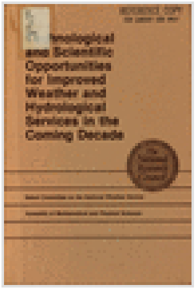

Technological and Scientific Opportunities for Improved Weather and Hydrological Services in the Coming Decade (1980)

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Technological and Scientific Opportunities for Improved Weather and Hydrological Services in the Coming Decade

Select Committee on the National Weather Service
Assembly of Mathematical and Physical Sciences
National Research Council

National Academy of Sciences
Washington, D.C. 1980

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

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

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

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A limited number available from
Select Committee on the National Weather Service
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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MEETINGS

<u>First Meeting</u>: 1-3 November 1979
National Academy of Sciences
Washington, D.C.

Briefings by senior NOAA, NWS, NESS, ERL representatives.

<u>Second Meeting</u>: 27-28 November 1979
NWS Central Region
Kansas City, Missouri

Briefings on NWS forecasting, hydrological, severe storm, and field station operations.

<u>Third Meeting</u>: 10-11 January 1980
NWS World Weather Building
Camp Springs, Maryland and
National Academy of Sciences
Washington, D.C.

Briefings on NWS central forecasting operations and research, automated information generation, climatic forecasts; NESS operations and prototype interactive data display systems; GTE Viewdata; Bell Laboratories telephone developments; COMSAT and other satellite communications operations.

<u>Fourth Meeting</u>: 6-7 February 1980
NOAA Environmental Research Laboratories
Boulder, Colorado

Briefings on remote-sensing developments, mesoscale modeling studies, PROFS.

<u>Fifth Meeting</u>: 10-11 March 1980
National Academy of Sciences
Washington, D.C.

Final discussion, review of report.

EXECUTIVE SUMMARY

GENERAL INTRODUCTION

The U.S. National Weather Service (NWS) produces daily some 500 weather and hydrological information products that reach the nation in a variety of ways. This weather information is vital to the public in making everyday personal decisions, in providing warnings of weather conditions hazardous to life and property, and to private and public user groups in making important day-to-day and weekly decisions of economic and policy importance. While studies made of the economic value of weather and hydrological information show large returns on the investment in forecasting, the full value to the public is probably beyond analytical determination. Weather is probably the greatest common denominator to all segments of society.

NWS is a cost-effective government agency. Its weather and hydrological services, including the costs of the National Oceanic and Atmospheric Administration (NOAA) satellite program and supporting physical and technological research, have an annual per capita cost of about $1.50, while an additional $7.50 per capita is spent annually by the private media in disseminating NWS-supplied weather information to the public.

General Conclusions

There will be scientific and technological opportunities in the coming decade to make substantial improvements in the quality and quantity of weather and hydrological services, including initiation of new kinds of services that have been impracticable to establish in the past. These services will provide weather information that is required by an advanced society to provide timely warnings of hazardous weather and flooding; optimize the production of food and fiber and the production, distribution, and conservation of energy; manage water resources; provide vital planning and scheduling assistance to the transportation and construction industries; and increase the general well-being of the individual citizen.

The U.S. Government recognizes both civilian and military users of weather information. While the Air Force and the Navy in particular are responsible for satisfying military requirements, the National Weather Service of NOAA has the principal responsibility to meet civilian needs. The Committee was impressed by the high level of cooperation and interagency backup provided by these various government agencies and recognized the essential support in advancing the art of meteorology provided by other government agencies, particularly the National Environmental Satellite Service (NESS), the Environmental Research Laboratories, and the Environmental Data and Information Services (EDIS) of NOAA; the Federal Aviation Administration of DOT; the National Aeronautics and Space Administration; and the National Science Foundation. These contributions together have resulted in the commonly held belief that the United States of America provides outstanding leadership among the meteorological services of the world.

Continuing progress in improving the National Weather Service will require effort in many areas. Although the areas overlap and cannot be completely separated, the Committee has identified four major groupings of effort, each of which is treated in this report: (1) user needs, (2) sensors and sensor systems, (3) data assimilation and processing, and (4) dissemination of weather data and information.

User needs are, in part, affected by what technology can offer. Growth of sensor and computer technology is accelerating. Capabilities for data dissemination are expanding at an explosive rate.

While improved sensors and increasingly larger capability in data processing will greatly enhance the flow of weather data and information, the Committee foresees an increased demand for professional meteorologists to tailor this larger information base to user needs.

The public needs and deserves new and improved weather and hydrological services, and appears to be willing to accept a higher investment to achieve them. The Committee concluded that the rate of progress toward better services is not limited by technology.

The Committee believes that the current planning and development in NOAA is forward-looking but conservative, and addresses many but not all of the important needs. The Committee's conclusions and recommendations take into account the current status of planning and place emphasis on missing or underemphasized elements in NOAA's planning effort.

General Recommendations

NOAA should seek a substantial increase in its funding to support improved and new weather and hydrological services. While the Committee cannot and should not prepare a detailed plan and corresponding budget, it has examined some of the typical implementation and operating costs of new observing capabilities, data processing systems, and information services. Recognizing that the manifold technological opportunities must be balanced by a prudent use of funds, the Committee recommends a fiscal increase of 15% per year in constant dollars for at least the next 5 years. This would result in the doubling of annual expenditures by the end of the 5-8-year period. The Committee is aware of the concern of the public and the government about inflation and the need to bring the federal budget into better balance, but also believes that the recommended increase in expenditures would pay for itself many times over by increases in national productivity and reduction in loss of life and property, and would thus constitute a prudent investment by the nation.

Correspondingly, NOAA should seek a substantial increase in personnel, including professional meteorologists and hydrologists, as well as technologists, to take advantage of the increasingly larger data base and information flow of observed and processed weather and hydrological information. This personnel should: (1) tailor information to meet user needs, and (2) identify user requirements leading toward improved weather and hydrological services.

USER NEEDS

Conclusions

In order to plan for services and maximize the return on investments, NWS needs to have systematic information on who users are, what products they need, which formats are most useful, and what time schedules are required by various categories of users.

There is an inadequate effort in NWS to make the public aware of what is available in the form of advisories, forecasts, guidance products, and climatological information. There also is an inadequate mechanism for transferring weather and hydrological information and knowledge of applications to specific users.

Most users of weather and hydrological information need a professional meteorologist or hydrologist to interpret the information or data and give assistance in applying the information to a specific need. The human interface between the information bank (often computer-generated) and the user world also provides to NWS a valuable channel for feedback from users on details of their needs, successes, or problems in using NWS information to meet these needs. In many instances, special data services or interpretation required by a user may exceed NWS resources, or it may not be appropriate for a federal agency to supply such special assistance; in such cases, private meteorological services fill an important need.

There are inadequate planning mechanisms in NWS to merge user requirements with the opportunities afforded by technological developments.

Recommendations

NWS should establish an ongoing user program to:

- identify significant user groups and categorize them by such factors as protection of life and property, size and potential economic impacts (the needs of national defense must also be considered);
- define specific user needs in terms of products, forecast periods, frequencies, etc.; and
- project benefits and costs of providing alternative levels of weather and hydrological data and information services as a basis for rational allocation of future NOAA resources, and for assessing user charges where significant and incremental costs are identified for specific services tailored to specific groups.

This program should become the basis for an ongoing NWS policy to provide two-way communication between user groups and long-range NOAA planning.

NWS should establish a public education effort designed to:

- increase public awareness of the services and information available; and
- educate users on interpretation of the information and how to apply it.

This effort should include the preparation and distribution of manuals and other educational materials for user groups.

NOAA should take steps to assure that NWS is given appropriate credit as the source of weather information used in radio and television broadcasts, in the printed media, and by private meteorological services.

NWS should staff its field offices as required to assure the availability of professional meteorologists and hydrologists or applications specialists at these offices to:

- provide the general public and, where appropriate, special user groups with interpretation of weather and hydrological information; and
- provide feedback from the public, state climatological programs, and private industry on local requirements to NWS planning groups.

NWS should establish a central planning group that will assess user requirements for weather and hydrological information and services, and will plan for the satisfaction of these requirements, where appropriate, through the application of new technology. The planning group should provide, on a continuing basis, 5- and 10-year staffing, technical, and fiscal plans and programs.

SENSORS AND SENSOR SYSTEMS

Many new capabilities for observing the entire atmosphere using surface-based remote sensors as well as space-based sensors are becoming available. In addition, there are important and new opportunities for automation of weather and hydrological observations at the surface using direct as well as inferential techniques. Some of these capabilities are presently available or will be available in the immediate future; others can be expected to materialize later in the decade. New communication capabilities, coupled to computers processing these data into meteorological information, promise not only to improve the quality of meteorological and hydrological information but also to provide it to the user on a much more timely basis.

Conclusions

Pilot programs, tests in operational environments, and prototype field experiments, such as the Prototype Regional Observing and Forecasting Service (PROFS) program, are necessary to determine and order priorities among the wide selection of sensors and combinations of sensors (on space platforms as well as on the surface).

The early identification of the development of mesoscale phenomena requires both surface and upper-level observations from surface-based stations as well as from geostationary satellites. The continuity of existing surface observational systems must be assured until new or improved systems are in place and are proven effective.

Temperature and moisture information from satellite soundings is important, but the full potential of these data has not yet been realized.

Better measurements of the wind field are essential for improving synoptic and mesoscale analyses and forecasts. Steps can be taken in the *immediate future* to improve the capabilities of existing space platforms and sensor systems, as well as surface-based techniques, to give improved but still not complete determinations of wind fields. *In the longer term*, a satellite-based Doppler IR lidar system (provided that the feasibility of the technique will have been demonstrated) should permit the measurement of wind fields on a global basis, which is essential to extend the time range of forecasts.

Recommendations

The Committee recommends a continuing program of evaluation of new concepts of sensor networks and pilot programs (such as PROFS) so that future weather and hydrological networks can evolve from proven building blocks. Long-term support is needed to assure the viability of such a building-block approach. Where appropriate, new sensor systems should also meet the needs of weather observations relevant to climatic studies. New sensor systems should also take account of international collaborative possibilities together with national and regional initiatives.

Continued efforts should be made to improve the reliability of vertical temperature and moisture soundings, including development of better statistical bases for data retrieval, improved correction procedures to reduce contamination, and addition of horizontal (limb) soundings to identify the height and temperature of the tropopause.

A new, imaginative, and diversified effort is required to improve the current systems for wind-field determination for use in synoptic and mesoscale forecasts. The following approaches promise significant improvements *in the immediate future*.

- Improvement in wind-field determination using vertical temperature sounder data appears feasible if these data are analyzed in conjunction with data obtained by polar-orbiting limb scanners, ground-based sounders, and independently derived cloud-altitude and sea-surface data (such as from buoys).
- Addition of multichannel and stereo capability to geostationary meteorological spacecraft promises to give better information on wind fields (from the movements of clouds and water-vapor fields as derived from satellite imagery). Such an augmentation of present systems should be an international effort involving the meteorological spacecraft of all nations, including, for example, the synchronization of scans insofar as possible to facilitate stereo analysis of the images.
- Collection of wind data from aircraft and ships that carry appropriate instrumentation is cost effective and amenable to evolutionary system development, with the additional bonus that some data-sparse regions will be covered. The possibility of international collaboration should be explored to broaden the observing program.

The Committee supports the existing proposals for modernization of the weather radar network (NEXRAD), in particular the deployment of storm-detection Doppler radars, so that the present radar network, now more than 20 years old and obsolescent, is replaced in a timely fashion. The possibility should be investigated for increasing the sensitivity of Doppler storm radars so that clear-air operations might be feasible to supply wind fields.

On *intermediate time scales*, the deployment of radars of the type being developed by NOAA/ERL for wind profiling purposes* also appears to hold substantial promise as a source of wind information. The Committee recommends the deployment of a small number of such prototype radars, variously spaced. The potential of these systems is so high that a realistic assessment of their costs, maintenance, and performance is needed as early as possible. They would

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*As distinct from the area-scanning storm or weather radars, these wind-finding radars are approximately vertically pointing systems that operate also in clear air. Fixed-beam antennas are used to produce a pattern from which the Doppler-shifted returns are analyzed to provide the wind components (e.g., vertical, east, north).

form a key element of the system of the future even if their use were limited to providing wind information for mesoscale forecasting.

The Committee is persuaded that direct measurement of altitude-resolved global wind fields using a satellite-based IR Doppler lidar holds promise as the long-term solution of the wind-field problem. The Committee urges that NOAA, together with NASA, move toward an early on-orbit demonstration.

In parallel with the technical initiatives described above, NWS should carry on an effort to evaluate the effectiveness, in the sense of improving forecasts, of the new types of data that will be returned by these initiatives.

Because of the importance of the tropical regions in governing global weather patterns, the Committee is persuaded that the desirability and utility of a low-altitude, low-latitude meteorological satellite should be re-examined.

The Committee recommends that opportunities should be maintained to deploy experimental meteorological sensors at geostationary altitude.

The data collection phase of the Global Weather Experiment (1979) has been completed very successfully. NOAA should insure that funding is provided for use of the resulting comprehensive data set for research purposes as well as for evaluating, through the use of simulation experiments, the benefits of new sensor systems in improving weather forecasts.

DATA ASSIMILATION AND PROCESSING

Conclusions

Communication of observations from around the world is inadequate to meet the complete data needs of NWS. Some of the links are too slow, and some of the data reach NWS too late or not at all.

Current computer systems supporting NWS and NESS are obsolescent and inadequate to meet evolving requirements. There is a need for finer computing resolution to improve precipitation forecasts, for example, as well as for improvement of processing of satellite data, and to support increased research activity to improve data analysis and assimilation and model realism.

Present computer planning is addressed predominantly to upgrading the NOAA computing complex located in Suitland, Maryland. There is little long-range planning that addresses in a comprehensive and integrated way such items as data sources and their communication support, computers at Suitland and in the field, networking of computers, and network standards.

Recommendations

NOAA must proceed vigorously to upgrade the computer systems available for conventional data processing, for satellite data processing, and for numerical weather prediction.

The Automation of Field Operations and Services (AFOS) communication and display system, which has encountered some delays, must be completed expeditiously.

Time-lapse satellite images merged with other data should be made available at Weather Service Forecasting Offices (WSFO) as soon as possible.

The NWS should develop operational objective mesoscale analysis procedures, including surface hourly observations. Prototype procedures exist today in a number of university research groups.

Mesoscale prediction models will be developing rapidly in the coming decade. The NWS should plan for their operational use, recognizing the substantial computer resources required.

NWS should take the lead in encouraging a WMO modernization of the global communication network for conventional surface-based data.

NOAA must commence in a formalized way to plan comprehensively for the computer/communication networks that will be required in a future environment for the NWS — an environment that is data-rich, product-diverse, and interactive.

To make best use of NOAA programming talent, emphasis should be placed on developing only the software which supports the human/computer interface and is unique to the NWS mission. With increased professional capabilities in the field, applications software for local problems can be developed and supported by local talent.

DATA DISSEMINATION

The communications industry has developed and is developing an impressive number of new communication systems that can serve to collect and disseminate weather information and support services to a wide range of users, including the general public.

It is not necessary that the National Weather Service sponsor new communications technology — it is only necessary that NWS choose the most economical service to meet a particular need.

Conclusions

Satellite communication systems will offer inexpensive broadband capability for both worldwide point-to-point communication and regional broadcasts. They will also make possible expansion of the current capability of remote-sensing readouts. For example:

- Satellite ground terminals are proliferating at a rapid rate. The Public Broadcasting System (PBS) network, for example, offers opportunities to disseminate weather information as a public service. This can be done as a caption channel without interference with other transmission, or as a regular television broadcast program, such as "AM Weather."
- Direct broadcasting to home television sets from satellites will become available within this decade.
- Cable television (CATV) offers opportunities for direct weather dissemination and may, in the future, also offer two-way communication possibilities with interactive capability.
- Regular broadcast television can offer the capability of weather dissemination through broadcast interruption, through the use of captions, or through utilization of the television retrace time.

The telephone system also offers several types of improved communication links:

- touch-tone reporting from human-attended observation posts (e.g., state police offices);
- dissemination on request through either advanced types of information distribution such as the code 800 system, or through the use of home television sets to display information from telephone-accessed data banks; and
- FAA weather information for general aviation through the voice response system (VRS), which could also include other weather information.

Terrestrial links will also offer broadband capability using digital format on coaxial cable or optical fiber transmission links.

NOAA Weather Radio, "AM Weather," and the FAA's voice response system are successful in bringing weather information readily to the public.

In the design and introduction of new data collection and dissemination systems, NWS should be sensitive to the cost and change-over transition time imposed upon its specialized users, such as universities, private meteorologists, and weather modifiers.

The NWS dissemination system should remain highly decentralized. If a field station is a unique source of data or information, it must be prepared to disseminate the data or information electronically as required.

Specific warnings need to be directed to affected areas as mesoscale observational and forecasting capability increases in the future.

The public will need, and demand, a wider variety of information presentation in the future.

Recommendations

NWS should plan for extensive use of satellite communication capability in the future.

To make optimal use of modern communication capability, an all-digital format is recommended.

Further uses of telephone systems should be explored, including touch-tone data reporting and code 800 distribution for remote-location weather information.

The implementation plans of NOAA Weather Radio should be completed. The possibility of adding channels should be investigated. Legislation should be prepared to require inclusion of NOAA Weather Radio (which is linked to the Civilian Defense Alert System) channels to all appropriate new radio and television receivers.

The AFOS system is a good step toward a capable two-way communication system linking all forecasting offices. The possibilities of upgrading the system in the future to take advantage of broadband communication systems should be studied.

Ways to implement site-specific warnings, using such means as direct-broadcast TV and CATV, should be studied.

A study should be made of what new presentation formats will be needed and feasible in the future for the public and user groups, e.g., time-lapse sequences, special graphics, false color. Even if NWS itself does not produce such formats, NWS information should be in a form suitable for input to the computer graphics systems that will produce them.

SELECT COMMITTEE ON THE NATIONAL WEATHER SERVICE: REPORT OF FINDINGS

1. STATEMENT OF TASK

The Administrator of the National Oceanic and Atmospheric Administration (NOAA) requested that the President of the National Academy of Sciences establish a committee to "evaluate the probable impact of scientific and technological developments on the operation of the National Weather Service" (Appendix A). The study was to emphasize the functional aspects of the incorporation of new technology. (Organizational details within NOAA and the question of public/private division of responsibilities were being addressed in other studies.) NOAA asked that the Committee examine technological advances in systems for observing, data handling, and communication with regard to opportunities for developing new weather services or significantly improving existing services.

2. WEATHER SERVICES AS AN INFORMATION SYSTEM

The National Weather Service (NWS) of NOAA is essentially an organization for collecting, processing, and distributing weather information. A complex system of people and machines transforms the raw weather observations and data into the final products needed by the public and many specialized user groups. Technology plays a key supporting role, but at some points in the system, humans are indispensable, as will be discussed in Section 5.2 and also in the Committee findings (Section 7).

The basic global data base derives from the following:

- upper-air stations (about 140 in the United States, about 1000 worldwide);
- land-surface stations;
- a few special weather ships and many commercial ships of opportunity;
- aircraft of opportunity; and
- satellites.

Most of the observations from these observational systems are exchanged internationally (observations of purely local interest are usually kept in the country in question, but may be available on request or published in summary form).

A discussion of the various steps of data processing and transformation into weather information products is given in Section 7.3.1.

In addition, NWS keeps track of and forecasts smaller weather events in local regions, especially severe weather phenomena — storms, frost conditions in sensitive agricultural areas, and other conditions hazardous to life, property, or human activity.

Some background information on the status of NWS observational capability and forecasting success for small and synoptic scales, for longer, climatic-scale weather events, and for hydrological services is given in Section 6.

Some 500 information products, produced mainly by computer-driven automatic graphic systems, are available each day at the NWS National Meteorological Center (NMC) and distributed by a number of NWS field offices for their regional and local use; a few of these products are also distributed directly to users. The distribution of these materials is summarized below.

3. CURRENT WEATHER INFORMATION DISSEMINATION SYSTEMS

Direct information from NOAA is available in most major population centers via NOAA Weather Radio, a network (some 70% complete now) of FM stations in the 2-meter band (nearly the same as commercial FM and some television bands). It is estimated that some 90% of the population will be reached by these broadcasts when the network is fully implemented in 1980. The remaining population lives either in sparsely populated regions where it will be impractical to implement stations and data preparation services, or in mountainous regions where propagation (line-of-sight at these wavelengths) limits service.

Weather information products (observations, forecasts, warnings, summaries, etc.) are made available several times a day via NOAA Weather Wire to users who wish to implement a connection to this service. Most newspapers, radio stations, and television stations, for example, use this information as bases for summary weather statements to the public. A program called "AM Weather" is distributed to some 150 Public Broadcasting System television stations via communications satellites. Many commercial television stations employ professional meteorologists and many have organized their own volunteer observing networks. They use complex graphics, sometimes supplied by commercial vendors, to display the information. Weather information and forecasts supplied by NWS are also available in most major population centers through the courtesy of the telephone companies; recorded forecasts similar to those broadcast on NOAA Weather Radio are thereby made available. Such private and semipublic distribution of information to the public constitutes a major capital and operating investment by the private sector (as discussed in Section 5.1) and is the major source of weather information to the public.

These kinds of services serve well to disseminate information on the larger-scale weather events: the general weather for today and trends for the succeeding few days. Television and radio stations also broadcast alerts for special situations, such as tornadoes, high winds, hurricanes, floods, and severe thunderstorms. NOAA Weather Radio provides an automatic signal to turn on sets equipped with a standby capability.

Through the Federal Aviation Administration (FAA), special weather information is also available to general aviation by means of telephone briefings from local airports. A new system, automatic Voice Response System (VRS), which may be accessed through touch-tone telephones, is now operating on a test basis in two local demonstration areas (Washington, D.C., and Columbus, Ohio). FAA plans to deploy this system nationwide. En route and terminal information is also available.

There are, however, some notable deficiencies in the current distribution system. NOAA Weather Radio, when completed, will reach only about 90% of the population; it will probably not be practicable to extend NOAA Weather Radio coverage completely to all areas. Moreover, in areas that will be covered, not all users have equipment to receive the broadcasts. It is already mandatory to include the weather channels on new marine equipment. These could also be incorporated in automobile FM sets, and it would be a straightforward and low-cost matter to add the channels to newly built TV and home FM receivers.

At the present time, warnings are broadcast to large regions instead of being directed more specifically to localized areas most likely to be affected by severe small-scale events.

The large-scale weather information products issued centrally in Washington have a twice-a-day cycle, taking some 8 hours from observation time to the time when all products are distributed. Thus, this information is late in reporting changes in the large-scale patterns, especially as related to fast-breaking weather events. Additionally, these twice-daily summaries may not be available at the optimum local times in the United States. The international observational and data exchange system is geared to the observational time cycle of 0000 and 1200 Universal Time and it will be some time before the strictly synoptic system (i.e., observations made at these coordinated times) is gradually replaced by a continuous flow system of observations from satellites and from automatic, continuous, ground-based sensing and remote soundings systems. When such systems come into being in the next decade or so, there will be need for vastly improved information processing and distribution systems to get near-real-time information to the public and to users who need to respond to such timely information.

4. PUBLIC AND PRIVATE INVESTMENTS IN WEATHER INFORMATION DISTRIBUTION

4.1 Private Meteorological Services

There is considerable private for-profit meteorological business activity in the United States. There are some 250 private consulting meteorologists certified by the American Meteorological Society, with an annual gross income of the order of from $5 million to $10 million. There are about 50 meteorological information businesses in operation grossing about $10 million to $50 million. This estimate does not include private weather modification services and is necessarily a rough estimate since detailed figures are not publicly available. In most cases these individual consultants and private weather companies use NOAA weather information and process it further to provide customized information products for users who require such personalized or value-added services. In many private, competitive situations, users require proprietary services inappropriate for a federal agency to supply directly, thus the private sector fills an important service need.

In addition, many companies incorporate their own meteorological staffs and data collection capabilities; the commercial airlines are a good example. The annual cost of such services is estimated to be of the order of from $10 million to $50 million. All in all, private meteorological information services in the United States probably account for $100 million or more annually.

4.2 Cost of Public Weather Distribution

NOAA operates a Weather Wire and Weather Radio service; these direct costs are not considered here. The public side of the NOAA Weather Radio investment is in the receiving sets that the public buys. It is estimated that there are approximately 15 million receivers currently in use for NOAA Weather Radio. Some of these are part of multi-band sets. Many are special-purpose radio receivers; consumer grade receivers are priced in the range of $15 for a modest receiver to $40 for a crystal-controlled, signal-activated receiver; institutional grade receivers are in the cost range of $100 to $350. The annual public investment may be of the order of $100 million for receivers. As the public becomes more aware of this service, the investment will increase.

In most centers of large populations, there are multi-line telephone facilities for NOAA weather information (similar to the information broadcast on NOAA Weather Radio). For example, in New York there are some 1,600 lines; in Washington, D.C., there are about 850 lines, etc. It is estimated that there are about a billion calls per year for this telephone information. Based on a minimum toll from a pay telephone of 10¢, the total value of this service, from the viewpoint of the telephone service alone (supported as a public service by the telephone companies), is of the order of $100 million.

Approximately 4 million minutes of air time are scheduled each year for television weather summaries. The average "cost" (not advertising value) is about $135 per minute. The total cost, then, of television weather dissemination is about $500 million. It is estimated that about 120 million minutes per year of radio time are devoted to scheduled weather information. Based on an average cost of about $8.30 per minute, the total annual cost is about $1,000 million.

The total aggregate *annual* cost, taking a conservative view of the "value" of weather information to the public (in terms of willingness to bear the cost of its dissemination) comprises about $1,500 million per year for television and radio, about $100 million per year for telephone service, and about $100 million per year for NOAA Weather Radio receiving equipment — for a total of $1,700 million. It is likely that this rate will increase. Not all of the above amounts, of course, are direct out-of-pocket expenses, but, nevertheless, they represent a reasonable estimate of an expense attributable to someone other than the federal government.

5. COSTS OF CIVILIAN WEATHER SERVICES AND THEIR BENEFITS

5.1 Costs of Services

NOAA budgeted some $350 million in FY 1980 for weather operations and supporting research (NWS, the National Environmental Satellite Service, and some elements of the Environmental Research Laboratories). The next largest civilian expenditure — some $90 million — was by the FAA. The National Aeronautics and Space Administration (NASA) allocated about $57 million, mostly for supporting research (development of new spacecraft, experimental systems, etc. — not all of which will find their way into NOAA operations). In consideration of NOAA alone, and taking into account that the U.S. Bureau of the Census population projection for 1980 will be about 225 million, the major civilian weather service has an annual per capita cost of $1.55. All civilian weather services in FY 1980 total about $515 million — an annual per capita cost of $2.29. The data given in Table 1 are based on current estimates (per taxpayer and per household) from the Census Bureau.

TABLE 1 Annual Costs of Daily Weather Information

	NOAA	All Civilian Agencies	Non-Gov't
Acquiring weather data, per capita	$1.55	$2.29	
Disseminating weather data, per capita			$ 7.55
Acquiring weather data, per taxpayer	$2.48	$3.65	
Disseminating weather data, per taxpayer			$12.06
Acquiring Weather data, per household	$4.35	$6.40	
Disseminating weather data, per household			$21.12

The dissemination costs given in Table 1 are a minimum estimate, in that they do not include the cost of newspaper coverage or the cost of special additional coverage by public news media in times of severe weather events such as flood, wind, hurricane, tornado, severe hail, heavy rain, snow, icing, etc. For some of these events, television and radio outlets put on special crews and devote much costly air time to this service.

5.2 Benefits from Services

There have been a number of general and specific studies on the benefit-cost aspects of weather information. These numerous studies are at times spotty and selective, and often do not include many other factors that affect the economics of a situation. A few examples will serve to illustrate some of the dimensions.

In February 1978, a large-scale severe winter storm developed over the Northeast of the United States. The snowstorm struck on a Sunday night. It was, in the opinion of many weather experts, the most severe storm event documented in the region. One week later, Providence and Boston still had restricted traffic flow. While the NWS forecasts during this period provided much useful general guidance to the public, improvements in the observing and forecasting techniques of the kind addressed in this study would have increased their value and timeliness.

The NWS forecasts could not serve some very specialized needs in this weather emergency. For example, a large food distribution company had employed the services of a private meteorological consulting firm, which used the NWS information to make a more detailed estimate of the storm development as related to the company's operations. Based on the private value-added forecast, the food company notified food outlets that regular Monday night deliveries would be advanced in time, to take place over the weekend. Motel rooms were booked for drivers and warehouse personnel. Snow removal provisions were made for the warehouse. Shipments moved 2 days earlier than normal. By Monday evening most of the region was paralyzed, but the food company had accomplished some 90% of the delivery rounds from Delaware to Massachusetts (*Business Week*, February 27, 1978).

This example illustrates at least two important points: (1) As good as the weather services are at present, substantial room remains for improvements in important details for severe weather events — severity, duration, better pinpointing of locale, e.g., the kind of mesoscale, timely forecasting discussed in this study that is becoming possible using new technology. The forecast accuracy now available is useful, *if the forecast is used*. Improved forecast accuracy in the future will more than pay the cost of improvement, *provided the forecasts are put to use*. (2) There are important customized services that the NWS cannot supply to individual users. Private services perform an important economic role in that they contribute significant added value to the NWS information. These private services, however, must depend on the NWS to supply accurate and timely basic forecast guidance. Improved forecast and dissemination services will facilitate improvement in the specially designed, value-added, customer weather services undertaken by private industry.

A number of studies have been undertaken with respect to weather information for commercial aviation. A study in the United States in the early 1970s (B. Beckwith, *Bulletin of the American Meteorological Society*, September 1971) discussed the many details of aviation needs, including safety, of course, and better route planning. In the face of increasing fuel costs, current studies on benefits of forecasts to route planning for minimum fuel use indicate important benefits, including not only saving in fuel costs, but also indirect benefits of on-time flights and avoidance of severe delays arising from weather by rerouting (e.g., trading a small inconvenience for a greater one).

In the mid-1960s, upon taking up his new duties and finding no useful benefit-cost information in his country, the Director of the United Kingdom Meteorological Office undertook a study of the benefits versus costs of the services provided by that office (B.J. Mason, *Weather*, November 1966). With respect to commercial aviation, his conservative estimate, including fuel, operations, timeliness, cost of insurance, etc., put the benefit-cost ratio at 6.5 to 1. A larger ratio was estimated for general aviation. A number of other applications were reviewed in this study, but the closing remarks were reserved for public use of weather information. Dr. Mason assumed, mainly for convenience value, that an average family makes one weather-related decision a day. Putting a value of twopence (2.5¢ U.S. currency) on this decision, a value that he hoped "does not flatter the ego of the professional meteorologists," he found a benefit-cost ratio of 15 to 1! Dr. Mason (now Sir John Mason) concluded "that the Meteorological Office gives the taxpayer excellent value for their money; that, even so, the meteorological advice is both underused and undervalued; and that we should be able to make an even larger contribution to the national economy in the future." That was 14 years ago. The Committee finds that the situation is no different today, as discussed in Section 7.1.

In a later study, a meteorologist from New Zealand, while on a visit to a U.S. university, conducted a study on the information transfer processes involved in use of weather information as related to business activities (W.J. Maunder, *Weather*, January 1973). The author admits that benefit-cost ratios derived in the study seem to be high. He remarks that "if this high benefit-cost ratio is to be realized, then the atmospheric scientist must not only work closely with experts in particular weather-sensitive enterprises, but must also provide the decision-maker in the various weather-sensitive enterprises with the appropriate weather information and in the most useful form." He summarizes by quoting a colleague: "The art and science of weather prediction and the application of lessons from past climates to future climatic probabilities will yield great economic and social benefits in the future, provided the communication media allow the fullest two-way contact between the producer and the consumer. It is throughout a problem in communication and marketing." Another quote from a colleague summarizes some aspects of the communication and human parts of the system:

> . . . In some important instances, the greatest contribution a meteorologist can make is to find a way to establish real communication between a certain group of decision-makers and the meteorological system. This is not to say that all a National Weather Service has to do is to provide information to management (or to the general public), and then wait for the economic benefits to become obvious to all concerned. But it surely is true that no economic benefits will accrue to the meteorological information system from a weather-sensitive segment of the economy in which the persons making management decisions are (1) not aware of the availability of meteorological information; (2) aware of the potential value of meteorological information, but do not have any channels through which such information may be received.

This study highlights an important aspect in the planning of the communication systems of today and tomorrow and implies some important considerations. New communication capabilities using advanced technological means will enhance the flow of information from the producer to the user. However, there are some kinds of information not transferable merely by electronic means; there is a critical and important interplay between producer and user that takes place on the human perceptual and intellectual level, not on a computer-based level. As the Committee discusses below, the human part of the chain is and will remain indispensable. Here the human will be aided by technology, not replaced by it.

As a quite different dimension to the value of weather information, a recent study (W.F. Zeltman, *Bulletin of the American Meteorological Society*, September 1977) traces the development of private consulting and business groups in the weather information field. From 1954 to 1979, the number of businesses increased by a factor of more than five. There has also been a significant shift in the kinds of services offered. Forensic services, for example, increased from a nearly insignificant proportion in the late 1960s to become the fifth prevalent weather service. This indicates the high need and economic importance of reliable weather information for legal and insurance matters. On the other hand, some areas show evidence of strong underutilization of weather information; construction and hydrology are two surprising entries in this low-utilization category. Is it because users do not appreciate what information is available and how it can be used?

NOAA commissioned a public survey study in the Denver area, and also queried aviation industry representatives in four U.S. locations, in connection with its efforts to develop a "Prototype Regional Observing and Forecasting Service" (PROFS). The purpose of the study was to determine if significant economic and convenience benefits might result if selected immediate and 12-hour local weather forecasts were improved. Major findings included:

- Urban householders are twice as likely to use a weather forecast for recreational activities than for commuting to work.
- Rain and snow forecasts are used more often than other types of forecasts for days on which shopping trips are planned.
- A substantial majority of urban householders were unable or unwilling to estimate potential economic savings accruable from improved weather services.
- Urban householders perceive 30-minute local forecasts as more valuable than 3-hour forecasts, with 12-hour forecasts seen as least valuable.
- Current rain forecasts are used most often by Denver area dryland wheat growers.
- Improved rain and wind forecasts would be of greatest use to dryland wheat growers.
- Alfalfa and corn growers within 100 km of Denver would be most likely to use improved rain forecasts.
- Livestock raisers could benefit most from improved snow and low-temperature forecasts.

- The estimated annual value of improved forecasts ranges from over $1 per acre for corn and barley to nearly $4 per acre for alfalfa.
- Improved rain, hail, and wind forecasts would significantly improve work schedule convenience for farmers.
- Aircraft and air crew operating costs and wasted passenger time could be reduced significantly with improved local 0 to 12 hour forecasts.

In the Denver area, the advertising and news directors of the major television outlet (in terms of viewer coverage) report that weather information is an important ingredient in their sales picture. They do not foresee a significant expansion in the scheduled time that they allotted to weather news, but their station would be most pleased to have more details on local weather events and more advanced graphic material. Their contact with the public shows that the average listener regards weather as the major news event that influences an individual and the individual decision processes: is it going to rain, snow, or blow or will the sun shine on *my* head?

From these kinds of sample studies and reports, the Committee concludes that we are far from reaching a point of diminishing returns in the utility and benefit-cost aspects of improved weather information. But additional benefits will not accrue simply by making technological improvements. A healthy producer-client dialogue must exist to make sure that weather data are tailored and interpreted to meet the need, that the information is communicated to the client, and that the data are used intelligently. Here, "intelligent" is not meant as "smart," but rather in the information theory sense of using weather data as part of the total intelligence at the disposal of a user to make important personal, business, or policy decisions.

6. REVIEW OF CURRENT STATUS OF NWS FORECAST SERVICES

It is characteristic of the physical nature of the atmosphere itself, its driving forces, and its relationships with the surface conditions (land and ocean) that there is a rather distinct separation of concentration of energy between small and large weather phenomena. Examination of the distribution of atmospheric energy versus space scales revealed that there are two major peaks. One peak occurs at a space scale of some few thousands of kilometers with an associated time scale of days to weeks (this is called the *synoptic scale* of weather disturbances). The other peak occurs at a short scale between a few tens of kilometers to one hundred or so kilometers (called *mesoscale* disturbances) with the associated time scale of hours to a day or so. Furthermore, atmospheric phenomena are not random; the atmosphere functions in preferred modes. Knowledge of such families of patterns is useful in forecasting and interpreting weather phenomena.

Comments are given first on the status and future prospects for synoptic forecasts. There are fundamental relationships of the data requirements and information products generated for this range to those of the mesoscale (short-range), and also to the longer-range, climatic forecasts (monthly, seasonal, and interannual ranges).

6.1 Synoptic-Scale Forecasts (up to 1 week or so)

Technological advances in the 1920s and 1930s (the development of the radiosonde), in the 1940s (radio/radar techniques of tracking the radiosonde balloons), and in the 1950s (electronic advances and the invention of modern high-speed computers) made possible that which meteorologists earlier in the century had proposed but were impractical at that time — mathematical models of the circulation of the atmosphere with real global data to specify the atmospheric state. The first numerical predictions of atmospheric flow were carried out in the 1950s on an experimental basis. Thus a new technological tool was introduced to study the atmosphere and to make automated forecasts — the numerical simulation model of atmospheric flow.

At the time of this study (nearly 30 years later), after much scientific and technical development and an intense international effort to improve the global data base, the synoptic-scale forecasts are produced automatically. Many kinds of guidance advisory products are produced for a variety of uses; most are produced automatically by computer-driven graphics systems. The northern hemisphere forecasts of the wind and temperature fields at several levels in the atmosphere, plus the surface pressure, form the basis for local interpretation by professional meteorologists. Useful forecasts extend to periods of from 3 to 5 days. The "skill" of a 36-hour forecast (that is, a measure of how much better it is than climatology) has improved from about 55%*

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*A "skill" of 50% means that one is wrong (or right) half the time based on long-term weather statistics (climatology).

(slightly better than climatology) in 1955, when forecast models were first used operationally, to about 75% in 1978; there are reliable signs that "skill" continued to improve in 1979 owing to better data bases. In addition, the "skill" at 3 days is now better than the "skill" was at 1 day in 1955. Forecast "skill," as used here, is a mathematically defined quantity with reference to a 36-hour forecast of winds at the 500-mb altitude level, and is thus not directly related to the degree of forecasting success of real weather at the surface, which is more difficult to quantify in a standard way. The "skill" factor, however, is a convenient and standardized way by which modelers compare the results of different kinds of models, and by which to judge improvements in forecasting ability over the years.

With continued improvements in the global data base, and better representation in the models of important physical processes, the "skill" will continue to increase and the usefulness of the forecast will continue to lengthen in time. The theoretical limit has been postulated to be in the range of from 10 to 15 days, but the practical limit may be somewhat shorter.

6.1.1 *Data Bases*

The global observing system for large-scale circulation features consists of the global surface and upper-air radiosonde networks, with important supplemental information from ships and aircraft and contributions from operational satellite systems (temperature and moisture soundings; wind fields derived from tracking of appropriate clouds). The global observing system was augmented during the internationally organized World Weather Experiment in 1979 by many special observing efforts. This special effort in 1979 produced the most complete global data set yet available, which is being used to assess the benefits to be gained by significant improvements in the global observing system. Full study of the 1979 global data set will take several years, but some early conclusions, summarized here, give insight into what will be necessary in the future. The technological implications are addressed in Section 7.2.

- The motion field (winds) of the atmosphere, especially in situations where energy transformations are taking place, contains important independent information that cannot be inferred with the completeness desired from the mass field alone (as specified by temperature profiles and surface pressures).

- The vertical distribution of temperature, as inferred from upwelling radiances in certain carbon dioxide and oxygen bands that are measured from satellite systems, is an important addition to the global observing system, particularly over the oceans and in land regions where the surface-based networks do not supply adequate coverage. In regions where observations are sparse, use of satellite-supplied temperatures improves the analysis considerably, even though there remain problems in data quality; in data-rich regions, the improvement is only marginal. It is believed that the perceived limitations to utility of these temperature observations arise from several effects. First, as a result of the physics of the radiation processes and interpretation of the observed radiances, the vertical resolution of the vertical satellite soundings is inherently limited and will never approach in resolution those of radiosonde observations. (Horizontal soundings, usually called limb soundings, offer the possibility of providing good vertical resolution at levels above those where clouds are prevalent.) A second problem is that spectral intervals selected are sensitive mainly to energy emitted from CO_2, but all the channels are also sensitive to some degree to energy emitted by other atmospheric constituents — O_3, H_2O, and aerosols. The energy from these variable constituents measured at the satellite contaminates the sounding and cannot be removed completely. Thus, a certain level of statistical noise is introduced into the satellite-derived temperature soundings. A third problem is that the temperature retrievals are statistical, not absolute. The statistical base may be inadequate in some important regions. Finally, an independent reference point on the vertical profile is required and the temperatures of important inversions, such as the tropopause, are not obtained satisfactorily. In addition to these inherent limitations, the current and operationally expeditious manner in which the satellite-derived temperatures are used (that is, by converting them into surrogate radiosonde profiles) is probably not the optimum use of this information. Nevertheless, because these observations have uniform global coverage and good horizontal resolution, and derive from a uniform data system, it is believed that satellite radiance observations in the infrared, as well as in the microwave (a different set of limitations apply here), will continue for some time to be the most practical observing technique to provide observations over the oceans for the determination of the mass field.

- Observations from ships and aircraft are highly useful in the data-sparse regions. The newly developed Automated Satellite Data Relay (ASDAR) systems used experimentally in 1979 on wide-body commercial jet aircraft equipped with inertial navigation systems provided highly useful wind and temperature information along the flight tracks, often in regions where other *in-situ* observations were nonexistent. These automated systems have added significantly to the many single (non-ASDAR) aircraft wind reports gathered and used by the National Meteorological Center. These wind observations are of direct value to aviation in the short term for aircraft routing, and are particularly valuable to all weather services as input to the numerical forecasts. Ship observations of wind, surface pressure, and temperature are extremely valuable for forecasting and for shipping operations. Automatic data relay through satellite systems makes it quite practical to implement an efficient and automatic data collection system.
- During the 1979 Global Weather Experiment, nearly 300 simple buoys, carrying pressure and temperature sensors, were deployed in the Antarctic and the southern parts of the Atlantic, Pacific, and Indian Oceans. Sensor observations were relayed via satellites, which also localized the buoys. Countries in the Southern Hemisphere found these observations extremely useful in improving the surface analyses in their region, and they are working toward operational use of such buoys. It was found, for example, that the storm centers in the "Roaring Forties" were actually more intense and longer-lived than had been inferred from the occasional ship measurements made in these regions. The United States has a practical interest in helping to continue the buoy system. The Southern Hemisphere cannot be neglected if reliability of a northern hemisphere analysis for behond 5 days is to be achieved. In addition, long-term monitoring of the state of the surface conditions, especially over large oceanic areas, is important to the study of mechanisms responsible for climatic variability (as discussed below).

6.1.2 *Data Communications*

The meteorological services of the world cooperate through the World Meteorological Organization (WMO) to operate a global telecommunication system (GTS) for the collection of observations and the distribution of processed information. Observations are encoded manually or automatically and introduced into the telecommunication system shortly after agreed-upon standard observational times (e.g., 0000 and 1200 Universal Time) for upper-air soundings). The amount of data is not very large for most observations; satellite observations, and especially imagery, are a major exception. The trunk line of the global system, connecting the major meteorological centers, operates at a data rate of some 2400 bps (bits per second), but feeder lines are often much slower. However, the bit rate itself is not necessarily the main bottleneck. Modern techniques could allow enormous increases in capability. Reliability is the keynote. Some useful observations reach the National Meteorological Center (NMC) too late for inclusion in the daily forecast cycles; some never arrive. The United States assists some countries directly in improving their communications capability. Efforts are also under way in the World Meteorological Organization (which is a coordinating agency, not an operative one) to expand the ongoing voluntary international assistance given to countries for such operational improvements.

Internal communication in the United States system is controlled from the NMC facility near Suitland, Maryland (in the vicinity of Washington, D.C.). On-line communication switching computers are overworked at present, but plans are under way for an upgrade that should allow for a more efficient communication system. The communication links and capabilities are being designed with a view to the increase in observations that is planned for the future and to the establishment of modernized communication circuits connecting the 50 Weather Service Forecasting Offices (WSFO) to NMC. The effort is part of the Automation of Field Operations and Services (AFOS) implementation (as discussed below).

6.1.3 *Numerical Models*

NMC includes a substantial research effort in improvements in various kinds of models, including those used to make forecasts. Work is under way, for example, on better models to optimize analyses of observations to produce smoothed information fields and to extract more useful information from remote-sensing systems (such as those for temperature inferred from satellite observations of upwelling radiances). For forecast models, more realistic and feasible representations are being developed of important physical processes that influence evolution of weather events but cannot be carried explicitly in an operational model (e.g., characteristics of the planetary boundary layer, cloud formation, precipitation mechanisms).

Improvements in data bases as mentioned above, improvement in model realism, and better use of observational information seem likely in the future. Significant increases in computational resolution also seem likely. Moreover, the physical improvements in models will increase demand on computer capability. It is known also that computational resolution must be increased to improve some kinds of forecasts. These factors will require greatly increased computer speed, along with greater size and ease of access of the memory. This matter will be addressed in Section 7.3.

6.1.4 *Field Use of Information/Prediction Production*

For the synoptic-scale forecasts, all observations are assimilated at NMC, and the northern hemisphere forecasts are made there. The data cutoff time for the limited-area, fine-mesh model (LFM) is 1 hour and 40 minutes after observation time, T. The forecast is normally completed, then, including the model output statistics (MOS), at T plus 4 hours. (MOS and their signifcance are discussed in Section 7.3.1.) The final prognosis and guidance products are completed at about T plus 8 to 9 hours. The first forecasts and the following more complete forecasts and information products are communicated to the 50 Weather Service Forecasting Offices (WSFO). There the professional meteorologists interpret the centrally produced information in terms of their local situation, terrain, and climatological history of the area. They also make use of local, more detailed observations and guidance material derived from computer products by meteorologists in the NMC Forecast Division.

In order to facilitate the production of the regional forecasts and advisories, several years ago NOAA initiated the development and implementation of a plan for the Automation of Field Operations and Service (AFOS), which receives data from a moderate-speed communication system connecting NMC with all 50 WSFOs. AFOS provides the capability to display, using video computer terminals, computer-generated text and graphics. The forecaster can call for a great variety of information and view several products simultaneously. Some data manipulation and interaction are possible. Information received and generated at each WSFO is communicated to the Weather Service Offices (WSO) in its region, where AFOS equipment is used to produce and disseminate advisories of an even more local character.

Automated forecast support for local regions is also evolving. For example, the forecast for North America will supply the basic information on the large-scale weather patterns. A local data bank at a WSFO or WSO will store statistical/climatological information on the kinds of weather that have happened in the past, and under what conditions. The professional meteorologist will then use the data bank to support interpretation of the weather situation and judge the likely weather evolution.

In order to make full use of the AFOS capability, additional meteorologists will be required in the field. Part of this need can be met by automating many of the observational functions and converting technical slots to meteorological positions through retraining of staff. To meet the full need, and provide opportunities for improved services and producer-customer feedback, additional meteorologists will be needed at the field offices.

6.2 Monthly and Seasonal Forecasts

NMC includes a unit that issues advisories for 1 and 3 months in terms of whether the temperature and precipitation will be above or below normal. Currently the work is based mostly on statistical regression analysis. There are no useful precursor signals or known mechanisms that can be invoked to make deterministic forecasts. The Climate Analysis Center is examining the existing data base (some 30 to 40 years in length for upper-air soundings) for clues as to possible future approaches to improve the forecasting skill (at present, just better than climatological). Investigation of several physical processes is also under way to see if additional clues can be found to understand the physical basis of climatic variability.

The goals are to be able to produce better advisories, with longer lead time, and to extend the scale to the interannual range. It is generally agreed that the major limitation now is scientific, not technological. However, significant improvements in the global data base needed for synoptic-scale forecasts will be valuable for studies of climatic variability and improvements in forecasting in this range. Long-term monitoring of ocean surface and upper-layer characteristics, elements of the earth's radiation budget, and solar variability should be continued to provide information critical to an improved understanding of climatic variability.

In view of the need to maintain long-term coherence of data sets for such studies, care must be taken in the implementation of changes in data collection, reduction, or summarization procedures to preserve the essential features of the historical data. It is important to provide a continuous and coherent data record against which historical and contemporary climatic fluctuations can be compared.

6.3 Mesoscale (Small-Scale) Depiction (Nowcasting) and Short-Time Forecasts

The present organization of observing systems, data collection, and synoptic analysis does not provide all the information needed to make real-time, reliable descriptions of current weather systems on a local basis, with updating as needed to account for rapid changes. The synoptic-scale analyses and forecasts discussed above do not and cannot depict the fast-breaking changes in local weather (squall lines, changes from rain to snow, severe thunderstorms, hail, tornadoes, flash floodings, etc.). In part this limitation is technological; there are insufficient observations available of small-scale weather events. Some volunteer networks do exist, but they are limited in time and space, and at crucial periods of severe weather the volunteers often may not be able to provide the needed observations because of other commitments.

To reach the goal of accurate and reliable depiction of local weather events, in near real time, it will be necessary to develop a practical, fully automated system capable of observing the atmosphere at short intervals in time and space. NOAA is supporting development of such a capability in its research division in conjunction with the NWS and the NESS. The Prototype Regional Observing and Forecasting Services (PROFS) is a critical step toward developing the local data observation, collection, and processing capability required. A 3-year plan has been organized for completion of systems planning and implementation of a pilot array of various sensors to service a local forecasting unit.

There are currently other questions that require further research. Pilot operational experimentation would be helpful. For example, the coupling mechanisms between the synoptic and mesoscale phenomena are not well understood and need investigation. It is not known explicitly how and in what circumstances energy is transformed in small-scale severe events and the relation of such energy transformation to events on the synoptic scale. There is not enough understanding of how mesoscale phenomena develop within synoptic-scale disturbances. There are some precursor features of the synoptic-scale and mesoscale that make certain types of severe weather likely, e.g., as related to tornadic occurrences.

Interesting examples of newly perceived and important mesoscale weather phenomena are the large mesoscale convective cluster systems, which are just now being investigated in detail. These latter systems seem to account for much of the severe summer weather in North America. They are quite different from wintertime disturbances and should receive research attention. A significant effort in NOAA is being devoted to understanding these mesoscale phenomena. They are easily spotted in their mature phase, when they are the size of a midwestern state. In this phase, they often become stationary, regenerating along the upwind or inflow edge and dissipating along the downwind edge. When the inflow is moist, heavy rains occur. *Post hoc* analysis, for example, showed that the Johnstown, Pennsylvania, flood of 1977 was the result of such a summer system. The Colorado Big Thompson flash flood in 1976 may have had a similar origin.

It appears most important to find out how and under what conditions these convective clusters form. For example, it seems possible to spot the early stages from hand-drawn surface charts using high-resolution surface observations. These observations are available, but at present are not routinely analyzed at NMC. Understanding these and other important mesoscale systems, how they originate and evolve, and the translation of research techniques into operational practices require the attention of skilled people equipped with adequate tools — interactive information processing and display equipment plus the data.

The many mesoscale phenomena currently being studied represent a class of important meteorological activity that has been neglected until recently in the research community and in the operations of weather services. The importance of these phenomena to public safety, however, has been recognized for some time. Theory and technology have now advanced to a point where research and pilot operations in mesoscale analysis forecasting are feasible. The Committee believes these activities should be given high priority.

Considerable research is also being carried out in the Environmental Research Laboratories (ERL) of NOAA on the use of fine-scale models to introduce into analyses important details of local forcing, such as terrain. Such small-scale refinements in analysis and simple forecasting models are thought to permit a substantial improvement in realism over the large-scale advisory products and forecasts produced centrally in Washington. This may indicate a need for a two-tier information system: centrally produced synoptic analyses, based on the global observing system, fed to regional offices (WSFOs) where local mesoscale (small-scale) information is introduced to transform the synoptic (large-scale) weather information products into more detailed local advisories. This information transformation process will be site-specific, taking into account the various local factors that experience and theory show to be relevant to production of local palpable "weather" under the conditions of the large-scale flow and pressure patterns.

6.4 Hydrological Services

NWS includes a considerable effort in hydrological services that are related to weather. For example, river and stream flow forecasts, including flooding, are obviously related to precipitation and, in some regions, to snow-melt conditions. NWS hydrological activities include research on river, stream, and snow-pack measurements, implementation of networks, development of numerical modelling techniques for a variety of forecasting needs, and the production of many forecast and guidance products. The hydrological services of NWS are quite analogous to weather services, *mutatis-mutandis*, including the longer-range, such as extended streamflow forecasts.

NWS operates 12 River Forecast Centers, which prepare river and flood forecasts and warnings for approximately 2,500 communities. River forecast models include such factors as soil moisture accounting, snow accumulation and ablation, reservoir operations, dynamic wave routing, dam-break, and extended streamflow predictions. These new models are a major change from the empirical/statistical models of the past. There is also under way in NWS an effort to identify the hydrological user community and its needs.

Mention is made throughout this report, as appropriate, of hydrological services, but the Committee did not cover this aspect of NWS operations and technological opportunities in depth. This selection was not dictated by any priority consideration, but more by the condensed time schedule of the study. The Committee believes that the NWS hydrological services are important. The Committee wishes to make clear that its support of the needs in NWS for increased observational, computing, and data-dissemination efforts apply to the hydrological as well as to the weather services.

7. COMMITTEE FINDINGS AND RECOMMENDATIONS

The U.S. Government recognizes both civilian and military users of weather information. While the Air Force and the Navy in particular are responsible for satisfying military requirements, the National Weather Service of NOAA has the principal responsibility to meet civilian needs. The Committee was impressed by the high level of cooperation and interagency backup provided by these various government agencies and recognized the essential support in advancing the art of meteorology provided by other government agencies, particularly the National Environmental Satellite Service, the Environmental Research Laboratories and the Environmental Data and Information Service of NOAA, the Federal Aviation Administration of DOT, the National Aeronautics and Space Administration, and the National Science Foundation. These contributions together have resulted in the commonly held belief that the United States provides outstanding leadership among the meteorological services of the world.

7.1 User Needs

For many years the National Weather Service and its predecessor organization apparently operated on the assumption that if they produced a good product someone would come to get it and use it. In earlier and simpler times, this may have been valid. The role of the National Weather Service, however, in educating the public as to the availability and use of its modern, comprehensive products has been too small. The past decade has seen some advances; the NOAA Weather Wire, NOAA Weather Radio, and "AM Weather" are outstanding examples of efforts to disseminate more widely the products of their work. Commercial television and the telephone companies have helped also. Private meteorology has grown and is providing many special services. Overall, however, the rate of utilization of information supplied by the National Weather Service is still too low. Users are currently left largely to their own devices in determining what is available and how to use it; many are unaware of the information available. As a result, the potential benefits of the excellent information currently available are not being fully realized. User confidence in short-range forecasts is compromised by the lack of confidence in medium- and long-range forecasts.

7.1.1 *Definitive User Study*

The National Weather Service considers that its primary responsibilities are to provide:

- warnings of severe weather and flooding for the protection of life and property;
- public forecasts for land and adjacent ocean areas for planning and operation; and
- weather support for (1) production of food and fiber, (2) management of water resources, (3) production, distribution, and use of energy, and (4) efficient and safe transportation.

The spectrum of potential users of weather information is broadening with each passing day. No comprehensive listing of the uses of weather information is presented here, although a number of authors have listed some of these users and examined the value of specific uses (as summarized earlier in Section 5.2). The largest proportion of users of weather information obtains that information from commercial radio and television broadcasts, and much of this "use" is in the same category as news and sports. No action may result from receiving the information, but people desire to know what is going on and are stimulated by weather events as by other events in the world around them. While it may be said that weather is a spectator sport and diversion for many people, the public does need to know about hazardous or unusual weather situations. The "recreational" aspect of weather is economically very significant as witnessed by the very large sums (when compared with the total National Weather Service budget, as summarized in Section 5.1) spent on weather dissemination by commercial broadcasters. This wide diversity of interests and potential benefits emphasizes the need for a definitive user study to:

- identify significant user groups and categorize them by such considerations as safety of life and property, size, potential economic impacts, and needs of national defense;

- define specific user needs in terms of products, forecast periods, frequencies; and
- project benefits and costs of providing alternative levels of weather information service as a basis for rational allocation of future NOAA resources and for assessing user charges where significant, separable incremental costs are identified for specific services tailored to specific groups.

The user survey should be initiated in the context of establishing a mechanism to provide continuous feedback from the users as to the effectiveness of the information provided and their evolving needs. As such, it should be a continuing function rather than a single study.

7.1.2 *Public Information and Dissemination Programs*

Once the user community has been clearly identified, its needs defined, and the economic impacts of various levels of information estimated, the problem of designing an information and dissemination system must be addressed. The NWS needs to provide leadership in public education and to stimulate innovation in dissemination techniques. The overwhelming majority of small businesses or individual workers is not utilizing the available weather information effectively. Moreover, they have no resources or channels of communication to use to inform the NWS that a different product at a different time would be useful to them.

The National Weather Service has a responsibility to see that users understand what weather information is available and how it should be interpreted for maximum impact on public health and safety and national productivity. The average user has little background, for example, in the concepts of risk and probability and only a marginal basis for translating numerical predictions of specific weather variables into terms that will relate directly to specific plans or needs.

A major study is needed to define the public education required to raise the level of awareness of the excellent weather information currently available. Once additional interest and a higher level of use are generated, the feedback will enable the NWS to tailor and modify its products in accord with user needs. There is little or no evidence that this loop has been closed today. Even in those areas where efforts to improve dissemination are clearly evident, it is not evident that studies have been done to assess the effectiveness of these efforts.

Productivity increases and reductions in losses will be in proportion not only to the quality of the information available, but also to how well the consumers know what information is available, how they may gain access to it, and how to use it. A series of user manuals should be produced for wide distribution to all users. These should provide clear, concise information on the types of NWS services available, procedures for obtaining them, and information on interpretation and use of the products. The design of future dissemination systems must take into account the broad spectrum of users and recognize the similarly broad spectrum of types of data and information that must be supplied. All members of society are the beneficiaries of dissemination of the information, because it results in better planning, reduced losses, and higher efficiencies and productivity for the society. Consequently, a rational basis must be provided for addressing the needs of all classes of users according to the ultimate benefits to be derived. The fact that some users may be using the information for profit is an indication of an appropriate and socially beneficial role of a federal agency such as the NWS. Thus, the NWS must be concerned about providing timely and high-quality data and information to all its users. This is a significant and endless responsibility and will require continuing analysis and research to insure that it is being met.

As an aid to improving the National Weather Service image, it is suggested that organizations and media distributing National Weather Service products be required to credit the National Weather Service explicitly as the source.

7.1.3 *Additional Professional Meteorologists and Hydrologists*

Many potential users of weather information require some level of professional consultation in order for them to use the data or information effectively. For this clientele, the system of dissemination must have a professional interpreter between the information and the individual user who acts on the information. Many television and radio outlets treat weather as news and entertainment; this has a positive effect of increasing public awareness, but the limited time that can be devoted on commercial television and radio often does not permit dissemination of information with the needed details. As a result, people who must make weather-related decisions must then seek other sources to be sure than an important part of the information has not been lost or distorted. A telephone call to obtain a recorded weather forecast (one billion calls per year) or tuning into NOAA Weather Radio will in many instances provide the additional information needed. In some cases, end users of information for decision making are able to telephone an NWS meteorologist to get information or advice.

Many corporations with activities that are weather sensitive have direct access to NWS data and products through leased lines or satellite links; many have their own meteorologists who produce the needed information. A large number of corporate and professional users deal with meteorological consulting firms that have access to NWS data and products. Others, such as universities, use current NWS data and products in their instructional and research programs. The military services provide their own analyses of basic NWS data. Nonmilitary federal agencies include the Interior Department's Water and Power Resources Service (formerly Bureau of Reclamation), which utilizes NWS data in its weather modification research program as well as in its planning and operations. The Federal Aviation Administration (FAA) provides briefers and, via the NWS, meteorologists in the Air Route Traffic Control Centers to interface with general aviation users, the safety and economy of whose operations are significantly affected by weather.

General aviation (i.e., all aviation activity except certificated air carriers and the military) includes nearly 200,000 aircraft (99% of the total) flown by some 800,000 pilots. These are largely nonprofessional aviators, who do not have access to private weather services and who, therefore, depend almost exclusively on information obtained from the NWS through FAA briefers. This segment of the aviation community is expected to increase in size and activity through the foreseeable future.

As aircraft capabilities increase (power, performance, and instrument sophistication) and general aviation pilots become better trained and more ambitious in their utilization of light aircraft under instrument flight rule (IFR) conditions, a significant safety consideration appears. Pilots need accurate, timely, and specific preflight weather information (reports and forecasts) for thousands of locations throughout the nation. There is also a need for timely dissemination of weather changes that could affect flight safety.

Of particular interest to the majority of the general aviation aircraft (those aircraft limited by performance capability to the lower, cloud-prone levels of the atmosphere) is information relating to the height of cloud tops and the location of regions where turbulence and structural icing is probable. Experience has demonstrated that not only is there a lack of valid information in these areas, but also these conditions are responsible for a significant number of hazardous incidents. It appears that as a result of new technology in data-gathering for micro-, meso-, and synoptic-scale weather, the NWS will have available a wealth of new information, which can also be used as a basis for special reports, forecasts, and information on hazardous meteorological trends of great interest and concern to general aviation.

Two fairly recent developments are remarkable as examples of facilitating the dissemination of weather information to NWS-dependent pilots: one is the AM Weather program available through satellite feed to the PBS system; the other is the voice-response system, which enables instant access to nationwide weather information through touch-tone telephone (currently on a demonstration basis in Washington, D.C., and Columbus, Ohio). These systems enable general decision making during preflight planning, which should be followed when necessary by more specific consultation with a professional meteorologist or at least a specifically trained technician.

Interviews with private meteorologists and their clients and with agricultural, aviation, and other industrial users reveal that the degree of knowledge on the part of the meteorologists of the operational problems of the client and the ability to discuss the interaction between weather and operations constitute two of the principal values of private weather services. This is apart from the timeliness and area, or spot, specificity of the prediction. The client is more likely to use the meteorological guidance if it is in the context of his immediate concern. Variables of specific interest may be wind, precipitation, humidity, visibility, or temperature on any specific day, but if the client knows that due attention has been placed upon the element critical to the immediate problem of the client, and a degree of confidence is transmitted, then the information is acted upon. Moreover, there is also feedback to the meteorologist. This helps the meteorologist to plan the use of time and decide what special analysis of data will benefit the client for a given operation. The answer often generates another question that will evoke the useful answer. A general forecast with no feedback often does not do the job. In summary, the professional talent at the interface between the data system and the user is a critical element of the weather information system.

We are long since past the time when the responsibility of the Weather Service was to simply give a forecast on the assumption that the information would be used correctly. The point to be emphasized is that many potential users of weather information cannot effectively use the data or information except with consultation. For this clientele the system of dissemination must have a professional individual between the information and the person who acts on the information; such professionals are either the private consultant or meteorologists at NWS field offices, as discussed above.

Centralization of many of the functions of the Weather Service was a logical and correct judgment on the part of the NWS. For the past 30 years it has resulted in staff savings and better products. As a result, the agency/user role has changed. Reduction in the professional level of NWS personnel at the user interface, along with reduced staff in proportion to population and weather information needs in response to higher-level government pressures, has taken its toll. In some cases the provision of a meteorologist at the user interface should logically be the responsibility of the business or governmental agency requiring the service. In other cases, however, a requirement for additional NWS staffing is apparent. The ongoing user program recommended by the Committee should provide a basis for making these decisions.

7.1.4 *Continuing Planning Function*

The user community and its needs are in a constant state of evolution. Data collection, analysis, and dissemination techniques are seeing a developmental explosion. *Ad hoc* treatment of needs, technology, and their potential interaction cannot help but result in significant inefficiencies and lost opportunities for service and individual and national benefit.

There is a distinct need for a planning group within the National Weather Service, the responsibilities of which would include the user program and its continual updating. This group would also combine the study results with analyses of evolving technology in order to develop rational plans for future improvements within the National Weather

Service, improvements that would meet user needs and could be justified on the basis of benefit-cost analysis. Such a function must be a continuing one in recognition of the high rates of change in both technology and the user community. In the absence of such a continuing planning function the strong tendency will exist for the National Weather Service to adjust its operations to evolving technology, with the users left to utilize whatever becomes available. A genuine two-way feedback mechanism will be of great importance in identifying those operations that benefit service areas of high need and potential benefit, and thus in stimulating technological development to support such new, needed operations.

7.1.5 *Conclusions*

In order to plan for services and maximize the return on investments, NWS needs to have systematic information on who users are, what products they need, which formats are most useful, and what time schedules are required by various categories of users.

There is an inadequate effort in NWS to make the public aware of what is available in the form of advisories, forecasts, guidance products, and climatological information. There also is an inadequate mechanism for transferring weather and hydrological information and knowledge of applications to specific users.

Many users of weather and hydrological information need a professional meteorologist or hydrologist to interpret the information or data and give assistance in applying the information to a specific need. The human interface between the information bank (often computer-generated) and the user world also provides to NWS a valuable channel for feedback from users on details of their needs, successes, or problems in using NWS information to meet these needs. In many instances, special data services or interpretation required by a user may exceed NWS resources, or it may not be appropriate for a federal agency to supply such special assistance; in such cases, private meteorological services fill an important need.

There are inadequate planning mechanisms in NWS to merge user requirements with the opportunities afforded by technological developments.

7.1.6 *Recommendations*

NWS should establish an ongoing user program to:

- identify significant user groups and categorize them by such factors as protection of life and property, size, and potential economic impacts; the needs of national defense must also be considered;
- define specific user needs in terms of products, forecast periods, frequencies, etc.;
- project benefits and costs of providing alternative levels of weather and hydrological data and information services as a basis for rational allocation of future NOAA resources, and for assessing user charges where significant and incremental costs are identified for specific services tailored to specific groups.

This program should become the basis for an ongoing NWS policy to provide two-way communication between user groups and long-range NOAA planning.

NWS should establish a public education effort designed to:

- increase public awareness of the services and information available, and
- educate users on interpretation and application of the information.

This effort should include the preparation and distribution of manuals and other educational materials for user groups.

NOAA should take steps to assure that NWS is given appropriate credit as the source of weather information used in radio and television broadcasts, in the printed media, and by private meteorological services.

NWS should staff its field offices as required to assure the availability of professional meteorologists and hydrologists or applications specialists at these offices to:

- provide the general public and, where appropriate, special user groups with interpretation of weather and hydrological information; and
- provide feedback from the public, state climatological programs, and private industry on local requirements to NWS planning groups.

NWS should establish a central planning group that will assess user requirements for weather and hydrological information and services, and will plan for the satisfaction of these requirements through the application of new technology where appropriate. The planning group should provide, on a continuing basis, 5- and 10-year staffing, technical, and fiscal plans and programs.

7.2 Sensors and Sensor Systems

The basic variables needed as input to numerical dynamical models of the atmosphere are temperature, moisture, and wind throughout the volume of that part of the atmosphere related to weather (i.e., up to an altitude of about 30 km), and the pressure at the surface. The gases of the atmosphere obey well-known physical laws, which provide very useful relationships between some of the basic variables. These relationships can often be used to estimate a needed variable from other observations. For example, in mid- and polar latitudes, where the geostrophic relation is strong, it is possible to estimate winds from a knowledge of pressure and temperature fields. All practical sensor systems, then, must provide measurements of either the basic variables directly or provide reliable means to infer them from other observable atmospheric phenomena.

During the past two decades, technology has made possible important developments in the use of satellites to observe the atmosphere, primarily for measurements of temperature and moisture; techniques have also been developed to obtain wind measurements, but to a more limited extent. The satellite-based techniques have been aimed primarily at supplementing the radiosonde upper-air network, particularly over the oceans. The results have been very useful to date. At the same time, opportunities have been recognized for significant improvements. The principal potential advantages of a satellite-based system are more uniform global coverage, increased horizontal resolution, more uniform instrumentation, and simpler data collection; the disadvantages are poorer resolution in the vertical (which is a physical and not a technical limitation) and the nonsynoptic nature of satellite observations (which could be a future advantage, as mentioned in Section 3) and failure of a satellite (which in some cases eliminates a major source of data for a considerable time).

Satellite systems also have very long lead times from the development of concepts to the implementation of practical operational systems. In this connection, the possibility is sometimes raised of eventually replacing radiosonde networks by satellite techniques. While this possibility must be kept open for the future, and serves as a challenging goal for technological development, there will continue to be a need for a considerable time for a wide variety of observing systems to meet all operational and research requirements. Therefore, in the following discussion of new technological opportunities, nonsatellite as well as satellite opportunities are discussed. No explicit discussion of radiosonde systems is included. Actual deployment of these systems over land areas has about reached the practical limit of extension in many regions, but there are cooperative efforts organized through the World Meteorological Organization (WMO) to keep improving the radiosonde networks in the developing countries and in those few ocean areas where there are feasible island locations. The ultimate limitation of radiosonde networks is the impracticality of global deployment.

7.2.1 *Temperature and Moisture from Satellite Systems*

Temperature and moisture distributions in the vertical are obtained from analysis of measurements of infrared and microwave radiances emitted by atmospheric constituents. The radiances are measured at the spacecraft by downward-looking sensors; thus, the temperatures and moisture content derived from the radiances constitute a vertical profile. Observations made looking horizontally from the satellite toward the limb of the earth (thus, "limb soundings") also have a useful function, as is mentioned below. A perfect radiation theory predicts the radiance signals for any given temperature profile; conversely, it is in principle possible to infer the temperature profile from the observed radiances. The radiation theories are, however, imperfect in practice, with sources of uncertainty arising from water vapor, aerosols, clouds, and imperfect knowledge of the transmission functions.

The alternative procedure being followed is to establish empirical inversion algorithms based on regression analysis of satellite radiances and radiosonde temperature soundings that are collocated in space and time. These regression formulas are then used to estimate what the radiosonde soundings would be at times and places where only radiance information exists. Although, in principle, satellite soundings should be able to match radiosonde accuracies, in practice, they have errors of at least twice those of radiosondes. The sources of additional error are thought to be unresolved interference problems (clouds, water vapor, aerosols, etc.), inadequately chosen data sets for developing the regression formulas, and residual programing errors in the inversion process. This latter source cannot be ignored for a computer program that has grown to the complexity of this one.

Until recently a major difficulty also arose from the lack of ability to separate soundings that were good from those that were poor. Now, by using microwave soundings as a means to improve the quality control of IR soundings, and having the use of a human-computer interactive display system to aid the editing process, much better quality control is possible. Satellite soundings, however, still need additional improvements.

First, measurements of absolute values of temperature need improvement. Instrument noise and interference from clouds in the field of view (cloud noise) degrade the basic accuracy of the system. Accuracy can be improved by improving the signal-to-noise performance of the instrument and obtaining better horizontal resolution so that the instrument "sees" between the clouds.

Second, vertical resolution of temperature soundings should be improved. This is particularly important for severe weather predictions where the issue of the vertical stability of the atmosphere is crucial. Greater vertical detail of the temperature structure can be obtained by improving the spectral resolution of the instrument. An improvement of about an order of magnitude in spectral resolution is needed to achieve a significant improvement in vertical detail. However, achieving an order of magnitude in spectral resolution may be difficult and costly.

Complementary data are of significant assistance in improving the retrieval of the temperature structure from soundings. Many inversion schemes (i.e., algorithms to derive temperatures from radiance measurement) are available, but, unfortunately, none of them can produce *closure* and give *unique* answers. A particular inversion scheme may give better results in a given meteorological situation than another scheme, but under other conditions the reverse could be true. By and large, the present retrieval schemes tend to agree more with each other than they do with the real atmosphere. The situation is not likely to change until additional complementary information needed to force closure is available. Several possibilities exist to obtain such complementary information:

● Reference sea-level temperatures and sea-level pressures are available to help force closure, such as from drifting buoys proven successful during the Global Weather Experiment, 1979.

- In addition, means to observe ocean surface temperature from satellites have also improved. The present accuracy is satisfactory for the purposes of temperature retrieval, but for other purposes, such as the study of air-sea interaction, further improvement is needed.
- Knowledge of tropopause temperature and altitude are critical in forcing closure of inversions. In the present sounding and retrieval schemes, these measurements are very difficult to obtain accurately. In fact, errors in sounding tend to be greatest at the tropopause levels. Attempting to sound the atmosphere with vertical scans alone, even if it could be done monochromatically, cannot resolve the vertical structure to the extent required. On the other hand, horizontal scanning toward the limb of the earth (limb sounding), optimized for tropopause height retrieval, has the potential for excellent vertical resolution near the tropopause level and above, where the interference of atmospheric particulates and clouds is small or nonexistent. A combination of vertical and limb-scanning techniques used together will give data much better than will either technique used separately.
- The coupling of sounding data with information on cloud heights should also improve the retrieval of atmospheric temperature profiles. Excellent cloud-height information can be obtained using stereo techniques applied to geostationary satellite imagery. Having cloud-height information derived independently of knowledge of cloud properties will make it possible to improve greatly the sounding in cloudy areas. In principle, this added information should make it possible to improve the vertical resolutions at low levels — possibly at the top of the boundary layer.

A concentrated and imaginative attack to resolve the difficulties that are still being encountered will yield a significant improvement in the temperature sounder performance in the near term at minimal costs.

Most of the preceding discussion has centered on analysis for temperature information. Moisture profiles are also very important and are obtained through similar analysis procedures. Here, however, the amount of information that can be obtained is, in practice, more limited in vertical resolution than that for temperature. As is discussed below, moisture observations of a different kind can be used in a very special way for the derivation of wind information.

7.2.2 *Wind Information from Satellite and Nonsatellite Systems*

Among all issues faced in the area of instrumentation, the very limited capability for the measurements of wind fields (used for synoptic as well as for mesoscale forecasting input) stands out as needing urgent attention. There is a consensus among modelers, whether doing operational forecasting or research, that wind information is critical to continued improvement in forecasting. Despite this consensus, the investment now being made to improve the wind data from cloud imagery is minimal. The Committee believes that the time is ripe to bring the global wind measurement effort up to a level commensurate with the efforts to obtain global temperature and moisture measurements.

The Committee believes that feasible short-term improvements are available that could and should be implemented quickly. Such action would improve the situation markedly in this critical area. These improvements, however, will not yield the fully global system, with adequate vertical and horizontal resolution, that is required. To reach that goal, the Committee believes that at least one long-term possibility exists. These opportunities are discussed briefly below.

7.2.2.1 *Wind Information Inferred from Temperature Fields*

As mentioned above, the physical laws of gases relate temperature to winds, which provide a very useful way of inferring a wind field from temperature measurements in regions where the wind is not or cannot yet be measured directly. This relationship, called the thermal wind balance relation, is most useful in the mid-latitudes. At the principal scale of large-scale disturbances of interest, a temperature error of $1^{\circ}C$ and a wind error of 2 meters per second are roughly equivalent.

The improvements in accuracy, detail, and reliability for the temperatures mentioned above in Section 7.2.1 will also improve the wind-field determinations. Recent experiments, using human-computer interactive systems, have shown that such thermal winds derived for mid-latitudes can be very useful in studies of weather phenomena.

However, it has also recently become clearer that the balance relations are most trustworthy in translating information from winds to temperatures, not vice versa. In the tropical regions, and for the smaller scales everywhere, wind information becomes relatively even more valuable. Thus, it is very important to pursue also the improvements in direct observations of winds.

7.2.2.2 *Direct Observations of Winds — Satellite Techniques*
It has been demonstrated very clearly that tracking of appropriate clouds can provide accurate and useful wind-field information. Special efforts were made for the Global Weather Experiment, 1979, and are being continued for routine operations. Clouds, however, do not always occur where wind data are wanted, nor do they always occur in just the right configurations and altitude distributions for analysis most useful to forecasting. In addition, there is as yet no satisfactory way to determine accurately enough the heights of the clouds being tracked. Finally, experience with the special data sets for the 1979 experiment shows that very careful positioning of the sequences of cloud images is necessary to maintain the accuracy inherent in the tracking technique, and that advanced interactive computer-driven display systems are essential in making the best wind derivations. There are technical means currently available for tackling all these problems. The question is one of making the decision to do it. As mentioned earlier, the Committee strongly recommends that the NOAA and NASA investments in resources and staffing for wind derivations be brought to a level of effort commensurate with that for temperatures, so that improved wind-field determinations can be brought into operational use as soon as possible.

In the short term, such efforts should address at least four important factors:

- Altitude determinations must be improved markedly. Stereo processing of images is one way to accomplish this. To do so, however, will require international collaboration among the satellite operators to synchronize insofar as possible the scan rates and timings between the pairs of geostationary satellites with overlapping fields. If, in the future, satellite-borne lidar becomes feasible, such lidar will make possible very accurate determinations of cloud altitude.
- Water-vapor fields can be imaged from geostationary satellites. Sequences of such images can be used to trace air movements and thus wind fields can be derived in regions where there are no suitable clouds. Here, altitude is also critical, and the same remarks apply as above.
- Much more careful attention must be paid to accurate positioning of the images to improve registration in the image sequence. Otherwise, the inherent accuracy of the technique is seriously compromised.

• Advanced interactive data systems have to be made available for the analysis of cloud fields for wind determinations.

For the longer-range future, it appears that it might be feasible to use infrared laser-ranging systems (lidar) to derive winds. This technique depends on analyzing laser signals returned from scatterers in the atmosphere, such as aerosols; the back-scattered signal is shifted in frequency in proportion to motion of the scatterer. This technique, called Doppler analysis, is capable of providing wind vectors under the path of a low-altitude, polar-orbiting satellite with very good horizontal and vertical resolution. The requirement, however, is that rather powerful lasers be used. It remains to be seen if feasible satellite-borne laser systems of suitable power can be developed. Initial simulation tests, as well as actual hardware tests of systems flown on research aircraft, are promising. Plans are being developed by NOAA and NASA for tests leading to an orbital demonstration on a Space Shuttle flight. The Committee strongly endorses this development program as the only concept now in sight that promises to provide an operational, truely global wind determination system in the future.

7.2.2.3 *Other, Nonsatellite, Wind Systems* Other, immediately available, techniques for improving the ability to measure wind fields should also be exploited:

1. Wide-body aircraft equipped with inertial navigation systems can provide — via satellite relay — data on wind fields over areas of the globe (the oceans) typically devoid of any other meteorological instrumentation. The value of such a system was demonstrated during the Global Weather Experiment, 1979. At the present time, a few aircraft are equipped with Aircraft Satellite Data Relay (ASDAR) systems to provide wind-field measurements. International efforts to expand the fleet of these platforms to encompass the international wide-body fleet of several hundred aircraft would result in a substantial addition to the global data base on winds. The possibility of utilizing data from private INS-equipped aircraft should also be investigated.
2. Such an aircraft-based network of wind-field instrumentation should be supplemented with analogous ship-based instrumentation that would provide information on surface

winds. This information would be in addition to wind information now available from surface ships. As in the case of aircraft, adding the appropriate instrumentation to a fleet of ships that are operationally useful to NWS could be implemented on a relatively short time scale, and could be expanded through international cooperation.

7.2.2.4 *Radar Networks* The current weather radars operated by the National Weather Service (Department of Commerce), and Air Weather Service and Naval Oceanography Command (Department of Defense) are rapidly reaching the end of their useful lives. The next generation weather radar (NEXRAD) will replace these aging radars and provide essential weather radar data to the Departments of Commerce (DOC), Defense (DOD), and Transportation (DOT), and other governmental and nongovernmental users. NEXRAD is being designed for joint acquisition and joint use by DOC, DOD, and DOT. As a storm detection radar system, NEXRAD will take advantage of both conventional and Doppler radar technology, and the operational capability of the system will be enhanced by the use of internal automatic data processing equipment. A Joint System Program Office (JSPO) has been formed and is staffed by members from DOC, DOD, and DOT. The JSPO will be the focal point for the acquisition of NEXRAD. Because of the status of the current aging radars, NEXRAD installation must begin by 1986 and be complete by the end of the 1980s. The possibility that such a storm radar network could contribute wind-field measurements for use in synoptic and mesoscale forecasting should be investigated. In particular, possibilities may exist for the use of the Doppler storm radars at higher sensitivities to get clear-air returns. A modern storm radar network will also supply valuable input information for hydrological forecasting.

Other radar techniques to obtain vertical wind profiles, now under development in the NOAA Environmental Research Laboratories, also offer promise for obtaining clear-air and all-weather winds as a function of height remotely from the surface. The higher frequency with which one can obtain wind information from such techniques, compared to rawinsondes is a significant advantage for mesoscale forecasting. Early field tests under operational conditions of such radar techniques seem well warranted. Not only would such instrumentation contribute greatly to the information needed for mesoscale forecasting, but it could be of great help in aviation-related meteorological forecasting.

7.2.2.5 *Summary of the Wind Measurement Situation* The steps described in Section 7.2.2, each in itself an incremental improvement, taken *together* would substantially improve the quality of the wind-field input into synoptic and mesoscale numerical models. It is also important to determine whether such an improved data input would actually result in an improved forecast. Field experiments recently concluded (the Global Weather Experiment, 1979) will shed light on this important question.

7.2.3 *Use of Existing Resources*

Orderly planning is essential so that systems and networks that have proven their worth in the past are not abandoned or dismantled until the value of new instrumentation has been demonstrated. The network of surface-based observations, for example, is particularly valuable for mesoscale forecasting; yet this network has been thinned by attrition. NWS has now recognized the need to reverse this trend by installing automatic observing stations. The use of automated surface-based weather monitoring stations, which incorporate state-of-the-art sensor technology, is now a real and cost-effective option. Some suitable sensor systems are now under prototype development. The Committee endorses such action in view of the importance of such stations to mesoscale forecasting.

Finally, it is important to consider issues of the continuity of the data base before replacing or significantly modifying existing networks. All new systems recommended in this study should be implemented to provide a suitable overlap with existing systems to protect the continuity of the data base.

7.2.4 *Total Systems Consideration*

It is the Committee's opinion that in the immediate future the environment in which NWS will operate will be data rich as well as rich in the availability of many possible choices in the instrumentation mix. Such a future suggests that the evaluation of the operational value of the various possible choices and combinations of instrumentation will have to be institutionalized; mechanisms to perform various prototype field experiments and pilot projects will be required. The current NWS effort with respect to the Prototype Regional Observing and Forecasting Service (PROFS) is an important step in this direction. The issues of data handling, reduction, and transmission should be fully addressed at an early date in such planning and prototype experimentation. Considerations of total systems design, including the costs of operations and maintenance, reliability, redundancy, life-cycle costs, and content and form of output products should be considered in order to make intelligent choices in the mix of instrumentation that will serve most effectively and economically the needs of NWS and the user community.

7.2.5 *Conclusions*

Pilot programs, tests in operational environments, and prototype field experiments, such as the Prototype Regional Observing and Forecasting Service (PROFS) program, are necessary to determine and order priorities among the wide selection of sensors and combinations of sensors (on space platforms as well as on the surface).

The early identification of the development of mesoscale phenomena requires both surface and upper-level observations from surface-based stations as well as from geostationary satellites. The continuity of existing surface observational systems must be assured until new or improved systems are in place and proven effective.

Temperature and moisture information from satellite soundings is important, but the full potential of these data has not yet been realized.

Better measurements of the wind field are essential for improving synoptic and mesoscale analyses and forecasts. Steps can be taken in the *immediate future* to improve the capabilities of existing space platforms and sensor systems, as well as surface-based techniques, to give improved but still not complete determinations of wind fields. *In the longer term*, a satellite-based Doppler IR lidar system (provided that the feasibility of the technique will have been demonstrated) should permit the measurement of wind fields on a global basis, which is essential to extend the time range of forecasts.

7.2.6 *Recommendations*

The Committee recommends a continuing program of evaluation of new concepts of sensor networks and pilot programs (such as PROFS) so that future weather and hydrological networks can evolve from proven building blocks. Long-term support is needed to assure the viability of such a building-block approach. Where appropriate, new sensor systems should also meet the needs of weather observations relevant to climatic studies. New sensor systems should also take account of international collaborative possibilities together with national and regional initiatives.

Continued efforts should be made to improve the reliability of vertical temperature and moisture soundings, including development of better statistical bases for data retrieval, improved correction procedures to reduce contamination, and addition of horizontal (limb) soundings to identify the height and temperature of the tropopause.

A new, imaginative, and diversified effort is required to improve the current systems for wind-field determination for use in synoptic and mesoscale forecasts. The following approaches promise significant improvements *in the immediate future*.

- Improvement in wind-field determination using vertical temperature sounder data appears feasible if these data are analyzed in conjunction with data obtained by polar-orbiting limb scanners, ground-based sounders, and independently derived cloud-altitude and sea-surface data (such as from buoys).
- Addition of multichannel and stereo capability to geostationary meteorological spacecraft promises to give better information on wind fields (from the movements of clouds and water-vapor fields as derived from satellite imagery). Such augmentation of present systems should be an international effort involving the meteorological spacecraft of all nations, including, for example, the synchronization of scans insofar as possible to facilitate stereo analysis of the images.
- Collection of wind data from aircraft and ships that carry appropriate instrumentation is extremely cost effective and amenable to evolutionary system development, with the additional bonus that data-sparse regions will be covered. The possibility of international collaboration should be explored to broaden the observing program.

The Committee supports the existing proposals for modernization of the weather radar network (NEXRAD), in particular the deployment of storm-detection Doppler radars, so that the present radar network, now more than 20 years old and obsolescent, is replaced in a timely fashion. The possibility should be investigated as to increasing the sensitivity of Doppler storm radars so that clear-air operations might be feasible to supply wind fields.

On *intermediate time scales*, the deployment of radars of the type being developed by NOAA/ERL for wind profiling pruposes* also appears to hold substantial promise as a source of wind information. The Committee recommends the deployment of a small number of such prototype radars, variously spaced. The potential of these systems is so high that a realistic assessment of their costs, maintenance, and performance is needed as early as possible. They would form a key element of the system of the future even if their use were limited to providing wind information for mesoscale forecasting.

The Committee is persuaded that direct measurement of altitude-resolved global wind fields using a satellite-based IR Doppler lidar holds promise as the long-term solution of the wind-field problem. The Committee urges that NOAA, together with NASA, move toward an early on-orbit demonstration.

In parallel with the technical initiatives described above, NWS should carry on an effort to evaluate the effectiveness, in the sense of improving forecasts, of the new types of data that will be returned by these initiatives.

Because of the importance of the tropical regions in governing global weather patterns, the desirability and utility of a low-altitude, low-latitude meteorological satellite should be reexamined.

The Committee recommends that opportunities be maintained to deploy experimental meteorological sensors at geostationary altitude.

The data collection phase of the Global Weather Experiment (1979) has been completed very successfully. NOAA should insure that funding is provided for use of the resulting comprehensive data set for research purposes as well as for evaluating, through the use of simulation experiments, the benefits of new sensor systems in improving weather forecasts.

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*As distinct from the area-scanning storm or weather radars, these wind-finding radars are approximately vertically pointing systems that operate also in clear air. Fixed-beam antennas are used to produce a pattern from which the Doppler-shifted returns are analyzed to provide the wind components (e.g., vertical, east, north).

7.3 Data Assimilation, Computer Requirements

There are two general kinds of data-assimilation problems facing the NWS. The first is the information chain discussed in Section 2:

1. collecting observations from around the world;
2. analyzing them to generate global definitions of the state of the atmosphere;
3. adjusting this state to be suitable as the initial state of a numerical weather prediction model;
4. carrying through the prediction computation; and
5. converting the results into meaningful weather forecast information for distribution to society.

This total process is characterized by its automation and its objectivity.

The second type of data problem revolves around presenting output processed data to a forecaster in a manner to permit subjective interpretation. New sensor, communication, information, and display systems are permitting an increase in information handling that could eventually overload a human interpreter. The information system, then, must be flexible and controllable, and have computation and recall characteristics to facilitate the human interpretive processes. The computer systems must complement the human mental circuits, not overload them.

In principle, any deductive or inductive interpretation process used by a human should be translatable into memory manipulation, clue or pattern recognition, data combinatory processes, etc.; that is, *rubrics* $\longrightarrow$ *algorithms*. Significant progress in civilian and military research strongly indicates that with time many subjective techniques will be automated. Whether or not full automation of all interpretation of small-scale, short-time weather processes will ever be possible, it is clear that the human interaction with the information field will continue to be an indispensable function. The AFOS plan to incorporate data banks of local effects (i.e., local climatology) is a sound beginning in gaining experience with human-computer interactive interpretive systems and will facilitate transfer of know-how from humans to computer

7.3.1 *Objective Analysis and Forecast Methods*

1. Collection and initial data processing. The temperatures, humidities, and winds at standard pressure levels

from the global networks are formatted as teletype messages for transmission on a global telecommunication system (GTS) to forecasting centers around the world such as the National Meteorological Center (NMC). Miscellaneous other sources of data, such as aircraft reports, also feed into the GTS. The GTS, the organization of which is largely the responsibility of the World Meteorological Organization (WMO), has grown in a somewhat haphazard way through several decades. The time is now ripe, after the recent completion of the 1979 Global Weather Experiment, for a new look at this basic communication network. This requires, of course, cooperation between many nations through the WMO, but the NWS should play a leading role, since the United States is the major world user of meteorological information.

The data brought to NMC by the global telecommunication network is fed into a data processing system, which has also grown in a somewhat haphazard way. It is clear that the conventional data flow rates do not strain data processing technology. The more difficult problem at NMC is the replacement of obsolescent equipment without interrupting the operational flow. Thus NOAA should acquire for NMC use data processing hardware and software that minimizes the demands of the programming staff so that they may concentrate on the more specific needs of NMC, for example, such as for graphical display development.

In the United States, satellite data processing is handled by one of the three IBM 360/195 computers in the NOAA computer facility at NMC, Suitland, Maryland (near Washington, D.C.). These computers, another of which is used for the forecasting model calculations, are obsolescent and must be replaced without interfering with the operational forecast cycle. Here too, as with the conventional data processing equipment, emphasis must be on the reliability of acquired hardware and software with a minimum demand on the NOAA programming staff.

2. Analysis. Objective analysis of the observations consists of appropriate interpolation in space or time to define, for a particular time, the three-dimensional fields of meteorological variables that best fit the observations. The statistical theory of the optimal analysis procedure that minimizes analysis error is well understood, and there are no serious problems in implementation.

3. Initialization. The next step in the forecast cycle is to convert this best estimate of the state of the atmosphere into an initial state for a prediction model. Here, great care must be taken. For example, "fast" modes may be

excited mathematically but do not occur in nature. The initialization procedure requires finding the slow model state most compatible with the analyzed atmospheric state. We now understand the nonlinear contraints that define what is called the slow manifold of realistic model states. Considerable progress is being made on combining the statistical procedures of optimal analysis and the dynamical constraints of a model. Account must be taken of the discrepancy between the dynamics of a model and that of the real atmosphere, which leads to some differences in the corresponding slow manifolds. Here also, there seem to be no serious problems in implementation. These considerations lead to a theory of the relative value of observing different variables, which has already been alluded to in discussing the importance of wind observations.

4. Prediction. The next step in the forecast process is to carry out a prediction with a numerical model. Theoretical studies show that the rms (root mean square) error in a prediction model, even if it were "perfect," is expected to double every 2 or 3 days owing to the inherent instability (and small-scale unresolved processes) of the atmosphere or any model of it. Thus, there is, considering the initial analysis errors, a theoretical limit of 10 days or so in the range of useful prediction. Present models are not perfect, and forecast "skill" becomes marginal after about 3 days for some types of weather and after about 5 days for larger-scale phenomena.

Present operational models use data supplied on a horizontal grid of about 400 km; the computations are carried out on a grid of about 100 km. An important source of model error is limited resolution imposed by limits in available computer speed. Limited-area models, in which horizontal resolution is increased at the expense of horizontal coverage, show clear gains in skill until influences from the boundary contaminate the interior forecast. These results permit a fairly accurate estimate to be made of the benefits of any future increase in available computing power.

Present evidence is that decreasing grid spacing below about 100 km will have limited impact on prediction of the mid-latitude cyclonic wave structures but a considerable impact on the prediction of precipitation patterns of importance for forecasts of weather.

Advances in computer technology clearly provide opportunities to meet the current computing limitations in synoptic modeling. It follows that NWS, in taking advantage of computing advances, and in recognition of the large capital investments involved and the long life cycle of computing equipment, must plan far ahead in implementing any computer replacement procurement. To the extent possible, computers should be of the type readily available in the commercial market and should require minimum software modification to meet NWS requirements.

5. Meaningful objective weather forecasts. Weather in a particular location is generally not predicted directly by a model but through a regression technique known as model output statistics (MOS). Correlations are established between specific weather variables and nearby grid point model variables by analysis of past records. Regression formulas are then developed for converting predicted grid point values into estimates of the weather variable. Future model development should be accompanied by associated MOS development in order to extract the most useful information from the model. There appear to be no fundamental difficulties in carrying out such developments.

7.3.2 *Subjective Analysis Methods*

The automated observing, analysis, initialization, prediction, and MOS sequence so far described is as objective as possible; it is designed to be as free as possible of human decisions, except for some quality monitoring. The output of this sequence, however, must be acted on by individuals. For example, the MOS technique does not automatically spot the extreme or the rare events, which often can be detected by experienced forecasters. Here, the second kind of data assimilation problem becomes important.

The AFOS system being implemented by the NWS provides data and graphical display capability at the principal forecast offices around the nation connected by a data transmission system to NMC. Products from the forecast sequence at NMC can thus be transmitted and displayed every 12 hours for the guidance of the local forecaster. But much more can be made available to the forecaster even now, for example, from the dense network of surface observations made hourly and from local radar observations of storm cells. In time, additional important input will come from other regional remote-sensing techniques being developed, e.g., by the PROFS program.

Geostationary satellite imagery is currently not planned to be transmitted directly over the AFOS network so that, useful as it is for providing local information, it must be received and displayed in a different way.

7.3.3 *Long-Range Information System Planning*

It is clear that the National Weather Service is pointing toward a data-rich future characterized by such non-traditional sources as:

- automated ground-based sensor networks in the spirit of PROFS;
- automated river gauges;
- automated reporting packages aboard aircraft or ships in the spirit of ASDAR;
- a surface network of Doppler weather radar;
- satellite visual and infrared imagery; and
- satellite wind, temperature, and other data, such as from soundings, lidar, and water-vapor channels.

From such sources the National Weather Service can expect continuous or nearly continuous streams of data. Processing capability must be planned as part of any advanced data source and not be treated as an after-the-fact retrofit; otherwise the entire data-information system will not function well.

It is also clear that the National Weather Service can anticipate a future in which diverse products will be delivered to a multitude of users, e.g.,:

- those of the traditional kinds,
- those customized to special needs,
- those electronically forwarded to other automated systems, and
- those delivered on a subscription basis to private users.

It is equally clear that the National Weather Service can anticipate a future of more complex predictive and forecast models that are nested in the sense that various ones interface and provide mutual boundary conditions.

There are already trends toward a data-processing capability of some level in the field. For example, AFOS provides a graphical display capability with some aspect of local data manipulation. Furthermore, PROFS promises mesoscale analysis supported by localized data sources but driven by a synoptic overview.

To be sure, there are many uncertainties in the National Weather Service future, but the broad outline is apparent:

- A multiplicity of measuring sources periodically or continuously putting data into a network.

- A variety of computing facilities that provide computational resources to the network. The Suitland center will not be *the* single place at which all weather data are handled; rather it will be simply one of the resources on the network available to all network users.
- Field installations — probably all having some level of computational power — using local source data or model-produced results from the network as needed, and entering onto the network locally derived results or model outputs for the use of others.
- A variety of end-product sites that will produce widely used products for their own use or for others.

Suitland is now the source of all or most of the objective forecast products. In the not-too-distant future, end products by objective means will be produced at other NWS locations. At that time, much of the National Weather Service data and computer network will function as an information production line. Into one end will flow data; from the other end will flow end products. In between will be computers, communications, automated interfaces — all functioning with minimum oversight from people and servicing the weather needs of the country. On top of the production workload will be that of new computer program development, experimental model runs, research on new services, etc. These activities will require computer support from the network and will receive it as, and from wherever, available.

Hence, the Committee concludes that consideration of system-level and architectural details of the information infrastructure that will support the National Weather Service in the future must be commenced now — for a variety of reasons:

- Capital investments being made now for new computers, communications, or other capabilities will be with the National Weather Service into at least the 1990s.
- Decisions being made now about computers must not foreclose future options.
- The planning for the Suitland upgrade must not be seen as a stand-alone replacement of computing machinery, but rather as one of the steps toward a future whose characteristics are generally outlined above; therefore, it is a step the details of which must mesh with the general system architectural long-term planning.
- The design and development of systems such as PROFS and following efforts, and of automated sensors, must not be

isolated efforts but rather should be integrated with overall network concepts, data-handling procedures, reliability guidelines, and general architectural standards.

Thus, it is apparent that planning for the information future of the National Weather Service is much more than a simple consideration of computer equipment. The ramifications of such planning reach into research efforts now under way from which are expected to materialize operational systems. Network issues such as interface standards, data-exchange standards, data-exchange arrangements, network control mechanisms, etc., are all items that must be addressed at the beginning. To do otherwise would risk that the National Weather Service find itself with a variety of items that could be integrated only with undesirable, possibly costly, and certainly time-consuming redesign and retrofit. It is clear that the planning effort as now constituted should be expanded to one of broader scope, and should operate under the highest authority of NOAA so that all pertinent activities are coordinated.

7.3.4 *Conclusions*

Communication of observations from around the world is inadequate to meet all the needs of NWS for data. Some of the links are too slow, and some of the data reach NWS too late or not at all.

Current computer systems supporting NWS and NESS are obsolescent and inadequate to meet current requirements. There is a need for finer computing resolution to improve precipitation forecasts, for example, as well as for improvement of processing of satellite data. Finer computing resolution is also needed to support increased research activity to improve data analysis and assimilation, and model realism.

Present computer planning is addressed predominantly to upgrading of the NOAA computing complex located in Suitland, Maryland. There is little long-range planning that addresses in a comprehensive and integrated way such items as data sources and their communication support, computers at Suitland and in the field, networking of computers, and network standards.

7.3.5 *Recommendations*

NOAA must proceed vigorously to upgrade the computer systems available for conventional data processing, for satellite data processing, and for numerical weather prediction.

The Automation of Field Operations and Services (AFOS) communication and display system must be completed expeditiously.

Time-lapse satellite images merged with other data should be made available at Weather Service Forecasting Offices (WSFO) as soon as possible.

The NWS should develop operational objective mesoscale analysis procedures, including hourly surface observations. Prototype procedures exist today in a number of university research groups.

Mesoscale prediction models will be developing rapidly in the coming decade. The NWS should plan for their operational use, recognizing the substantial computer resources that are required.

NWS should take the lead in encouraging a WMO modernization of the global communication network for conventional surface-based data.

NOAA must commence in a formalized way to plan comprehensively for the computer-communication networks that will be required in a future environment for the NWS that is data-rich, product-diverse, and interactive.

To make best use of NOAA programming talent, emphasis should be placed on developing software that supports the human-computer interface and is unique to the NWS mission. With increased professional capabilities in the field, applications software for local problems can be developed and supported by local talent.

7.4 Dissemination of Weather Data and Information

The communications industry has, or is developing, an impressive number of new communication systems that can serve to collect and disseminate weather information and support services to a wide range of users, including the general public.

It is not necessary for the National Weather Service to sponsor new communications technology; it needs only to choose the most economical service for a particular need.

7.4.1 *Satellite Systems*

Meteorological observations from sensors are disseminated to various NWS centers where they are assimilated and converted into useful information that is then distributed to various types of users. Communication, obviously, is a vital part of the information chain.

Communications satellites offer unique opportunities to handle both the data and information dissemination aspects in new and potentially more useful ways than are offered by the present weather information network. The advent of competitive communications satellite links has brought substantial savings (Figure 1) to the public, although the cost of most other elements has escalated with inflation. Thus it is now possible to provide the user with improved services at a lower communications cost.

In the following sections, we discuss data rate requirements for meteorological data, information rates available now and anticipated over the next decade, the availability of local input-output points in networks, and some data on basic costs.

1. Data rates and data-transmission possibilities. Meteorological sensor data rates vary depending upon the resolution required. Simple temperature readings require only a few bits, whereas a GOES (Geostationary Operational Environmental Satellite) data-collection terminal transmits 100 bits per second, and a GOES-D, E, and F VAS (VISSR* Atmospheric Sounder) may run at 14 megabits per second (Mb/s) (high resolution).

The available data rates from the common carriers of today and the near future range from the very low speeds used for burglar alarms and teletype, through voice, to video and high-speed data. Table 2 shows some of these rates.

Most of the present terrestrial communications networks have been built around the analog voice service, i.e., telephone. The huge investment inventory in this service requires that most data be modified to look like analog voice by using slow data rates in the 2.4 to 4.8 kilobit per second (kb/s) range. However, some specially conditioned lines run at 9.6 kb/s. Several sources of 56 kb/s service are available with terrestrial telephone and

*VISSR — Visible-Infrared Spin-Scan Radiometer.

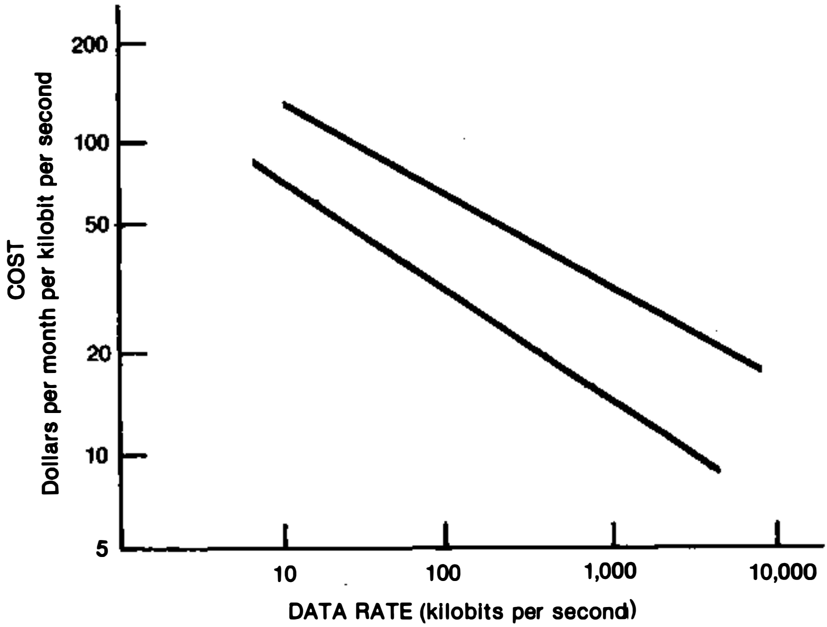

FIGURE 1 The economy of scale in communications

TABLE 2 Common Communications Rates

Teletype	24-96 b/s
Voice	3 or 4 kHz
Facsimile	
4 minutes per page	2.4 kb/s
1 minute per page	9.6 kb/s
Sub-minute ("smart" facsimile)	9.6 kb/s
High Speed	56 kb/s
Video	
Freeze-frame	4 kHz
Full commercial TV	6 MHz
Meteorological scanner data	1.3[a]-28 Mb/s
Data	
Low speed	2.4-9.6 kb/s
Medium speed	56 kb/s
High speed	1.544 Mb/s and up

[a]Bit rate reduced by use of a two-speed tape recorder (fast record, slow playback)

business networks, but the number of locations is limited. American Telephone and Telegraph routes provide private service at 1.544 Mb/s for private users. Digital formats could be employed to take better advantage of these capabilities.

Satellites have expanded the capabilities and breadth of service. An earth station located in Bluenose, South Dakota, has the same digital capability as one in Boulder, Colorado, or Baltimore, Maryland. This capability frequently is 56 kb/s and occasionally 1.3 to 1.5 Mb/s. Additional nodes (earth stations) can be added, and traffic (data and information) routed in response to needs. When it is 9:00 a.m. in New York and Washington, D.C., East Coast traffic requires nearly total satellite capacity; by 5:00 p.m. Pacific time, the traffic balance has moved to the West Coast. Transponders (the satellite receiver-transmitter chains) are operated at rates up to 64 Mb/s, a capacity that is normally time shared among many users, with individual user bit rates per user up to 1.544 or even 6 Mb/s. Although the terrestrial distributed data system has a practical throughput limit of 66%, several satellite systems operate at about 94%, almost doubling the information value. Thus it is difficult to make a comparison of terrestrial and space communication facility costs.

Currently, industry offers moderate bandwidth (50 kb/s) digital services via satellite. In the next few years, a wider variety of services will be available, including very high data rates and specialized data schemes, such as packet transmission and multiple access. Analog and digital meteorological traffic (data or information) may flow through one or several NWS networks (just as it does at present).

2. Terminals. A few years ago there were two dozen domestic earth terminals, each costing about $1 million, in the United States. Today, there are over 2,000 earth stations (most receive only TV), and from 150 to 200 stations are added each month at reasonable prices. In a few years, there will be over 10,000 of these television terminals serving the 50 states, Puerto Rico, and U.S. territories. Further into the future, we can expect the growth of radio services (Mutual, AP Radio News, RKO-Radio, etc.), and millions of direct-broadcast satellite-to-home receivers. Progress in the numbers, types, and uses of earth terminals is as impressive as is progress in development of spacecraft.

These thousands of terminals provide a widely distributed, already-paid-for network of earth stations for the collection of data and distribution of meteorological information.

3. PBS possibilities. The Public Broadcasting System (PBS) currently employs some 150 earth stations and has abandoned surface distribution. Instead of a chain of common carrier microwave towers, which last year would have cost $15 million, the PBS network now has four simultaneous programs being fed via Westar I at an annual cost of $11 million. In addition, each program chain can accommodate up to 6 audio channels. Alternatively, 2 audio channels and a 1.79 Mb/s channel can be carried in each chain.

The PBS, an organization that receives partial public funding, may be a particularly attractive means of disseminating weather information to the public. It already carries a caption channel in the vertical interval of the television signal. Alternatively, the vertical retrace time can be used to display weather or other data-bank information on PBS or commercial channels. Inclusion of PBS-TV station material in CATV systems extends the coverage even further; for example, the National Captioning Institute, in collaboration with ABC, NBC, and PBS, is now using this means of reaching the hearing-impaired audience.

4. Direct broadcasting. Experiments have shown that direct satellite broadcast to television sets is feasible. Broadcast could be wide coverage or coded (to "smart" receivers) by telephone area code, postal code, and the like. The COMSAT MARISAT, serving about 200 ships, has a "calling all ships" capability.

5. Costs and quality. The costs of satellite service have decreased over the past 15 years and stand out as one of the few exceptions that run counter to the inflation trend that has prevailed in the United States for some time. In addition, within these costs better service may become available. For example, earlier mention was made of the nearly doubled throughput offered by digital services and satellite providers when comparing (for example) a 56 kb/s satellite circuit with a 56 kb/s terrestrial circuit.

Satellites have been used successfully to increase the quality of the television service provided by PBS, the number of real-time television locations (rather than tapes sent by mail to Alaska, Hawaii, or Puerto Rico), and the diversity of program material (4 simultaneous programs compared to 1). Satellites have also enabled the inclusion of new services using present equipment.

7.4.2 *Expanded Use of Telephone Systems*

There are about 150 million telephones in the United States. The capital and operational investment is very large, and continuing expansion is under way. New technology (e.g., optical-fiber transmission lines) is making possible a significant increase in data rate, reliability, and types of data-transmission services. The telephone network is unique in supplying a fully switchable communication system.

For example, touch-tone telephones can be used to transmit simple code groups from many 24-hour human-attended operations, such as state police stations and highway toll stations. While it is envisaged that automated ground observations will eventually be expanded greatly, use of such observational possibilities could fill in some of the gaps in a transition period to full automation. Moreover, notwithstanding high success in automating many kinds of observational techniques, there may remain some important weather characteristics that are better reported by humans.

Telephone systems provide ready access to some advanced types of information distribution systems. For example, the code 800 telephone subscriber service now can offer stored-program routing of incoming calls. This may make it possible to offer the public a fully national system of weather information, for use as personal information with regard to knowledge of weather events affecting distant friends and for travel planning, and for business use such as planning of shipments, inventory control, etc. The desired terminal location could be encoded by additional code groups to the 800 access code. Telephone services will also make possible access to centrally managed data banks, as outlined below.

7.4.3 *Television Presentation of Weather Data Bank Information*

Considerable experimentation is now under way in the use of home television sets specially equipped with interactive microprocessors to access data banks. Systems such as Teletext are in pilot operation in the United Kingdon; other systems are in operation in France, Finland, Germany, and Canada. In the United States, a system called Viewdata is under development. The Viewdata system consists of data banks accessed by telephone, to which data suppliers have continuous access for updating their entries. Data is encoded in "pages" suitable for computer-terminal type display by a home television. Color capability is available to highlight information. Part of the video presentation can be flashed for added emphasis. At present, there are about 300 pages in an experimental data bank; the ultimate capacity will be 250,000. Uses envisaged include shopping via "catalogs," business reports, weather text, and graphics. Investigations of marketing possibilities, use charge structures, etc., are under way.

7.4.4 *A Look to the Future*

Private development of a diverse variety of communication possibilities in the United States will make available to NWS in the future as much communication capacity and as many kinds as needed, at very cost-effective prices. To interface optimally with the available systems, NWS must start preparing now for the communication systems of the future. NWS should continue with in-house interface developments to meet particular needs.

7.4.5 *Conclusions*

Satellite communication systems will offer inexpensive broadband capability for both worldwide point-to-point communication and regional broadcasts. These systems will also make possible expansion of the current capability of remote-sensing readouts. For example:

- Satellite ground terminals are proliferating at a rapid rate. The Public Broadcasting System (PBS) network, as an example, offers opportunities to disseminate weather information as a public service. This can be done as a caption channel without interference with other transmission, or as a regular television broadcast program, such as "AM Weather."
- Direct broadcasting to home television sets from satellites will become available within this decade.
- Cable television (CATV) offers opportunities for direct weather dissemination and may, in the future, also offer two-way communication possibilities with interactive capability.
- Regular broadcast television can offer a capability of weather dissemination through broadcast interruption, through the use of captions, or through utilization of the television retrace time.

The telephone system also offers several types of improved communication links:

- touch-tone reporting from human-attended observation posts (e.g., state police offices);
- dissemination on request through either advanced types of information distribution, such as the code 800 system, or the use of home television sets to display information from telephone-accessed data banks; and
- FAA weather information for general aviation through the voice response system (VRS), which could also include other weather information.

Terrestrial links will also offer broadband capability using digital format on coaxial cable or optical fiber transmission links.

NOAA Weather Radio, "AM Weather," and the FAA's voice response system are successful in bringing weather information readily to the public.

In the design and introduction of new data collection and dissemination systems, NWS should be sensitive to the cost and change-over transition time imposed upon its specialized users, such as universities, private meteorologists, and weather modifiers.

The NWS dissemination system should remain highly decentralized. If a field station is a unique source of data or information, it must be prepared to disseminate the data or information electronically as required.

Specific warnings need to be directed to affected areas as mesoscale observational and forecasting capability increases in the future.

The public will need, and demand, a wider variety of information presentation in the future.

7.4.6 *Recommendations*

NWS should plan for extensive use of satellite communication capability in the future.

To make optimal use of modern communication capability, an all-digital format is recommended.

Further uses of telephone systems should be explored, including touch-tone data reporting and code 800 distribution for remote-location weather information.

The implementation plans of NOAA Weather Radio should be completed. The possibility of adding channels should be investigated. Legislation should be prepared to require inclusion of NOAA Weather Radio (which is linked to the Civilian Defense Alert System) channels to all appropriate new radio and television receivers.

The AFOS system is a good step toward a capable two-way communication system linking all forecasting offices. The possibilities of upgrading the system in the future to take advantage of broadband communication systems should be studied.

Ways to implement site-specific warnings, using such means as direct-broadcast TV and CATV, should be studied.

A study should be made of what new presentation formats will be needed and feasible in the future for the public and user groups, e.g., time-lapse sequences, special graphics, false color. Even if NWS itself does not produce such formats, NWS information should be in a form suitable for input to the computer graphics systems that will produce them.

7.5 Estimate of Incremental Costs of Recommended Action

In this section, the costs of improved and new services are estimated to give a rough idea of the fiscal dimensions of the additions to the NOAA efforts in weather services that the Committee recommends as important and feasible. The assumptions made in arriving at these estimates will be given. It should be noted that the Committee does not intend this information as definitive budgetary recommendations, as the Committee was not able to go into detail in this area, but rather as planning guidelines. It will be seen that the total recommendations fall within what the Committee believes is a feasible annual increase for any technological agency — some 15% of the initial base budget for some years, then leveling off with time.

7.5.1 *Resource Trend for NOAA Weather Activities, 1967-1979*

Among meteorologists there is a well-known (and probably apocryphal) story of the irate citizen who stormed into his local weather office: "You made a forecast for light rain and it frosted and snowed and ruined my young plants in the garden!" "Weeelll," the weather man observed, "our yearly budget for the Weather Bureau is $15 million, and there are 150 million people (circa 1949) in this here country, so our weather service costs you 10¢ a year. Here's your dime back!"

The most recent figures available pick up the story in 1967 at an annual budget of $120 million, which includes meteorological satellites. Table 3 shows the annual budgets from 1967 to 1979, in dollars of 1967 and also as reduced to the 1967 base level, as well as staffing figures and population figures from the Bureau of the Census. The budgets of the Satellite Service of NOAA and a portion of the Environmental Data and Information Service of NOAA are also shown, since these expenditures are in support of the total NOAA weather activities.

As seen in Table 3, the real dollar expenditures for 1979 are lower than 1967. The small rises in 1970 and 1971 appear to be partly due to a slowdown in inflation. The total staff has remained nearly level throughout this period. The NWS staffing and real-dollar funding has declined with respect to population. Yet, in spite of what the Committee considers underfunding and understaffing of the NOAA weather services, productivity rose, and many new services and products were instituted. The expansion of services under severe budgetary restrictions was in part due to a strong effort to automate, to reduce the need for increasing the staff wherever possible by using computers and computer-driven communications and graphics. The Committee notes, however, that the understaffing, particularly by professional meteorologists and hydrologists, cannot continue without seriously compromising the value of the weather and hydrological information to the users, as discussed previously in Section 7.1.

7.5.2 *Cost Estimates of Committee Recommendations*

During the briefings with NOAA personnel, and through the documentation supplied, the Committee had access to cost estimates for new observing technology. In addition, some Committee members are familiar with costs of information processing and data display systems. Thus, the Committee was able to arrive at some very general cost estimates, which are summarized here to supplement the Committee's recommendations.

In the case of upper-air remote-sensing systems, such as those for PROFS, estimates are based on the desired array configuration that would give adequate mesoscale information around the array as well as supply the required

TABLE 3 Resource Trend for Weather Activities, 1967-1979

		Producers Price Index	NWS			EDIS[a]			NESS			Totals[b]		
FY	Population[c] (millions)		Full-Time Employees	Budget ($K)	1967 ($)	Full-Time Employees	Budget ($K)	1967 ($)	Full-Time Employees	Budget ($K)	1967 ($)	Full-Time Employees	Budget ($K)	1967 ($)
67	199	100.0	5022	91592	91592				320	30643	30643	5342	122236	122236
88	201	102.5	4980	95546	93216				317	30995	30239	5297	126541	123455
89	203	106.5	4938	101929	95708				326	31767	29828	5262	133696	125536
70	205	110.4	5035	113364	102685				357	7459	6756	5392	120823	109441
71	207	114.0	5189	131951	115746	222	2900	2544	377	24997	21927	5788	159848	140217
72	209	119.1	5197	113730	95491	224	3100	2603	430	28365	23816	5651	145195	121910
73	210	134.7	5140	124672	92555	224	3300	2450	556	37154	27583	5921	165126	122588
74	212	160.1	5162	134505	84013	224	3432	2144	665	61692	38533	6051	199629	124690
75	214	174.9	5044	145458	83166	241	5070	2899	658	63869	36517	5943	214397	122582
76	215	183.0	4996	174968	95611	273	5462	2985	651	71327	38977	5920	251757	137573
77	217	194.2	5015	179916	92645	270	6636	3417	648	89756	46218	5933	276308	142280
78	218	209.3	5074	194287	92827	285	6935	3313	643	94288	45049	6002	295510	141189
79	220	235.5	5044	201088	85388	288	9000	3822	626	97799	41528	5958	307887	130738

[a] The Environmental Data and Information Service is responsible for data archiving and access to the data for research and other studies. Data are given here for that proportion of EDIS resources estimated to be directly related to weather services.

[b] These totals do not include research efforts at ERL, some of which are related to NWS.

[c] These population figures are from the Census Bureau and are rounded off to the nearest million.

information for the synoptic-scale analyses. Here, it is possible that a gradual evolution will take place — an automated upper-air system based on PROFS experience supplanting the balloon-borne radiowindsonde systems. However, this is not certain, and for this reason the upper-air remote-sensing estimates are based on new capital costs and installation expenses, not incremental replacement costs. It is also possible, perhaps probable, that operation of fully automated upper-air systems in the future will be quite efficient in terms of required staffing. However, since they will be complex and high-technology systems, they will require maintenance personnel at a higher professional level than current nonprofessional personnel. The same goes for AFOS and especially for future advanced AFOS systems. Thus, no estimate can be made, at least by the Committee, of changes in personnel numbers or total costs. However, as recommended in Section 7.1, the Committee believes that professional meteorologists and hydrologists must be available at field stations, their main duty being to interface between the weather information and the user. For this reason, the Committee includes here an estimate of the costs for one additional professional meteorologist or hydrologist at 250 stations in order to emphasize the importance of this recommendation.

7.5.2.1 *Planning Functions and Contract Studies* In the Committee's recommendations, planning functions are specified for identification of user gorups and their requirements, educational work, planning for use of advanced information display techniques, and for integrated technical, staffing, and fiscal plans to meet user requirements.

It is assumed that these functions could be carried out by one NWS planning group. In addition, it would appear that contractual arrangements would be useful with university and education groups and private research groups to conduct special user studies, perhaps to prepare educational materials, etc., in coordination with the NWS planning group.

Planning Group (8 senior and 4 support staff, travel and overhead)	$1,000,000/year
Study Contracts	$2,000,000/year

7.5.2.2 *Additional Professional Meteorologists and Hydrologists* One professional meteorologist or hydrologist at each of 250 stations at $80,000 annual salary and overhead, phased in over a period of 10 years.

Initial year cost, 25 people	$2,000,000
Add-on cost, each year	$2,000,000
Annual cost at end of 10 years	$20,000,000

7.5.2.3 *Observing Systems Technology* A few of the systems endorsed in this study are well defined, and costs are sufficiently known to make useful budget estimates. For many of the systems, however, the evolution is in a very early stage. Trade-offs between technical performance and system costs will have to be studied. Much information of the kind to be obtained in the PROFS type of in-service experiments will be needed to make final systems decisions.

Nevertheless, the Committee agreed that it would be useful to make some estimates, based on the best current information. These estimates are given in the spirit of providing representative examples of costs of the kind of systems that will be needed. The reader is cautioned, therefore, to accept these estimates as guidelines to representative costs of probable systems, and not as a budgetary shopping list.

- Winds (e.g., ASDAR, ship systems, lidar, radar). ASDAR costs are well defined. It will cost about $150,000 for a one-time engineering effort to provide an FAA certified prototype for manufacture; production units will cost about $15,000, including installation. Production costs for ship use will be about the same. It will be feasible to purchase and install about 20 such aircraft and ship units a year.

Costs for tests and preparation for on-orbit development of the lidar wind system are less well defined. Based on current experience, costs will be about $8 million a year; the Committee recommends that these costs be shared by NOAA and NASA. These costs will need to be incurred over a 5-year period, at which time the on-orbit test will take place.

Radar costs would cover wind-profiling clear-air radars of some type, perhaps those that will be tested as part of PROFS. The final decisions on a national radar wind system will depend, to some extent, on the experience to be gained with PROFS, the experience to be gained with NEXRAD (discussed below), and system trade-off studies.

In summary, taking into account a reasonable implementation schedule of aircraft and ship automatic data units, costs to NOAA of the lidar development and test program, and the implementation and use of prototype networks of wind-profiling radars, a total cost over the next 10 years is estimated to be about $80 million.

- Radar network. The national storm radar system needs complete upgrading (NEXRAD) before the end of this decade, owing to the rapid deterioration of the current obsolescent radar systems. NWS estimates that the NEXRAD implementation will cost about $250 million.
- Surface automatic stations. It is becoming apparent that fully automatic stations for surface observations are necessary for aviation use, e.g., at airports, and for mesoscale and hydrological data gathering and forecasting. There will be a variety of sensor systems employed, and the range of complexity of the stations needed must be a function of their location and local needs. It is estimated that the total network cost will be about $75 million.
- Remote sensing for upper-air observations. It is a goal to evolve automatic remote-sensing stations that will provide the upper-air information needed (temperature, moisture, winds). Sensor systems will be tested in the PROFS effort. As an example of estimated costs, one full PROFS installation would consist of a central station with four branch stations approximately equidistant from the central station. All would be equipped with radar and IR/microwave temperature/moisture profilers. An ancillary network of about 40 automatic surface stations would provide the needed ground-level observations. The capital costs for one full PROFS installation would be about $5 million, with an additional $5 million for housing for sensors, power installation, line costs, temporary or contractual personnel for installation, and training of local operating personnel. The running costs would probably be similar to a current radiosonde installation (power and staffing). Taking into account the present cost estimates for a full installation along with an estimate of a realistic rate of implementation of new upper-air systems in the next 10 years, it is estimated that about $100 million should be allocated to this item.

7.5.2.4 *Computing, Interactive Processing, Display, and Communications* The NOAA central computing facility at Suitland will need upgrading during the coming period to keep pace with increased computing requirements of improved models for data processing and forecasting and also those of new products. Based on the current investment and plans for the near-term upgrade, it is estimated that $100 million should be allocated to this need.

Interactive processing systems and data-display equipment will be needed at the field stations to make full use of AFOS and mesoscale network capability for both weather and hydrological services. For the medium-term upgrading of these facilities, it is realistic to plan for such computing improvements for 100 large field stations, for a total cost of $100 million. About 100 small field stations should also have increased computing and display capability, for a cost of $30 million.

One of the weakest links in the NWS information system is communications: gathering of observations, communication of predictions within NWS, and provision of weather and hydrological information to the nation. It is estimated that $50 million should be invested to modernize these communications systems so that broadband, efficient (digital) data and product transmissions will match the need for input data and distribution of weather and hydrological information to users.

7.5.3 *Summary of New Financial Requirements for 10 Years*

The approximate or representative costs associated with the recommendations of the Committee are summarized below in tabular form. It must be emphasized again that these representative costs are not definitive budget estimates, nor should they be interpreted as inclusive or exclusive. They are given here to illustrate the magnitude of the investments required by NOAA to realize fully the new technological opportunities to upgrade significantly weather and hydrological services to the nation.

Planning and Studies	$ 30,000,000
Planning at $1 million per year	
Studies at $2 million per year	
Additional Meteorologists and Hydrologists	$110,000,000
Observing Technology	
Winds (aircraft/ship systems, lidar, radar)	$ 80,000,000
Radar (NEXRAD)	$250,000,000
Surface automatic stations for aviation, mesoscale and hydrology	$ 75,000,000

Upper-air remote-sensing stations	$100,000,000
Computing, Interactive Processing, Display, and Communications	
NOAA central computing facility	$100,000,000
100 large field stations	$100,000,000
100 small field stations	$ 30,000,000
Communications/dissemination	$ 50,000,000
	$925,000,000

The Committee cannot propose how the annualization of this total should take place over the 10 years. It may not be feasible to have a one-time substantial increase ($92.5 million per year) and then a level budget, adjusted annually for real dollars. It may be more realistic to plan for a gradual buildup. The Committee believes that it is both prudent and feasible to accommodate a 15% annual increase in real dollars, at least in the first 5 years, to get the program started. The budget might then gradually level off toward the end of the 10-year period.

It is clearly beyond the information available to the Committee and to its charge from NOAA to go further, but it is clear that a real and realistic increase in budgets over the next 5 years or so will enable NWS to improve greatly its services to the nation through the implementation of new technology. For example, an annual increase of 15% would produce over 5 years a doubling of the budget, which should also be adjusted for real dollars.

APPENDIX A

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Washington, D.C. 20230

THE ADMINISTRATOR

August 3, 1979

Dr. Philip Handler
President
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Dr. Handler:

As you are aware, recent discussions have been held between representatives of NOAA and the Academy in which NOAA expressed its interest in examining the impact of recent scientific and technological developments on the operation of the National Weather Service in future years.

Established remote sensing technology, the existence of real-time observations from polar-orbiting and geostationary satellites, and new techniques of communication and data dissemination have made possible the development of an effective very short-range forecast system to provide warnings of severe storms and other weather phenomena. Such a capability, combined with a substantially improved dissemination system capable of providing timely information to governmental agencies, industry, and the general public, could revolutionize the fundamental nature of the weather services of this country. In addition, the current interest in climatology will result in increased demand for the rapid distribution of climatological predictions and information.

In view of these developments, NOAA must critically analyze how it can best meet its increasing responsibilities. To assist NOAA in this analysis, I request the National Academy of Sciences, in cooperation with the National Academy of Engineering, undertake a study to evaluate the probable impact of scientific and technological developments on the operation of the National Weather Service. I request that the study emphasize a functional examination of the subject — evaluating how the National Weather Service can optimize the use of new technology in developing improved services for our nation. Other issues of public policy, such as the organizational structure of the division of responsibility between the public and private sector, should not be addressed in this study.

The Academy should attempt to make the results of the study available to NOAA by March 1, 1980. This schedule will enable NOAA to use the study in conjunction with preparation of the FY 1982 budget. Dr. George S. Benton, Associate Administrator of NOAA, will be pleased to work with the Academy on my behalf to assist in making the necessary arrangements.

We look forward to receiving a proposal from the Academy and appreciate your willingness to assist in this important endeavor.

Sincerely yours,

Richard A. Frank

Copy: Dr. White

APPENDIX B

GLOSSARY

AFOS — Automation of Field Operations and Services

Data communication equipment and data display equipment are organized together in the AFOS system to facilitate the use, by forecasters, of a variety of textual and graphical information and displays. A national communication system will join all 50 Weather Service Forecasting Offices with NMC. The AFOS will have some data-bank capability to support local forecasting, and some data manipulation and limited computational capability. From each WSFO, communication lines will link to AFOS units at each Weather Service Office to provide local data capability.

Analysis

Analysis in meteorology designates the process in which individual data points form the basis from which to derive a map, consisting of series of isovalue lines (pressure, wind, hunidity, temperature, etc.), to depict a field. Data points cannot simply be connected. Usually, the data points are too sparse. In addition, some judgment is used to depict the patterns. When a human makes the judgment, the process is called subjective analysis. A very experienced human can use intuition to add considerable value to an analysis. When the judgment is made through the use of a numerical model, the process is called objective analysis. A computer model must incorporate realistic assumptions and numerical treatment of the relationships between its atmospheric variability. An advantage of the objective method is its consistency; once the assumptions are tuned and the model works well, it continues to work well.

ASDAR — Aircraft Satellite Data Relay

An automatic relay system that extracts wind, position, and temperature information from the inertial navigation system on suitably equipped aircraft, and relays the information to ground stations via the geostationary meteorological satellites. The system could also be adapted for use on ships with either manually or automatically read observations.

CATV — Cable Television

A system of hard-wire distribution to homes or other end points using coaxial cable. The broadband characteristics of the coaxial cable permit many television or audio channels to be disseminated in this manner.

ERL — Environmental Research Laboratories of NOAA

Research in modelling, atmospheric and oceanic physical processes, and observational technology is carried out in ERL, partly as basic research and partly in support of NOAA missions.

FGGE — First GARP Global Experiment; also called (in the United States) the Global Weather Experiment

The major field phase of an internationally planned and conducted effort, the Global Atmospheric Research Program (GARP), in which the nations of the world cooperated through the World Meteorological Organization (WMO), and the nongovernmental, international scientific bodies and national research organizations cooperated through the International Council of Scientific Unions (ICSU). A joint ICSU/WMO scientific committee prepared the scientific rationale and implementation proposals, which were then, through the WMO, considered and implemented as possible by the various national meteorological services. FGGE covered the period November 1977 through November 1979. Two Special Observing Periods were designated (January-February and May-June 1979) during which intensive special observing programs were initiated, in particular, to obtain vertical wind profiles in the tropical belt.

GOES — Geostationary Operational Environmental Satellites

Satellites that orbit the earth at zero inclination (i.e., around the equator) at an altitude such that the orbital velocity is equal to the earth's rotational velocity. The satellites maintain their station constantly over one particular longitude; hence, the term "geostationary." The present GOES system is a spinning cylindrical spacecraft. The spin maintains the axis direction constant in space, and provides a lateral scan across the earth's disc. A stepping mirror in the telescope provides a transverse scan. In this way, a "picture" is built up of the earth's disc, taking about 20 to 25 minutes to complete the full frame. For FGGE, international cooperation resulted in 5 geostationary satellites spaced around the equator to provide full coverage of the tropical and mid-latitude regions.

GTS — Global Telecommunications System

The nations of the world cooperate through the World Meteorological Organization to install and maintain an international communication network (mostly land lines, cables, radio circuits, etc.) for the flow of meteorological observations (low to moderate bit rate) to analysis centers and the flow of information products back to the nations.

INTELSAT

An international consortium of private and government satellite communication organizations to provide internationally coordinated broadband communications.

IR Doppler Lidar for Satellite Use

A system that would use an infrared laser to sound the atmosphere from satellite altitude. The laser would be pulsed and used as a lidar (i.e., a laser radar) so that vertical resolution would be obtained. The laser pulses would be reflected by scatterers in the atmosphere (aerosols, water droplets, etc.). If the scatterers are in motion, the return signal would be Doppler-shifted by an amount corresponding to the radial component of the velocity of the scatterer. The laser beam would be swept in a conical beam along the orbital path, and thus the direction and magnitude of the wind field would be obtained in any region where there are appropriate scatterers.

The technique has been demonstrated in ground and aircraft tests, and is being developed further to see if a feasible system can be employed for satellite use. Power requirements are very high, and this is one of the major design challenges for this satellite-borne system.

Limb Scanning

A technique of satellite observations in which the sensor is pointed toward the limb (horizon) of the earth. The viewing beam is very narrow, and the sensor-pointing angle is adjustable so that the limb is scanned vertically. Provided that the spacecraft has adequate altitude control, this method allows observations to be made with very good vertical resolution. The observations can be made only above those regions where clouds occur. However, the method works, in general, down to tropopause levels or slightly below. The trade-off for the high vertical resolution is that the horizontal resolution is poor, about 1000 km, as a result of the viewing geometry.

MOS — Model Output Statistics

An objective method of weather forecasting based on a statistical combination of predictors derived from the output of numerical models. Forecasts may be based on the statistical relationship between predictors and predicted at one locality (single station approach) or over a region (generalized operator approach).

NESS — National Environmental Satellite Service of NOAA

The unit of NOAA that is responsible for the implementation of operational meteorological satellites, both low-altitude polar-orbiting and high-altitude equatorial-orbiting spacecraft. Research on sensors, techniques, data processing, and data utilization are also carried out within NESS, in coordination with NWS and NASA in appropriate cases.

NEXRAD — Next Generation Radar

The next radar network, an evolutionary upgrade of the national storm surveillance radar network, which is now obsolete. Doppler radars will be installed at some locations to obtain information on the movement of storm systems. FAA and DOD are cooperating in this radar upgrading effort.

NMC — National Meteorological Center of the National Weather Service

The central numerical data and analysis and forecasting unit of NWS, located near Suitland, Maryland (in the Washington, D.C., region). Research is also carried out on physical and mathematical improvement of forecasting models, generation of information products, and possibilities of climatological forecasting.

NOAA — National Oceanic and Atmospheric Administration, a unit of the Department of Commerce

Includes fisheries and coastal zone management activities, as well as research in oceanic and atmospheric processes, and the National Weather Service. NWS is an evolution of the former U.S. Weather Bureau.

PROFS — Prototype Regional Forecasting and Operations System

A combined effort of ERL, NWS, and NESS to develop a sensor system complete with data processing and display to make high-resolution observations and provide the needed information to a forecaster for interpretation of mesoscale weather. The concept, at this time, includes infrared and microwave profiling systems for temperature and moisture profiles, clear-air Doppler radars for wind profiles, and an extensive network of ground stations for surface observations and weather conditions. Each PROFS installation would ideally consist of a square array with a central station. At each corner of the array, wind radars and profilers would give information through the tropopause; at the central station a more powerful radar would give wind profiles into the stratosphere. The ground-based profilers would complement the satellite observations taken looking down, and would provide information on the heights and temperatures of inversions — information which is critical to improvement of satellite-based soundings. It is expected that such an array, located at each rawinsonde site, and eventually in place of the rawinsonde station, would meet fully the needs for the synoptic analyses and would also provide an increase in horizontal resolution by a factor of about 2 over the present upper-air network. This increase in resolution would improve the synoptic-scale analyses and provide detailed information approaching the mesoscale.

RFC — River Forecast Center

There are 12 NWS River Forecast Centers, which are the first-echelon offices for the preparation of river and flood forecasts and warnings for about 2,500 communities.

VAS — VISSR Atmospheric Sounder

This system is analogous to the infrared sounders used on the low-altitude polar-orbiting meteorological satellites. It will be installed on one of the high-altitude equatorial-orbiting geostationary satellites in the near future to ascertain its applicability to severe storm and mesoscale observations. The unit should permit observations every 30 minutes or so, instead of 2 or 4 times a day as provided now from the polar orbiters.

VISSR — Visible-Infrared Spin-Scan Radiometer

The primary instrument on the meteorological geostationary satellite designed to provide a latitude-longitude raster-scan image of the earth's disc in a particular wavelength — visible light for high-resolution daytime observations, and infrared for lower-resolution images in the day but also for nighttime images.

VRS — Voice Response System, organized by the FAA and NWS

Provides automated computer-driven voice forecasts for pilots. The system is accessed thorugh touch-tone telephones, which permit requesting weather information via coded inquiries in the desired terminal or en route locations.

WMO — World Meteorological Organization, a specialized technical agency of the United Nations; its origin is the International Meteorological Organization.

A coordinating agency through which the national meteorological services plan cooperative efforts and set international standards for observations, data reporting, codes, etc. WMO also coordinates various research activities with respect to improved meteorological services, investigations of weather modification possibilities, and environmental issues such as the status of the ozone layer.

WSFO — Weather Service Forecasting Office

There are 50 such major regional field offices of NWS. The staffing includes professional meteorologists.

WSO — Weather Service Office

These are smaller offices than the WSFOs, supplying needs in smaller and local regions. Staffing does not generally include professional meteorologists.