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Atmospheric Climate Data
Problems and Promises

National Research Council, Washington, DC

Prepared for

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The report discusses the explosive growth in the quantity and diversity of weather and climate data, the growing handicap that the distinction between "weather" and "climate" in NOAA imposes on the efficient management and use of data, and the uncertainty induced by the lack of clear commitment and consistent policies regarding federal roles and responsibilities in operating and maintaining the national weather and climate data system and in providing related services. Various recommendations are offered.

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Atmospheric Climate Data

Problems And Promises

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Panel on Climate-Related Data
Board on Atmospheric Sciences and Climate
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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DEDICATION

Helmut E. Landsberg
1906 - 1985
Professor Emeritus
The University of Maryland
College Park, Maryland

Professor Landsberg was a great source of wisdom and inspiration for all of us. His contributions were numerous and invaluable. As both a friend and colleague, he was sorely missed at the conclusion of the panel's work. We dedicate this report to his memory.

Preface

In the National Climate Program Act of 1978, Congress left no uncertainty as to the importance of climate-related data to the success of the national climate effort. The act called for specific program elements regarding:

- Global data collection, monitoring, and analysis to provide reliable, useful, and readily available information on a continuing basis.
- Management and dissemination of climatological data, information, and assessments, including consultation with current and potential users.
- International cooperation in climate research, monitoring, analysis, and data dissemination.

The act also provided for an Intergovernmental Climate Program that would, among other things, support "atmospheric data collection and monitoring on a statewide and regional basis" and provide "information to users within the State regarding climate and climatic effects."

The Board on Atmospheric Sciences and Climate has long recognized the many potential benefits of meteorological and climatological services to the nation and the key role played by climate-related data and information in realizing these benefits. In its report, *Toward a U.S. Climate Program Plan* (Climate Research Board, 1979), the board recommended that the federal government:

> Formulate a conceptual framework for a CIS (Climate Information System) as a basis for future planning of the climate data, information, and services component of the U.S. Climate

> Program. The framework should provide for the effective management of climatic data, the transformation of these data into useful climate information, and the rapid delivery of data and information to users.

A later report, *A Strategy for the National Climate Program* (Climate Research Board, 1980), identified and ranked specific recommendations regarding observational and data management needs at both the national and international levels. Many of these recommendations were subsequently incorporated into the first five-year National Climate Program Plan. This report also envisioned the phased development of an Intergovernmental Climate Program with activities centered in the areas of climate information services, climate data acquisition and analysis, and climate effects studies.

With the implementation of the National Climate Program, the board has sought to provide more specific advice on key data-related issues. A 1981 report by the board's Panel on the Effective Use of Climatic Information in Decision Making, *Managing Climatic Resources and Risks* (Climate Board, 1981), focused primarily on the delivery of climate data and information to users. It recommended that the National Climate Program Office take positive steps to coordinate federal management and use of climate information. It also highlighted the importance of networks of local experts and continued representation of user interests throughout the climate-information system.

The role of decentralized climate services involving both the public and private sectors was especially emphasized by the board's Panel on Intergovernmental Climate Programs in a 1982 report, *Meeting the Challenge of Climate* (Climate Board, 1982). This panel analyzed the utility of climate services in a wide range of activities to identify user needs and consequent requirements for an effective information system. The principal recommendation of the panel was that "the National Climate Program Office should take a leadership role in the development and support of a coordinated, nationwide system of climate services involving both the public and private sectors." It felt strongly that such a nationwide system should build on existing state and regional climate programs and on existing networks of experts in both the public and private sectors.

Recognizing that the delivery of climate data, information, and services is intimately tied to the entire national system for acquiring, archiving, and disseminating climate-related data, the board established the present Panel on Climate-Related Data in 1984. Specifically, the board charged the panel with formulating recommendations for actions to improve this system at the state, regional, and federal levels. As part of this task, the panel was asked to review the scope and development of climate-related data, the value of such data as a national resource, previous studies of data issues, and the strengths and weaknesses of the present data system.

"Climate" is an inherently imprecise and open-ended concept. Narrowly defined, data relevant to climate might be said to comprise simply the observed statistics of the classical weather elements—temperature, precipitation, wind, and so on, over the land surface where people live and work. Mariners and aviators would perhaps favor a broader definition that might include ocean waves and currents, winds, and temperatures in the free atmosphere, and the boundaries and characteristics of snow and ice on land and sea. Scientists seeking to understand the behavior of the earth's climate system would no doubt call for far more information on changing solar radiation, satellite observations of cloudiness and radiation fluxes, the ocean's composition and deep circulation, the characteristics of the land surface, the atmosphere's chemical composition, the earth's biota, and so on. Finally, those concerned with the relationship of climate to human affairs would demand a vast amount of information on the sectors of society influenced by climate.

At the outset of its work, the panel recognized that a truly comprehensive review of climate data in the broadest sense would be beyond its grasp. But where to begin, and how far to go? The panel chose to focus on a limited subset of climate data—observations of the past variation and statistical character of the classical weather elements as recorded by the world's weather observing networks. These observations document reasonably well the characteristics of atmospheric variability near the earth's surface over the regions of human activity. Thus, they provide the raw material for most practical *applications* of climate information to the planning and management of society's work. Moreover, since the bulk of these data are obtained and managed by NOAA, the panel could clearly focus on the related institutional issues.

The narrow scope adopted by the panel, however, leaves unexamined an extremely broad range of issues. For example, oceanic data are of vital and growing importance for both research and practical applications. Indeed, the major research programs of the World Climate Research Program are largely oceanographic in character. Satellite observations provide uniquely valuable global coverage, but present formidable problems of data transmission, archiving, and dissemination. NOAA is by no means the only agency engaged in obtaining and managing climate data. These complex and important issues that are of especially pressing concern to the research community merit separate and intensive study before a truly comprehensive and integrated view of the management of climate data can be developed. Thus, the present panel's work should be considered only as an initial contribution to a larger task.

During the panel's study, the National Climate Program Office requested that the Board on Atmospheric Sciences and Climate review progress in implementing the National Climate Program and help define directions for the next five-year National Climate Program Plan. In response, the board held a workshop in July 1985 in which several panel members participated. The workshop report, entitled *The National Climate Program: Early Achievements and Future Directions*, points out the advances in technology and changes in expectations vis-a-vis data and information services that have occurred in recent years. This has led to the growing obsolescence of the distinction between "weather" and "climate" in the administration and management of the national data system. The report identifies several areas where more progress is urgently needed, especially in light of the rapid modernization of data collection systems in the National Weather Service and elsewhere. A fundamental problem, the workshop noted, is the lack of a coordinated national program for climate services. All of these issues are addressed in more detail in the present report.

The panel met five times between March 1984 and January 1986. Panel members and staff also met informally on several occasions. The group is grateful to the National Climatic Data Center for hosting its second meeting in July 1984; to the Illinois State Water Survey for hosting its third meeting in November 1984; and to the National Meteorological Center for hosting its fourth meeting in March 1985. Thanks are also extended to the American Meteorological Society for its assistance in holding an

informal discussion at the 1985 Annual Meeting in Los Angeles and the panel's final meeting at the 1986 Annual Meeting in Miami.

The panel also wishes to acknowledge the diverse and substantive inputs provided by many different individuals, too numerous to name, from both the private and public sectors. Special thanks are extended to Margaret Courain of the National Environmental Satellite Data and Information Service, Ken Hadeen of the National Climatic Data Center, and Alan Hecht of the National Climate Program Office for their support of the panel's work.

Finally, the panel thanks John S. Perry and Robert S. Chen of the Board on Atmospheric Sciences and Climate staff for their extensive and substantive contributions to the preparation of this report.

Werner Baum, *Chairman*
Panel on Climate-Related Data

Contents

Executive Summary

Technologies developed in recent decades for collecting, processing, and utilizing weather and climate data have revolutionized meteorology and climatology. Satellites now routinely monitor weather and climate conditions at both regional and global scales. Advanced radar provides early warning of dangerous weather situations and high-resolution data on atmospheric structure. New generations of computers support ever-more complex mathematical models for weather and climate predictions. Innovative telecommunications technologies permit rapid, automated distribution of meteorological and climatological data and derived products at reasonable cost on local, regional, and global scales.

These startling technological advances have brought many benefits and the promise of many new ones—including better weather and climate forecasts, more timely and reliable warnings of dangerous weather events and climatic episodes, and increased efficiency in many sectors of the nation's economy.

They have also brought new problems. Foremost among these is the *explosive growth in the quantity and diversity of weather and climate data*, growth that could overwhelm the capabilities of current data systems in the United States. Indeed, this growth threatens the integrity of the climatic networks and data bases on which these systems depend. Technologies for the quality control, storage, and retrieval of data, although increasing in sophistication, have not kept pace with the flood of new instruments and techniques for data collection and the burgeoning demand for timely, high-quality weather and climate data from around the world. Nor have the institutions responsible for maintaining basic weather and climate data systems had the resources to do much more than respond in ad hoc fashion to any but the most pressing demands for data and for information services. Difficult choices now face these institutions regarding how to handle the vast amounts of new data. These choices will inevitably influence the fate of all data, new or old, and will likely have profound effects on the reliability, efficiency, and utility of the national weather and climate data system for decades to come. This report centers on the atmospheric component of this flood of data, a stream primarily managed by the National Oceanic and Atmospheric Administration.

A second major problem is the *growing handicap that the distinction between "weather" and "climate" in NOAA imposes on the efficient management and use of data.* Numerous applications of weather and climate data require careful integration of real-time, near-real-time, and past data on atmospheric, hydrologic, and related parameters. Close integration of data base management and research functions is also critical to maintaining both high-quality data sets and high-quality research. The present separation of data responsibilities between the nation's operational weather agency, the National Weather Service (NWS), and its environmental data service agency, the National Environmental Satellite and Data Information Service (NESDIS), hinders such integration. For example, the Cooperative Observers Network, by far the largest network in the United States, is operated by NWS, but data from the network are handled for the most part by NESDIS. In addition, there appear to be some instances of less-than-optimal allocations of data-related resources, insufficient integration of data management and dissemination, and inflexibility in meeting important climatological needs. New institutional arrangements are needed to improve cooperation and coordination of data activities at both operational and planning levels.

A third major problem intensified by rapidly changing technologies is the *uncertainty induced by the lack of clear commitment and consistent policies regarding federal roles and responsibilities in the operation and maintenance of the national weather and climate data system and the provision of related services.* This uncertainty continues to hinder development of both public sector and value-added private sector applications of weather and climate data throughout the nation. Changing cost structures, uncertain access to data, a confusing array of federal agencies with overlapping missions, the potential for cutbacks in critical federal services, and the threat of competitive federal activities make the environment for innovation difficult at best. One consequence has been the uneven development of climate data bases and associated services across the nation.

These problems are by no means insurmountable. Most ingredients for an innovative and responsive data system already exist. In both the public and private sectors, many new approaches and methods have been developed in recent years, despite the problems noted above. These represent important opportunities to improve productivity and efficiency in agriculture, water and energy management, transportation, construction, and other economic sectors throughout the country. New methods are constantly being developed. The challenge to government is to develop appropriate institutional mechanisms to make techniques and data resources available to users and potential users and to actively promote the effective and efficient use of weather and climate data throughout the nation's economy. With this challenge in mind, the panel has developed a number of recommendations, discussed in greater detail in the body of this report.

The most critical need is for strong leadership and coordination by the federal government with the support and representation of all of the major contributors to and users of the national weather and climate data system:

Recommendation 1: The federal government should clearly articulate an integrated national policy covering its obligations and limitations in (a) the observation and monitoring of the weather and climate; (b) the collection, processing, and management of weather and climate data; (c) the retention and archiving of weather and climate data; and (d) the provision of weather and climate information and services.

This policy should identify federal agency roles in all aspects of data and services and coordinate diverse inputs from both the public and private sectors.

A second critical need is to streamline the management of weather and climate data within the federal government:

Recommendation 2: The federal government should recognize the users' need for a continuum in the management of weather and climate data. NOAA should therefore reassess its existing *institutional arrangements with the objective of improving the coordination of weather and climate data activities.*

NOAA's role in the national weather and climate data system is central. To facilitate coordination within NOAA and between NOAA and other agencies, the following is recommended:

Recommendation 3: NOAA should establish a central data officer for weather and climate data with a clear mandate, broad authority, and sufficient resources to (a) conduct systematic and impartial studies of requirements for weather and climate data and of new technologies for efficiently meeting these requirements; (b) coordinate planning for new weather and climate data management, communication, and dissemination systems throughout NOAA; (c) develop clear standards for data collection and instrumentation, consistent and efficient quality control, and cost-effective data archiving and dissemination for basic observations, derived parameters, gridded data sets, and special-purpose data sets such as those obtained in field experiments; (d) ensure the continuity, careful management, and coordination of key climate networks, data bases, and publications, including the cooperative and baseline observing networks; and (e) act as coordinator and arbiter in decisions concerning resource allocation, technological modernization, and data preservation, both within NOAA and in cooperation with other agencies, and serve as a focal point for coordination with the World Weather Watch program of the World Meteorological Organization.

Many opportunities exist to introduce and enhance the use of weather and climate data throughout the nation's economy, with potentially large savings and payoffs for relatively small investments by the public sector. Therefore,

Recommendation 4: The federal government should increase active promotion of the application of weather and climate data in both the public and private sectors, including continued documentation and demonstration of the broad utility and value of such data.

Such outreach activities might include the funding of sector or regional studies and the organization of seminars and workshops. Consideration might be given to formation of a federal-state-private sector board to coordinate these activities, many of which might be keyed to the 1990 census and the impacts-oriented climatic atlas recommended by the 1985 Woods Hole workshop (Board on Atmospheric Sciences and Climate, 1986).

The panel views these recommendations as important early steps toward an institutional structure for climate data management that can meet the challenges of rapidly changing technology and growing national needs for data and services. What is most critical, however, is that the federal government seriously examine its handling of weather and climate data from a broad, long-term perspective, and that it establish mechanisms to ensure sensible, government-wide planning and implementation of data management.

1
Introduction

If the weather did not vary from day to day and place to place, there would be little need for climate data—one set of numbers would suffice for any purpose. But in reality, the earth's climate is highly variable on a wide range of time and space scales. Temperature, precipitation, wind, and other climatic parameters often change rapidly in only a few hours or a few kilometers. Climatic episodes such as droughts and heat waves may persist for months but end in a day. Weather events like hurricanes, thunderstorms, and tornadoes generate highly localized and transient extremes—and too often leave extreme damage in their wake. High-resolution, high-quality, and timely climate data are thus critical to understanding our climate and to improving decision making regarding its varied opportunities and hazards.

Technologies for gathering climate data of high resolution and quality have advanced rapidly in recent years. Sophisticated instruments utilizing new electronic and optical techniques can measure many different climate and climate-related parameters continuously and automatically. Satellites provide not only large- or even global-scale observations, but also measurements with resolutions of a few hundred meters or less. New Doppler radar instruments can continuously monitor atmospheric winds, permitting more rapid and reliable detection of wind shear, severe storms, and tornadoes. Inexpensive microcomputers have greatly increased the capabilities of automated weather stations and drastically reduced their costs.

Increasing data resolution means increasing data volume. A typical meteorological satellite may generate several trillion bytes of data over its lifetime, enough to fill tens of thousands of high-density magnetic computer tapes. Doppler radar systems such as the next generation radar (NEXRAD) planned by NOAA can generate comparable amounts. Even a small, automated weather station is capable of producing millions of bytes of data in a year.

The variety of data is also increasing, not only because of new instrumentation, but also because the uses for—and users of—weather and climate data are growing in sophistication. For example, systems to detect and pinpoint the location of lightning strikes are now in widespread use by electric power utilities, forest managers, aerospace and defense facilities, and hazard meteorologists. Many municipal and county governments utilize automated precipitation and streamflow stations in flood-prone areas. Recently, a company in the United Kingdom has begun to map and monitor winter road surface temperatures in order to improve sanding and salting operations. Farmers often measure precipitation, soil moisture, and other parameters to ensure more efficient and effective applications of water, fertilizer, and pesticides.

These new technologies and applications create unparalleled opportunities for increased economic efficiency. new products and services, reduced damages from climatic extremes, and many other improvements. Unfortunately, the magnitude and rapidity of change have stretched the ability of the present weather and climate data system to support even current levels of activity efficiently. Although many elements of existing services are exemplary, many others fall short of what is needed and feasible. The present system thus poses a major obstacle to the attainment of the potential benefits of weather and climate information envisaged in the National Climate Program Act.

This report analyzes some of the weaknesses in the present system in the face of change and makes recommendations to remedy them. It also highlights some key areas where straightforward action can lead to substantially more effective and efficient utilization of weather and climate data. Within this exceedingly broad area, the report focuses on a narrow, but fundamental class of information—data on the classical weather elements acquired, held, and disseminated primarily by NOAA. This consciously narrowed scope neglects a number of important areas, notably the oceanic and satellite data so important for research. However, it does address the data most useful for immediate practical applications in the planning and management of the nation's economy.

Actions to improve the effectiveness of this component of the climate data systems do not require large investments of resources by the federal government but rather commitment, sensible leadership, and careful coordination of all those involved.

2
Climate Data: Changing Definitions and Needs

Systematic collection of climate data began in the nineteenth century. Many data were collected as part of early attempts to define resources and to predict the weather. The climate was recognized as part of the geographic endowment of localities and regions. It was general knowledge that weather and climate set boundaries for various human activities, principally agriculture, and that they influenced clothing, housing, heating, and modes of transportation. The primary concern was with temperature, precipitation, and wind. The convention was to deal primarily with the mean values of these elements, even though there was early recognition that extreme values had great practical importance.

In the twentieth century, the importance of weather and climate in decision making has increased, and the scope of observations and their use has changed. The greatest change came with the advent of aviation, when weather data became "four dimensional" and operational. Growth in needs for both short-range forecasts and statistically sophisticated analyses of past data for planning has spurred rapid scientific development in atmospheric sciences. Military needs (e.g., military aviation, ballistic calculations, chemical warfare) have placed premiums on these developments. This was particularly true in World War II and subsequent hostilities.

Civilian needs and applications have also steadily expanded. A key area of growth is the use of weather data collected for forecast purposes to evaluate the "immediate past" in relation to long-term mean values or past extremes. Climatologies and climate "scenarios" are used to assess crop production on a current basis and to assess the likely impact of hazards such as drought, floods, and severe storms. Disaster relief has become a worldwide affair, and climate data a critical input into disaster monitoring. Local and regional effects of air pollution require new types of climatological analyses. Plant location and siting, especially for nuclear power installations, have created new demands for climate data. Energy crises have increased needs for wind and solar radiation data. Energy-efficient housing and building construction have become a new focus of attention for climatologists.

On a broader scale, the fluctuations of climate and their causes have become the target of intensive research. Practical aims include the diagnosis of possible anthropogenic climatic changes and their impacts on the earth's ecosystems and resources, and the search for methods for predicting the state of the atmosphere beyond the usual limit of weather forecasts of about 5 to 10 days. Past climate data are still the mainstay of such predictions. New physically based methods of prediction are also emerging, and their development is dependent on the timely availability of coordinated climate and climate-related data for large regions.

2.1 ELEMENTS OF THE PRESENT NATIONAL SYSTEM

The present system for handling weather and climate data in the United States involves numerous federal and state agencies, thousands of individuals, and many different businesses, universities, and other private institutions. The flow of data is complex. Notably, data are typically labeled as either "weather" data or "climate" data and are often managed separately. However, there is really a continuum from the point at which observations are made to the point at which derived information is used and archived. Because of this continuum, each element of the national data system is critical to the attainment of the overall utility and value of weather and climate data in the nation.

The sequence of events is that at regular synoptic weather stations the observations are taken and electronically transmitted to a forecast center. A permanent record is also made at the station. The main forecast center in the United States, the National Meteorological Center (NMC), makes an initial quality control check and enters the data into a computer model for the weather forecasting process. Immediately thereafter the same observed weather data are essentially labeled climatic data.

In cooperation with the U.S. Department of Agriculture (USDA), NMC issues the first climatological product, the *Weekly Weather and Crop Bulletin*, a venerable publication first issued in 1872 and now in its 72nd volume, having appeared earlier under a different title, *Weekly Weather Chronicle*. The Climate Analysis Center (CAC) at NMC also prepares the *Climate Diagnostic Bulletin* and the *Climate Anomaly Monitoring System* (CAMS) on a monthly basis. In addition, it furnishes the World Climate Program (WCP) with a brief monthly world weather anomaly chart.

It should be noted here that the NMC is part of the National Weather Service (NWS), which is also responsible for the management of the Cooperative Observers Network. This network is the backbone of climatological information for the country. It is maintained to fulfill the obligation to "establish the climate of the United States," which was laid down in the organic act establishing a civilian Weather Bureau in 1890.

Yet the data collected at these stations flow through another channel. They go in manuscript form to the National Climatic Data Center (NCDC) as do the original hard-copy data from the U.S. synoptic stations. Some cooperative stations also furnish current temperature and precipitation observations to NMC and the offices of the state climatologists, where these exist. At NCDC the materials are subjected to fairly rigid quality control checks. They are machine-processed for two monthly publication series: *Local Climatological Data* for the synoptic stations and *Climatological Data* by states for the cooperative network. Finally, the material is microfilmed and enters the archive at NCDC, which by delegation of authority by the U.S. Archives is the depository for U.S. weather data. NCDC is the main provider of climate-related data to the user community. It is currently managed by the National Environmental Satellite and Data Information Service (NESDIS), which is on the same organizational level within the National Oceanic and Atmospheric Administration (NOAA) as the NWS.

In addition to the synoptic and cooperative station networks, there are many other sources of "specialized" climatic data. Observations are taken on a wide variety of parameters, ranging from soil temperature and moisture to surface solar radiation to upper air temperatures and humidities. Measurement networks are typically operated by governmental agencies or other organizations for specific purposes, e.g., water management, flood control, air pollution monitoring, and hazard and resource assessment. Data may be gathered on a routine or sporadic basis and often provide much greater detail on environmental phenomena than can be obtained from general national networks. In general, data of this type are sent to NCDC on a regular basis to be archived. However, this is usually voluntary on the part of the originating organization, and there are no established coordination mechanisms by which the NCDC can ensure the completeness, quality, and timeliness of specialized data sets.

Dissemination of data sets to users normally occurs directly via the source of data or indirectly through the NCDC or other intermediary such as a private consultant or a state climatologist. These intermediaries often provide additional "value-added" services such as repackaging data in easier-to-use form, reformatting them to user specifications, or combining them with other types of data. While many data are distributed through regular or irregular publications such as those mentioned above, a large proportion is disseminated in response to direct user requests.

2.2 END USE AND END USERS OF CLIMATE DATA

The ultimate goal of the national system for climate data is to assist "end users" with their "end uses" of climate data. Here, the term "end" is used to distinguish actual applications of data to specific problems within various sectors of the economy from intermediate stages of data use and dissemination primarily by the climatological community and the media. End uses vary greatly, from the utilization of weather records in scheduling outdoor events to the incorporation of snow, ice, and wind loading information into building designs to the assimilation of large amounts of climatological data into complex agricultural models. End users also vary, ranging from the individual farmer or gardener worried about cumulative sunshine and precipitation to giant oil companies concerned with climatic extremes experienced by oil platforms and tankers. In general, the greatest variation in data needs occurs between end uses, primarily with respect to data type, frequency, and spatial coverage. Data needs also vary with the type of end user, especially in reference to the form of dissemination. Some end users need data primarily for long-range planning and design, while others utilize both weather and climate data operationally on a real-time basis. For the latter, the timeliness of data is often extremely important—delays in the system can in some cases make data virtually worthless.

It is useful to categorize end uses in terms of major sectors of the economy. As a starting point, Table 2.1 lists the economic sectors typically used by economists (e.g., Bureau of the Census, 1984, p. 483). Many valuable end uses of climate data can be found in each sector. In some such as agriculture, climate data are used regularly in both planning and operations by production managers (farmers), financial advisers (bankers and insurers), suppliers (seed, fertilizer, and equipment vendors), and distributors (grain companies and marketing cooperatives). In others such as mining and communications, utilization of climate data may be relatively sporadic, but can nonetheless be extremely important.

The diversity of end uses and potential end users is constantly increasing. For example, the report *Meeting the Challenge of Climate* (Climate Board, 1982) notes that new opportunities for taking advantage of climatic resources can arise from:

1. Technological developments, such as solar and wind energy systems or new insulation methods, that generate new uses of climatic resources or better adaptations to climatic hazards and conditions.
2. Social changes, such as altered population levels or policy decisions, that change the patterns of use of climatic resources (e.g., water supplies) or permit different ways of dealing with climate (e.g., insurance mechanisms and building codes).
3. Long-period climatic fluctuations or climatic changes on local, regional, or global scales, perhaps due to anthropogenic influences such as emissions of radiatively active trace gases, urban development, or watershed modifications, that alter the mean climatic conditions or the likelihood of extremes to which society is currently adapted.

Changes of this kind are rapidly making traditional definitions of end uses and end users obsolete. Today's users are much more likely to need unusual combinations of conventional and unconventional data, sophisticated data processing and analysis, and both real-time and historic data.

Serving this growing diversity of end uses and end users in an effective manner poses a difficult challenge. Many potential end users are not aware of the availability of climate data or of

TABLE 2.1 Economic Sectors and End Use Examples

Economic Sector	End Use Examples
1. Agriculture, forestry, and fisheries	planting, irrigation, harvesting, pest management, livestock production, fish harvesting, fire control, international trade
2. Mining	mining operations, land reclamation, environmental assessment, offshore drilling
3. Construction	building design, construction scheduling, facility maintenance, highway construction
4. Manufacturing	plant site selection, pollution control, worker and material access to plants
5. Transportation	road salting and sanding, rail operations, ship routing, runway design, airline scheduling
6. Communications	telephone line repairs, emergency planning, microwave transmission
7. Electric, gas, and sanitary services	load management, reserve planning, air quality management, conservation, sewer system design and operation, water resources management
8. Wholesale and retail trade	marketing of weather-related products, consumer access to retail outlets, food distribution

TABLE 2.1 (continued)

9. Finance, insurance, and real estate	crop/hail, flood, flood, wind, and ice/snow loading insurance, resource assessment
10. Services	legal substantiation, hospital operations, recreation and tourism planning
11. Government	military operations, emergency management, public facility planning, snow removal, employment opportunity assessment, scientific research

the many data-related services offered by both private and public sector groups. Nor are their specific needs and problems well defined or commonly recognized by the data community. This means that the climate products and services available for some end uses like plant site selection may not be as sophisticated as those available for other end uses like irrigation scheduling, aviation, and air quality modeling. The technical capabilities and financial resources of end users themselves also vary considerably, which influences not only the immediate opportunities open to individual end users but also the long-term opportunities for using climate data open to the economic sector as a whole.

It is thus instructive to examine in detail several areas in which the use of climate data is well established and still expanding. These essentially provide reference points against which the development of climate data applications in other areas can be compared.

2.2.1 Agriculture

Agriculture's success depends in large measure on its ability to cope with climate. This has been achieved through breeding new varieties, land selection and conservation practices, and improved understanding of market variations as induced by climate. All of these require weather and climate data. Without rapid and ready access to climate data and information, agricultural productivity would be reduced, the U.S. competitive position on world markets would be jeopardized, and its ability to monitor crop developments and to plan for food emergencies would be seriously impaired.

Agriculture has traditionally made extensive use of weather and climate information. In the eighteenth and nineteenth centuries, there was great interest in the climatic suitability of land for settlement. The development of improved technologies for food production, processing, and transportation has led to the more precise tuning of agricultural production to climate and markets. Recently, attention has focused on understanding production in its global context and on regional droughts and their implications for human welfare. The need to monitor such events was made dramatically clear following the 1972 drought in the Soviet Union that led to a trebling of grain prices in the U.S. and world markets. The major droughts of 1972-1973, the economic effects of frost on the Brazilian coffee crops, and the poor harvest weather for European sugar beets in 1975 further disrupted international food trade in the early 1970s. This instability has caused policy analysts, economists, commodity traders, and others to clamor for access to climate data.

Crop yields are largely the product of soils and the weather over a season. Monitoring climate and interpreting it in terms of crop response using crop/climate relationships provide valuable information on national and world agriculture. Monitoring systems that advise on the onset or failure of monsoons have a potentially major role in assisting farmers in developing countries. Such monitoring has been undertaken by federal agencies and private concerns interested in international food production. For example, USDA operates a worldwide monitoring facility jointly with the NWS. This facility provides information on the world food situation to the Secretary of Agriculture and to other national planners and policy makers concerned with markets, assistance, and stress produced by food shortages.

Monitoring systems exploit historical climatic data to determine plant response relationships and to compare the severity of events. Indices based on climate data, such as the Palmer Drought Index and the Soil Moisture Index, are used to assess the areal extent and intensity of hazardous events. Satellite-derived information on cloud cover, temperature, snow cover, and precipitation provides valuable additional information, particularly where conventional data are sparse. For example, the sustained lack of cloud is a good indicator of potential drought. Infrared radiation estimates of ground temperatures supplemented with actual surface measurements can be used to assess crop conditions. All of these monitoring methods rely on both conventional and new data sources.

Many other aspects of agriculture benefit from the use of weather and climate data. These include irrigation, crop selection and production, planting, pollination and harvesting, erosion control, pest and disease control, and livestock and pasture management (e.g., see Climate Board, 1982). For example, the control of pests and disease is achieved most effectively by knowing their response to climatic parameters and acting when they are most vulnerable. Special state and regional networks are being established to improve such understanding and to provide climate-based advisories upgraded to the latest weather conditions. As farming increases in sophistication, farmers will want much more high-quality climatic data, with increasing detail and more parameters and in both real and near-real time.

In large measure, increasing demand for data stems from the increasing availability and capability of computers. Continuing advances, such as the introduction of parallel processing, will further increase the potential of computers in agriculture. Computers make possible the evaluation of management alternatives given different climatic conditions. They facilitate crop zonation studies and permit prediction of the effect of altered climates on production. They are being used increasingly by farmers. For example, the University of Nebraska Automated Weather Data Network is linked to AGNET, an interstate network that makes weather data and the university computer hardware and software available to irrigators who own a personal computer. The cost-benefit ratio for an automatic station based on this activity is estimated at 1:250 (Rosenberg et al., 1983). Such nonfederal observing systems can make important contributions to the national data system.

2.2.2 Energy

The energy sector requires climate data for both demand and supply planning and for operations. Climate is a major determinant of demand since energy is used to offset cold, heat, wind, excessive precipitation, snow, ice, and other climate-related hazards. Defending against and exploiting the variable nature of climate are major activities in the design of energy systems as well as in their efficient use. On the supply side, climate data are used in energy exploration, transportation, storage, transmission, and distribution (e.g., Climate Board, 1982; McKay and Allsopp, 1980). Many environmental problems such as acid rain and the atmospheric transport of toxics are closely associated with energy activities, and many of these require climate data for their assessment and mitigation.

About one-third of the energy used in North America is used to counter adverse climate. The more significant demands relate to space heating, water heating, air conditioning, refrigeration, transportation, and agricultural uses (e.g., irrigation and crop-drying). The main method of reducing these costs is to improve technological design utilizing climate data. For example, with the rapid increase in the costs of energy, construction codes have begun to emphasize energy efficiency in addition to other requirements for physical safety and shelter from wind, cold, heat, and rain. Generating the climatological data and statistics needed for energy conservation and for the exploitation of renewable energy alternatives has been a major activity over the past decade. The required information is usually site- and time-specific so that the task is a continuing one. Similarly, for operational activities such as irrigation, the need for data, both recent and current, is continuing.

The use of energy for heating and cooling is easily estimated from climate records. This is done routinely by NCDC for states and regions of the United States using population-weighted data. Up-to-date data are required by energy controllers and suppliers to plan against undesirable shortages or surpluses. Such information has been particularly valuable during recent energy shortages. For example, during the cold winter of 1976-1977, temperatures dropped up to 6°C below normal across an area centered on the Ohio Valley. This caused heating costs to rise some 50 percent and had a severe impact on local supplies, so that emergency action was required. The resulting cost increases and diversion of purchasing power for the central and eastern United States were estimated to be at least $2 to $5 billion (*The Business Week*, February 14, 1977). Events of this kind have spurred routine assessments of the impacts of climate anomalies on society using climate and climate-related data.

Climate data are required to assess most renewable resource supplies and their variability. Statistics on temperature, wind speed and direction, solar radiation, cloudiness, and other atmospheric characteristics are typically used in designing integrated solar and wind energy systems and equipment. Similar data, including precipitation and runoff measurements, are necessary for hydropower planning and management. A major concern in all such systems is the reliability of supply. Climate variability must therefore be considered in designing reliable storage and/or backup systems.

The search for new energy sources and shipping routes has led to increased demand for climate data in offshore and coastal areas. Such data are used in equipment design, facility planning, route selection, and environmental assessment. For example, Murphy et al. (1977) suggest that a 3 percent savings in fuel is possible by using meteorological information in ocean route selections. Frequently, information is needed to solve rather unique problems that may require new technology, e.g., defending against freezing sea spray and low-temperature-induced brittleness of metals in polar regions.

Other demands for climate information range from the siting and operation of thermal or nuclear plants to managing seasonal changes in additives to gasoline. Climate and weather data are used to improve operational efficiency in the selection and use of fuels and the assessment of transportation hazards such as snow, ice, and winds. Designers and managers increasingly recognize the need to account for natural hazards such as floods and tornadoes in the safe design of large public and commercial energy facilities. Air quality concerns must be addressed along with strategies for achieving economic operation such as in selecting the optimum mix of fuels consistent with atmospheric conditions. With the increasing length and complexity of energy distribution systems, the frequencies of lightning strikes and excessive wind loading of transmission lines and support structures are escalating. Climatic records often provide an important indicator of the magnitude and distribution of these hazards. New types of monitoring systems, e.g., for lightning strikes, are also being used. Other climatic considerations include the evaporation of cooling water, the formation of fog downwind of cooling ponds, and the creation of thermal plumes by the discharge of cooling water.

2.2.3 Water Resources

Water is vital to all forms of life and to most human endeavors. Major water uses include household consumption, agricultural irrigation, energy generation, transportation, manufacturing, mining, recreation, and sanitation. In many if not most areas, supplies of fresh water are limited relative to rapidly growing demand and are highly variable in both quantity and quality. This has led to more careful development of and control over water resources and increasing integration of water management across watersheds and large population regions. Principal management objectives remain the stabilization and augmentation of water supplies, reduction of flood and drought damage, and maintenance and enhancement of water quality.

The atmosphere is the primary source of fresh water and, through evaporation, the main consumer. Climate data and information are thus critical to the management of water resources. Climate data are used in designing storage, drainage, and irrigation systems; estimating water yields, snowmelt rates, and cooling water requirements; and projecting water demand, lake levels, and flood potentials. Other frequent uses pertain to soil and coastal erosion; seiche and storm surge; and river, lake, and sea ice formation and melting. In many instances, as with major reservoirs and water distribution systems, substantial amounts of capital are involved. For example, the construction costs for a proposed diversion of 10,000 cubic feet per second from Lake Superior to the Ogallala area have been estimated at $19.6 billion (De Cooke et al., 1984). Failure to consider climatic factors at the delivery and source areas could lead to very expensive errors.

Although precipitation is usually a dominant concern, data on a variety of related parameters are frequently required. This is particularly true when sophisticated computer-based modeling techniques are employed, e.g., in flood forecasting and reservoir management. Current and historical data on the diurnal regimes of wind, solar radiation, humidity, air and soil temperature, soil moisture, and snow cover are typical inputs. Data on soil type, slopes, precipitation intensity, and cloudiness may also be used. Adequate monitoring, comprehensive data bases, and effective data management systems are therefore crucial.

Other data needs relate to climatic variability and change. For example, urban development may significantly affect downwind precipitation, including thunderstorm frequencies. This may make existing sewer and drainage systems obsolete. Since most such systems have lifespans of 50 years or more, consistent and detailed data on past, present, and future hydroclimatic conditions are likely to be important.

Mitigating drought is a major concern. The most drought-prone areas are the semiarid lands such as the U.S. Great Plains. In 1977, these lands accounted for almost one-fifth of the nation's agricultural output.

Drought has implications on local to global scales, affecting food supplies and social stability as well as being a major cause of famine and soil degradation. The impacts of regional drought within the United States were massive in 1976 and again in 1980. Its occurrence elsewhere in the world usually involves the United States in emergency and long-term development aid. Long-term aid frequently includes introduction of drought-resistant crops, water development, and water conservation measures, all of which can benefit significantly from the use of climate data.

Drought may also exacerbate other problems. For example, it tends to increase pollution concentrations in rivers and lakes because dilution decreases. Water quality managers therefore need data on the likelihood, severity, and duration of drought episodes to ensure that water supplies meet water quality standards.

2.2.4 Climate Systems Research

The climatological research community is itself a major end user of climate-related data. Such data are an intrinsic part of the research process. Systematic study of the processes governing the earth's climate on local, regional, or global scales requires careful observation and data analysis. Theoretical models must be tested against observed "reality" represented by data. Complex computer models use large quantities of diverse data to simulate environmental conditions as realistically as possible. Studies of the impacts of climatic variability and change often combine climate data with data from other fields to assess interrelationships between climatic phenomena and human activities and welfare.

Many research needs for climate data can be satisfied by conventional data archives, but most require specially collected data. In many instances, the spatial and temporal scales of the processes under study demand that large quantities of highly perishable conventional and remotely sensed data be collected from all parts of the globe. Even experiments on the microscale, e.g., studies of the boundary layer over a specific terrain, can generate enormous volumes of data.

Over the past 20 years, major experiments on the meso- to global-scale have been undertaken to improve understanding of the climate system and improve climate prediction. The Global Atmospheric Research Program (GARP) organized a host of field experiments such as the First GARP Global Experiment (FGGE) in 1978-1979, the GARP Atlantic Tropical Experiment (GATE) in 1974, and the Alpine Experiment (ALPEX) in 1983. Several additional field programs such as the Tropical Ocean/Global Atmosphere (TOGA) Program (1985-1994) and the World Ocean Circulation Experiment (WOCE) are now in progress or being planned for the next decade under the auspices of the World Climate Program (World Climate Research Programme, 1985). Other efforts may also be undertaken in the next decade as part of initiatives such as the proposed International Geosphere-Biosphere Program (U.S. Committee for an International Geosphere-Biosphere Program, 1986). Mesoscale studies such as the Generation of Atlantic Lows Experiment (GALE) in 1986 and the proposed National STORM (Stormscale Operational and Research Meteorology) Program (University Corporation for Atmospheric Research, 1983) also involve huge data volumes.

Efforts of this kind require vast amounts of background data such as surface pressure, winds, and sea surface temperatures. Typically, the field phase of such measurement efforts utilizes satellites, ships, drifting buoys, radiosondes, and other platforms operated by many different cooperating nations. This necessitates the operation of one or more international data centers and affects most national data management activities. The capability to assemble and evaluate and, if necessary, repair or adjust large sets of background data is also important.

In addition to intensive field programs, there is a continuing need for long period data sets to understand changes in the earth's environmental system and to examine global changes in the atmosphere and ocean associated with certain events such as the El Niño or atmospheric blocking. It can be very deceptive if only one such event is studied without comparing it to several others. Of prime importance are various "historical" data sets involving surface, marine, and upper-air measurements from around the world (e.g., Climate Research Committee, 1983). However, since most instrumental measurements extend back only a century at most, a variety of proxy methods are also used to obtain qualitative or quantitative estimates of conditions in the distant past.

Data are also needed to cope with a number of pressing scientific problems pertaining to the long-range transport of air pollutants and climatic variability and possible changes (e.g., Board on Atmospheric Sciences and Climate, 1983, 1984). Since carbon dioxide, methane, and other trace gases can affect the climate, it is necessary to know how the atmospheric concentrations of these are changing and to isolate the sources and sinks. If one source for methane is rice paddies, data will be needed on the changing amount of land used for rice, the relation to irrigation practices, and the changing use of fertilizer. Although many detailed measurements are needed to understand a process, many do not have to be carried out routinely in the future.

Many data sets are heavily used once they become readily available. For example, Australia began twice-daily southern hemisphere analyses in 1972. These first became available at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, in 1977. From 1978 through 1984, there were 62 separate requests from 48 users for the grid data. There were an estimated additional 20 uses of it for on-line computing at NCAR.

At NCDC, about 4 percent of the data requests come from universities, or about 3200 requests during a year from this research-oriented community. The typical university subscribes to several NCDC publications. The state climatological offices also receive data requests from many university departments. For example, the Colorado Climate Office has received requests from 25 different research departments.

The availability of data for research has improved greatly in the last decade. However, research is still often constrained by data availability and cost. Many data sets are not available in computer-compatible form. For those that are, the most recent data must often be coded separately and merged with existing files. Very often inadequate documentation, incompatible formats, missing values, and other problems hamper data use.

Data costs have generally decreased but may still become substantial. For example, the current charge for a copy of a magnetic tape stored at NCDC is about $125, roughly 10 times the cost of the magnetic tape itself. Several magnetic tapes are typically required to obtain data for multiple parameters and/or multiple stations. Selective extracts can be substantially more expensive. In general, however, costs of this magnitude can be incorporated into research grants. Larger data sets, e.g., from satellite instruments, entail much larger data expenditures, often on the order of $10,000 or more. These typically require much more advance planning and come under much closer scrutiny by funding agencies.

2.3 THE VALUE OF CLIMATE DATA

As the previous sections illustrate, climate data can be extremely valuable in a wide variety of economic activities. Moreover, their value is constantly growing as data become more complete, more timely, and more useful for an increasing range of activities. Unfortunately, careful quantitative analyses of the value of climate data are rare, and even qualitative assessments are available in only a few economic sectors. This has made it difficult to increase recognition of the utility of climate data in many sectors. It has also contributed to problems in justifying the relatively small investments needed to augment or at least maintain key elements of the existing national system for climate data.

In recent years, there has been an increasing effort to monitor the impacts of weather and climate events on the national economy. For example, the Center for Environmental Assessment Services (CEAS) of NOAA has estimated that the severe winter of 1982 led to direct losses on the order of $8 billion in a three-month period. Production losses, property damage, increased energy and transportation costs, and agricultural losses each amounted to some $1 to $2 billion (CEAS, 1982). Thompson (1977) indicates that defensible weather losses amount to about two-fifths of the total. This gives some indication of the magnitude of the potential value of climate data in each sector and to the nation as a whole. However, most estimates of this kind are still very crude and subject to important methodological deficiencies. The latter include possible double counting of certain types of losses, omission of indirect effects and opportunity costs, and inadequate quality control of data sources. Recent efforts in the United States and abroad to improve impact assessment techniques show considerable promise (e.g., Kates et al., 1985; Parry et al., 1988; Easterling and Riebsame, 1988; and Borisenkov, 1985), but much further work remains to be done.

Another problem has been that record keeping regarding the use and value of data have generally been poor. NCDC, for example, classifies user requests in terms of the end user rather than the end use. The result is that it is known that many individuals, lawyers, and business managers use NCDC data, but not what they use it for and how they use it. Moreover, there are important sectors of the economy in which end uses tend to be irregular and end users are widely scattered or obtain weather and climate information through indirect channels. This is often the case in the mining, construction, and wholesale and retail trade sectors. Unfortunately, the net effect is that these sectors tend to draw less attention and fewer resources in the national data system than is warranted.

It is also important to recognize that the value of climate data extends beyond the economic benefits of increased efficiency or reduced economic losses. Significant health, safety, and general welfare benefits may also accrue. Although it may be possible to assign rough economic values to such benefits, e.g., through "willingness-to-pay" estimates of the value of public goods, they should still be considered in their own right. These noneconomic benefits may be classified as "physiological," "psychological," and "sociological."

The physiological value of climate data pertains to the physical health, safety, and comfort of people. Land use planners and architects draw on knowledge of historical climatic conditions in providing shelter from the elements, healthful living and working environments (e.g., vis-a-vis air and water quality and aesthetics), and comfortable and convenient facilities. Engineers explicitly or implicitly utilize climate data in designing bridges, dams, roads, and other facilities for safe operation. Real-time and predictive climate information may also be used to ensure that health, safety, and comfort are maintained.

The psychological value of climate data lies in benefits to mental health arising from improved information and design. Examples of such benefits are better mental preparedness and reduced mental stress during adverse climatic episodes and increased enjoyment of one's surroundings in both the everyday environment and recreational settings. For instance, information on weather and climate conditions around the world may alleviate an individual's worries about family or friends or make his or her vacation more enjoyable because of poor conditions at home. (Of course, the opposite situation is also bound to occur.)

The sociological value of climate data relates to the resolution of social and political decisions faced by individuals, communities, or society as a whole. For example, information about the climate of specific regions may be an important factor in migration decisions. Climate data may aid in appropriate planning for parks and greenbelts in urban areas. The development of alternative responses to aquifer depletion or desertification based on climatic data may provide the means to preserve traditional lifestyles or other cultural preferences.

Both the economic and noneconomic benefits of climate data discussed above require much further exploration. An important task will be to assess systematically these benefits for all sectors of the economy. This should be done using a comprehensive, clearly defined, and widely recognized classification scheme such as the Standard Industrial Classification System (Office of Management and Budget, 1972; Office of Federal Statistical Policy and Standards, 1977). The results will need to be translated into a form understandable to the public and to relevant economic and social decision makers throughout the nation. The climatological and meteorological communities, with the support of appropriate funding agencies, should take the lead in carrying out this critical task.

Even without such a comprehensive study, the fragmentary examples discussed above indicate that the benefits of climate data are large and diverse. Also, they are almost certainly growing, given the many ongoing technological and social changes that are affecting the utilization of climate data and demonstrated by the rapidly growing volume of requests for climate data. It is the panel's view that *clear understanding of the increasing value of climate data throughout the nation's economy should drive decision making regarding investments in and management of the national system for climate-related data.*

3
New Technological Promises

A great variety of new data-related technologies have been introduced in recent years, and even more are under development. These technologies promise tremendous improvements throughout the national data system, from data collection all the way to data dissemination and use. While it is certainly beyond the scope of this report to identify all new technologies and assess their advantages and disadvantages, it is useful to highlight some innovations, both recent and imminent, and briefly to discuss their potential implications for the national climate data system.

3.1 OBSERVING SYSTEMS

New technology has wrought dramatic improvements in weather and climate observation, data communication, and data processing in the past two decades, and even conservative forecasts anticipate more improvement in the near future. In particular, our capability to gather data, especially at remote sites, and to communicate these data to a processing center in a time frame useful for operations is expanding greatly. This is making more data available on a real-time basis (i.e., within minutes or hours of observations) for weather monitoring and forecasting. It is also rapidly increasing the quantity of data and information available on a near-real-time basis (i.e., within days or weeks) for a variety of applications. These developments have important implications for the climate data management system and promise great benefits in a wide variety of applications.

The most observable impact of technology on weather and climate data is the rapid growth in data volume. This growth is primarily due to new observing systems, especially remote sensing systems such as Doppler radar and satellite-based instruments. However, an important contribution to data volume is also the "processing" of data as part of the collection phase. For example, many new systems require large quantities of ancillary data (e.g., information on satellite positioning and instrument orientation) and sophisticated, data-intensive analyses of actual instrument "readouts." This aspect of data generation is likely to increase in importance in the future.

It is useful to look briefly at several categories of weather and climate observing systems, the recent impact of technology on them, and some implications for the future.

3.1.1 Conventional Data

The impact of technology on conventional data collection has centered mainly on the collection of routine observations from heretofore data-sparse areas. Unmanned observing stations can now operate at remote sites, usually with solar power, on-site digitization of the data, and sometimes even limited processing and housekeeping using a built-in microprocessor. Many stations of this kind have the ability to transmit data to a central facility either "on command" or on a regular schedule by telephone or radio transmitter. Others can store data for long periods for occasional retrieval.

Notably, the growth in volume of conventional data due to technology has not been large in comparison with other types of observing systems. The future appears to favor steady evolution of conventional data collection via federal networks. A potentially significant development in conventional data collection is the growth of state and regional networks that use automated stations and telecommunication systems to obtain data in real time. The expectation is that these networks will serve specialized needs and thus have a complementary rather than competitive relationship with conventional federal data.

3.1.2 Satellite Data

Satellites have opened up new opportunities for collecting weather and climate data in the past 25 years—and new vistas in data volumes. One GOES satellite generates some 20 gigabytes (i.e., 20×10^9 bytes) of data per day, more than 1000 times the 10 megabytes per day for the total of all conventional meteorological data collected in the field-of-view of that same GOES satellite. Other satellite systems, such as TIROS-N, N-ROSS, METEOSAT, and GMS also generate large quantities of data, making the total volume of satellite data even more overwhelming.

But volume does not necessarily reflect scientific significance. Satellite measurements are remote measurements, usually of electromagnetic radiation in selected portions of the electromagnetic spectrum. Much calibration, processing, and verification are needed to relate these measurements to conventional in-situ measurements and to make them "meaningful" to the general user. Careful analysis and judicious selection of data are required. One immediate problem is therefore what and how much satellite weather and climate data to collect and archive to preserve a climatologically significant record for analysis.

The volume of satellite data will certainly continue to increase, perhaps at an increasing pace. Technology is opening new areas of the electromagnetic spectrum, such as the microwave region, to remote sensing exploitation. Furthermore, present-day satellite sensing techniques are "passive," i.e., they rely on naturally emitted radiation. New satellite systems such as the Navy Remote Ocean Sensing System (N-ROSS) are opening the door to a whole new era of "active" remote sensing, involving laser- and radar-based instruments with even greater data volumes (e.g., Schnapf, 1985).

3.1.3 Radar Data

To date, most radar data are available only in the analog format and are archived as radar images. Thus, they are difficult to use in climatological analyses and of limited practical utility in climate applications. However, recent developments in digital radar systems suggest that quantitative measures of rainfall may be possible.

In the next decade, NEXRAD will add huge volumes of digital data to our inventories. Basic decisions about archiving and use of these data will need to be made. As with any technology awaiting introduction into the operational arena, we can expect significant advances in understanding and applying specialized radar data to weather and climate problems (e.g., National Research Council, 1985).

3.1.4 Other Data

This category encompasses atmospheric wind profilers, laser-based systems, pollution monitoring systems, and other systems not specifically mentioned above. Atmospheric wind profilers, which utilize Doppler radars to measure atmospheric motion in the troposphere and stratosphere (Balsley and Gage, 1982), are likely to move into the operational environment in the next few years, if the current demonstration network proves successful. Ground- and aircraft-based lidar systems have recently been used to investigate the transport and diffusion of pollutants and water vapor in the troposphere (Uthe et al., 1985; Melfi and Whiteman, 1985). Systems of this kind not only provide new types of data on atmospheric parameters but also much greater spatial and temporal resolution than conventional instrumentation such as radiosondes. Future technological advances promise more types of observing systems in the future, many of them based on remote sensing methods.

An area of technology that has already contributed significantly to observing-system improvements is microprocessor technology. To date, improvements have largely been in data communications (as discussed in the next section) and in the versatility of the data collection system. Many systems now provide for automatic scaling, limit checking, modification of the data collection scheme with changes in the data, and so forth. In the future, it should be possible to convert data into information at the point of collection. This is already being done to some extent in the satellite field as on-board processing. However, much more could be done. This is perhaps the most exciting area of improvement offered by technology.

3.2 COMMUNICATIONS

Communications has always been, and probably will always be, the lifeblood of operational meteorology. There is probably no more eloquent demonstration of this fact than to cite the NWS's origins in the Army Signal Corps. While the same has not been true in the past for climatologists, the rapidly blurring distinction between weather and climate discussed in this report is also rapidly obviating the climatologist's need to accomplish his or her mission with "old" data.

The same technology that holds such promise for improving observing systems, namely the microprocessor, also holds great promise for communication systems. There has already been a great shift in communications from the analog to the digital domain, especially since much data digitization can now be performed at the collection site. Digital communications in combination with powerful microprocessors create the capability for essentially error-free data transmission through error detection and correction techniques. Thus, data bases constructed on-line can now be free of transmission errors, traditionally a major source of error.

New communication technologies also give relatively cheap and fairly high-speed access to data bases. For example, modems now available for under $2,000 provide auto-dial, auto-answer capability with full error detection and correction at speeds up to 10,000 bits per second over a switched network (dial-up telephone links). Capabilities such as these eliminate the need for dedicated and expensive communication links. Real-time access to data is essentially available to all those who need it.

Another area of technological development in data communications is in the collection of data from remote or inaccessible areas. This has been made possible through the improved capabilities and decreasing costs of transmitting and receiving equipment, microprocessors, solar cells, satellite links, and so forth. Remote data collection platforms have become compact, reliable, long-lived, and inexpensive. Such platforms are helping climatologists, meteorologists, hydrologists, oceanographers, and others fill major gaps in data coverage.

Technological progress in data communications encompasses software as well as hardware improvements. This area is often neglected in planning for new systems, but is often the most critical to their success. In many instances, total software development costs may exceed hardware costs by an order of magnitude. In the communications area, software is crucial because it permits communication between different systems and between equipment manufactured by different vendors. At present, limitations in software are a major obstacle to large-scale networking and error-free communications. At a minimum, a range of communications standards and protocols will be required for different types of communications. This issue is now beginning to receive attention, so that some alleviation if not resolution of problems may be expected in the future.

3.3 DATA PROCESSING

Some of the most startling technological advances have been made in the area of data processing. In the past several decades, computer processing power as measured by the number of instructions that can be handled per second has increased by some four orders of magnitude. Data handling and transfer rates have also improved significantly. At the same time, costs have dramatically decreased, so that today's microcomputer priced at only a few thousand dollars possesses computational abilities comparable to those available from the multi-million-dollar machines of the 1950s.

Still, present-day minicomputers and mainframes, as well as most existing "supercomputers," are essentially serial processors. The computer's central processing unit (CPU) obtains its instructions and data from its memory step-by-step, pausing after each step or calculation to send the results back to memory. All of this happens at what a human would consider blinding speed, but the frequent delays as the CPU waits for data to come and go are long to a system that measures time in billionths of a second.

The next generation of superfast computers will probably be available in the early 1990s. In this new technology, already employed in some applications, operations will occur in parallel rather than serially. Many small processors will work on varied tasks simultaneously, constantly communicating with each other. This should lead to enhanced supercomputing capability at a price from 10 to 30 percent of the cost of current supercomputers. Concurrent processing architecture should also find its way into microcomputers in the 1990s, greatly increasing their computational power and ability to access large data sets.

Another area of promise is in more efficient systems for data handling. This involves improved software, more integrated operating systems, more user-friendly software, greatly improved data base management systems, and possibly specialized data base computers. Telecommunication and local area networks are also improving, allowing easier access to data sets from remote locations and rapid transmission of large amounts of data. All of these are now in differing stages of development.

Data software and systems will be further enhanced through the use of intelligent systems and artificial intelligence (AI) techniques. These techniques attempt to put more decision-making capability into computer software and hardware in order to reduce the burden that human experts must now bear. The greatest near-term potential will probably be in the area of automatic, real-time data quality control. Combined with new data management methods, AI techniques should provide a potent means for enhancing data quality while reducing data handling costs. However, such techniques performed in real time should never replace careful checking and repair of data sets for quality and completeness in delayed time.

Almost all of these technological advances are pushing down the unit costs of processing data. Planning for the next generation or two of systems should consider these falling costs.

3.4 DATA ARCHIVING

Several different types of media are currently being used to archive data. These include paper records, microfiche, magnetic tape, and magnetic disk. The problems of paper are obvious: volume, cost, vulnerability, and so on. Microfiche is proliferating and is easier to use, but one must create, store, retrieve, and access it. Its primary disadvantages are that it is not computer compatible, and it is often hard to read.

Magnetic tapes are the basic archival methodology for digital data today, but they present an ever-increasing problem. The data densities and storage capacity they can provide are becoming increasingly limited relative to the tremendous quantities of data generated by satellites and other instruments. They are difficult to handle and store and require careful environmental control. Each time a tape is used it must be picked up from its storage bin, moved to a computer, loaded, accessed, unloaded, and put back. Processing very large data sets often requires that data be pulled off a variety of tapes. This is inconvenient and costly. Also, tapes lose data in time if they are not periodically rewritten.

Finally, the magnetic disk is beginning to approach its physical limit in data storage capacity although higher capacity equipment continues to be developed. It will certainly continue as a key method for staging and processing data in a dynamic mode, but it is not the right medium for archiving data.

Several emerging technologies offer improved archiving capabilities at lower costs. New high-capacity magnetic disks are beginning to come on the market. Unfortunately these are still not adequate for most archival purposes. Also available are small, high-capacity tape cartridges. These are an improvement on the current tape situation but still present difficulties in finding and accessing sequential data.

The mass storage system that appears to hold the most promise in the long term, particularly for climate and weather data, is based on laser "optical disk" technology. In this system, a laser beam driven by digital input essentially burns a hole or raises a bump on the surface of a disk. The presence or absence of a hole or bump can be read by a low-powered laser beam as a binary bit. The data can be written only once but read many times. This superficially simple concept offers a data density 10 times that of current magnetic disk technology. It is eventually expected to yield densities 100 times that of magnetic disks.

Optical disks come in a variety of sizes. A 5-1/4-inch disk available today stores 100 to 500 megabytes of data. A 12-inch disk may hold 1 gigabyte (1000 megabytes) of data per side or a total of 2 gigabytes of data. Future 14-inch disks are expected to hold up to 4 gigabytes of data per side or 8 gigabytes of data per disk.

Optical disks and disk drives are now available for single-unit drives for both mainframe and microcomputers. Their costs are dropping rapidly. A drive is now available for under $1,000 wholesale that can fit into a standard microcomputer disk drive slot.

Optical disks have also been collected in a "juke-box"-like unit in which 64 to 150 of these platters can be kept on-line. One unit now available can keep some 100 disks on-line, a total of 200 gigabytes of data. Another that is under development (probably available in 1987) will provide approximately 150, 14-inch disks on-line for a total of 1.2 terabytes (1200 gigabytes) of data. More of these devices will likely be available in the near future. Today, a 200-gigabyte juke box can be purchased for $95,000 to $125,000. Compared with previous systems, these systems provide an extremely low per character cost—on the level of the cost of paper storage. They also promise substantial savings in archiving the massive volumes of data generated by satellites. It should be noted, however, that present optical disk costs are still higher than those for some magnetic media, and that the costs of most media are likely to drop significantly in the future.

A major advantage of optical disk storage is the degree of data permanence that it provides. Current estimates are that data on an optical disk can be guaranteed for 10 years, and much longer lifetimes are possible. The environmental control needed for this storage medium is minimal. The disk surface is protected by a plastic coating, so that disks may be stored in a cabinet without special racks or constant temperature and humidity. Research is ongoing to develop erasable optical disks, that is, disks on which data can be written, erased, and then replaced. It is not clear whether this will even be possible or practical, so it is unlikely that such technology would be available before the early 1990s.

Happily, the future user community for this mass storage method has already begun to plan for its utilization. A number of committees have been established to develop standards for hardware, software, and interfaces. Also, several scientific and commercial organizations have begun to develop methodology for indexing, cataloging, and updating data on optical disks.

Other archival technologies are also emerging. For example, a standard 5-1/4-inch laser CD-ROM (compact disk, read-only memory) disk can now be used to record 550 megabytes of data. We will also see an increasing use of microfilm graphics, stored in digital form, that can be called up from archival devices. This will permit more ready access to either digital data or associated graphics at low cost and high speeds.

3.5 DISSEMINATION

Historically, climate data were communicated in published form. Processing, transcribing, and quality control of climate data were slow and tedious. Data files were small, and the capacity to deal with large volumes of data in real time did not exist.

Climate data publications continue to be an indispensable tool for the great majority of end users. Publications provide rapid and versatile access to a wide variety of data at low cost. They generally provide important supplementary information on data sources, data quality, and data use and help prevent repetitious extraction from source documents. Continued distribution of key publications to individuals, businesses, libraries, and others is critical and can indeed greatly enhance the utility of data disseminated by other means.

With the arrival of electronic media, user requirements have changed, and the volumes of data requested have grown rapidly. Computers arrived concurrently with and contributed to a "knowledge explosion" that has both created a greatly expanded demand for climate data and made their supply necessary and possible. They not only facilitate publication but also provide new opportunities in the storage, handling, and processing of climate data by the user.

Civilian users currently obtain climate-related data from a variety of service outlets. These include:

1. *National*—NCDC, CAC, CEAS, and NCAR.
2. *Regional*—Regional climate centers serving the mutual interests of a group of states.
3. *State*—Climate services dedicated to state interests operated by the state climatologist or state agencies.
4. *Local*—NWS local offices, private companies, libraries, and so on.

The current proliferation of microcomputers and personal computers in the home and office combined with the ongoing modernization of communication networks is rapidly increasing opportunities for direct on-line interaction with data. One example of this is "videotex," a generic term for interactive services in the home via computer or television set. Such services are likely to include access to certain climate and weather data, depending on demand.

Another area of interest is the effort to incorporate "natural" or conversational language into the interface between users and data base systems. This would permit the lay person to access data and information without having to learn a great deal of computer jargon. Similarly, development is under way of a common "front end" for heterogeneous data bases. Since many data bases are not compatible with each other, a high-level data base management system could be used as a common entry point to diverse data sets. Essentially, such a system would provide access to a data set regardless of its structure.

The CD-ROM technologies will potentially permit dissemination of large quantities of data at extremely low cost. CD-ROM disks are approximately 3-1/2 to 5-1/2 inches in diameter and can store as much as 352 to 500 million digital characters. The user cannot write on these disks. They do not need a great deal of care and can be utilized continuously. The cost per disk should be on the order of $10 once master copies have been produced. Disk readers, which interface with personal computers, may drop to less than $200 each.

Innovation is also occurring in the dissemination of weather warnings and other information via computer networks and electronic mail. Many such networks have been developed by private sector groups who provide value-added information services. Competition in the marketplace has engendered numerous innovative graphical and textual products at rapidly decreasing costs per unit of information. These products are reaching an increasing number of users in a variety of economic sectors.

Many of these new dissemination channels take advantage of improved methods for "packaging" information. For example, sophisticated graphics packages have been developed for displaying weather and climate data in three dimensions, in multiple colors, and in combination with photographs, maps, or animation. Speech synthesizers are already in common use in telephone-based applications. Many of these capabilities have been transferred to microcomputers, so that users can themselves control data presentation to suit their own needs.

3.6 UTILIZATION

Traditional users of climate data were concerned primarily with the historical perspective, i.e., using the historical record to predict levels of future risk or simply to delineate the nature of climate parameters that identify average resource potentials. Data in the form of tables, diagrams, and maps were usually desired. Mean values, and perhaps maxima and minima, were the primary concern.

Most end users still have these interests, but there have been major changes in demand particularly for research, resource and environmental management, and risk assessment. End users now expect more from their data and are becoming more sophisticated in their use. Although most requests are still for hard copies of data, a rapidly growing number of users request data in electronic form. More users recognize the variability of climate and therefore desire data on frequencies, extremes, and other aspects of variability. Many utilize sophisticated models and algorithms to convert available data into usable information. Innovative uses in nontraditional areas such as construction, recreation and tourism, transportation, and urban planning are expanding data needs to new parameters, new locations, and unusual spatial and temporal scales.

Demand is also growing for current as well as comparative historic data for more locations and parameters. For example, the North Central Regional Climate Center supplements data received from NOAA's AFOS system with data from state and other sources. The combined data set provides more precise interpretation of the climate at the county level, greatly assisting local industry and others. Activities of this type necessitate a change from the traditional sequencing of data processing and quality control practices. They take advantage of "fast" transfer functions, computer models, and "real-time" data processing capabilities. Ongoing technological developments in microcomputer hardware and software will almost certainly enhance these capabilities further and make them even more economical.

Decision makers are also increasing their use of computers and computer-based models. Their demands are usually for site-specific data, estimates of risk, and packaged information. They frequently require spatial and temporal detail that is not found in national archives but must be estimated by interpolation or extrapolation. Typical of these demands are those for construction, environmental assessment, and facility siting on land and offshore. Time scales range from short for operations to long for strategic planning. Public sector requirements often consider larger spatial scales. These requirements often depend on the initiatives or concerns of government and the community at a specific time. Definition of this diverse need and development of the capacity to respond require consultation with the suppliers and users—government, research, and private—on a continuing basis.

One example of the innovative and highly successful use of climate data is the University of Nebraska's Automated Weather Data Network. In early 1985, this network consisted of 43 stations that are automatically interrogated daily. Most stations are in Nebraska with some in Kansas, South Dakota, and adjacent states. The system provides data to AGNET, a computer system that provides farmers with information and applications relating to crop and livestock production and marketing. The climate data were accessed more than 15,000 times in 1984 for use in problems such as irrigation scheduling and crop development assessment. This demonstrates the utility of data systems tuned to end user requirements. Similar facilities could be used advantageously by other end users in a number of areas and sectors.

3.7 SYSTEM ARCHITECTURE

A critical but often overlooked area of technological progress is in designing advanced system architecture. Such architecture may encompass:

1. Virtual elimination of manual data entry and transfer.
2. Rapid assimilation of real-time data for use with historic and near-real-time data.
3. Improved quality control in both real- and delayed-time mode.
4. Better feedback between different data functions.
5. Closer monitoring of facility usage and costs.
6. Greater simplicity and consistency in user access and interface.
7. Flexible data transfer and interchange with other systems.

For example, it is now possible to conceive of a system where data are managed from collection to use entirely in digital form, thereby reducing time delays and transcription and transmission errors to a minimum. Experts and end users would have access to the methods used at any particular stage of data processing. They could rapidly compare and combine current data with long-term climatic statistics or with data on the recent past. They could also easily transfer data and information between different users of the system and to or from the system in any of a variety of formats and media. The end user or facility manager would know what costs were being incurred on a real-time basis. A simple, consistent user interface would reduce the investment necessary for a potential user to take advantage of the system.

Elements of such integration are now emerging in present and planned systems. For instance, extremely fast, high-volume data transfers are now possible between many computers using ground and satellite communication networks. Networking of microcomputers and mainframes of different manufacture is increasingly commonplace. Optical scanners, inexpensive digitizers, touch-sensitive screens, and speech synthesizers and interpreters are among the many new input-output devices now becoming available. A recent innovation has been the development of software "emulators" that simulate the operation of one type of computer on another. These permit greater "device independence" for many applications and facilitate intercomputer compatibility. There have also been increasing calls for the development of user interface standards that would increase the consistency of computer use across different applications. This would also have the potentially beneficial effect of providing guidance to hardware developers regarding optimum hardware configurations to meet user needs. Many of the innovations have been or are being incorporated into meteorological and climatological data systems such as NOAA's Automation of Field Operations and Services (AFOS) System, its planned Advanced Interactive Processing System for the 1990s (AWIPS-90), and the UNIDATA program being implemented by the University Corporation for Atmospheric Research (UCAR).

4
Problems Stemming from Change

The technological advancements described in the previous chapter have the potential to revolutionize meteorology and climatology. Tremendous volumes of data are flooding in. Improved quality and timeliness of conventional data greatly increase their utility and versatility. New types of data are opening up new areas of application, new opportunities for economic and social benefit ranging from reduced losses due to climatic extremes to increased utilization of the nation's valuable climatic resources.

The critical task ahead will be to manage the introduction of these new technologies into the existing data system in a manner that:

1. Preserves the basic integrity and continuity of the data.
2. Maintains and improves the system's overall efficiency and effectiveness.
3. Permits flexibility in and balanced evolution of system components.
4. Enhances the system's accessibility and ease-of-use.

None of the above are trivial concerns given the limitations of the existing data system and the magnitude and speed of technological changes currently under way. For example, new data collection systems could easily overload existing communications and archival facilities if proper planning and coordination were lacking. Subtle incompatibilities between systems could be very expensive to remedy. The rapid rates at which equipment and software often become obsolete could have a severe impact on system maintenance, flexibility, and integration. The rapid introduction of technologies increases the range of technologies—primitive to advanced—that must "coexist." Difficulties at any point in the system could seriously compromise data quality, completeness, and timeliness, and therefore the eventual utility and value of the data to users.

These dangers are symptomatic of three major problem areas identified by the panel. First, the explosive growth in the quantity and diversity of weather and climate data may be straining the capabilities of the present national data system, with potentially serious consequences for its overall effectiveness and integrity. Second, the arbitrary separation between "weather" and "climate" activities within the federal government appears to be imposing an increasing handicap on the efficient management and use of data. Third, the lack of clear and consistent policies regarding federal roles and responsibilities in the operation and maintenance of the national weather and climate data system and in the provision of related services create an uncertain environment that hinders the development of new data applications in both the public and private sectors. These three problem areas are discussed in more detail in the following sections.

4.1 GROWTH IN DATA DIVERSITY AND VOLUME

As described in the previous chapter, new satellites, radars, and other observing systems are rapidly coming on-line and will undoubtedly increase the volume of climate data by an order of magnitude or more. New types of sensors and new data processing techniques also increase the diversity of climate data and the variety of supplementary data needed (e.g., regarding instrument type and operating procedures and conditions). Growing demands for real-time monitoring and assessment of climatic conditions combined with the decreasing costs and increasing sophistication of automated observing stations are leading to more frequent observations of more parameters in more locations.

Unfortunately, there appears to be a continuing gap between data "creation" and data "maintenance" technologies in many key areas. That is, our ability to generate new data and derived information has tended to outstrip our ability to store and access data safely and efficiently. Whether new technologies such as the optical disk described in the previous chapter can close this gap is uncertain. Careful planning is certainly necessary to prevent major data losses and ensure that adequate storage and access facilities are available.

Where the inability to accommodate rapid growth is perhaps most serious, however, is in the dissemination and use of data. No matter how sophisticated the instrumentation and processing, data are of little value if potential end users are not aware of them or do not have the capability to deal with them. Even today, relatively few users have access to the large computers, specialized equipment, and technical expertise needed to download and process large quantities of satellite information. This processing must be taken into account in the original planning for data systems, if data are to be made available at reasonable cost and in usable forms. Likewise, early consideration must be given to data base management and dissemination systems to ensure fair and reasonable access to data.

Indeed, the diversity of data and data sources is now so great that users cannot in general be expected to find the data they need on their own. This is especially true for activities in which end users are highly disaggregated and have relatively little technical training, e.g., in agriculture or construction. Active assistance, ranging from computerized data bases, catalogs, and directories to targeted outreach programs, is critical.

A related difficulty is that personnel who understand the requirements of the expanding "information" environment and the associated new technologies and their application are scarce. In general, management itself does not really understand the problem and how to address it. Moreover, the institutions, laboratories, and government agencies who deal with data and information in most cases do not have the ability to respond to any but the most basic queries nor the resources to acquire the latest data processing and archiving technologies.

Another serious aspect of the growth in data volume and diversity is the potential for damage to the continuity and integrity of existing observational networks. Despite the most careful advanced planning, unexpected problems such as budgetary cutbacks, equipment failures, cost overruns, and personnel cuts force difficult tradeoffs between new and existing systems. Too often, it is the less glamorous—but no less valuable—existing systems that suffer. For example, in recent years, the Cooperative Observers Network, the Solar Radiation Network, and the Reference Climatological Station (RCS) Program have suffered from inadequate attention and resources. (This issue is discussed in more detail in Section 5.5.)

There is of course no panacea for problems caused by rapid growth. Nevertheless, effective preventive and ameliorative actions are possible. Sensible planning, conscientious management, and firm leadership will be needed to find and implement such actions in a timely and equitable manner.

4.2 SEPARATION OF WEATHER AND CLIMATE DATA MANAGEMENT

Recent technological advances have highlighted the growing problems stemming from the separation between "weather" and "climate" data functions within the federal government. This separation was formalized when NOAA's predecessor, the Environmental Science and Services Administration (ESSA), was established in the mid-1960s. Responsibility for observational networks was retained by one line component, the National Weather Service, while responsibility for "nonweather" data processing and archiving was given to another line component, the Environmental Data and Information Service (now a part of NESDIS). In recent years, the separation of management has led to unbalanced allocations of resources between closely related functions, inefficient and inadequate integration of data activities, and, in some instances, inflexibility in meeting important climatological objectives.

Examples abound. In the 1960s, many climatological stations were moved from urban locations to more rural airports to satisfy expanding aviation needs. Little consideration was given to long-term climatological requirements. In the 1970s, the federal government ended federal support of the State Climatologist Program. Only recently have state-supported state climatologists regained their former levels of activity as an important channel for data dissemination in a number of states.

A more recent example illustrates the type of problem that can occur with present administrative arrangements. For many years, temperature measurements have been taken with a standard mercury or alcohol thermometer in a wooden shelter. Maintaining these thermometers and shelters is becoming very expensive. New electronic sensors embedded in molded-plastic housings are now available that could be installed and maintained at a much lower cost. The NWS has been developing and testing sensors of this kind for a number of years.

The new sensors are well suited to both weather and climate needs. Weather needs can be met with a sensor that provides the current temperature and the 24-hour maximum and minimum values. Most climate needs can also be met with these observations. However, the ideal climate observation is for all sensors to report the maximum and minimum values for the same 24-hour period. At present, this is not the case, because most observers in the cooperative network are unpaid volunteers who record observations at a variety of times throughout the day and night. The development of a new sensor afforded the opportunity to move all observations to a common local time. It was only necessary to incorporate an inexpensive electronic clock into the sensor so that values could be recorded at a standard time for later reading by an observer. Unfortunately, this simple climatic requirement was not met in the design of the sensors that are now being installed. A unique opportunity to improve the utility of climate data was missed, and the problem of nonuniform observing times for temperature remains.

Problems also exist in the current arrangements for data quality control. As noted in Chapter 2, data from synoptic stations and cooperative observers are sent in paper form to NCDC to be archived. At NCDC, the data are thoroughly checked for errors using both machine algorithms and human examination. Likely errors are flagged, and a list of these is typically sent—at a much later date—to the NWS regional office responsible for the observations.

Notably, there is no established coordination mechanism by which NCDC can ensure that sources of error are identified and corrected. Management of the cooperative observers in a region is typically only one of several responsibilities held by a NWS employee. The time and travel funds available for visiting cooperative sites and for checking on possible problems are usually very limited. Many NWS offices find it difficult to maintain even their own observing stations in proper working order and in relatively undisturbed surroundings. This is especially true for the many NWS offices located at airports, where expansion of both jet aircraft and automobile traffic over time can compromise measurements.

Similar difficulties are often encountered in research because of the variety of data sources, incompleteness of many records, uncertainty as to the nature and quality of data, and the diversity of parameters, measurement, and derivation procedures employed. Gridded data sets produced as byproducts of operational numerical weather prediction, or specially processed for research from more complete sets of basic observations, are particularly valuable in climate system research and long-range forecasting. They require special care in documentation and quality control. A particular problem is that quality control procedures used operationally can degrade the quality of data for research and other purposes. The research community usually has little say in what quality procedures are employed since they are an operational matter. The data management system must allow for appropriate consultation with the research community and other major end users in developing, implementing, and altering quality control procedures.

Other problems relate to the end user's access to data. In general, the public does not understand the distinction between weather and climate data. After an unusual weather event or during an extreme climatic episode, NWS offices are typically flooded with requests for information about past occurrences and records. Such requests can take up large amounts of forecasters' valuable time. Also, NWS personnel do not usually have access to the full range of climatic data that may be relevant, nor do they necessarily have appropriate climatological training vis-a-vis the use and value of climate data.

Even sophisticated end users find the existence of multiple contact points in NOAA confusing and frustrating. For example, it may take only a few moments of computer access to obtain up-to-date data from the CAC but weeks or months to get comparable historical data from the NCDC. In fact, NCDC has only recently been able to access the AFOS System used in every NWS Weather Forecast Service Office to manipulate data in real time for forecast purposes. Similarly, the AFOS system is not designed and operated to accommodate the diverse, high-volume, real-time interests of the academic community. Indeed, the costs associated with obtaining some data have acted as a deterrent to research. Recognizing this problem, UCAR has recently initiated a program called UNIDATA, designed to overcome this interface problem. UNIDATA has two objectives: (1) to enhance the university community's ability to use new technologies and (2) to achieve substantial savings through commonality of interface, facilities, and facility operation. Efforts such as this must overcome substantial obstacles in designing a system that is sufficiently powerful and economical yet flexible enough to accommodate a wide range of often incompatible inputs.

Such problems are particularly distressing in light of rapidly changing technologies and end user needs. As noted previously, new communications and data processing technologies have created many opportunities to improve quality control, data availability, and data access in the present national data system. Careful integration of system architecture and considerable managerial flexibility will certainly be necessary to take advantage of these opportunities. Unfortunately, because of the present separation of weather and climate data management, such integration and flexibility will be difficult to achieve. Strong actions by management may well be necessary to remedy this basic problem.

4.3 UNCERTAINTY IN FEDERAL ROLES AND RESPONSIBILITIES

The federal government plays a central role in the management of the national climate data system and in the provision of related services. Other public and private sector groups depend greatly on the vast resources and unique capabilities that it manages for the public good.

Unfortunately, there are several key areas in which the federal government has failed to articulate clear and consistent policies regarding its roles and responsibilities. These areas include:

1. The support of basic federal data services.
2. The provision of specialized data services.
3. Data accessibility and cost recovery.

In all of these areas, overlapping federal agency missions and changing federal priorities have contributed to confusion and uncertainty. This has hampered the use of climate data in both the public and private sectors throughout the nation.

In the area of basic federal data services, there appears to be little coordination and long-range planning to respond to changing technologies and needs. Currently, data are processed and stored in a variety of forms and formats, in a number of locations, and by different groups. Compatibility is often limited. Although much progress has been made by NOAA and others in developing data directories, there is still no comprehensive source of information as to what data are where and in what form. Data are obtained from a variety of sources with little coordination. Questions of data quality often arise. The acquisition, implementation, and improvement of electronic communications systems and computer hardware and software appear to occur in a piecemeal and poorly coordinated fashion. For example, NCDC utilizes computer equipment from many different manufacturers that have been worked into a system with great effort and cost. This unplanned mixture is less efficient, more costly, and possibly less reliable than if it had been planned systematically. Moreover, there appears to be no carefully designed plan for improvement of the situation.

The provision of specialized data services is another serious concern. The federal government may well be justified in providing certain specialized services that serve critical public safety, national defense, or other public interests. However, it has often reserved the option to begin new services or end existing services in other areas such as agricultural warnings and climate forecasting where its responsibilities are less well defined. The key issue is not whether the government should provide these services, but that the initiation or termination of a service disrupts the plans and activities of other public and private sector groups. Such disruption has occurred with the State Climatology Program, the Solar Radiation Network, and frost warning services. Clearer definitions of long-term federal roles and responsibilities need to be developed in collaboration with other public and private sector contributors to and end users of the national climate data system.

The last area of concern pertains to data accessibility and cost recovery. The value of climate data often depends to a large degree on its rapid application immediately after identification of a problem. Rapid and certain access at a fair price is therefore critical. Pricing is of particular concern given the extent to which public funds and volunteer observers are used in the national data system. Moreover, data and information are unusual commodities that may require special consideration. For example, government-wide prepayment requirements were recently instituted at NCDC despite its very low nonpayment rate. These requirements appear to have increased the average customer service time significantly. Such unnecessary delays can severely reduce the value of the NCDC data and, among other things, lead to reduced NCDC usage and therefore lower levels of cost recovery.

All of these problems make the development of timely and effective services in both the public and private sectors difficult at best. Indeed, a major consequence may have been to increase the uneven development of climate data bases and other services across the nation. This is particularly evident in states where state governments have taken strong leadership roles in defining state involvement in climate data activities. While innovation and diversity in state and regional climate activities are clearly desirable, large extremes in development could increase problems of incompatibility, redundancy, and inadequate quality control in data generation, dissemination, and use. Coordinated planning led by the federal government and involving local, state, and regional interests in both the public and private sector is certainly necessary.

5
Institutional Concerns and Opportunities

The opportunities and problems identified in the previous two chapters pose a significant challenge to institutions currently involved in climate data management. These institutions have the responsibility to respond to rapidly evolving technology and changing user needs with leadership and sensible planning. The latter will require careful review of institutional roles and responsibilities regarding such issues as state and private sector participation in the national data system, support of the international data system, maintenance of key networks and data bases, and improvement of dissemination and end user services. To provide a starting point, a number of these institutional concerns are discussed in detail in this chapter.

5.1 STATE AND FEDERAL ROLES

Both state and federal governments reap direct and indirect benefits from the use of climate data. Direct benefits accrue from improved efficiency and better planning in government operations and programs and from reduced losses of life and public property due to adverse climatic conditions. This is amply demonstrated by the extensive use of climate-related data by state and federal agencies involved in managing water supplies, public lands, roads, air quality, and other public resources. Likewise, indirect benefits originate with greater efficiency and reduced losses in the private sector, leading to more employment, more tax revenues, and lower government compensation payments (e.g., for business losses, workmen's compensation, and unemployment insurance).

It is thus clear that both federal and state governments have important stakes in ensuring that climate data are available and are utilized within their jurisdictions. Where their concerns overlap, as in water management, public safety, and disaster preparedness, coordinated activities in data collection, management, and dissemination are certainly necessary. Cooperation in other application areas is also clearly warranted in the interest of efficiency and responsiveness to user needs. Indeed, cooperative climate programs were specifically mandated by the National Climate Policy Act and have been given high priority by advisory groups (e.g., Board on Atmospheric Sciences and Climate, 1983; Climate Board, 1982). Unfortunately, their implementation to date has been very limited.

Specific state and federal roles and responsibilities for climate data have developed over time and are in many cases specified by legislation. It is important to clarify these roles to ensure rational development of climate data management throughout the nation. In the panel's view, specific responsibilities include:

Federal	State
• Establishment of minimum standards for observations	• Adherence to minimum standards for observations
• Operation of basic national observational networks	• Operation of additional networks as needed at the state level
• Operation of a national data communications system	• Use of the national data communications system
• Maintenance of a national archive	• Maintenance of a state-level archive
• Coordination with states	• Coordination with the federal government and adjacent states
• Dissemination of data and information	• Dissemination of data and information

The federal government's responsibilities are greater than those of states because of its national mandate. Indeed, state responsibilities are to a large degree optional, since they depend on a state's sensitivity to climate and its willingness to cooperate.

Clarification of these responsibilities in terms of specific commitments and activities is needed to assist other elements of the national data system in making decisions about their own levels of activity. For example, federal decisions about access to data in the national communications network and in the national archives will affect the efficacy of regional climate centers that involve neighboring states. The degree to which the federal government provides tailored climatological information to specific industrial sectors will influence private sector decisions about capital investment and activity levels. It must be emphasized here that the key issue is not the specific responsibilities that state and federal governments do or do not assume; rather, it is the clear definition of state and federal roles in the national climate data system to enable other contributors to and users of the system to assess the opportunities and constraints that will exist in the future.

5.2 REGIONAL CLIMATE CENTERS

For several years, NCPO has encouraged and provided partial funding support for regional climate centers in the north central and northeast states. The rationale for these centers is found in the NCP Act, which identified "mechanisms for intergovernmental climate-related studies and services . . ." as a program element (Section 5.d.4), and authorized the Secretary (of Commerce) "to make annual grants to any State *or group of States* [emphasis added] . . . to conduct climate-related studies or provide climate-related services" (Section 6.a).

The main recommendation in the report of the Climate Board (1982), *Meeting the Challenge of Climate*, was that NCPO "take a leadership role in the development of a coordinated, nationwide system of climate services involving both the public and private sectors through collaboration with existing state and regional climate programs and by encouraging the further development of such programs."

The National Climate Program Office's approach has been innovative. Instead of forming regional climate centers in the usual manner, i.e., as a federally initiated, planned, and funded association with states, NCPO encouraged states to take the lead in initiating and planning regional centers and to share in total funding. This approach to forming a partnership with states to conduct regional climate studies and provide services has been handicapped by lack of strong federal funding but has been energized by state initiatives in, for example, identifying regional needs not previously met, and adopting new technology to collect and disseminate data in a timely and economical manner.

The regional centers approach, while a promising mechanism for applied climate studies and services, suffers from uncertainties at both the federal and state levels. At the federal level it remains to be determined how regional centers can help federal agencies carry out their responsibilities. At the state level, problems range from operational matters (where to locate the center and decisions about committing resources out of state) to different perceptions of the need for climate services. These problems notwithstanding, encouraging progress has been made in demonstrating the feasibility of such centers in a nationwide system.

5.3 UTILIZATION OF THE PRIVATE SECTOR

In the past several years, a new industry has developed 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 by a number of innovative communications technologies. The sources of the data are primarily the NMC's "family of services," the CAC's user port (Finger et al., 1985), and the Global Telecommunications System (GTS) of the WMO.

The private sector now participates in the weather/climate "network" in three major functional categories: data collection, value-added processing, and dissemination.

5.3.1 Data Collection

Although the vast majority of climate data are routinely collected as operational weather data by international governments or by the cooperative climate observers, there are a number of data sets with potential value as climate data that are collected by the private sector. For example, power plants and industrial plants (e.g., smelters) often collect wind and stability data in response to the Clean Air Act and lightning-strike data to protect against damage from electrical storms. Many offshore oil platforms have fairly long records of wind and weather in worldwide coastal regimes ranging from the South China Sea to the Arctic Circle. Maritime weather forecasting firms have collected many years of special reports from ships at sea. The latter data are often from relatively remote locations and usually do not find their way onto the WMO GTS circuits. Normally, the private sector collects these data in direct response to an economic need and may consider the data proprietary. Nevertheless, these special limited data sets do represent a potential resource of new climate-related data. To make available this resource would require efforts to locate these data and resolve various policy and legal questions. There are also serious issues regarding data quality that would need to be resolved.

5.3.2 Value-Added Processing

The role of the private sector is much more important in the value-added processing of climate-related data. As noted above, the private weather and climate information services industry continues to grow. A primary stimulus has been competition in the market that has forced the various vendors to listen to customer demand and to develop a wide assortment of value-added products and services. These are based primarily on standard NOAA products available via teletype, facsimile, and data link from NWS and NESDIS.

The addition of economic value is the result of additional quality checks, reformatting of coded data into plain text, generation of clever graphics and maps (e.g., weather satellite images with radar overlays), summarization of data in convenient statistical forms, the provision of combination products (e.g., weather data combined with crop estimates), and the operation of specialized models (e.g., for air pollution and statistical forecasts).

Most such products reflect customer demand for current "weather" products. However, private sector users and vendors now have the computer capabilities to generate specialized climatologies that meet their economic needs. Other climatological products such as those provided by NOAA's CAC and NCDC are also available to the private sector for further value-added processing and distribution to their clients. It is interesting to note that a growing number of users of private data services may be found within the federal government (e.g., the Federal Aviation Administration, the Department of the Interior, and the Department of Defense) because the private sector can often react more rapidly than NWS to requirements for tailored products at an attractive price.

It is unlikely that private vendors would provide generalized archival services like those of NCDC without a well-defined customer base. Nevertheless, the private sector does have that capability. In general, however, economic realities dictate that the private sector react primarily to specific customer demands for tailored services.

5.3.3 Dissemination

Dissemination is a principal area of growth in the private sector. Vendors of climate information and services can reach a broad customer base rapidly and directly by a variety of communications options such as terminals, microcomputers, facsimile machines, telephone (e.g., synthesized voice), low-cost satellite links, and the commercial media. Furthermore, there are many private consultants who perform important climate-related information services by using data from various (usually state and federal) sources and solving specific problems for their clients. These services include a substantial number of applied research contracts for governmental as well as private customers.

A number of private firms also provide climate "forecasts" for periods of a month or more in advance. Some of these forecasts are based on proprietary models, while others utilize the outlooks produced by the CAC to solve specific problems raised by customers.

It is fairly certain that the majority of sales come from supplying current "weather" information. However, the capability exists to provide much greater levels of climate-related data and information services. The further development of these services will require significant investment, better educated users, and possibly a significant increase in the skill of climate forecasts.

In summary, the private sector is currently very active in providing information services for weather and climate applications. The industry has developed by providing more convenient products tailored to user's needs and by capitalizing rapidly on the emergence of new computer and communications technologies. Today, thousands of clients receive weather and climate data over private service networks. Rapid growth in this type of service can be expected to continue, assuming that the private sector continues to have electronic access to the data sources in NOAA at a fair market price.

The National Oceanic and Atmospheric Administration should ensure that any actions taken to modify and improve the federal activities in the generation and management of weather and climate data and information will not restrict the ability of the private sector to be a full participant. Specifically, the private sector should be:

1. Included in the planning for future weather and climate services.
2. Allowed unrestricted access to weather and climate data at a fair market price.
3. Allowed to compete for services in both the commercial and government marketplace.

5.4 INTERNATIONAL ASPECTS

The primary international body concerned with climate-related data is the World Meteorological Organization (WMO), a specialized agency in the United Nations family. WMO and its predecessor, the International Meteorological Organization, have recognized the importance of climate data for over a century. In 1979, WMO cooperated with the United Nations Environment Program (UNEP), the United Nations Food and Agriculture Organization, the International Council of Scientific Unions (ICSU), and other international bodies to establish the World Climate Programme (WCP). Because of the global nature of climate and U.S. interests abroad, the activities of WMO and the WCP have a marked bearing on U.S. climate-related data programs.

The WMO formulates and recommends data standards and coordinates international meteorological data acquisition and archival programs. These activities are indispensable to the practice of atmospheric science and to the application of climate data in a variety of fields. WMO regulations established by member countries mandate standard procedures and the free international exchange of data. Furthermore, WMO cooperates with other international agencies and organizations on specific data requirements, e.g., the International Civil Aviation Organization (ICAO) regarding aviation data needs. WMO's Commission for Climatology recommends procedures to be used at climate stations and for the handling of climate data. The Commission for Basic Systems specifies arrangements for the exchange and processing of data, which is accomplished through the World Weather Watch (WWW) using the GTS.

The United States is a member of the WMO and a major participant within it. The United States both provides and receives data through the GTS and other WMO systems. The data received from abroad are indispensable to many critical meteorological and climatological activities. The United States is also a major supporter of the WCP and has been influential in its planning and implementation. It has a major interest in maintaining world data standards and consistent data management practices. In so doing, it has assumed many different obligations in data and data management. Certain of these commitments are identified in Appendix B. Of particular note are the obligations to maintain World Data Centers for Meteorology, Glaciology, and Oceanography and to supply data to other World Data Centers. The panel views these obligations and commitments as crucial elements of both the national and international climate data systems.

5.5 CONTINUITY OF NETWORKS AND DATA BASES

Early in the study of atmospheric phenomena it was recognized that observations at single stations were inadequate to assess and predict the complex motions of the air. Beginning in the eighteenth century, coordinated observations were proposed and networks of observational stations were organized. In the middle of the nineteenth century, the advent of the telegraph made possible the first attempts to predict migratory weather systems. In the United States, the lead was taken by the Smithsonian Institution, which established a nationwide net of voluntary cooperative observers. By the time the weather and climate service was consolidated as the Weather Bureau in 1871, hundreds of cooperative observers had been incorporated into a system of full-time observing stations operated by government personnel. These first-order stations were first operated by the Army Signal Service and after 1890 by civilian observers under the USDA. Stations were located mostly in major cities. With growing aviation needs in the 1940s most were transferred to airports, and the administration of the weather service became a responsibility of the Commerce Department. By that time, the Cooperative Observers Network had grown to over 10,000 stations.

Data from both first-order and cooperative stations are of widespread utility. In addition to conventional uses for agriculture, aviation, and forecasts for the general public, they are used to manage heating and air conditioning, water and fuel supplies, surface transportation, and construction. They have become valuable tools in land use planning, pollution control, recreation, and advertising. They often become legal evidence. A reasonable density of observations is required, and so many stations have been established, particularly in areas of highly variable precipitation. Many are operated by agencies other than the NWS or are privately maintained. The United States now receives a very high value from the cooperative network at a very low cost since most of the observers are unpaid.

The value of these observations is greatly enhanced by continuity at a specific location. Long, continuous records permit comparisons of weather influences on crop yields, water use, and fuel consumption during different time periods. They also permit rational establishment of insurance rates for weather damages by hail, wind, and floods. Such records are essential for meaningful computation of climatic risks and other spatial and time characteristics of climate. The reliability of statistical measures, such as variability, extremes, durations, and return periods used in planning, design, and climate research, resides in the homogeneity of the data set. The analysis of some aspects, such as periodicities and the standard deviation of extremes, can require very long time series to obtain significant results. When locations are changed and records are interrupted, these statistics are suspect except for the intervals of homogeneity.

The use of data in operational models also demands continuity of record. For example, many operational procedures used in hydrology are based on regression equations estimated from historical records. The loss of stations used in a regression equation can significantly degrade its utility in important economic and social decisions. This is a common occurrence of serious concern to water managers. Inadvertent errors can also arise as a result of relocation of measuring sites. This hazard is minimized by maintaining continuity of sites, flagging changes within the archived data, and ensuring easy access to station histories.

Specific mention must be made of the Reference (benchmark) Climate Stations (RCS). These are long-record stations at locations where environmental change and encroachment are minimal, such as parkland or experimental farms. These stations must be maintained as steadily as possible to permit studies of climatic fluctuations, trends, and changes. Climate per se is such an important element in human and general ecology that its continuous surveillance is mandatory. Such monitoring is particularly critical because of the evidence that human activity can bring about climatic alterations, some of which might be highly undesirable.

Networks will, of course, change continually for economic, scientific, and other reasons. Indeed, the increasing cost of operating manned stations is a sufficient incentive when cost-effective alternatives such as automated instrumentation are available. Also, new technologies like remote sensing now provide invaluable information that was previously unavailable. Nevertheless, despite the attractiveness of such new technologies, a conventional core system is still needed for traditional uses and to provide ground truth for the interpretation of remotely sensed data. Whenever changes are required, correlations must be developed between the data from the longer-term station to be closed and its replacement.

Because not all needs for climatic data can be completely anticipated, it is imperative that the observational material from first-order and cooperative stations be promptly published. Publications such as *Local Climatic Data* and *State Climatological Data* prepared by NCDC should continue to be made available through libraries and state climatologists' offices and for subscription and purchase by individuals.

Observations are taken by cooperative observers once a day. The primary measurements are maximum and minimum temperature and daily precipitation and snowfall. A number of these cooperative stations report precipitation in real time if over 0.5 inches falls (for flood work). Some data are also gathered in real time for agricultural uses. There have been increasing pressures to make more of the data available either in real time or with time delays of one week rather than two months. It is possible that some state climate offices could quickly enter a selection of their own data into a computer and transfer it to NCDC. Still, for perhaps 50 to 60 percent of the stations, it may not matter if there are time delays of one to two months before they are available. Since NOAA, the Department of the Interior (DOI), the Department of Defense (DOD), and USDA all have data gathering networks, it may be that a combined effort could be used to gather the data.

The resulting real-time data and delayed data should be made readily available to everyone.

Another aspect of maintaining data continuity is the preservation and recovery of old data sets. Many paper records start decaying when they are 100 to 200 years old. A number of records at NCDC will have to be microfilmed or they will be lost forever. NCDC had supported an expanded microfilm effort for several years but has recently been forced to scale it back.

The United States has excellent digital files of daily precipitation and maximum and minimum temperatures from many stations starting in 1900. There are good files of upper air data from 1948 and good surface observations of winds, humidity, and so on, from 1948. Some earlier data are available for U.S. Air Force stations. Unfortunately, data for the 1930s Dust Bowl period are not in a form that can be used. Study is needed to determine what subset of the data on the patterns of temperature, precipitation, winds, and humidity during that period should be recovered. This may lead to the preparation of 6-hourly surface data from about 50 stations for 30 years (2.19 million observations). The cost would be under $300,000. A selection of the upper air data should also be prepared for that period.

5.6 MANAGEMENT OF ARCHIVAL ACTIVITIES

A key factor in ensuring the continuity of data bases is the sound management of data archives. Unfortunately, present archives have developed largely in an opportunistic manner. Careful, long-term planning is urgently needed. Such planning should not "lock in" or "lock out" a particular technology or equipment type, but rather should set up an effective mechanism for balancing the need for flexibility and responsiveness against the need for consistency and continuity. Any such mechanism should be able to address the following questions regarding the management of an archive:

1. How centralized or distributed should the archive be, i.e., should data be concentrated in one place or should segments of the data be distributed in a variety of nodes on a network or in libraries or offices? A special concern is the political and organizational sensitivities involved. Another is the communications capability that would be required to access an archive regardless of its structure.

2. Who should manage the archive? Should the managing organization be part of a larger institution with other data-related responsibilities or should it be responsible only for the archive itself? This would likely affect the degree of coordination with other relevant groups and the setting of priorities with respect to data management activities.

3. How should the archive be managed? Is it easily accessible at all hours? How large a staff is available? What are its policies regarding cost recovery? Should everything be automated? What should be done by hand?

4. How should the directory or catalog of the information and data in the archive be structured? How many levels of directories should there be? What form should the directories take? What attributes should be listed within a directory? Should there be a full description or just a cursory description of the data? Can a directory be developed that could handle both in-house data sets and references to data sets held by others? How can data from different data sets in different formats be accessed? Is it possible to preview or browse through data sets?

5. What additional standards are needed in archiving? If large quantities of data must be stored with both updating and continuous access, guidelines for file structures, file handling, data input, and record formats will certainly be necessary. These must be coordinated on both national and international levels. There should also be methods for dealing with noncompatible data sets.

6. How should the actual hardware and software used to store and manipulate data in the archive be selected and updated? Since data volumes grow and technologies change, provision must be made for the evolution of hardware and software so that long-term continuity is maintained.

5.7 QUALITY CONTROL OF DATA

Major problems occur in the use of climate data because of insufficient, inadequate, or inappropriate quality control. Quality control is used to remove errors in data. Among the common causes of error are those of observation, copying, entering data onto forms, and transmission on communication circuits. Other common sources of error are instrumental malfunction and bias and the improper handling and exposure of instruments. Still other problems arise in the use of data due to their inappropriate interpretation as a result of inadequate information on changes of site, exposure, and instruments, and of undocumented changes in observing procedures.

Quality control is a process that should begin even before data are collected and that should continue throughout the data's useful lifetime. It involves more than data management per se. Instrument design, good operating procedures, and feedback from users are of vital importance in maintaining data quality. In turn, quality control provides the system operator with urgently needed information on how well the data acquisition and transmission components are functioning. An effective quality control program is vital to archiving: the alternative is to risk very costly errors in decision making as a result of sometimes very erroneous data.

Quality control usually involves space, time, and consistency checks. Spatial checks are used to remove spurious local fluctuations in data. Caution must be used so that information is not lost that is essential for other purposes. Procedures should ensure that the original data are saved along with the corrected values. Checks for time continuity can often enhance data reliability within find tolerances. For example, time checks using pressure and pressure tendency easily identify inconsistent or obviously bad values. The accuracy of a ship's location is readily verified by comparing it with others along its route. A surprising number of ship reports erroneously locate vessels in unusual locations (e.g., the Sahara Desert) for want of suitable quality checks. With satellite data, whole scan lines may be bad or the navigational information may be in error. Problems of this kind often require sophisticated quality control techniques.

The quality control process should not impede access to data nor lead to data degradation. Rather, it should facilitate use, make known possible hazards in the data, advise on adjustments and corrections made, and retain the originally reported value for inspection if there is any uncertainty. Corrections should only be applied when enhancement is certain to result. Access to data should not be delayed, but the user should be advised of the level of quality control that the data have received. Improvement in data sets may occur in incremental steps, and some enhancements may follow as a result of usage. Care should be taken in deciding levels of control. Some very simple checks are the most powerful, and there is a decided risk of distorting data by complicated control procedures that are not readily understood. Unusual reports on phenomena should not be suppressed on the basis of a reviewer's opinion. Reports of early jet-level winds were rejected in World War II as unrealistic because of our ignorance at the time. Some seemingly bad data can be salvaged. For example, ship barometric pressure records may have large biases; however, these records should not be discarded because they can be repaired once the nature of the bias is known. Similarly, faulty quality control decisions can obscure real differences that exist spatially in climate. Errors have often been made in adjusting winter temperatures near open lakes or at high elevation because they disagree with those for other well-known sites.

5.8 OPPORTUNITIES FOR IMPROVED DISSEMINATION AND USER INTERFACE

It cannot be stressed enough that, regardless of how much effort is put into collecting, processing, and archiving data, it would all be worthless if the means to disseminate information to end users is lacking. With the new communication and dissemination capabilities now available, the opportunity exists to improve services greatly. With increasing end user sophistication and expectations, new methods for transmitting, displaying, and applying data and information in user-friendly forms will certainly be required. It is also important that users know where to go to obtain the data and information they need. The main features of a user interface sought by end users are summarized in Table 5.1.

The increasing availability of communication networks, computer terminals, and microcomputers raises a number of questions regarding the dissemination of data and information. How do we factor such improved hardware into planning? What kinds of personnel are needed to handle these new approaches? How many people will be needed, and with what kind of training? How much service should be provided to users today at what cost? How much should be automated? How much requires human input? What should be charged for data or information?

Charging for data is a major issue at present. The Office of Management and Budget has decided that the costs of disseminating federal government data must at least be recovered. In many cases, slightly more than actual costs should be charged to compensate for the implicit institutional contribution.

TABLE 5.1 Features of a User Interface Sought by Users

Access	There must be easy access to archival holdings through the identified source. The data management system must be responsive to the diversity of needs imposed by the user community and should facilitate access in a cost-effective manner.
Archive	The archive must have depth, completeness, homogeneity, quality, and relevant data holdings. The integrity of the archived data must be assured, care being taken to ensure that degradation does not occur through observational procedure, transmission, quality control, or inability to preserve potentially useful data files. The integrated archival system should incorporate all relevant data, standard and nonstandard, in common formats and provide suitable indicators of data limitations.
Communication	Responses and documentation must be easily understandable by users.
Compatibility	The data delivery system should be compatible with user systems, capable of responding on a variety of user media (e.g., electronic, paper, or micrographic). WMO observational standards should be employed. Quality control of data must be standardized.
Consultation	Consultation must be available on the meaning of the data and its processing, interpretation, and use.
Context	Information on instrumentation, exposure, observing practices, quality control procedures, and changes therein must be documented and available.
Cost	Charges for the provision of data services must be fair and consistent.
Knowledge	Information on data holdings, their utility, and service functions of archive centers must be made available from the identified sources.

TABLE 5.1 (continued)

Limitations	All data limitations (constraints to their interpretation or use) must be identified. Altered data must be identified (flagged) and the nature of the alteration specified. In the case of nonstandard data, methods should be available for their "normalization." The use of WMO-recommended standardized procedures for acquisition should be strongly promoted and be the norm for governmentally supported networks. If only poor-quality data are available, however, users should not be denied access until the data are improved.
One-Stop	All of these capabilities should generally be available to a user through a single contact or by specific referral.
Processing	The archival center should have a data processing service capability including utility programs.
Referral	A referral system for climate and climate-related data must be in place and highly visible and accessible to users. The referral system should enable the identification and location of nonstandard as well as standard data.
Responsiveness	The response to requests for data must meet reasonable user deadlines; archiving should be on a real-time basis; direct access to files or publications is preferred. The data system must be responsive to existing and changing needs for data and user technology.
Scope	A wide range of data should be available directly or by referral, including (within reason) data from related environmental disciplines and economic, demographic, and other data useful for applied studies and for assessments of the value of climate data.
Visibility	The user must be made aware of the data access points and their features.

No dissemination system can rely solely on automation. Human intervention must be available. At the least, a person is needed to explain a method to an end user or to respond to questions. How should complaints and problems be handled? To what degree is the system manager liable for incorrect information or poor data quality? How much documentation is needed to support the data and information provided?

Many different types of end users will access climate data: lawyers, farmers, military personnel, newspapers, and so on. Specialists familiar with particular areas or disciplines should be available when data and information are disseminated in order to better respond to the particular audience. Models of these kinds of operations currently exist in other disciplines. It may be necessary to retrain personnel to use new methods and understand new questions.

Dissemination should be more than simply responding to a query. Bibliographies, directories, and summaries are necessary. These should be published periodically and distributed through user-oriented channels so that present and potential users can find and make use of the data. Articles should be written in "end user" publications and a reasonable level of publicity maintained so that people know what is available and how to start a query process.

Educational material should be developed and included in routine climate publications, in trade and professional journals of relevant user communities, in popular journals, and in other publications directed at both general and specialized audiences. A regular publication such as a biannual newsletter or a column in a professional journal on data management should be issued to keep relevant user communities current on data developments and use. These materials should be disseminated among and by federal agencies, state climatologists, and other centers and agencies that are in contact with actual and potential users. Opportunities provided by workshops, professional association meetings, user trade fairs, expositions, and the like should be exploited.

User workshops should be held routinely for research and application sectors at the national to state level. The purpose of the workshops should be both to inform the user community and to acquire knowledge that is needed to enhance the utility and functioning of the data system. Users must have ample opportunity to make recommendations regarding data services. A process should be established to ensure appropriate consideration and communication of proposed actions.

A pressing need is to develop a library of existing work on climate applications. At present, there is no single place where even half of the many books, articles, reports, and other materials on climate applications generated in the past few decades can be found. Nor is there a single listing of all publicly supported research involving climate data applications. A central library would be an invaluable resource for those interested in the value of climate applications or in the development of new applications. Such a library should be made accessible via standard computer networks.

The building industry is one example of a highly fragmented community of end users of climate data. Manufacturers, designers, contractors, and building owners and managers operate in sequence but are almost entirely independent of each other. It would be virtually impossible for this community to coordinate and maintain compatible data collection facilities such as a solar radiation network consistently for any period of time. On the other hand, this community would have a vested interest in contributing to a public data network tailored to their needs for a specific period. Indeed, such a participatory network might greatly enhance their interest in and use of environmental data, with potentially great economic and social benefits. One initial step should be to create data collection station packages with standardized quality control that can be utilized by various end use groups for a minimum of five years. Using such standardized packages as a base, it should be possible to improve understanding of their needs for data and information and of the potential benefits of meeting such needs.

It is clear from the many questions raised above that there are many unresolved issues regarding dissemination and user interface. Careful planning will be necessary to respond effectively in the next few years to these problems.

6
Recommendations for Action

6.1 AN INTEGRATED PROGRAM FOR WEATHER AND CLIMATE DATA

As discussed extensively in this report, a variety of weaknesses exist in the system for handling weather and climate data. These weaknesses highlight the continuing lack of coordination in data collection and management within the federal government. Coordination of data activities requires constant attention at both the policy and working levels. There must be continual feedback and interaction among all the participants in the data system, including those responsible for observations, quality control, data analysis, data archiving, equipment procurement, and data dissemination. There must be recognition of the substantial and continuing value of climate data to the nation. There must also be an institutional mechanism for implementing and enforcing improvements.

Unfortunately, despite the coordination efforts of the NCPO, no mechanism has yet been effective. Ad hoc meetings, interagency committees, and advisory panels have tended to be too transitory and have lacked the power to follow up on their recommendations. A major task at a high level in the federal government is therefore to improve coordination and collaboration both within the government and with other groups:

> *Recommendation 1: The federal government should clearly articulate an integrated national policy covering its obligations and limitations in (a) the observation and monitoring of the*

weather and climate; (b) the collection, processing, and management of weather and climate data; (c) the retention and archiving of weather and climate data; and (d) the provision of weather and climate information and services.

Specifically, such a program should integrate the organization and administration of major data gathering, processing, archiving, and dissemination activities as much as possible. It should include effective mechanisms to enforce consistency and coordination within and between agencies when necessary. Federal data policies and plans and the limits of federal government responsibility and activity should be clearly articulated. A primary goal should be to improve feedback throughout the weather and climate data system, e.g., between data producers and users, policy and working levels, operational and procurement personnel, and public and private sectors.

6.2 REMOVAL OF THE DISTINCTION BETWEEN WEATHER AND CLIMATE DATA

Since the formation of ESSA (NOAA's predecessor) in the mid-1960s, the primary responsibility for "weather" and "climate" has been in different major line components of the agency. Separation of the two made it possible to emphasize the "unity" of atmosphere, oceans, and lithosphere by organizing all retrospective data responsibility for the three within a single major line component. This may have been a sound and proper organizational decision at the time, but much has changed in the two decades since then. The panel thinks it is now appropriate to reexamine this structure for the following reasons:

1. As discussed previously, the distinction between "weather" and "climate" has become much more vague in the sense of data use, largely as a result of significant changes in data communication and computer processing. The gap between real-time data use for weather forecasting and retrospective data use for a multiplicity of purposes has become filled by near-real-time use for climate monitoring, irrigation scheduling, and the like. The entire process from original observation to data storage and retrieval has become a continuum with no logical point for a complete "hand off" from one manager to another.

2. The responsibility for station establishment, maintenance, and abolishment now lies in one major line component of NOAA, while the responsibility for describing the climate lies in another. The observational requirements for weather forecasting and for climatic applications are not always compatible, much less identical. Both needs should always be weighed.

3. Fiscal realities dictate that resources be applied with the utmost effectiveness. It appears likely that some additional dollars could be transferred from administrative costs to actual data handling costs by reducing the amount of coordination, consultation, and so forth required by the "weather-climate" split now built into NOAA.

4. There also are non-data-related reasons for reexamining the situation. Not least among these is that the public does not understand this bureaucratic division between weather and climate. Citizens reasonably look first to the NWS, not NESDIS, when questions or problems arise; one might argue that the government should adjust to the citizens rather than the converse.

> *Recommendation 2: The federal government should recognize the users' need for a continuum in the management of weather and climate data. NOAA should therefore reassess its existing institutional arrangements with the objective of improving the coordination of weather and climate data activities.*

6.3 ESTABLISHMENT OF A NOAA DATA OFFICER

The National Oceanic and Atmospheric Administration plays a central role in the national weather and climate data system. It operates most of the major observing networks, including radar and the operational polar-orbiting and geostationary satellites. It processes and stores most of the conventional data collected in the United States and in much of the rest of the world. Through the National Climate Program Office located in the NOAA Administrator's Office, it helps coordinate the National Climate Program and the U.S. contributions to the World Climate Program.

Unfortunately, many of these activities are administratively scattered throughout NOAA's organization. For example, as noted earlier, the National Weather Service operates the Cooperative Observers Network, but it is the NCDC, part of NESDIS, that processes the collected data. This has led to problems such as those described in Chapter 4 of this report.

The problem is made even more complex by the many other agencies and organizations that have binding agreements with NOAA. For example, experimental satellites are managed by the National Aeronautics and Space Administration, but the data they generate are often NOAA's responsibility. The Federal Aviation Administration works closely with the NWS in providing aviation weather information. DOD is both a major source and a major user of data. NCAR, which handles large amounts of data in a research mode, is operated by a university consortium for the National Science Foundation. NOAA itself is part of the Department of Commerce, and many of its administrative policies are therefore controlled at the departmental or even cabinet level.

The panel of course recognizes that any administrative structure in an organization as large as NOAA will necessarily divide some functions arbitrarily. In light of this, the panel makes the following recommendation:

> *Recommendation 9: NOAA should establish a central data officer for weather and climate data with a clear mandate, broad authority, and sufficient resources to (a) conduct systematic and impartial studies of requirements for weather and climate data and of new technologies for efficiently meeting these requirements; (b) coordinate planning for new weather and climate data management, communication, and dissemination systems throughout NOAA; (c) develop clear standards for data collection and instrumentation, consistent and efficient quality control, and cost-effective data archiving and dissemination for basic observations, derived parameters, gridded data sets, and special-purpose data sets such as those obtained in field experiments; (d) ensure the continuity, careful management, and coordination of key climate networks, data bases, and publications, including the cooperative and baseline observing networks; and (e) act as coordinator and arbiter in decisions concerning resource allocation, technological modernization, and data preservation, both within NOAA and in cooperation with other agencies, and serve as a focal point for coordination with the World Weather Watch program of the World Meteorological Organization.*

The data we are collecting and storing can be considered to be a national resource. It costs a great deal and is important to many people. To put this house in order in the most efficient, cost-effective way will at a minimum require a single management point with the necessary responsibilities and the authority to do what is necessary.

The panel strongly believes that the establishment of a data officer would be an important first step toward providing the coordination, planning, and direction necessary to make sure that climate and meteorological data meet national needs in the coming years. Additional actions of both a policy and an administrative nature may well be warranted. Such actions should be developed as an integral part of the national program discussed in Recommendation 1.

What follows are some responsibilities and tasks that should be assigned to the data officer.

6.3.1 Studies of Data Requirements and Options

At present, there is a pressing need for detailed examination of specific requirements for weather and climate data and of new technological alternatives for meeting these requirements. A broad perspective on the entire national system for handling weather and climate data is required. Sustained cooperation on the part of the federal agencies involved would be necessary.

The panel strongly believes that the data officer would be in an appropriate position to manage systematic and impartial studies of data requirements and options. On the one hand, the data officer would have the expertise and familiarity with relevant issues to ensure that studies are of sufficient depth and realism. On the other hand, the data officer would be able to balance institutional and other considerations in the context of broad data issues and improving technological capabilities.

6.3.2 Coordination of Planning

The data officer should be the main focal point for coordination of planning all along the continuum of data management, including data handling, communications, storage, and dissemination.

Liaison committees of data collection groups may be helpful. These should include state and regional organizations, the various federal agencies, and private sector groups. Such committees should permit frank discussions of data flow, formats, communication protocols, and so on. A liaison committee involving data system operators at all levels should address problems of data storage and access, computer system operations, and data interchange.

Coordinated planning to ensure the compatibility of systems at all stages of data management should be developed. Such planning should encompass hardware and software development, acquisition, implementation, operations, and maintenance and would allow for evolutionary development of a smoothly operating national system or systems. Planning in these areas should be both long- and short-term and take cognizance of state-of-the-art technological and computer developments, new techniques in data base development and utilization, telecommunication advances, and changing user needs, requirements, and access methods.

Coordination of planning by the data officer would permit the development of an optimum approach at all levels, with full opportunity for all concerned to provide input, alternatives, and recommendations. The needs, goals, and constraints of the various members of the community must be carefully considered. Plans should also be flexible and dynamic, allowing room for experimentation with advanced technologies such as AI techniques, new satellites, and new types of data.

6.3.3 Standards, Quality Control, and Archiving

In the area of weather and climate data, a variety of standards exist and many others are being developed under the auspices of different groups and organizations such as the World Meteorological Organization, ANSI, the National Bureau of Standards, and the American Society for Testing Materials. Basic standards for meteorological observations are set internationally within the World Meteorological Organization. However, the application of scientific standards is not universal, and there are no widely accepted standards for software and hardware for climate data management systems. Indeed, different standards are sometimes used even within the same agency, as well as between agencies. This can be extremely wasteful and inefficient in the long run. The need for common guidelines and standards is evident in the recent proliferation of data communication protocols developed by different manufacturers. Since so many players are involved in data internationally, nationally, and regionally, strong leadership, coordination, and cooperation are essential. In the panel's view, this presents an opportunity for the data officer to take a leading role.

Of urgent concern are the development and improved application of standards for data acquisition and quality control. One approach would be for the data officer to make formal agreements with various groups and organizations such as the National Bureau of Standards, state agencies, professional groups, and manufacturers. These agreements should give the data officer the responsibility for establishing and promulgating standards relating to weather and climate data processing, especially within NOAA. Such standards should be developed as necessary by technical work groups or specialists from the community and should be fully reviewed by the community. Standards not only would improve the efficiency of data collection, processing, and dissemination, but should also make system design and development easier and less costly. At all phases of standards work, the community of collectors, users, and systems people must be consulted and involved.

The need for quality control is universally accepted. However, it is a difficult task and must be considered over the full range of data activities, from original input through storage and output (see Section 5.7). The data officer should provide this comprehensive view of quality control, working closely with the groups responsible for quality control at each stage.

Cost-effective data archiving and dissemination require that the end uses and end users of the data be known, and that the users be adequately informed about data sources and access. Of special concern are the development of an inventory and directory or catalog of the data and information; systematic improvement of the hardware used to archive the data; refinement of the human-computer interface; and improved marketing analyses to ascertain user needs and preferences. Many difficult decisions also need to be made, for example, regarding what data to archive or to discard, what data to convert from paper records to digital formats, what satellite and radar data to retain, and what costs to recover from end users. The data officer should play a leadership role in all of these decisions.

6.3.4 Key Climate Networks, Databases, and Publications

The data officer should have sufficient authority to ensure that key climate networks, data bases, and publications—such as those discussed in Section 5.5 of this report—are consistently supported and carefully managed in accordance with both statutory requirements and user needs. A particular concern is the continuity of monitoring and data archiving activities, since even small lapses can significantly damage their scientific, economic, and public policy value. The data officer should at a minimum have sufficient resources to supplement activities where necessary in "emergency" situations. Additional authority, e.g., in the planning and budgeting processes, may also be necessary to ensure that problems are dealt with effectively at an early stage. Clearly, the data officer must work closely with both the relevant operating agencies and the user community to determine long-term needs and develop effective strategies for meeting them.

6.3.5 Coordinator and Arbiter in Data Decisions

Because of the magnitude of the data handling and storage problem, some form of central oversight and coordination is a necessity for better service and more cost-effective actions. Completely decentralized management of data resources without such coordination tends to lead to continued incompatibilities, poor resource allocation, and inconsistent application of technological modernization. Coordination and arbitration by the data officer would improve the likelihood of clear direction, optimal and balanced allocation of scarce resources, and coordinated innovation. This coordination and arbitration does not of course mean centralized handling and control.

6.4 PROMOTION OF THE APPLICATION OF WEATHER AND CLIMATE DATA

Many decision makers are unaware of the need to consider climate as a factor in decision making. The perception is widespread that climate is a constant. Great surprise is often expressed when climate or weather extremes occur. When they do, the general reaction is that "the climate must be changing."

Unfortunately, our memories are short. Climatologists recognize that decision makers are likely to remember only the previous year or so, unless there are unusual circumstances. For example, most energy supply companies request heating-degree data only for the current and past year. Following a sequence of three unusually cold years in the late 1970s, fuel oil companies near the Great

Lakes experienced major surpluses after the climate returned to more normal conditions. They assumed that every year would be like the last. Recognition of the variable nature of climate could have enabled economies through hedging strategies.

Climate has revealed a most diverse character over the past century. A major use of the climate data base is to permit the identification and quantification of climate hazards and opportunities that have occurred in the past and which could therefore occur again. Another use is in the spatial comparison of opportunities and hazards. For example, comparative values of aridity can show which locations are most suitable for irrigation development, solar energy, and raincoat marketing.

Having such utility in mind, the National Climate Program Act of 1978 noted the lack of a "sustained and coordinated program of climate monitoring, analysis, information dissemination, and research." It specified as one of its purposes "improving services relating to climate, particularly the dissemination of climate-related data and information." It also specified "the periodic publication of reports in appropriate professional, trade, and popular journals describing the form and manner in which the data are available."

Attainment of the program objectives and national social and economic goals is dependent on optimal use of data, not just the existence of an optimal management system. Optimal use depends on user understanding of the potential offered by the weather and climate data system. This in turn requires that NOAA maintain and improve its existing expertise in data services and applications and provide leadership in the development of needed awareness and capabilities throughout the user community. Existing efforts to demonstrate and communicate the benefits of the many uses of climate data must be continued and expanded to the user community. Research findings that are of significant relevance to data users in other fields of activity should be made generally available in easily understood forms.

> *Recommendation 4: The federal government should increase active promotion of the application of weather and climate data in both the public and private sectors, including continued documentation and demonstration of the broad utility and value of such data.*

The climatological and meteorological community should assist in this effort by actively helping to improve understanding of the value of climate-related data with respect to economic, health, safety, and general welfare considerations in each major end use sector of the economy. It will be particularly important to move beyond conventional studies of the use of climate information in agriculture, energy and water management, and military operations. Innovative studies, seminars, workshops, and so on, should be organized to deal with the application and value of climate information in all sectors, including the building industry, medical and legal services, emergency preparedness, recreation and tourism, and multimedia resource (e.g., air, water, and soil) management, and on both national and regional scales.

The potential value to be realized through the technical opportunity now available has scarcely been probed. A major objective of the above studies should be to clarify the quantity and quality of data needed by each end use sector, the priorities given to different data, and the degree of data base flexibility that is required in the long term. These needs and priorities should form the basis for the judicious allocation of resources among elements of the national climate data system and for decisions about future investments in the system.

It will be important to entrain all sectors of our national life in these efforts. For example, consideration might be given to formation of a federal-state-private sector board to coordinate climate outreach activities. The NCP workshop held at Woods Hole in the summer of 1985 (Board on Atmospheric Sciences and Climate, 1986), for example, recommended the development of a new climatic atlas closely keyed to the needs of users, and linked to the data base of the 1990 Census. This board might take the planning of this atlas as an initial focus for its work.

A key element of any effort to promote the application of weather and climate data should be the development of data access points at which end users could obtain both real-time and historic data in "one stop." Coordination or even consolidation of access points, e.g., via a central clearinghouse, is needed so that timely, complete, and interdisciplinary information is provided to all end users. This would greatly reduce both confusion about data availability and the costs of obtaining the desired data. At the data access points, it would be useful to provide technical support in the application areas served and to maintain comprehensive libraries on relevant work in applied climatology. The number of data access points, their geographic distribution, their affiliation (i.e., public versus private sector), and their mode of operation should depend on the needs and distribution of end uses and users. More detailed monitoring of both end uses and end users and more sophisticated analyses of their needs will certainly be required. It is also important that these data access points be made an integral part of the nationwide system of climate services suggested in the report *Meeting the Challenge of Climate* (Climate Board, 1982).

7
Conclusion

The foundation for all climatological and meteorological analysis and reporting is data. Once collected, it is a basic resource. How our institutions deal with the management of this resource will affect the accuracy, reliability, and utility of national weather and climate information for years to come.

A variety of technological and societal changes are fundamentally altering our capabilities for handling and utilizing weather and climate data. Where these changes will lead is uncertain, but the promise is tremendous. Indeed, the words of Helmut Landsberg in 1946 are still appropriate in many respects:

> . . . the unlimited climatic resources of the United States still await exploration and exploitation; they wait to be tapped. They promise full returns by better adjustment of our homes and health, our agriculture and technology, to the atmospheric environment (Landsberg, 1946).

The panel strongly believes that implementation of its recommendations would be a significant early step toward realizing this promise. The analysis and recommendations in the present report focus on atmospheric climate data; further study of other data, especially oceanic and satellite data, should be undertaken. Other actions may certainly be necessary after further detailed examination of the issues. The basic challenge, however, is this: *the federal government must seriously examine its handling of weather and climate data from a broad, long-term perspective and establish mechanisms to ensure sensible, government-wide planning and implementation of data management.* If this challenge can be met, all other problems should be solvable and the bright promise of climate-related data will be fulfilled.

TABLE 6.1 (continued)

Limitations	All data limitations (constraints to their interpretation or use) must be identified. Altered data must be identified (flagged) and the nature of the alteration specified. In the case of nonstandard data, methods should be available for their "normalization." The use of WMO-recommended standardized procedures for acquisition should be strongly promoted and be the norm for governmentally supported networks. If only poor-quality data are available, however, users should not be denied access until the data are improved.
One-Stop	All of these capabilities should generally be available to a user through a single contact or by specific referral.
Processing	The archival center should have a data processing service capability including utility programs
Referral	A referral system for climate and climate-related data must be in place and highly visible and accessible to users. The referral system should enable the identification and location of nonstandard as well as standard data.
Responsiveness	The response to requests for data must meet reasonable user deadlines; archiving should be on a real-time basis; direct access to files or publications is preferred. The data system must be responsive to existing and changing needs for data and user technology.
Scope	A wide range of data should be available directly or by referral, including (within reason) data from related environmental disciplines and economic, demographic, and other data useful for applied studies and for assessments of the value of climate data.
Visibility	The user must be made aware of the data access points and their features.

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Appendix A: Acronyms

AFOS	Automation of Field Operations and Services
AGNET	Agricultural Network
AI	Intelligence
ALPEX	Alpine Experiment (GARP)
ANSI	American National Standards Institute
AWIPS-90	Advanced Interactive Processing System for the 1990s
BPI	bits per inch
CAC	Climate Analysis Center (NOAA)
CAMS	Climate Anomaly Monitoring System
CBS	Commission for Basic Systems (WMO)
CD-ROM	Compact Disk, Read-Only Memory
CEAS	Center for Environmental Assessment Services
CIS	Climate Information Sytem
CLIMPAX	Climate Impacts and Adustment Experiment
CPU	Central Processing Unit
DOD	Department of Defense
DOI	Department of the Interior
ESSA	Environmental Science and Services Administration
FGGE	First GARP Global Experiment
GALE	Generation of Atlantic Lows Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	General Circulation Model
GMS	Geosynchronous Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GTS	Global Telecommunications System
ICAO	International Civil Aviation Organisation

ICSU	International Council of Scientific Unions
IMO	International Meteorological Organization
METEOSAT	Meteorological Satellite
MIPS	Millions of Instructions per Second
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center (NESDIS/NOAA)
NCPO	National Climate Program Office (NOAA)
NESDIS	National Environmental Satellite and Data Information Service (NOAA
NEXRAD	Next Generation Radar
NMC	National Meteorological Center (NWS/NOAA)
NOAA	National Oceanic and Atmospheric Administration
N-ROSS	Navy Remote Ocean Sensing System
NWS	National Weather Service (NOAA)
RCS	Reference Climatological Station
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
STORM	Stormscale Operational and Research Meteorology
TIROS-N	Television Infrared Observation Satellite-N/NOAA Series
TOGA	Tropical Ocean/Global Atmosphere
UCAR	University Corporation for Atmospheric Research
UNEP	United Nations Environment Program
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WCP	World Climate Program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch

Appendix B: International Responsibilities For Climate-Related Data

HELMUT LANDSBERG

The United States is a member of the World Meteorological Organization (WMO), a specialized agency of the United Nations. The body is a successor to the International Meteorological Organization (IMO), founded in 1873 to foster cooperation in meteorology among the nations of the world and promote uniform practices of observing and reporting.

Since its inception, the IMO and later the WMO included climatological procedures in their rules. Much of these in recent decades have been regulated by the WMO Commission for Climatology, which has set the pace for six decades in the field and has had three U.S. presidents since 1951. With the creation of the World Climate Program (WCP) in 1979, the WMO identified climate, and thereby climate data, as a high-priority concern.

A vigorous WCP is vital to the attainment of major elements of the U.S. international and domestic goals, in particular those espoused by the National Climate Program. For example, the ability to monitor and develop climate prediction capabilities requires global data and understanding. Data from the Global Telecommunications System (GTS) are used by the World Food Board of the U.S. Department of Agriculture, by the U.S. State Department, by private companies that monitor food production abroad, and also by the Assessment and Information Services Center of NESDIS (in support of the Agency for International Development). For such reasons, the United States has been the major proponent of the WCP, influential in its design and implementation. A major component of the program is dedicated to data. An essential instrument, in which the United States has a major role, is the World Weather Watch (WWW), through which the United States receives global information needed for assessment and research.

The international operational rules are laid down in several WMO documents. Basic definitions and desired procedures are contained in the *Technical Regulations.** Aside from standards for meteorological observations, Chapter A.2.4 (6 pp.) is completely devoted to climatological practices. Three sections deal with climatological data and specifically state that all meteorological observations, even if made for other purposes, become climatological data after their original use. Quality control of these data and those taken at climatological stations is an obligation of WMO members. Maintenance of an archive and an inventory of climatological data is urged. As to international requirements, the regulations mandate an international exchange of data from selected locations (CLIMAT stations) after the end of each calendar month over the WMO telecommunications network. The list of locations was recently expanded to enhance assessment of crop conditions, drought, and other climate anomalies abroad that affect trade, assistance and security, and also to provide a better basis for understanding the global climate and for its prediction.

The WMO Commission for Basic Systems (CBS) specifies arrangements for the exchange and processing of meteorological and climate data accomplished through the GTS and the Global Data Processing System. By means of these systems, weather data, forecasts, satellite data, and climate information are communicated throughout the world in operational, or real, time. Raw data are converted into information at data centers and further distributed on the basis of regional or national requirements. The World Meteorological Center in Washington is a major component of these global systems and has a central role in their performance, development, and use. The United States, as a collaborator within the WCP, is the major provider of climatological monitoring information and data to the global community, obtaining the raw data via the WWW and interpreting it in collaboration with the Soviet

* World Meteorological Organization, *Technical Regulations*, Basic Documents No. 2, WMO No. 49, Geneva (no date, loose leaf for continuous updating).

Union and Australia. The presidency of CBS has been held by the United States since 1978.

Climate data are published by the NCDC in the United States in a monthly publication, *Monthly Climatic Data for the World*, now in its thirty-eighth year. This is one of the most widely used sources of climatic data. (The United States has formally agreed in the relevant WMO bodies to issue this publication.) The regulations also urge the issuance and international exchange of national climatological data publications by national meteorological services. Other stipulations are for periodic revisions of so-called "normals" (30-year averages of surface temperatures and precipitation). Publication of upper air observations and handling of ship observations are also included in the regulations.

Other WMO recommendations for data handling and data use are contained in the *Guide to Climatological Practices.** This useful handbook outlines observational, standards, data processing practices, desirable publications (including formats), data presentations, and statistical analyses. For international data exchange, WMO and the International Civil Aviation Authority (ICAO) have agreed on sets of climatological summaries that must be available for all international airports. These have to be periodically updated by the weather services.

Another data publication that has been of great value in climatological research is the *World Weather Records.* This was started as a source of long-record weather stations by the Smithsonian Institution in 1922. This publication was taken over by the Weather Bureau after World War II and has been continued since NOAA. It is now produced by NCDC at the end of each decade, based on the monthly CLIMAT data. The series is now complete to 1970 and has earned the United States much praise from the international meteorological and climatological research community. The value of the long climatological series will remain high for the continuing monitoring of natural and man-made changes. International cooperation is indispensable for such studies. This is implicitly recognized by the National Climate Program Act. The legislative history of the act directs attention to the need for international data exchange for assessment of impacts of climatic anomalies.

* World Meteorological Organization, *Guide to Climatological Practices*, 2nd edition, WMO-No. 100, Geneva, 1983 (loose leaf format for continuous updating).

On a worldwide basis this is now organized in the World Climate Program, jointly arranged by the WMO, the United Nations Environment Program (UNEP), and the International Council of Scientific Unions (ICSU).

At the request of ICSU, the United States has agreed to maintain seven World Data Centers. These include: World Data Center A for Meteorology located at NCDC in Asheville, North Carolina; World Data Center A for Glaciology (snow and ice) in Boulder, Colorado; and World Data Center A for Oceanography at NOAA in Washington, D.C.

These centers are in addition to the WMO World Data Center at Washington and the High-Altitude Meteorological Data Center at Asheville. The United States collaborates with other countries to maintain these centers and to provide relevant information. For example, it supplies ozone data to the World Ozone Data Center in Downsview, Ontario, Canada.

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