

archival programs that should incorporate the optimum mix of manuscript, digital, and microform storage media. These two changes occurring at the same time provide a unique opportunity for climate services to move forward.

5.1 Weather and Climate--An Issue

Historically, the words weather and climate have referred to very different time scales. Weather is related to current atmospheric conditions. Climate is described by statistics of the atmosphere for a time period of several years to decades. These limited views leave a question of what to call the state of the atmosphere yesterday, last week, last month, last season, and last year. However, users of weather and climate information have little concern for this type of definition. If the information needed for yesterday, last week, or last month is not weather, it must be climate or vice versa. The emerging demand for near-real-time data in a period of hours, days, and weeks and information on a par with current technology brings into focus the point of view that weather and climate form a continuum in time.

The provision of timely and effective climate services depends, ultimately, on data resources available to the provider. In order to be valid, data must undergo a process that begins with original observations made according to accepted practice. The observations are collected, quality controlled, and stored for further use. Furthermore, these data must be cataloged, referenced, and made accessible for convenient retrieval, or they have little value.

At the federal level, the service function relative to meteorological weather and climate data resides in NOAA. The primary data sources include cooperative observers, surface synoptic stations, marine synoptic observations, solar radiation observations, upper air stations, satellite observations, radar observations, water level observations from tide gages, hydrological networks, and polar measurements.

The observation and collection of weather data is an NWS function, while the quality assurance, storage, management, and retrieval of these same data used for climate activities resides in the National Environmental Satellite, Data, and Information Service (NESDIS) at the National Climatic Data Center (NCDC). Nevertheless, NCDC has no explicit role in managing the collection networks.

Changes in the operation and maintenance of observing networks generally respond to NWS forecast and warning priorities with little regard for impact on climate records. For example, observing sites are generally located at airports or in urban areas that are not representative of the general area around the site. Sites may be moved or hours of operation may change causing major impacts on the data record. Furthermore, some new remote sensing equipment--such as the Low Level Wind Shear Alert systems being installed at airports around the country--does not allow for the recording of the meteorological data collected.

The NWS also provides some climate services through the Climate Analysis Center (CAC), including the following:

- selective data validation,
- temporary storage (up to 3 years) of selected worldwide data,
- tailored applications products, and
- dial-up access to its data base.

The Climate Analysis Center's (CAC) service role grew rapidly during the 1980s, and this trend is likely to continue. CAC's mission allows access to NMC's computer resources and full government funding, adequate to provide free services to the user community. Although CAC provides a valuable service, it does not have the mission to collect, quality control, and archive official climatological data. This mission resides with the NCDC. This sometimes leads to data set differences, but it must be recognized that CAC data sets are preliminary. Research quality data sets are the responsibility of NCDC. More extensive quality control procedures completed at NCDC may lead to differences in common data sets.

From the point of view of most data users, there is no significant distinction between weather and climate. In practice, many applications requiring meteorological data require integration of near-real-time weather data with past climate data. It is critical that the management of weather and climate data be streamlined within the federal government and that the gap in the availability of near-real-time data be filled. NOAA should review how the administrative separation of weather and climate functions affect its ability to address problems of data observation, collecting, archiving, and dissemination. It is timely to address this issue. While NOAA begins an

ambitious program to modernize the NWS, the future design of a climate delivery system should be addressed also.

5.2 Review of Activities (1978-1985)

Since the NCP was inaugurated in 1978, a number of activities have been started and several important products and services provided.

- **Interim Climate Data Inventory.** This inventory of historical climate data has been developed by NOAA's NESDIS and installed on an information retrieval system that can be accessed by telephone. The inventory has been published as the North America Climatic Data Catalogue (Part 1), which contained 770 descriptions of climate data files and related publications available in the United States and Canada.

- **Computer-Based Climate Anomaly Monitoring System (CAMS).** This system, developed by the National Weather Service's Climate Analysis Center, identifies and describes significant temperature and precipitation anomalies from analysis of global data received at the National Meteorological Center (NMC) and provides a mechanism for monitoring and analyzing climate anomalies in real time. Output from the analysis is the basis for the weekly and monthly climate bulletins that depict significant global climate anomalies and climate agricultural analyses by the Joint Agricultural Weather Facility (JAWF).

- **Monthly Climate Diagnostics Bulletin.** This summarizes global patterns and anomalies of atmospheric ice, snow cover, and several key climatic indices. Where necessary, descriptions of significant climate events are included each month, as was the case for the 1982-1983 El Niño.

- **Improved Monitoring of Global Crop Conditions.** The Joint Agricultural Weather Facility (JAWF), staffed by USDA/World Agricultural Outlook Board (WAOB) and NOAA/NWS/CAC employees, has expanded significantly its ability to monitor and assess weather conditions in major agricultural regions of the world. Its assessments of global weather and crop conditions, published in the Weekly Weather and Crop Bulletin, are used by USDA agencies to make national and worldwide estimates of crop conditions. JAWF also provides monthly assessments of yields for major commodity crops around the world, which

are incorporated into USDA's monthly world crop production estimates.

- **National Environmental Data Referral Service (NEDRES).** This serves as a clearinghouse for description and location of data bases and instructions on access.

- **Improvements in the National Climatic Data Center.** The statutory mission of NCDC is to archive the official weather records of the United States (from which climatic statistics are derived) and to process, summarize, and publish data sufficient to describe the climate of the United States, and to provide climatological data information services. The official climate data at NCDC are used, among other things, to establish climate norms and extremes for setting building codes or insurance standards. Knowledge of long-term behavior of climate is crucial in engineering construction, water allocation, and fuel distribution.

- **Regional Climate Centers.** Two regional centers have been established to demonstrate coordination of climate studies and data management, and initiate or strengthen delivery of climate information and services throughout the regions they serve. The Northeast Regional Climate Center (Cornell University) provides real-time weather and climate information to users via computer links and terminals with telephone modems. The North Central Regional Climate Center (Illinois State Water Survey) also collects real-time information on weather parameters and climate-affected conditions and is currently using state agencies to test access methods. Daily data for the system are derived from cooperative weather observers at 35 locations around Illinois, from 22 other NWS stations via Automation of Field Operations and Service (AFOS), and from the Midwest Agricultural Forecast Center, which digitizes and transmits weather observations by telephone line to the climate center in Champaign, Illinois. The North Central Regional Center also has assisted the NWS in developing a system for daily reporting of climate data by cooperative observers.

- **Automated Network.** Nebraska has developed a statewide Automated Weather Data Network (AWDN) with 25 weather stations that record hourly data (collected daily) on wind, temperature, relative humidity, solar radiation, precipitation, and soil temperatures. This network has been expanded to 46 stations in Nebraska and adjoining states for a regional drought monitoring and assessment program. Public access to data from this network is available on a dial-up system (AGNET). More

than 15,000 accesses were made in 1984. The data from AWDN, together with data collected from AFOS and cooperative observers, are used by the Nebraska Agricultural Climate Situation Committee. This group of specialists meets weekly during the growing season to consider recent and cumulative impacts of weather on agricultural operations and subsequently releases advisories to the public.

5.3 Priorities for the Future

Recent technological advances are providing new opportunities throughout the climate services system. New observing systems--both in situ and remote sensing--are increasing the frequency and coverage of meteorological and oceanographic observations. State-of-the-art capabilities in data processing and storage are greatly reducing the times needed for data assimilation and quality control. Most important, advances in communications and remote access capabilities are creating new opportunities for timely delivery and utilization of data and information.

Nevertheless, to make full use of these new capabilities, an organized climate services system must be set in place, supported, and maintained. It is especially crucial that the governmental components of this system be structured in an efficient and straightforward manner and that their roles and responsibilities be well defined. There is an increasing recognition of user needs for a continuum of weather and climate information and services. NOAA should thus consider possible new institutional arrangements to improve the coordination of weather and climate activities.

The existence and effective operation of this basic structure will be essential to the direct user of climate data and information, particularly to the private sector, which may want to seize the many new opportunities in climate applications that are surfacing.

5.3.1 NWS Modernization--Data

As a result of the NWS modernization program, there will be an explosion of conventional (e.g., Automated Surface Observational System (ASOS)) and new (e.g., Next Generation Weather Radar (NEXRAD)) data, which NCDC will be required to process and manage for climatological

purposes. NCDC's automated data processing capabilities already are stretched beyond its ability to meet today's needs. It is essential that NCDC be upgraded to be capable of handling the increase (by orders of magnitude) in data expected in the early 1990s.

From a climatological viewpoint, consequences of this situation will result ultimately in damaging tradeoffs between quality/timeliness and/or the actual termination of some climate services. It is essential that necessary resources are made available to ensure that such a situation is not allowed to occur.

NOAA should act quickly to modernize its capability to manage the national climate data resources by providing sufficient support to do the following:

- perform research and development of new technologies for collecting, validating, storing, retrieving, and communicating data.
- develop clear standards for data collection, quality control, archiving, and dissemination.
- ensure the continuity of key climate networks, including the cooperative observers, surface synoptic stations (including marine), and the solar radiation sites.
- develop adequate automated data processing and communication networks to meet user service requirements.

Other data management issues requiring attention include the following:

(a) Dissemination and use of climate data.

- Timely release of data collected at public expense after the use for its collection is met.
- Easy access, by other users and researchers, to data used in preparing climate products and reports for public dissemination.

(b) Data management to handle increased data loads.

- Volume of ocean and atmospheric data collection (1850 to present) by NOAA will double in the next five years, e.g.,
 - new land-based observing systems will provide data rates and volumes comparable to satellite data rates and may require compaction, selective sampling, or summarization, and

- new space observing platforms will provide a wide spectrum of data at very high rates and volumes of data that will require special data management adjustments and should be included in the operational plans for new systems.

(c) Technology.

- New instrumentation requires adequate documentation, calibration, and possible changes of quality control procedures. Data management guidelines are needed for automated weather observing systems being installed by states and the private sector. Industry standards should be adopted whenever it is feasible.
- Technology and flexibility of dissemination of climate data and climate products should advance with the sophistication required by users.
- New technology in digital storage capability, communications, and computer processing requires continual evaluation and possible change in every area of data management.

5.3.2 Delivery of Services

The dissemination and delivery of climate data and the information generated therefrom may often be delayed and/or inadequate to serve the needs of many users. This results in part because there are many participants (federal, state, and private sector) involved, and in part because the federal role still remains unclarified, which discourages other nonfederal groups from implementing delivery systems.

Timeliness of data and information is a key issue, for timely information has become a key ingredient in U.S. society and economic welfare.

Technological developments now allow revolutionary low-cost advances in data delivery, allowing opportunities for rapid and cost-effective demonstrations of the value to the nation of the National Climate Program. Newly established local and state computer-based climate data/information systems reveal an enormous potential for comparable development on regional scales. Such data base systems represent an effective interface between government sources (verified data) and marketing of value-added services by the private sector.

The concept of a nationwide service system has emerged from recommendations of an NRC panel and from an NCPO Workshop on Cooperative Climate Services. The present regional climate centers, supported by NCPO, provide a concept and a pattern for initiating a national system. NOAA should consider implementing the plan developed by NCPO for a nationwide system of climate services. Specifically, NOAA should do the following:

- provide operational support to the existing centers.
- continue its intergovernmental activity by establishing, with the states, new regional climate centers.
- develop high-speed weather/climate data transmission systems to serve climate user needs, including transmission of data to state, regional, and national climate centers. These systems should involve data from cooperative stations and/or special stations to help provide the spatial density of data needed in many climate-affected businesses.
- develop systems for delivering near-real-time climate data and information to serve state or regional needs.

5.3.3 Atlas

As discussed in Section 4.3.1, a comprehensive new climatic atlas is now needed for the United States.

5.3.4 Utilization of the Private Sector

In the past seven years, we have observed the rapid growth of a new industry in the private meteorological sector. Several firms have successfully entered the data and information services market by providing value-added weather and climate information to commercial and government clients via a number of innovative communications technologies. The sources of the data are primarily NMC's family of services, the CAC user port, and the Global Telecommunications System of the WMO.

These firms offer broadcast or request and reply delivery over telephone and satellite links to customers having a variety of receiving mechanisms ranging from synthesized voice over the phone to sophisticated microprocessor-based colorgraphics work stations.

Today, thousands of clients are being provided with weather and climate data over private service networks. The trend is for continued rapid growth assuming that the private sector continues to have electronic access to the data sources in NOAA at a fair market price. NOAA should ensure that any actions taken to modify and improve the federal weather and climate data and information program will not restrict the ability of the private sector to be a full participant. Specifically, the private sector should be

- included in the planning for future weather and climate services,
- allowed unrestricted access to publicly collected weather and climate data at a fair market price, and
- allowed to compete for services in both the commercial and the government marketplace.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

AFOS	Automation of Field Operations and Service
ASOS	Automated Surface Observational System
AWDN	Automated Weather Data Network
CAC	Climate Analysis Center
CAMS	Climate Anomaly Monitoring System
CARS	Climate Applications Referral System
CLIMAP	Climate/Long-Range Investigation, Mapping and Prediction
CLIMPAX	Climate Impacts Perception and Adjustment Experiment
DOE	Department of Energy
ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
EPOCS	Equatorial Pacific Ocean Climate Studies
ERBE	Earth Radiation Budget Experiment
ESIG	Environmental and Societal Impacts Group
FGGE	First GARP Global Experiment
FIRE	First ISCCP Research Experiment
GARP	Global Atmospheric Research Program
GCM	General Circulation Model
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Services System
IIASA	International Institute for Applied Systems Analysis
IMI	International Meteorological Institute
ISCCP	International Satellite Cloud Climatology Project
JAWF	Joint Agricultural Weather Facility
JSC	Joint Scientific Committee
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCP	National Climate Program
NCPO	National Climate Program Office

NCPBB	National Climate Program Policy Board
NEDRES	National Environmental Data Referral Service
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NROSS	Navy Remote Ocean Sensing System
NSF	National Science Foundation
NWS	National Weather Service
SCOPE	Scientific Committee on Problems of the Environment
TOGA	Tropical Ocean and Global Atmosphere Program
TOPEX	Ocean Topography Experiment
UNEP	United Nations Environment Program
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WAOB	World Agricultural Outlook Board
WCAP	World Climate Applications Program
WCDP	World Climate Data Program
WCIP	World Climate Impacts Program
WCP	World Climate Program
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

