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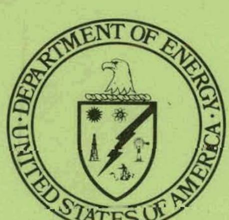
CLIMATE PROGRAM PLAN

Volume 1 of 2

Published January 1980



U.S. Department of Energy

Assistant Secretary for Environment
Office of Health and Environmental Research
Carbon Dioxide and Climate Research Program

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U.S. Department of Energy
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Washington, D.C. 20545

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PREFACE

The anomalies in weather and climate that have occurred within the past few years have had a notable impact on human activities. As a result, there has been an upsurge in interest in climate information useful for mitigating the effects of wide-spread extreme meteorological conditions.

In response to the severe societal losses due to climate fluctuations, A United States Climate Program Plan has been developed by the Interdepartmental Committee for Atmospheric Sciences at the direction of Dr. H. Guyford Stever, former scientific advisor to the President. This document is designed to help the nation gain the knowledge to react more effectively to climate induced problems and to provide a framework by which the climate activities of Federal agencies can be effectively pursued and coordinated.

The Federal agencies with missions that are sensitive to climate have approved this plan. Most have prepared or are in the process of preparing their own climate program plans both to help implement the national plan and to help carry out their mission more effectively. This is such a plan and addresses itself to the needs of the Department of Energy in areas where climate plays an important role.

As in the climate program plans of other agencies, this plan identifies priority research and service needs in five separate categories:

1. Impact assessment.
2. Diagnostics and projection of short-term climate variability, particularly seasonal and interannual anomalies.
3. Climate research.
4. Observations.
5. Data management.

In addition to the above, the Department of Energy Climate Program Plan addresses the problem of the development and coordination of personnel and resources, and calls for the development of special programs in the area of climate-energy relationships at the nation's universities. The main thrust of this plan involves an effort to reduce the uncertainty involved in the assessment of the impact of climate on power generation and the effects of power generation on climate.

Several areas, however, are not covered by this plan, such as: the effect of energy-produced pollutants on human health and ecosystems; problems dealing with day-to-day forecasting; severe weather phenomena; and climates of the distant past, i.e., paleoclimatology. The emphasis has been on anomalous conditions rather than types of weather within the normal bounds of tolerance.

This plan was prepared jointly by the Office of Health and Environmental Research under the Assistant Secretary for Environment and the Atmospheric and Geophysical Sciences Division of the Lawrence Livermore Laboratory (LLL) with the input from an ad hoc committee consisting of members from each of the groups within the Department of Energy that have weather and climate-related activities. Harry Moses, representing the Office of Health and Environmental Research, and Joseph B. Knox, Division Leader of LLL's Atmospheric and Geophysical Sciences Division, did most of the planning. The actual writing was performed by the Livermore group consisting of Joseph B. Knox, Michael C. MacCracken, and Frederick M. Luther. Members of the ad hoc committee were Bernard Baratz, William Bartley, William K. Coblentz, Kelley D. Divine, Walter Eckhardt, Jack E. Hennessey, Harold Jaffe, James C. Kellett, Jr., Joseph B. Knox, John E. Moriarity, Harry Moses, Robert F. Pigeon, Donald Shapero, A. Howard Smith, and Thomas U. Snyder. There are numerous others throughout the Department whose help and assistance is gratefully acknowledged.

I trust that the material presented in this Department of Energy Climate Program Plan will help each of the administrative groups, as well as the Department as a whole, to develop and coordinate their budget initiatives in climate-related areas with the result that the Department of Energy will carry out its mission more effectively. Further, we hope that this plan will serve its function in implementing the United States Climate Program Plan for the benefit of the nation as a whole.

Ruth C. Clusen
Assistant Secretary
for Environment

EXECUTIVE SUMMARY

The Department of Energy and its predecessors have had a long-term interest in the interaction between energy and climate. The DOE is responsible for assuring the current supply of energy, projecting the future energy demand, and developing the means for meeting the demand. Weather and climate have a profound influence on energy demand and on the means available for its delivery. Conversely, the large-scale use of conventional fossil fuels and alternative energy resources (e.g., solar, wind, geothermal, biomass, etc.) may influence weather and climate. The extent to which the impacts of these technologies can affect the climate and society's activities needs to be more accurately determined. Since weather and climate variations on time scales of days to a year are particularly important to the DOE mission, improvements in understanding of these variations would help to achieve the more effective operation of energy systems.

This Department of Energy Climate Program Plan establishes a framework for evaluating the present interrelationships between energy and climate and outlines a specialized, mission-oriented program to both better understand what the effects are and to better use available information in the planning and implementation of energy policies. The research needed to accomplish these objectives, however, focuses on an extremely complex physical system. This plan is intended to lay the groundwork for progress in narrowing the existing uncertainties in energy-climate relations. Thus, the DOE Climate Program will contribute to the U. S. Climate Program that is proposed as a government-wide interagency effort coordinating the diverse agency requirements and drawing on the particular resources of each.

To evaluate, substantiate and quantify the need for its research activities, the Department of Energy plans to undertake a major assessment of the interrelated impacts of weather and climate variability on energy and the present institutional tolerance to such variations. These preliminary studies will provide the basis for improved planning of research activities in the next decade. Pending these studies, DOE places top priority on evaluating the requirements for improvements in weekly, monthly and seasonal forecasts in order that energy allocation and planning on time-scales of less than a year can be made more effective. While the major research effort in this area will be coming from other agencies, DOE will conduct specialized research to assess the prospects for and to determine the accuracy needed in such forecasts. DOE will also conduct research to improve the means of using both available data and forecasts to more effectively plan, assess, and conduct energy-related activities. Streamlining of the many channels through which DOE receives and utilizes available data and forecasts is but one example. DOE also expects to be able to contribute to fundamental understanding of processes governing short-term climate prediction.

The NAS has recently pointed out that the impact of CO_2 emissions on climate will be the most important global scale energy-climate impact problem for the next few decades. In response to this important problem, the DOE formulated and implemented a CO_2 Effects and Assessment Program within Assistant Secretary for Environment during 1977 and 1978. Because of this special focus and the history of organization, the research plan for CO_2 effects research and related climate assessment has been prepared as a separate DOE document. To avoid redundancy, the details of this part of DOE climate work are not repeated in this document although a summary is included in Appendix C.

This document focuses instead on the need for assessing the cycles and budgets of the entire range of substances emitted in power production by the many technologies now in use. Emissions include but are not limited to Kr^{85}, particles, sulfur and nitrogen oxides, waste heat, and hydrocarbons. To provide the basis for assessing the impacts of these emissions, this plan calls for specialized, mission-oriented research to improve understanding of (1) processes that determine how these emissions are transported, transformed and scavenged in the atmosphere, and of (2) the natural processes that can be affected by energy activities. This latter category includes potential modification of surface properties caused, for example, by large arrays of solar collectors, extensive biomass production, and wind power modification of the boundary layer.

It should be stressed that the responsibility for program coordination and management of both the CO_2 Effects and Assessment Program, and the general DOE climate research program resides within the Office of Health and Environment Research-Assistant Secretary for Environment. The management plan, presented in Chapter 6, embodies the close-coupling between these two aspects of climate-energy research as well as DOE divisional user interaction in all phases of the climate research program. Ensuring feedback of climate program assessment findings on energy technology program plans, priorities, and energy policy is foremost in these considerations.

Based on both their sensitivity to climate fluctuations and their impact on climate, DOE will investigate the relative impacts and merits of various energy strategies. Fulfillment of this role, which was directed in the U. S. Climate Program Plan, must remain a long-range objective pending improved understanding of energy-climate interrelationships.

SUMMARY OF RESEARCH GOALS

To implement the DOE Climate Program Plan, DOE will support activities to address the following goals, organized here by categories given in the U. S. Climate Program Plan. These goals are described more fully in Chapter 5.

A. Impacts of Climate Variability

- To support a comprehensive technical, economic, and societal evaluation of the potential impacts on energy policy of various possible weather and climate fluctuations in terms of effects on energy resource, extraction, transportation, generation, distribution and use.
- To improve understanding of the impact of releases of heat and moisture from cooling facilities on local weather and climate.
- To examine possible use of improved 30-day and seasonal climate prediction methods for the purpose of better management of primary and alternative fuel supplies.
- To achieve more effective planning for operation of energy systems in extreme climate conditions and compliance with air quality standards by using the best available climate information.

B. Diagnosis and Projection of Short-Term Climate Variability

- To improve energy-related aspects of meteorological forecasts.
- To define the outlook for improved methods of seasonal climate forecasting that might lessen the impact of climate variations on the operation of energy systems by improving the management of critical fuels.

C. Climate Research

- To improve understanding of the chemical cycles and budgets of thermal, gaseous and particulate emissions from energy-related activities.
- To improve understanding of the processes that transport, transform, and scavenge emissions from energy-related activities.
- To improve understanding of processes that can potentially be affected by energy-related emissions and that may provide insight into or modify the response of such atmospheric processes.
- To develop, improve and apply unique measurement capabilities that will provide insight into atmospheric and climatic processes.

D. Observations Related to Climate Research and Services

- To examine patterns and trends of energy-related pollutant concentrations and meteorological variables affected by such concentrations.
- To measure atmospheric and oceanic parameters that determine the magnitude of alternative energy resources.
- To process and analyze data collected by others that may provide information needed to develop and implement energy policy and production.

E. Climate Data Management

- To develop an interactive, rapid-access data base of recent meteorological data that have particular relevance to energy systems.
- To provide a system of inventorying the data collected by DOE in order to make it more readily available within and outside of DOE.

F. Development and Coordination of Personnel and Resources

- To ensure that highly qualified personnel are available to carry out the DOE Climate Program.
- To carry out a broad-based, mission-oriented research program that provides optimum utilization of human and scientific resources.

G. International Aspects

- To maintain cognizance of the climatic implications of international developments in energy-related activities through participation in the exchange of technical expertise and specialized data.

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CHAPTER 1. ENERGY AND CLIMATE - AN OVERVIEW

A United States Climate Program Plan developed by the Interdepartmental Committee for Atmospheric Sciences (ICAS, 1977) provides a framework for the development and coordination of needed climate research and services within the Federal Government. The goal of the U. S. Climate Program is "to help the Nation respond more effectively to climate-induced problems by enabling the government to be aware of or to anticipate climatic fluctuations and their domestic and international impacts and to identify man's impacts and potential influence on regional and global climate." It is within the context of the U. S. Climate Program that the Department of Energy Climate Program will focus on those problems that are specifically related to the DOE mission.

As part of the United States Climate Program Plan developed by the Interdepartmental Committee for Atmospheric Sciences, the DOE is responsible for developing an understanding of and assessment capabilities for:

a. The effects of climate and climate fluctuations on man's generation of power,

b. The effects of power generation and its various fuel processes and/or control technologies on climate,

c. Development of blends of power generation and distribution modes that minimize adverse environmental and climatic effects.

The DOE Climate Program Plan focuses on these three major roles for DOE in basic and applied research. The purpose of this document is (1) to present background information relevant to these roles, (2) to identify the perceived and potential effects of energy technologies on climate that now merit assessment, (3) to define the need for research on the prediction of weather and climate variations and assessment of their effects on power production, and (4) to outline research goals appropriate to the DOE mission.

The Department of Energy Organization Act of 1977 assigns to the Department certain environmental responsibilities and functions. These include ensuring that the Department's policies and actions conform to national environmental laws and principles and conducting a program of research and development on the environmental effects of energy technologies and programs.

To meet its responsibilities, DOE must evaluate the environmental impacts and climatic effects of the energy options being considered by the DOE. Such activities must be responsive to the relevant portions of the National Environmental Policy Act and its requirements for evaluation, review, and consideration of the expected impacts and effects.

In 1977 the DOE Assistant Secretary for Environment established the Office of Carbon Dioxide and Climate Research. This office has the focal role for the federal government in all activities pertaining to CO_2, including evaluation of sources, climatic effects, social and economic consequences, suggested remedial measures, and interfaces with development of energy policy. Because action on CO_2 has already been taken, activities relating to CO_2 will not be included in this DOE Climate Program Plan. (See Appendix C for a description of the program.)

The Department of Energy and its predecessors have had a long-term interest in the interaction between energy and climate on both a regional and a global scale. The DOE is responsible for assuring the current supply of energy, projecting future energy demand, and developing the means for reducing and meeting the demand. Weather and climate variations on time scales of days to a year are currently perceived to be of greatest importance to the energy supply aspects of the DOE mission.

Weather and climate have a profound influence on the demand for energy and on the means available for its delivery, as was clearly evidenced in the eastern United States during the recent winters of 1976-1977 and 1977-1978. The shortage of natural gas during 1976-1977 and the coal shortage during 1977-1978 (due to cold weather coupled with a coal strike) are but two demonstrations of how weather interacts with the supply, distribution, and use of energy resources.

In addition to the direct, short-term impacts of weather and climate on man's activities, there are also many indirect effects. For example, droughts can suppress the amount of energy available from both hydroelectric and biomass sources. In terms of effects on energy, prolonged periods of extreme cold weather place high demands on natural gas and fuel oil supplies and electric peaking capacity, with commercial activity and industrial productivity being reduced if fuel supplies are interrupted.

Conversely, the large-scale use of conventional fossil fuels and alternative energy resources (such as solar, wind, geothermal, ocean thermal energy conversion, etc.) may influence weather and climate, the magnitude of the impact being dependent upon the amount and type of energy used. Power generation may affect the weather and climate by the atmospheric release of heat, moisture, particles and trace gases (such as CO_2, CO, NO_x, SO_x, oxidants, ^{85}Kr, tritium, and organic compounds) or by the alteration of the radiative and evaporative properties of the ground over large geographic areas. Changes in the atmospheric composition affect the transmission and exchange of solar and longwave radiation, which can in turn lead to changes in the temperature, moisture, and wind fields in addition to affecting air quality. These are only a few examples of the direct interaction between energy generation and climate.

Environmental control technologies offer the means by which reductions may be achieved in emissions to the atmosphere of pollutants from energy generation. In pursuing these controls, often obviously harmful pollutants can be converted into apparently innocuous emissions. Recent environmental experiences, however, have taught that solving one problem, if done without proper evaluation, can lead to more complex problems. A recent example in which the control technology used to reduce one problem may have produced another, possibly more serious, problem is the use of tall stacks. To reduce apparent health and ecological effects due to high concentrations of SO_2 around power plants, tall stacks were constructed so that emissions could be dispersed and better mixed before affecting surface concentrations. The increased time that SO_2 is then in the atmosphere, however, allows more SO_2 to be converted to sulfate particles. These particles, if acidic, may lead to greater acidification of precipitation (in conjunction with oxides of nitrogen) and an increase in atmospheric turbidity. It is clear that with such feedback processes acting in the atmosphere, proposed control options applied to the increasing variety of energy technologies should be examined periodically for adverse effects using the best available assessment information and methodologies. It is important to identify significant control technologies that, if applied to energy options on a large scale to meet increasing energy demands, may either have or prevent significant environmental consequences (e.g., carbonyl sulfide resulting from SO_2 control measures (see Appendix B), or remedial measures for CO_2).

It is in this current national and world-wide awareness of the role of energy in the interplay between societal activities and climate, including the effect of man on the earth's climate, and the impact of climate anomalies on these activities, that DOE is charged with developing and implementing important parts of the United States Climate Program for the benefit of and service to the American public and industry. The goal of this program will not be easily fulfilled because of the great difficulty of the problem. Nonetheless, this Plan is intended to lay the groundwork for progress in narrowing the scientific uncertainties inherent in energy-climate impact assessments. As this is accomplished this improved understanding will assist the DOE in more effectively carrying out its mission.

CHAPTER 2. THE EFFECTS OF WEATHER AND CLIMATE ON POWER PRODUCTION

Variations in weather and climate affect many areas of society. Areas that are impacted include the productivity of farms, forests and fisheries; land and water resources; commercial, military and private transportation and communications; and the requirement for power generation and the means by which power is generated. Each area of society has a different tolerance to weather and climatic effects, depending on the institutional structure involved. Now that energy is in short supply, society has become more acutely aware of the interaction between weather and power production. Whether it be intense thunderstorms or intense heat, cold winters or dry winters, mountain runoff or valley winds - all affect how energy is supplied and used.

Weather can loosely be defined as the state of the atmosphere, including such conditions as rain, cloudiness, temperature and winds. Weather is highly variable and includes severe storms, hurricanes, downpours, and intense cold and hot spells. Weather forecasts deal with the near-term and the next few days, over which time relatively accurate descriptions of events can presently be made. Theory indicates that the forecasting time can probably be extended out to a week for weather events with scales of several hundred kilometers. It appears unlikely, however, that extreme local weather conditions can be foreseen much beyond a day, although, as described below, there is hope that anticipated monthly and seasonal average conditions can be forecast.

Beyond the few days over which weather can be forecast, reliance is usually placed on climatology, which is the average of the weather conditions in a region compiled, as a function of season, over a number of years. Climate is defined to include this set of average (or usual) conditions as well as the range of extreme conditions that can occur <u>and</u> the likelihood of their occurrence. In the U. S., the period of time used historically to develop averages or "normals" for a particular period (e.g., a month) has been 30 years with such averages being updated or recalculated every ten years. If climatic conditions were essentially constant, with only year to year fluctuations, the averages would remain relatively constant. Climatic conditions are not constant, however and, in fact, it appears that climate has varied over all time scales. Both short (year to year) and long-term variations can be large, and both can be persistent. Thus there can be multiyear periods of drought and multimillenium periods of continental ice sheets. The former are perceived as a fluctuation; the latter (although very large) are often overlooked as being outside the range of consideration and because their presence would be evidenced in the short-term as a very small trend.

At present, there is only very limited skill (improvement over climatology) shown in NOAA forecasts of monthly and seasonal climates. Extensions of work using sea surface temperatures to forecast seasonal climates (Namias, 1978a) and, if shown to be valid, incorporation of statistical correlations in the future with solar-terrestrial activity (that may be anticipated several years in advance) offer hope that improvements can be made in the ability to forecast near-term (i.e., short- and intermediate-term as defined below) climatic fluctuations (ICAS, 1977).

In describing the effects of weather and climate variations on power production, we subdivide atmospheric behavior into four time-scales.

- Short Term is defined to mean that period of time over which detailed forecasting of specific atmospheric properties is reliable (currently up to 3-5 days) and over which responses to energy shortages are based on already in-place supplies. We will, however, restrict this domain to times of at least a day in the future, leaving to those actually producing the energy (as opposed to those planning and allocating it) the responsibility for responding to such shorter-term conditions as tornadoes, etc.
- Intermediate term is defined to mean that period of time over which short-term advance planning can alleviate potential problems of energy shortages, etc. Typically, this period ranges from weeks to a season or year.
- Medium term is defined as the period from one to ten years. This period corresponds to the time over which planning typically occurs to address questions of allocation of capital for energy generation facilities and resource utilization.
- Long term is defined as the period from ten to one-hundred years. This period corresponds to the time over which energy technologies typically can be introduced and become important contributors to national energy

supplies or over which new national energy supplies or new technologies mature and their large-scale use may aggravate environmental problems. Even longer time periods are not addressed in this Plan.

The rest of this chapter highlights some of the important areas where weather and climate variations affect power production and supply on each of the four time-scales.

THE SHORT TERM

Providing the vast amounts of power needed for this country requires reliance on many modes of generation, including domestic and foreign energy supplies. Variations in the weather and climate can influence how energy resources are found, extracted, transported, transformed, distributed and consumed. To some extent the diversity of sources protects us from impacts of unusual weather on any one source or area. But, by being able to better understand what can be expected on a day to day basis and even a few days into the future (i.e., the "short-term"), energy-related activities can be planned so as to reduce overall consumption, and the daily comfort of people in their homes and the efficient functioning of industry can be made more certain.

Table 2-1 shows that the range of impacts is extremely diverse. Many of the impacts are very important. If accurate climate predictions were available and utilized, it would be possible to mitigate many of the potential impacts through contingency planning.

DOE is already responding to many situations involving short-term atmospheric behavior. The focal points in the Department for the short-term use of weather data for managing the operation of energy systems are the Short-Term Emergency Planning Division of the Economic Regulatory Administration (ERA) and the Office of Regulatory Analysis and the Systems Analysis Branch of the Federal Energy Regulatory Commission (FERC). Real-time contingency planning, responses to the impact of extremes of weather on the operation of energy systems or on energy demands, and fuel consumption reports are typical activities of these groups. Problems of interest include increased energy demands related to extreme cold or heat, icing or freezing rain impacting on the operation of transmission lines, freezing of rivers impeding the availability of barge transportation and normal

TABLE 2-1. Effects of Atmospheric Variations and Potential Perturbations on Energy Resources

Time Scale of Impact / Energy Technology or Activity	Short-Term (days)	Intermediate-Term (months)	Medium-Term (years)	Long-Term (decades)
Utility Systems	Severe storm destruction of utility lines (e.g. icing, winds, etc.) System overloading due to unusual energy demands (e.g. heat waves, extreme cold)	Extreme seasonal climate fluctuations may stress utility system distribution capabilities	Interannual changes in storm tracks may affect the need for distribution capabilities of power over large regions	
Transportation of Resources	River flooding River and lake icing inhibiting barge traffic Ocean weather conditions control arrival of oil and LNG tankers	Weather/climate extremes can induce shifts in mode of fuel transportation Extent of sea-ice in arctic resource regions	Climate variations can affect relative merits of alternative fuel transport options	
Cooling Towers	River icing limiting cooling water supply	Drought limiting cooling water supply and higher temperature water releases	Limits on cooling water availability may require legislative or judicial action	Changing climate may alter design efficiency of cooling tower systems

TABLE 2-1. Cont'd

Energy Technology or Activity / Time Scale of Impact	Short-Term (days)	Intermediate-Term (months)	Medium-Term (years)	Long-Term (decades)
Overall Energy Demand Requirements	Weather induced demand peaks due to hot or cold spells	Climate conditions determine fuel and energy needs (e.g., dry periods increase power demands of irrigation systems)		Long-term trends could change regional or even continental energy demand patterns
Conservation (Heating/Cooling)	Extreme weather affects extent of conservation possible	Cold winters and hot summers affect demand, prices and need for conservation measures for "shortage fuels"	Variations in year to year climate affect effectiveness of various conservation actions	
Fossil Fuel Power Generation	Extreme weather affects ability to recover resources (e.g., hurricanes affect natural gas recovery in coastal locations, etc.)	Oil, coal, and natural gas production dependent on demand created by climate conditions Climate variations can affect oil, coal and natural gas storage requirements	Climate variations can affect performance of control options and implementation of fuel switching options	

TABLE 2-1. Cont'd

Energy Technology or Activity \ Time Scale of Impact	Short-Term (days)	Intermediate-Term (months)	Medium-Term (years)	Long-Term (decades)
Nuclear Power Generation (Including Waste Disposal)				Very-long variations in temperature and water supply may threaten isolation of waste repositories
Solar Power	Day to day weather affects light available for conversion Extreme wind may cause structural damage	Interannual variations in storm tracks may alter number of cloud-free days	Degraded atmospheric transmissivity may reduce effectiveness of solar collectors Altered patterns for storm tracks may reduce cloud-free days	Changing climate could alter design requirements of solar collector systems
Wind Power Conversion	Day to day weather affects wind resource Very strong winds may damage system		Interannual variations in storm tracks may alter wind resources	Climate variations can affect wind energy resources
Biomass	Day to day weather may alter plant reproductivity and affect harvest Severe storm damage to crops	Precipitation and water availability and quality influence biomass growth	Precipitation quality (e.g. acid rain) can affect trends in productive capability of the resource	Climate variations can affect forest management

TABLE 2-1. Cont'd

Time Scale of Impact / Energy Technology or Activity	Short-Term (days)	Intermediate-Term (months)	Medium-Term (years)	Long-Term (decades)
Geothermal	Day to day weather may affect control of noxious gas emissions, cooling water and condensate, and ground water quality			
Hydroelectric	Day to day weather may cause extremes in river flow and snowmelt	Seasonal precipitation controls water supply	Multi-year droughts can affect available water supplies	Changes in climate may affect water supply
Ocean Thermal Energy Conversion	Day to day weather, especially severe weather, may affect efficiency and operations of OTEC by inducing oceanic mixing	Interannual variations in ocean current strength may affect resource Ocean temperature variations may increase or reduce resource	Ocean temperature variations may increase or reduce resource, may necessitate relocation	Trends in climate may affect ocean currents and thermal gradients

cooling water, hurricanes interfering with the normal operation of natural gas wells in off-shore environments, precipitation rates in agricultural areas, and coastal forecasts required for liquified natural gas tanker unloading operations. Most of these examples require contingency planning and the identification of alternative supplies for either stand-by or current use. When required, emergency actions can be implemented by either ERA or FERC to reduce or alleviate the energy emergencies.

Appendix B describes a few case studies in more detail.

THE INTERMEDIATE TERM

The past few years have provided examples of the impact monthly and seasonal variations in atmospheric behavior can have on energy supply and distribution. The intense cold period in the eastern United States during December 1976 and January 1977 led to high demands for natural gas, the effects of which eventually spread to the west coast as gas supplies were diverted to the east. Although the winter as a whole in the east was not much colder than normal and total seasonal supplies were nearly adequate, the intensely cold months created such a large demand that the rate of delivering supplies was not adequate. Accurate forecasting of the weekly, monthly, and seasonal temperature patterns and the resulting energy demands would have permitted better planning of mitigating measures such as fuel switching.

Table 2-1 indicates that the intermediate-term behavior of the atmosphere can have a wide variety of impacts. Some impacts can affect the cost of energy. For example, the amount of water stored in mountain snow determines the amount of hydroelectric power that can be produced during the following year. Any shortfall in water supply must be made-up using more costly means of power generation. Accurate forecasts of spring rains and the rate of snow melt would permit more efficient (and therefore less expensive) use of available resources. Intermediate-term weather variations can also affect energy availability. For example, river or lake transport systems may be blocked by ice for extended periods, thus requiring the use of stockpiled fuels or provision of alternate means of delivery.

THE MEDIUM TERM

In the design and planning of energy generation and supply facilities, account is already taken of the normal climate and a range of extremes (e.g., flood and hurricane frequency, etc.) that is based on past records. We have already discussed the need for short- and intermediate-term warning about such events.

For the medium term what is needed for energy planning purposes are predictions of trends and cycles of climate that might strain energy supplies in ways that make facilities uneconomical or inadequate to meet energy needs. For example, several years of drought in the western United States have heavily impacted hydroelectric supply capability and limited cooling water supply while at the same time increasing the power demands of some irrigation systems. These are not cases involving direct threats to public safety; rather the existing energy supplies are simply less abundant and plans must be made for augmenting them (e.g., gas turbines, etc.). An increase in the frequency of extreme hot spells during successive summers is an example where the demand for energy might change in a way not normally foreseen by energy planners. Unusually cold or lengthy winters in northern regions where river or sea ice might block access of ships to port facilities would limit the amount and period over which oil might be transported to the United States.

As enumerated further by examples in Table 2-1, the issues related to medium-term behavior of the atmosphere concern potential trends and cycles that tend to make use of normal data for planning inadequate. Accurate projections of atmospheric behavior would certainly allow more efficient use of resources and improve capabilities for the siting and planning of new facilities.

THE LONG TERM

The "normal" climate serves as the basis for planning energy needs (demands) and assessing the possibilities for energy supply. Thus, to even a greater extent than for the medium term, understanding trends, cycles and changes in variability of atmospheric behavior can affect the planning for energy supplies in the future in important ways. Shifts in circulation systems or ocean currents could cause changes in climate which affect energy demand, the availability of such resources as cooling water, and the ability to develop biomass as an energy source. Table 2-1 lists a number of these potential effects. All could be alleviated to some extent by improved understanding of future climatic events.

CHAPTER 3. EFFECTS OF ENERGY TECHNOLOGIES ON WEATHER AND CLIMATE

The by-products of energy production and consumption released to the atmosphere, namely waste heat, gases (including water vapor), and particles, can affect climate on a local or regional scale, usually by affecting the atmospheric radiation balance. In addition, any technology that alters the characteristics of the surface of the earth over extensive areas (such as the projected use of solar collectors) can also have climatic effects by altering the energy and moisture balances at the surface. The effects of energy use in large urban areas, and the resulting impacts on local and regional climate, have received considerable attention in recent years (National Research Council, 1977, and METROMEX,* 1978). Effects range from alteration of temperature to modification of precipitation.

Projecting energy use and consumption (and the resulting emission patterns) into the next century, reveals that several effects of energy production and consumption have the potential of extending beyond the regional scale, eventually out to the global scale. A primary source of these effects will be increased concentrations of CO_2 (see Appendix C), but heat, particles, and possibly other gases may also prove to be important considerations in evaluating future energy policy.

In the discussion of the effects of weather and climate variations on power production (Chapter 2), it was convenient to subdivide atmospheric behavior into various time-scales. Although energy production has diurnal, seasonal and annual cycles, it is more convenient to discuss the effects of energy technologies on weather and climate in terms of the spatial scale of the effect. Some effects of power production may be intermittent, but the most significant effects result from continuous or persistent emissions that either impact the region near the source (e.g., H_2O and particles) or contribute to a build up of the global background concentration (e.g., CO_2, ^{85}Kr).

*METROMEX is the acronym for the Metropolitan Meteorological Experiment.

The spatial scales of importance to power production and climatic effects are:

- local (to distances up to tens of kilometers from the source)
- regional (to distances up to hundreds of kilometers)
- sub-continental (to distances up to thousands of kilometers)
- global (world-wide distribution).

Apart from very limited amounts of permanently stored energy, all energy that is generated is eventually dissipated and ends up as heat, regardless of the means of generation. The released heat may be concentrated at specific sites (e.g., waste heat at power plants) or it may be broadly distributed (e.g., space heating in businesses and residences). The climatic impact depends upon both the total amount of energy released and the amount released in a given area (flux per unit area).

The combined impact of population increases, changing patterns of population densities, and escalating per capita energy consumption has been to concentrate very large energy fluxes per unit area (flux density) in some regions of the world. In 1971, for example, the world average energy consumption was approximately 1.5 x 10^9 Btu/km^2 of land area per year (0.05 W/m^2). In the same year, New York City's Manhattan Island had a total energy flux density of approximately 3 x 10^{12} Btu/km^2 per year (100 W/m^2), which is very nearly equal to the global average net radiation (solar and longwave absorption minus longwave emission) at the earth's surface.

Figure 3-1 is a graph of energy flux density versus area. The solid line indicates the global average net radiation flux at the surface, and the dashed lines represent years circa 1970 and 2050. The scale of meteorological processes is indicated at the bottom of the graph. Current levels of energy consumption are insignificant in the global heat budget but can be significant on the local or regional scale.

Urban areas are typically warmer than the surrounding rural regions, thus leading to the term "urban heat island." A major portion of the urban heat island effect is caused by changes in the physical parameters of the area, namely radiative properties, moisture properties, evapotranspiration rates, and surface roughness. Another cause is anthropogenic heat rejection, which varies with season and latitude. In the cold northern climates during winter, anthropogenic heat in metropolitan areas may equal or exceed the amount of solar energy received. Energy conservation efforts may reduce the heat island effect.

FIGURE 3.1

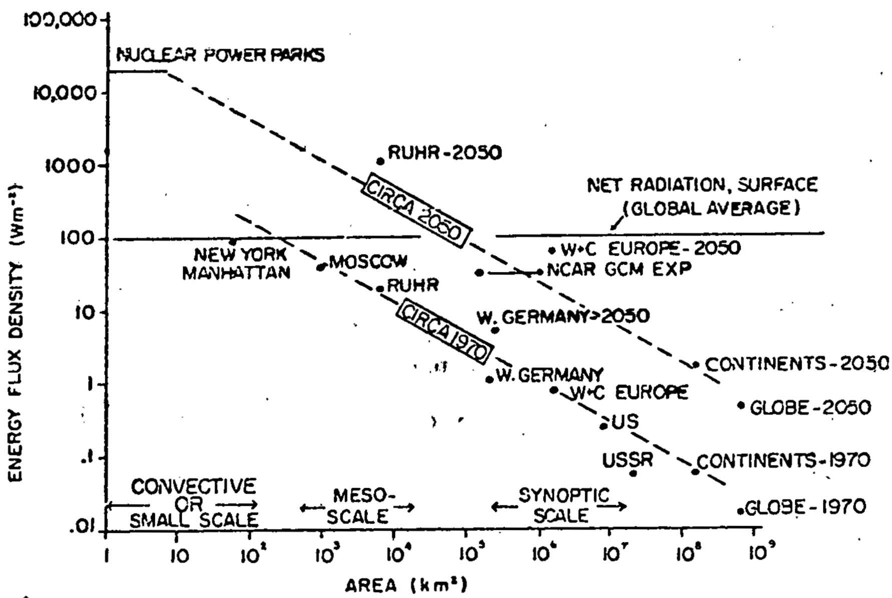

FIGURE 3.1. Energy consumption (W m^{-2}) plotted versus area (km^2) from Kutzbach (1974). Sources: Nuclear power parks, RUHR, W. Germany, continents, globe (Hafele, 1973). Manhattan, Moscow, Europe, United States, Soviet Union (Matthews et al., 1971). NCAR GCM Experiment (Washington, 1972). The solid line shows the net radiation balance at the surface, and the dashed lines represent years circa 1970 and 2050.

In addition to waste heat, large-scale particulate and gaseous emissions can also affect the weather and climate. The major sources of atmospheric particles are: wind-raised dust and sea salt, direct products of combustion, volcanic particles, organic products of plant and animal life, and indirect products of combustion (resulting from chemical conversion in the atmosphere of gaseous emissions). The major anthropogenic sources of particles are industrial production and processing of materials such as metals and cement, agriculture, and combustion associated with industrial, commercial and domestic needs. The particles directly emitted tend to be large and are usually radiatively important only on the local and regional scales. Secondary particles, which form from vapors in the atmosphere, are usually sub-micron in size ($<10^{-6}$ m in diameter), have optical properties which induce strong scattering of solar radiation, and can be carried by the wind over sub-continental and global distances. Increased energy consumption relying on fuel combustion without adequate controls may increase the atmospheric loading of both primary and secondary (indirect) particles. Atmospheric particles may also affect the nucleation and condensation of water vapor to form cloud droplets and, thus, the rates and pattern of precipitation. Hygroscopic particles may act as cloud condensation nuclei, thus affecting cloudiness and precipitation. Changes in cloudiness or atmospheric particle loading affect the transmission and scattering of solar radiation and the exchange of longwave radiation, thereby further perturbing the radiation balance, which in turn affects temperature patterns.

Gaseous emissions which are radiatively important, such as CO_2 and H_2O, may affect the climate directly by their radiative impact or indirectly by affecting the concentrations of other atmospheric constituents. CO_2 and H_2O are both strong absorbers of infrared radiation, but they are relatively transparent to solar radiation. Consequently, an increase in the atmospheric concentration of these species would act to reduce the flux of infrared radiation emitted to space. To restore the balance with incoming solar radiation, there would be an increase in atmospheric temperature. Estimates of the increase in the global average surface temperature due to a doubling of CO_2 from 300 to 600 ppm range from 1.5 to $3.0^{\circ}K$ (National Research Council, 1977; also see Appendix C below). Predictions of the future CO_2 increase due to combustion of fossil fuels suggest a doubling of the concentration before the middle of the next century.

Heat and moisture from cooling towers have been observed to affect the generation of cumulus clouds. Depending upon the stability of the prevailing air flow, the moisture and heat may lead to decreased stability increasing convective activity, and precipitation. Some have suggested this may lead to an increased frequency of thunderstorms and, possibly, tornadoes if employed on a large scale. Evaporation processes used to dissipate waste heat may also cause fogging and icing.

Other aspects of providing and distributing energy may also affect the weather or climate, but the magnitudes of many of the effects have not yet been assessed. Reservoirs behind hydroelectric dams alter important surface characteristics. Strip mining and similar processes of resource extraction cause vegetation to be removed, thereby exposing soil that has a reflectivity (albedo) different from the natural surface, thus altering the amount of solar radiation absorbed. The moisture retention properties are also altered, so energy that would have been dissipated as latent heat by evaporation is dissipated as sensible heat. In addition, particulate matter may be released to the atmosphere as wind-blown dust. These effects are likely to be local or regional in scale.

Transportation of crude oil and gasoline has the potential for inadvertent climatic effects. The use of supertankers offers the possibility of large oil spills or slicks at sea in the event of an accident. Very thin oil slicks extending over many square kilometers in higher latitudes or colder water would change the albedo of the ocean and reduce the amount of evaporation. These perturbations to the surface energy balance would affect the ocean-atmosphere exchange rates for moisture and sensible heat.

Other examples of how providing and distributing energy may affect weather and climate are given below for various energy technologies. The effects are summarized in Table 3-1 showing the spatial scale of the effect.

FOSSIL FUEL COMBUSTION (COAL, OIL, GAS)

Combustion of fossil fuels causes atmospheric emissions of primary particles and numerous gaseous species (SO_x, NO_x, CO_x, H_2O and hydrocarbons). The species SO_x, NO_x and hydrocarbons may be converted to secondary particles that can contribute to acid rain on the sub-continental scale and affect radiative processes and precipitation patterns, as already noted above.

TABLE 3-1. The Potential Effects of Energy Technologies on Weather and Climate.+

Energy Technology or Activity \ Spatial Scale of Impact	Local $(10\ km)^2$	Regional $(100\ km)^2$	Sub-Continental $(1000\ km)^2$	Global
Resource Extraction	Particle loading, albedo change →	→	→	
	Surface hydrologic properties →	→		
	Alternative energy technologies alter natural fluxes of energy. →	→		
Transportation Systems	Oil slick, spill →	→	→	
	Emissions from transportation systems. →	→		
Cooling Towers (Waste Heat)	Waste heat, moisture precipitation, temperature, cloudiness, vorticity, thunderstorms, tornadoes	→		
Overall Energy Demands	←	Urban effects, winds, temperature, precipitation	→	→
Fossil*: Coal Oil Gas	Gaseous emissions →	Oxidants →	→	
	$(SO_x, NO_x, CO_x, H_2O, HC)$ →	Secondary particles (SO_x, NO_x, HC) →	Acid rain, precipitation, albedo →	Albedo
	Primary Particulate Matter →	→		

*Effects of CO_2 are not considered in this table or program plan. See Appendix C.

+The arrows indicate the approximate range of spacial scales of the effect. The effect is mentioned under the spatial scale for which the impacts are likely to be the greatest.

TABLE 3-1. (Cont'd)

Energy Technology or Activity / Spatial Scale of Impact	Local $(10\ km)^2$	Regional $(100\ km)^2$	Sub-Continental $(1000\ km)^2$	Global
Nuclear	←	^{85}Kr →	→	→
Solar	Soil moisture, albedo, temperature, convection →	→		
Biomass	Soil moisture, albedo, temperature, convection →	→	←	CO_2 loss to atmosphere (deforestation)
	Gaseous emissions, particulates (like fossil) →	→		
Wind	Modification of planetary boundary layer →	Precipitation		
Geothermal	Gaseous emissions →	Sulfate aerosols →	→	
Hydroelectric	Albedo, temperature, moisture →	→ Controls flooding and effects of extreme weather		
Ocean Thermal Energy Conversion	Temperature, salinity circulation (currents), albedo →	→	synoptic activity →	CO_2 release

NUCLEAR

Routine emissions of ^{85}Kr, although at very small concentrations, are building up the global background concentration of this species. Ionization caused by ^{85}Kr decay increases the atmospheric conductivity. This increase in turn can affect the atmospheric electric field that is believed to be related to scavenging and precipitation processes in thunderstorms and severe convective activity.

SOLAR

The technologies being developed to provide electrical power on a large scale using solar energy include photovoltaic, distributed collector, and central receiver systems. The interception and collection of solar radiation by large arrays of reflectors and absorbers will alter the regional radiation budget (solar and longwave) and change the moisture retention properties of the earth's surface. Natural surfaces absorb 70-90% of the incident solar radiation; deserts 70-75%, and vegetated surfaces 80-90%. Portions of the solar energy absorbed are convected away from the surface as heat, used for evaporation, radiated away as longwave radiation, or conducted into the ground. If arrays of mirrors or collectors were placed over soil with a significant moisture content, evaporation would be restricted, thus affecting the moisture and radiation budgets.

Solar thermal collector systems that use large arrays of mirrors or distributed collectors use the absorbed solar radiation to heat a working fluid that in turn powers a steam turbine generator. Cooling towers are used for disposal of the waste heat (approximately 60% of the thermal energy absorbed in the working fluid). The solar thermal collector system reduces the normal amount of energy absorbed at the surface and available for heating the atmosphere in the region. This deficiency would have an effect like a high desert albedo. Cooling towers concentrate the energy and moisture released to the atmosphere, effects that may impact on weather and climate as already noted above.

BIOMASS

There are two approaches to the use of biomass as a source of energy. One is to cut down existing forests for firewood, such as is done on a large scale in South America and in other tropical locations. The second is to grow special crops for either their oil and rubber content or their combustible mass. Both aspects change the surface conditions (i.e., increase or decrease albedo, affect the moisture flux by changing evaporation or evapotranspiration rates) in ways that may lead to local, regional, or even larger-scale climatic effects (e.g., Potter et al., 1975). Deforestation also contributes CO_2 to the atmosphere, and biomass crops contribute gaseous and particulate emissions.

WIND

Individual wind turbine generators do not have a significant effect on the planetary boundary layer. However, many such wind turbine generators grouped together may extract energy from a region at a rate that is a significant fraction of the natural rate of kinetic energy replenishment (which averages about 2.5 W/m^2 over the U.S.). In this case there may be a significant change in the wind flow pattern of the planetary boundary layer, that may affect surface heat and moisture losses, temperature, and the precipitation rate on a regional scale.

GEOTHERMAL

Among the various gaseous emissions resulting from the extraction of geothermal energy, H_2S has the greatest potential for affecting weather and climate since it can be converted to sulfate aerosols (particles) through a chain of chemical reactions. As in the case of particles from other energy technologies, these aerosols may affect the regional climate by perturbing the radiation and condensation nucleii budgets.

HYDROELECTRIC

Reservoirs formed behind dams can alter important surface characteristics. For example, the evaporation rate is enhanced because of the increased water surface area, especially in the West during normally dry summer months. Changing from a vegetated surface to a lake surface also changes the albedo. The net effect is a change in the local and regional temperature and moisture distributions. Dams also help to reduce the effects of extreme weather by controlling flooding and by providing water for irrigation in times of drought.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

These facilities extract energy from the temperature difference between the surface and deeper water. Bringing the cooler, deep water to near the surface will reduce the sea surface temperature and alter salinity gradients. The extent to which ambient surface temperatures are lowered will depend on plant design and site conditions. A 100-240 MW OTEC plant may lower the surface temperature 2-3^{o}C. Near the equator changes in the sea surface temperature can affect the development of tropical storms. The pumping of large amounts of deep, nutrient-rich ocean water to near the ocean surface may cause formation of large plankton blooms, that would change the ocean albedo.

The artificial upwelling of deep ocean water caused by OTEC plants also may have an effect on the concentration of CO_2 in the atmosphere. The forced upwelling of deep ocean waters (containing about 15% more dissolved carbon than the ocean surface layers) is a potential source of atmospheric CO_2 if the water is discharged from the plant near the ocean surface. The microclimate at OTEC sites could be affected further if open cycle systems are utilized. Degassing procedures needed to ensure operating efficiencies may lead to the venting of concentrations of oxygen, nitrogen, and CO_2. The potential climatic impacts of these perturbations need to be assessed.

SUMMARY

The examples given above for the various energy technologies highlight the climate related issues associated with primary and alternative sources of power. There is no assurance that all of the critical issues have been identified, nor have assessments of the possible climatic effects been completed. There is a need for constant awareness of potential climatic effects, continued development of improved assessment capabilities, and regular updating of assessments. The DOE is charged with evaluating all of the potential effects on weather and climate from power production.

The DOE is preparing Environmental Development Plans (EDP) for each of the major technology programs. EDP's will provide a guide for planning and managing the climatic, environmental, health, and safety activities required by technology development programs, including identification of climatic and environmental issues, plans for solutions, and key milestones for environmental impact assessments and environmental impact statements.

CHAPTER 4. OVERVIEW OF THE UNITED STATES CLIMATE PROGRAM

Several U.S. and international organizations have prepared overview documents describing our understanding of the natural climate system and its variability and fluctuations as well as the potential to influence it. (See Appendix A for a summary of the behavior of the climate system.) During the last several years, activities have become especially intense among scientists and the public, prompting Congress to consider legislation that would establish climate prediction and research as a focused government program.

In developing the DOE Climate Program as a component of the U.S. Climate Program, the DOE has reviewed the pending legislation and the reports and plans prepared by other agencies. To put into perspective the elements of DOE's contribution to the U.S. Climate Program, this chapter describes the major elements of the U.S. Climate Program, the agency roles and interrelationships that are emerging, and the general role that DOE can be expected to play. It should be kept in mind that, whereas the official roles of each agency can be defined quite clearly, the development of capabilities in the various agencies can be expected to lead to considerable interagency sponsored research as the most effective means to addressing this important national issue.

It is widely agreed that there are five basic categories of tasks related to improving the understanding of the role of the climate on society and of society on climate. Briefly, as stated in A United States Climate Program Plan (ICAS, 1977), these five categories are:

1. Impact assessments of climatic variability on crop yields, livestock production, energy demand, land and water resources, transportation, national security*, and other activities.
2. Diagnosis and projection of observed climatic variations, particularly seasonal and interannual anomalies and fluctuations.
3. Research to gain basic understanding of natural climate variability and of man's potential impact on climate, such as the long-term growth of carbon dioxide.

*It is anticipated that national security will not be included in the United States Climate Program based on statements in the draft executive order establishing the Program.

4. Observations by satellite and other means to help determine the earth's radiation budget, air composition, sea-air interactions, and other processes that induce climate variability.
5. Management of the vast array of measurements needed for climate research and services - oceanic, atmospheric, hydrologic, solar, and other types of data.

Major roles in gathering and managing data, forecasting weather and climate, and carrying out basic climate research (Categories 2-5) will be played by NOAA, NSF, DOD and NASA. Data and understanding developed by these agencies will be used by a wide number of agencies in interpreting the impact of present and future weather and climate on their activities and to allow assessment of the impact of their activities on weather and climate (Category 1). In some cases this may require the user agencies to conduct or sponsor specialized research activities, but the major role will certainly be the use and application of capabilities developed under the direction of NOAA. A National Climate Program Office has been established within the Department of Commerce to provide a focal point for interagency coordination at the working level and to assist with related international activities and cooperation.

We will first consider the agencies responsible for providing data and understanding and then those agencies that are primarily users of the data. As indicated below, some agencies have joint roles.

OBSERVATION AND PREDICTION

The National Oceanic and Atmospheric Administration has taken lead responsibility in the development and coordination of the U.S. Climate Program. This activity would build on their present role in atmospheric monitoring, forecasting, weather modification, research, and intergovernmental coordination. As indicated by the central box in Fig. 4-1, this role will be central to the U.S. climate effort. NOAA also appears in Fig. 4-1 in a number of other roles that will be described later in this chapter.

The National Science Foundation has been the traditional source of funding for basic research into atmospheric processes by universities and the National Center for Atmospheric Research. NSF has led the way the past few years in supporting climate research through its Climate Dynamics Office and sponsorship of much of the U.S. contribution to the Global Atmospheric Research Program, the second objective of which is improved understanding of climate. In addition, NSF projects play an important role in supporting the development and training of the increased number of qualified researchers required to address these issues. This role is expected to continue under the U.S. Climate Program. As shown in Fig. 4-1, this role will be coupled with the research role of NOAA.

As part of its role of providing weather and climate information in support of military operations and national security, the Department of Defense maintains a comprehensive observation and forecasting program, and carries out extensive atmospheric research in support of its forecasting role. DOD was an early supporter of climate research through its Advanced Research Projects Agency ARPA program to assess the potential for deliberate climate modification by other nations impacting on U.S. security. A recent treaty under the auspices of the United Nations prohibits use of climate modification as a means of war. In terms of the U.S. Climate Program, DOD's extensive meteorological activities offer the potential for expanding cooperation with NOAA in terms of data exchange and applied research, although their major function will continue to be in support of national security.

A major role in data gathering and management is also planned by NASA, emphasizing the remote sensing capabilities available on satellites. This capability will provide important data to NOAA for use in forecasting weather and climate. NASA also plans to carry out research related to its primary data gathering

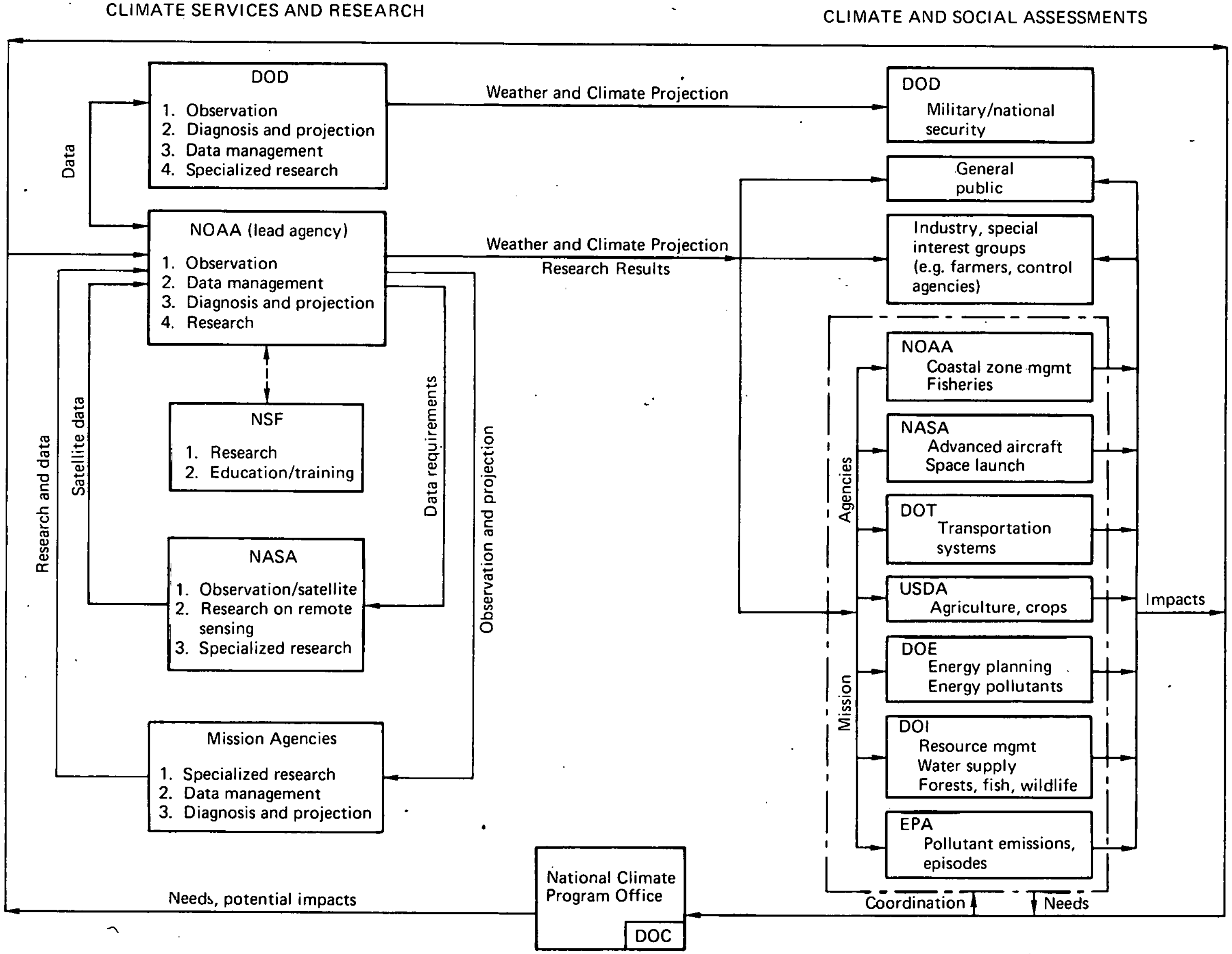

FIGURE 4.1. Schematic diagram of institutional inter-relationships of agencies participating in the U. S. Climate Program.

function in order to improve its ability to measure and interpret important parameters from space. Note that in Fig. 4-1 we also view NASA as a user of data in order for it to carry out its role of aerospace planning, space vehicle launch, etc. That role will be discussed further below.

MISSION AGENCIES AND ASSESSMENT

Numerous mission agencies will use the weather and climate data and the fundamental understanding of climate that is to be developed for planning and assessment. In addition, the industrial and commercial sector and the public will use the data. As indicated in Fig. 4-1, these groups get some of their information directly from NOAA, and some indirectly through other mission agencies that may forecast the potential impact of the future climate on their specific interests. This great variety is a clear indication of the pervasive influence of atmospheric events on our society and economy.

The second and third chapters of this report have described the many needs of the Department of Energy for information on weather and climate and its responsibilities in the conduct of research on the interaction between climate and energy production. The next chapter will describe the agency response to these needs and responsibilities. We will highlight below and in Fig. 4-1 only a limited selection of the needs of other governmental users of the data and understanding to be generated by the U. S Climate Program.

NOAA, NASA and DOD, and other mission agencies (DOE, DOT, USDA, etc.), in addition to supplying data, are users of data. NOAA is responsible for coastal zone management, for response to oil spills and numerous other activities in our shore areas. NASA is responsible for evaluating the impact of space vehicle emissions on the atmosphere and for planning space missions. DOD uses the data in many ways in support of its national security responsibility.

The Department of Transportation has supported extensive atmospheric research in recent years in order to improve understanding of the impact of aircraft emissions on the atmosphere. In addition, of course, DOT is responsible for assuring safe operation of U. S. transportation systems. Weather and climate can, of course, have major impacts on highways, aircraft, river transportation systems and the like.

The Department of Agriculture requires information on weather and climate to determine impacts on crops and crop diseases and pests, effects that can create either bountiful or restricted harvests. Accurate long-range forecasts could help in planning acreage needs for crops, optimum types of seeds, etc.

The Department of the Interior requires atmospheric data for forest and land resource management, water supply forecasting, fish and wildlife maintenance, and other purposes.

The Environmental Protection Agency requires data for use in evaluating pollutant impacts on the atmosphere (e.g., fluorocarbon effects on stratospheric ozone, automobile emissions on tropospheric oxidant, etc.) and in forecasting conditions conducive to air pollution episodes so that control measures can be taken.

COORDINATION

The DOE plan will focus on DOE's role, primarily related to issues of assessment of the interaction of energy and climate. To provide interagency coordination at the technical level and to coordinate activities going on under the auspices of the U.S. Climate Program, a National Climate Program Office (NCPO) has been established within the Department of Commerce. Clearly this office will have responsibility for coordinating the activities of NOAA, NASA, NSF and DOD in carrying out their major functions of data management, analysis, and forecasting as well as research conducted in these and other mission agencies. DOE also expects that NCPO will provide both an interfacing role to assure coordination among the mission agencies and a guiding role to bring the needs of the mission agencies for information to the attention of those agencies that are to provide data.

The U.S. Climate Program sets ambitious goals - developing an understanding of climate and civilization's impact upon it. Although climate has been studied for many years, we are still largely ignorant of the causes and mechanisms leading to such major phenomena of the past as continental ice sheets, century-long cold climates, and even our present relatively warm period. In fulfulling the role mandated to DOE, the projects that are a part of the DOE Climate Program will contribute to the overall goals of the U.S. Climate Program. Resources and capabilities sponsored and developed by DOE and its predecessors can play an important role in assisting other agencies to carry out their roles in the U.S. Climate Program.

CHAPTER 5. THE DOE CONTRIBUTION TO THE U. S. CLIMATE PROGRAM

The DOE contribution to the U. S. Climate Program focuses on topics of greatest urgency to the DOE mission. The DOE Climate Program is intended to be flexible with its initial efforts directed toward topics of immediate need to the DOE mission, with additional program elements phased in as tasks are completed and as new areas of needed research are identified. The specific tasks and objectives will evolve over the years in response to a continuing process of planning and review and to the progress made in understanding the complex interactions of the processes controlling the climate.

The specific objectives proposed rely in large part on existing core capabilities within DOE. Included among these capabilities are energy demand modeling, climate modeling, expertise in computational physics, and experience in the real-time use of meteorological data for regional environmental assessments. The DOE will rely largely on observational data available through NOAA and NASA. DOE will also make available its expertise and capabilities for use in support of the missions of these and other agencies. The DOE contribution described in the following sections is intended to correspond to the five broad activities that are essential parts of the U. S. Climate Program. An additional activity area has been included to ensure that the program can be effectively implemented and a section has been included on the international aspects of the energy-climate problem.

A. IMPACTS OF CLIMATE VARIABILITY

This activity of the U. S. Climate Program focuses on assessing the impact of climate variability on national activities. In the case of energy activities, the converse effects are also of importance. Therefore, the assessments to be performed by the DOE include the impacts of weather and climate variations on energy systems and the impacts of energy systems on weather and climate. These assessments will be performed over a range of time scales of interest, with priorities as summarized in Table 5-1. Efforts directed toward assessments on the shorter time scales will receive the highest priority initially, because they are

TABLE 5-1. Priority of DOE Climate Assessment Activities.

Time Scale	Effects of Climate Variability on Energy Systems	Impacts of Energy Systems on Weather and Climate
a. Short Term (days)	High Priority Initial Effort	High Priority Initial Effort
b. Intermediate Term (1 to 12 mo)	High Priority Initial Effort	Medium Priority Initial Effort
c. Medium Term (1 to 10 yrs)	Future Effort*	Future Effort*
d. Long Term (10 to 100 yrs)	Future Effort*	Future Effort* for non-CO_2 Effects

*Definitive objectives and priorities will be determined during the first few years of the U. S. Climate Program. Efforts are planned under the Climate Research Activity (Sec. 5.C) that will develop the capabilities necessary to perform these longer-term assessments in the future.

currently more clearly perceived to be of importance. However, the first goal of the DOE program in this category will be to evaluate the validity of these proposed priorities. Subsequent goals in this category are ordered by time scale of their impact.

GOAL: To support a comprehensive technical, economic, and societal evaluation of the potential impacts on energy policy of various possible weather and climate fluctuations in terms of effects on energy resource, extraction, transportation, generation, distribution and use.

While it has been especially apparent in recent years that weather and climate fluctuations can affect many energy-related activities, these effects have not yet been well quantified and interrelated, especially for new alternative energy technologies. In addition to the noted sensitivities, there is also a substantial capability of the energy supply system to tolerate weather and climate extremes. As a priority objective, DOE will undertake to define the magnitude, importance and consequences of potential stresses imposed by variations in weather and climate, including especially the coupling of energy use to such variations. Of particular importance will be an effort to better define the extent of progress needed to provide sufficient information for use in policymaking. Results of these studies will be used to update priorities for needed activities within the DOE Climate Program.

1. Short-Term Impacts (Days)

Day-to-day energy resource allocation, production and demand can be substantially affected by extreme weather conditions. With the increasing pressure on the nation's scarce energy resources, DOE has recognized the need to develop and improve its capability to tailor existing NOAA forecasts for use in overseeing regional-scale energy activities. Inclusion of professional meteorologists in short-term planning can be expected to improve information related to such problems as freezing rain impact on power lines, safety of offshore off-loading from LNG tankers, advance warning of severe weather situations, weather-related shutdown of offshore drilling platforms, freezing of coal stockpiles, river icing, etc. Prior assessment of and adaptation to such impacts can be accomplished largely by better use of available forecasts, and such action would likely significantly assist in DOE's performance of its mission. DOE's efforts to more effectively incorporate real-time weather information in the operations of energy systems and the management of energy emergencies are part of the normal mission of DOE and, although related to the DOE Climate Program, is not considered to be part of it.

On this time scale, one important study of the impacts of energy activities on weather and climate is proceeding, however, as part of the DOE Climate Program.

GOAL: To improve understanding of the impact of releases of heat and moisture from cooling facilities on local weather and climate.

The objectives are: to investigate the extent and nature of increased cloudiness, temperature effects due to shadowing, and increased precipitation resulting from rejected heat and moisture; to extend the analysis and results of the above conditions to large energy centers and assessment of their impacts; and to improve the understanding and representation of the radiative and physical processes related to the urban heat island effect in the region of major cities. An existing effort in this area is the METER* project, which is looking specifically at releases from cooling towers. Assessment studies have also been made of the potential impact of large power parks envisaged for the future on weather and climate, including possibly increased frequency of thunderstorms and tornadoes in the surrounding region. The DOE will augment these studies as necessary to reduce the uncertainties of the impact assessments.

2. Intermediate-Term Impacts (1 to 12 Months)

GOAL: To examine possible use of improved 30-day and seasonal climate prediction methods for the purpose of better management of primary and alternative fuel supplies.

The objectives are: to determine the required accuracy for 30-day and seasonal climate predictions to be useful in improving fuel management; to develop

*METER is the acronym for Meteorological Effects of Thermal Energy Releases.

more accurate regional demand models for electricity and other fuels utilizing climatic and engineering test data; and to investigate development and use of regionalized, seasonal climate predictions of heating degree days in the planning of natural gas curtailments. Evaluation is also needed of the required reliability of such forecasts to assure that their use does not jeopardize the nation's economic health in the event of failure of the forecasts. Existing efforts in these directions include development of energy demand models (e.g., at Colorado State University) and studies of the relationship between sea-surface temperature and regional climate (e.g., Massachusetts Institute of Technology).

3. Medium-Term Impacts (1 to 10 Years)

GOAL: To achieve more effective planning for operation of energy systems both in extreme climate conditions and in compliance with air quality standards by expanded use of available climate information and developing assessment capabilities.

Prospects for improving medium-term forecasts rely on better understanding of natural climate variability and secular climate relationships. Because it will take several years for the results of increased climate research to become evident, assessment studies of the impacts of energy systems on climate will not be a major focus until several years after the U. S. Climate Program has been initiated. During this interim period definitive objectives and priorities will be determined for evaluation of the impacts of climate on energy and energy on climate. It is intended that processes important in determining the energy impacts on climate be studied, for example, by use of perturbed climate state models. Some of the monitoring activities that will be important to these assessments are already planned (see Section 5.D).

4. Long-Term Impacts (10 to 100 Years)

Aside from planned activities related to CO_2 emissions, any additional studies required in this area will be proposed after a period of planning during which definitive project objectives will be determined. Some of the areas in need of assessment include Kr^{85}, thermal emissions, particles, and surface albedo changes. Recent activities include use of modeling capabilities at Lawrence Livermore Laboratory to assess the long-term global climatic effects of several anthropogenic and natural atmospheric perturbations (deforestation, volcanism, reduced ozone and solar variability). On-going research will lead to improvements in these modeling capabilities and in the understanding of climatic processes (see Section 5.C).

B. DIAGNOSIS AND PROJECTION OF SHORT-TERM CLIMATE VARIABILITY

Development of an improved capability for predicting short-term climate variability is a very high priority of DOE because of the impact on the operation of energy systems (Committee on Commerce, Science, and Transportation, 1977). Although weather predictions beyond several days are generally viewed as impracticable, there appears to be no theoretical reason why suitable spatial- and time-averaged variables cannot be predicted on a time scale of up to a few months (e.g., Schneider and Temkin, 1977). Based upon the history of extended weather forecasting, however, it is unlikely that rapid progress will be made in this area because of the difficulty of the problem.

Empirical studies have identified a significant correlation between sea-surface temperature (SST) anomalies and subsequent sub-continental scale temperature and precipitation anomalies. Bjerknes (1969) pointed out very clearly that short-term climate predictions would probably not be achieved until the ocean currents and temperature patterns are observed in a synoptic sense, i.e., in a manner similar to the real-time observations commonly available for weather-state definition. The geophysical community has yet to achieve this oceanic monitoring capability on a global basis.

Significant progress in short-term empirical weather and climate prediction is expected to come through development of more adequate observing systems, data bases, identification of appropriate short-term climate variability relationships, and the quantification of these relationships through modern statistical techniques.

GOAL: To improve energy-related aspects of meteorological forecasts.

The objective is to develop capabilities to improve forecasts in order to be better able to evaluate impacts on energy systems and their operations. Existing activities within DOE include studies of initialization procedures for numerical models so as to reduce initial errors, predictive mesoscale modeling efforts, and improvement of the mathematical techniques of computational physics (such as the finite element method) for use in such models. Efforts under the U.S. Climate Program will include a feasibility study of using improved mesoscale prediction methods (e.g., Kreitzberg, 1976) in critical energy areas on cases involving severe weather prediction on both the synoptic and regional scales, development of initialization procedures consistent with these numerical methods, and implementation of advanced numerical techniques for assessment studies. Verification studies, such as those associated with the intergovernmental SESAME* program, will also be encouraged.

GOAL: To define the outlook for improved methods of seasonal climate forecasting that might lessen the impact of climate variations on the operation of energy systems by improving the management of critical fuels.

The objectives are: to determine the relative skill of various competing methodologies for seasonal climate prediction as required by the DOE; to accelerate the application of modern statistical techniques (including principal component analysis) in determining relationships between sea-surface temperature anomalies and subsequent space-averaged climate states in the U. S.; and to develop improved methods of predicting sea-surface temperature for a period of at least 30 days in advance.

Under DOE sponsorship, the use of principal component analysis is being explored at MIT in regard to the preparation of 30-day forecasts of sea-surface temperature in the Pacific. Promising preliminary results have been obtained using a data base for the Pacific Ocean covering a period of several years. Research to improve the skill of 30-day forecasts, however, must also consider many other coupled processes and feedback mechanisms in addition to the SST anomaly. In a separate effort, development and testing of a detailed urban natural gas demand

*SESAME is the acronym for Severe Environmental Storms And Mesoscale Experiment.

model for space heating given engineering data on the type and number of structures in the community and bi-hourly wind and temperature data have shown very promising results for two cities of modest size (Fig. 5-1). Coupling of new climate prediction models with demand models may prove useful in short-term energy planning in the next decade. DOE efforts will be expanded to consider other processes that are also related to climate research (Section 5.C).

C. CLIMATE RESEARCH

Adequate physical insight does not now exist to permit assessment of many aspects of the potential impacts of climate on energy and of energy on climate. To develop the needed understanding, DOE will support climate research into many aspects of existing uncertainty, particularly those pertaining to the DOE mission. In addition, DOE will make available the resources of its national laboratories and other contractors to assist in the U. S. Climate Program.

Three major focuses of specialized climate research are planned, each of which builds on present research and capabilities. The first focuses on chemical cycles and budgets, the second on atmospheric processes that are especially important in affecting these cycles and budgets, and the third on climate processes that may be affected by the results of energy-related activities. In addition, research in a fourth area that builds on particular strengths within DOE offers the potential to advance fundamental understanding of climate.

GOAL: To improve understanding of the chemical cycles and budgets of thermal, gaseous and particulate emissions from energy-related activities.

Energy-related activities result in major releases to the atmosphere of heat, particles, radionuclides (e.g., ^{85}Kr), and gaseous and particulate compounds of carbon, sulfur, and nitrogen. The impacts of these releases depend on the extent to which they perturb natural cycles of these substances on local, regional, continental, and global scales. There are, however, major uncertainties in the budgets of these substances, in the processes by which they are transformed and scavenged, and in the relative role of natural and energy-related pollutants in perturbing climatic processes. Comprehensive evaluation of the impacts on

Figure 5-1

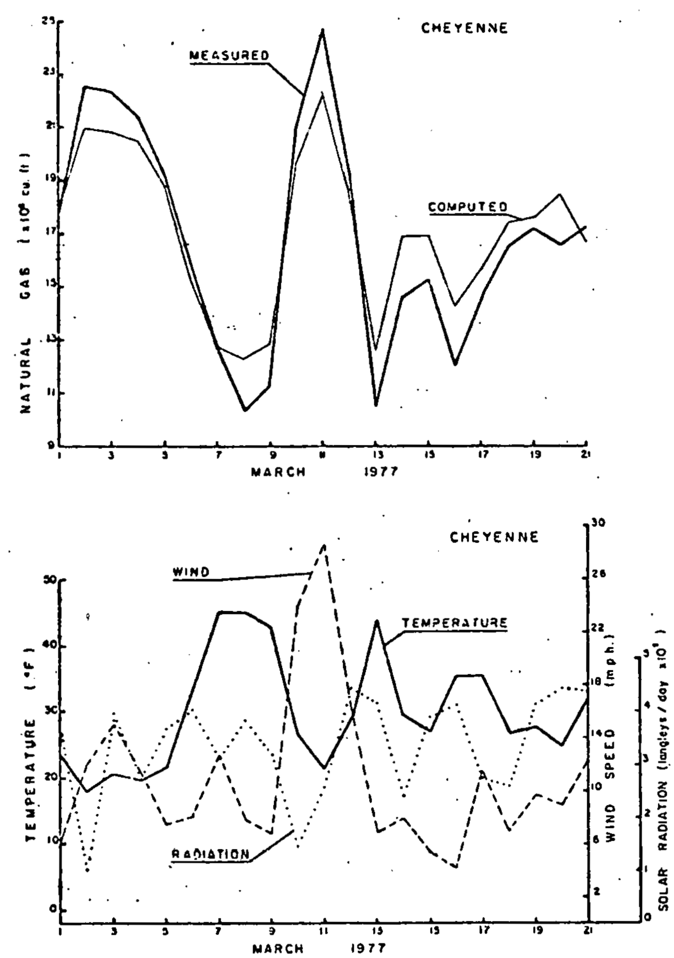

FIGURE 5.1. Comparison of the measured total daily and predicted space-heating natural gas consumption and the average daily weather data for Cheyenne, Wyoming during March 1977. [Source: Reiter et al., 1978]

climate of energy-related activities will require maintenance of up-to-date inventories and analyses of emissions, including trends in emissions that may result from new technological developments.

- Heat: Direct thermal emissions have been estimated with reasonable accuracy, especially in industrialized regions. Although the effects of such emissions on urban scales are becoming better understood, understanding perturbations on regional scales requires major research. Spatial redistribution of energy releases resulting from changes in energy technologies may require further assessment.
- Particles: Inventories of direct emissions of large particles (10^{-6} m) are becoming available. Climate effects, however, are more likely to result from small particles formed from gaseous precursors because of their greater light-scattering abilities. Evaluation of the global budgets of hydrocarbons and sulfur should be used to improve the present particle inventory, with additional consideration given to size distribution.
- Radionuclides: Of primary climatic interest is ^{85}Kr, which may modify atmospheric conductivity. A complete inventory back to the initial releases would allow evaluation of trends in regional and global background concentrations and the potential for effects. Study of the distribution of other radionuclides (e.g., those generated from past nuclear testing) is also important in understanding atmospheric transport processes.
- Carbon: Aside from the major climatic effects of CO_2, hydrocarbons (particularly methane) and CO can alter atmospheric chemistry. Carbon compound emissions affect photochemical oxidant concentrations in the lower atmosphere and ozone concentrations in the upper atmosphere. A comprehensive global budget of hydrocarbons is needed so that potential impacts can be assessed.
- Sulfur: Major governmental research programs are now focusing on the budget and cycle of sulfur oxide emissions. Climatically important effects include acidification of precipitation and formation of secondary particles in the lower atmosphere. Other sulfur emissions (e.g., carbonyl sulfide from natural sources and as a by-product of controlling fossil fuel emissions) may affect stratospheric aerosol concentrations. Because these changes in particle concentration may impact climate,

comprehensive sulfur compound budgets and emission inventories are needed.

- Nitrogen: Man-made emissions of compounds of nitrogen (NO from combustion, N_2O from agricultural lands, etc.) are believed to have important effects on tropospheric and stratospheric chemistry and to result in acidification and precipitation on a regional scale. Their role in tropospheric chemistry may accelerate production of light scattering particles. Comprehensive budgets and emission inventories are needed, since the uncertainties of the natural budgets are large (e.g., for N_2O, the uncertainty is about an order of magnitude).

Projects in this area would focus on development and maintenance of comprehensive continental and global budgets of emissions of the above substances, analysis of major uncertainties, development of measurement capabilities and carrying out of laboratory measurements needed to improve understanding of both natural and pollutant cycles and budgets.

GOAL: To improve understanding of the processes that transport, transform, and scavenge emissions from energy-related activities.

During their lifetime in the atmosphere-ocean system, thermal, gaseous, and particulate emissions can be transported, transformed, and scavenged by a wide variety of processes. Better understanding of the budgets and cycles, as well as the effect of the emissions on the climate, necessitates research to reduce the present uncertainties about these processes.

- Atmospheric Chemistry: Homogeneous and heterogeneous chemical processes can transform emissions from gases to particles, from relatively innocuous substances to climatically interacting substances, and by doing this, change their lifetimes in the atmosphere. Aerosol and cloud droplet chemistry is of particular importance because of the role of small particles in the atmospheric radiative processes. Understanding such processes requires theoretical, numerical, laboratory, and field experiments.
- Atmospheric Transport: The dispersal of thermal, gaseous and particulate emissions can affect climate from the regional to global scale. Transport of sulfur oxides to scales of 1000 km and beyond can lead to acidification of precipitation. Transport of carbonyl sulfide to

the stratosphere can result in modification of stratospheric aerosol. Development and use of relatively inert substances, for example long-lived radionuclides, have provided important information on atmospheric transport and such studies will be continued. Dynamic and diagnostic numerical models are being developed to study transport in complex synoptic, coastal and topographic regimes. DOE will continue such efforts as a means of understanding vertical and horizontal transport of pollutants and effects of weather on energy generation.

- Scavenging by Precipitation: Pollutants can be removed from the atmosphere by precipitation, either in the form in which they exist in the dry atmosphere or after chemical transformation in raining or non-raining clouds. This sink process can play an important role in pollutant budgets. Understanding the dependence of scavenging rate on particle size and pollutant characteristics is important to improve understanding of the lifetime of energy-related emissions in the atmosphere.
- Surface Interactions: Energy-related emissions can also be scavenged by plants, bacteria and surface chemical reactions on land and by exchange across the air-sea interface over the ocean and lakes. These processes are strongly dependent on the physical and chemical characteristics of both the pollutant and the surface. As with wet scavenging, surface removal processes play an important role in determining pollutant lifetime.
- Atmospheric Radiation: Many energy-related emissions are transformed by the atmospheric radiation they encounter. Some species undergo photochemical reactions in the lower atmosphere, others in the upper atmosphere. Thermal emissions are, to a large extent, dispersed by radiative processes. Thus, radiation plays a major role in ultimately determining the fate and budget of these emissions.

GOAL: To improve understanding of processes that can potentially be affected by energy-related emissions and that may provide insight into or modify the response of such atmospheric processes.

Global and regional climate is determined by the interplay of many individual processes, the interactions of which are, in many cases, poorly understood.

Reducing the present uncertainty in assessments of the response of this climate system to potential perturbations related to energy generation and use requires a quantitative level of understanding of the individual processes in order that the response of the fully coupled climate system may be understood. In addition, some of these processes can be altered by energy-related emissions, thereby leading to modification of the overall climatic response. The fundamental and specialized research program that is planned in pursuit of the DOE mission is intended to be fully integrated into the national research effort. Research objectives include the following areas:

- Atmospheric Electric Field: Increased radioactive decay of radionuclides can lead to an increase of the atmospheric ion concentration and of conductivity. With the prospect of substantial increases in the release of ^{85}Kr with the possible greater reliance on nuclear power, better understanding of the role of electrical processes in the atmosphere, particularly in terms of scavenging in convective systems is essential for the evaluation of the need for emissions control.
- Surface Characteristics: Energy-related activities change the surface evaporation potential, roughness, heat capacity, and albedo in many ways and on many scales. Examples include construction of dams for reservoirs, installation of wind generator and solar collector arrays, replacing forests with biomass production, accidental creation of oceanic mono-molecular films and oil slicks in colder oceanic waters or at high latitudes. Because the surface is the major medium in transforming incident solar energy into a driving force of atmospheric motions, better understanding is needed to evaluate how surface modification can lead to climate impacts.
- Solar-Terrestrial Relations: Because solar radiation plays an important role in determining climate and the initial effect of many energy-related emissions is primarily on radiative processes, improved understanding of the interaction between variations in solar radiation and the climate might play an important role in understanding energy/climate interactions. There is growing statistical and circumstantial evidence that small variations in solar output, in the solar magnetic field, and in solar orbital elements affect the earth's weather and climate. Understanding the physical processes involved is an important research

objective and is an area in which DOE can expand its research by building on existing programs. As actual data regarding the variability of solar radiation on the outer boundaries of the stratosphere-ionosphere became available from proposed NASA measurements, we shall explore the sensitivity of climatic simulations to the solar "inconstancy".

- Cloud Processes: Modification of the atmospheric concentration of particles and of surface characteristics has been shown to modify cloud and precipitation amounts in urban areas (e.g., METROMEX). The effects on larger scales and over longer periods are not well understood, yet are believed to be important.
- Ocean Dynamics: The ocean serves both as a long-term repository and as a natural source of many energy-related pollutants. Better understanding of the flow of chemical species in the ocean, of the ways in which energy processes (e.g., OTEC) may modify ocean dynamics and thermodynamics, and of exchange processes at the air-ocean interface is essential to evaluation of the interaction of energy and climate.
- Cryospheric Interactions: An important question in assessments on seasonal and longer time scales is the interaction between the atmosphere and snow, ice, glaciers and sea-ice. Snow and ice change the surface albedo (some energy extraction and generation processes do also) and thus affect the surface heat balance. Large changes in snow and ice extent affect the hydrologic balance and, in the extreme, the sea-level. Such changes in extent, because of the large albedo changes that occur, can amplify the magnitude of natural or anthropogenically-induced climatic changes.

GOAL: To develop, improve and apply unique measurement capabilities that will provide insight into atmospheric and climatic processes.

During the last thirty years, researchers sponsored by DOE and its predecessors have developed a wide range of measurement techniques that have provided unique insight into atmospheric processes and past climatic behavior. A primary focus in recent years has been development and identification of atmospheric tracers. Advantage has been taken of past injection of radioactive materials to determine transport processes in the atmosphere. For example, a molecular sieve system is now available on aircraft to sample for such tritiated compounds as HT, HTO (Mason and Ostlund, 1977). Inert tracers, including SF_6, deuterated methanes and several perfluorocarbons, have been and are being developed by DOE to improve understanding of atmospheric processes. Recent work to improve the capability for radiocarbon dating by use of mass spectroscopy also promises to play a role in unraveling past climatic behavior.

DOE will continue development of such techniques, including those relying on isotopic ratios, products of radioactive decay, remote sensing, and other advanced technologies as a means of assisting the national effort to understand the climate. DOE also has an interest in the development and improvement in remote sensing of pollutants and meteorological variables (wind and atmospheric turbulence) in order to reduce the cost of field experiments contributing to our understanding of the fate of pollutants on a regional scale.

D. OBSERVATIONS RELATED TO CLIMATE RESEARCH AND SERVICES

The Department of Energy plans to rely primarily on the data collection capabilities of NOAA, NASA and DOD for all routine meteorological and climatic data. Where appropriate, DOE will suggest that these agencies make measurements of additional climatic parameters that may indicate whether energy-related activities are affecting the weather and climate. DOE does expect, however, that, in cooperation with EPA, it will undertake measurement programs that monitor local, regional, and global patterns and trends of parameters directly affected by energy-related emissions and of quantities directly related to energy generation.

GOAL: To examine patterns and trends of energy-related pollutant concentrations and meteorological variables affected by such concentrations.

Of particular current interest, aside from measurement of carbon dioxide concentrations, are concentrations of sulfur and nitrogen oxides. DOE is cooperating with EPRI* and EPA in a major effort in the eastern United States to

*EPRI is the acronym for the Electric Power Research Institute, Palo Alto, California.

determine existing pollutant concentrations in the air and in precipitation. Atmospheric turbidity is also being measured as a means of estimating the effect of sulfur-particulate matter on radiation patterns.

On a national scale, DOE is collecting monthly samples of particle deposition by wet and dry processes as a means of measuring large scale distributions of energy-related emissions.

On the global scale, DOE supports measurement of the global inventories of radionuclides and other trace elements. Changes in the patterns of the concentrations of these species over time have provided important information on atmospheric transport. Continued support of this type of activity is planned.

In addition to routine measurement programs, DOE will, in the process of its extensive environmental research, participate in special field programs involving intensive measurement activities for short times (e.g., SESAME). Where possible these will be conducted in cooperation with activities and special programs of other agencies.

GOAL: To measure atmospheric and oceanic parameters that determine the magnitude of alternative energy resources.

A number of alternative energy technologies rely on conversion of energy available in nature. DOE will undertake, where necessary and in cooperation with measurement programs of other agencies, to measure parameters that relate to the extent of energy that may be available. Such parameters include:

- Solar Radiation: Upgrading of a NOAA network of instruments to measure solar radiation has recently been completed. Special research and site-specific measurements are currently underway.
- Wind Energy: Special research programs will be undertaken to measure both the wind energy generally available and the detailed wind characteristics at specific sites.
- Ocean Temperature Patterns: Site-specific measurements of ocean temperature are planned to assess the potential for OTEC projects.

GOAL: To process and analyze data collected by others that may provide information needed to develop and implement energy policy and production.

Although other agencies play major roles in collection and data banking of meteorological data, DOE must play a major role in processing and analyzing data in ways that can provide information pertinent to conduct of energy-related activities. As part of their missions, NOAA, NASA, and DOD will provide raw and processed atmospheric data from surface stations, balloons, satellites and other sources. Because of NOAA's focus on providing data for the general public, their analyses and interpretations of these data have not proven adequate for optimum use by DOE*. To better fulfill its mission, DOE will upgrade its analysis capabilities and augment its effort to provide the needed, specialized interpretations of data that will directly benefit improved energy planning. Such activities may include interpretation of several day NOAA forecasts in terms of impacts of weather on transportation and supply systems, interfacing heating and cooling requirements and available energy resources based on weekly forecast of major weather systems, evaluation of various types of satellite data in terms of application to short-term planning of energy-related activities (e.g., sea ice extent and transportation of northern energy resources, etc.) and so forth. Over the longer time scale, analysis of climatological data as a means of evaluating the possible impacts of future climatic variations on energy-related activities (e.g., nuclear waste disposal, cooling tower performance, etc.) will also be supported.

E. CLIMATE DATA MANAGEMENT

The ready availability of data is of significant importance to DOE. Decisions on the allocation of energy resources require that meteorological data be available in near real-time, particularly in times of high energy demand (e.g., winter cold spells, hot summer days, etc.) and in times of severe storms (e.g., destructive thunderstorm squalls, hurricanes, river-freezing cold spells, etc.) when transportation and distribution systems may be impaired.

Both assessment of the climatic impact of energy-related activities and of the impact on energy demand of weather and climate fluctuations require analysis

*Similar limitations in NOAA analyses also often pertain to industry, agriculture, etc., many of whom have resorted to use of consulting meteorologists to fill the gap.

of trends of meteorological data. While NOAA maintains needed archival storage of meteorological data, manipulation of data requires ready and rapid access.

DOE will also be making certain measurements that may be of use to other agencies. Data management capabilities are needed to make these data available.

GOAL: To develop an interactive, rapid-access data base of recent meteorological data that have particular relevance to energy systems.

The Office of Energy Data (OED), as a service to the Energy Information Administration (EIA), develops and maintains relevant data bases for EIA's many functions. DOE analysis and research scientists, policymakers, and technology program elements can all obtain assistance from OED in assembling necessary data for their needs. OED serves as the focal point for data management within DOE, deriving necessary data from numerous governmental data inventories. As part of this effort, a nation-wide data base, including NOAA meteorological information, is being developed and now includes historical data up to November 1976. Data from the energy industry are to be utilized extensively. For purposes of evaluation, this data base will, in all probability, be extended in time.

In addition to the planning and research uses of the EIA data bases, the Office of Short-Term Emergency Planning uses the NOAA data and forecasts in executing its operational responsibilities to assess weather impacts on the operation of the nation's energy systems.

DOE will continue this effort to assemble and make readily available the data needed to evaluate and predict impacts of climate on energy and energy on climate.

GOAL: To provide a system of inventorying the data collected by DOE in order to make it more readily available within and outside of DOE.

To be most useful, data must be widely and easily available. DOE will organize a data index to the various chemical and climatic data that it collects. The index will describe the types of data being collected, where and by whom they are being stored, and will provide information on how the data may be acquired. Such an effort is already being carried out in a number of research areas within DOE, including nuclear and chemical data and for regional air quality studies in the northeast.

F. DEVELOPMENT AND COORDINATION OF PERSONNEL AND RESOURCES

Just as for the U. S. Climate Program, the Department of Energy Climate Program will require the participation of highly qualified research and assessment personnel from all segments of the governmental, university, laboratory, and commercial research community. The problems and questions being investigated will be long-term, and their importance will increase as society's technological interdependence expands. For DOE, the next fifty years may see a shift from conventional (e.g., fossil fuel) to alternative (e.g., wind, solar, OTEC, biomass) technologies that have an even greater dependence on, although perhaps less impact upon, weather and climate.

In conducting this program, DOE will undertake a variety of efforts to ensure mission effectiveness. These efforts will focus on both the development of personnel and the development and carrying out of high quality research.

GOAL: To ensure that highly qualified personnel are available to carry out the DOE Climate Program.

While the NSF will continue to support graduate education of atmospheric scientists, their focus is properly on encouraging the technical basis for improvements to fundamental understanding of the atmosphere. DOE will, however, continue to support graduate education, especially in areas that provide the basic underpinning for the research tasks included within the DOE mission.

The DOE and its predecessor agencies have a long experience in supporting graduate education and university research and in developing special centers of excellence for programs of national significance. Graduate education has been enhanced by extensive support of research programs in universities. These have provided important research experiences for faculty and graduate students and have helped develop the base from which DOE national laboratories draw their talent for major comprehensive development and assessment activities. Post-graduate and graduate student education have also benefited from the efforts of the DOE national laboratories to actively involve such researchers in their activities through visiting or dissertation appointments, summer employment, consulting agreements, and even establishment of special university programs. For example, in 1963, the University of California established the Department of

Applied Science, Livermore-Davis to provide the opportunity for graduate researchers to participate in applied defense and energy research. Similar relationships with faculty members have provided an influx of new ideas and talent for the laboratories and an expanded range of experienced faculty members.

GOAL: To carry out a broad-based, mission-oriented research program that provides optimum utilization of human and scientific resources.

In conducting its research program, DOE will support research and assessment activities in those organizations that can lead to optimal performance. This will include support of research in the national laboratories, in other governmental organizations, in private research groups and in the universities.

The national laboratories have a long history of broad-based research of both a fundamental and applied nature. A wide range of unique capabilities exist, many involving use of highly advanced instrumentation and computer capabilities. These resources will also be made available to other government agencies in support of the U. S. Climate Program.

DOE also recognizes that other branches of government have capabilities that can be brought to bear on important aspects of the DOE Climate Program. Before developing major new research capabilities, other agencies will be invited to make available pertinent resources.

Private organizations, in particular non-profit research groups, have many resources in specific areas that can complement activities within the government and national laboratories. Assistance in areas of their expertise will be invited and supported.

DOE will also involve the university community to a large extent in carrying out its research and assessment activities. Universities offer unique opportunities for in-depth research on specific topics. The programs for climate research are intended to further the development of researchers by providing experience in carrying out impact assessment and planning activities related to energy technology and development. In undertaking support of such university activities, DOE expects to provide additional support for the following activities:

- Enrichment and enhancement of graduate student programs.
- Access by students and faculty to modern, large-scale computational facilities.
- Development of multidisciplinary research teams experienced in energy-climate problems.
- Conduct of some of the critical long-term research elements planned as part of the DOE Climate Research.

University programs would be encouraged to have primary thrusts in the following areas of climate research: climate process research; global budgets of nitrogen, sulfur, and other important gases; global and regional assessment methods for energy impacts; and diagnostic studies and seasonal climate prediction as related to projecting energy needs. It is anticipated that beginning in FY-1981 funds would be provided for climate research by augmenting some of the existing university programs.

G. INTERNATIONAL ASPECTS

GOAL: To maintain cognizance of the climatic implications of international developments in energy-related activities through participation in the exchange of technical expertise and specialized data.

Energy and climate are both global issues. Energy decisions by one group of nations can affect other nations. Climate variations in one area of the globe often occur simultaneously with variations in others, indicating that the global climate system is tightly intercoupled. Beyond their separate international aspects, energy activities and climate are intercoupled. For example, when climate variations affect energy use in one major nation, other nations will be affected as global distributions of energy resources are readjusted. Conversely, one nation's energy activities (e.g., emission of CO_2, Kr^{85}, or particulate matter) may affect the climate on a continental or global basis, thereby affecting other countries as well. It is for these reasons that DOE recognizes its responsibilities to participate in the international aspects of the U. S. Climate Program.

The DOE participation will consist of meeting several energy-climate related objectives. The primary responsibility of DOE will be to maintain cognizance of the climatic implications of international energy planning and activities. This will include provision for (1) maintaining up-to-date information on the global impacts of seasonal climatic fluctuations on energy resources, distribution, and use and (2) for continually assessing the impacts of energy policy and development on climate.

In carrying out this function DOE will participate in the exchange of technical information and assessments with respect to energy-climate relations. The DOE is already involved in technical exchanges with other nations in regard to atmospheric carbon dioxide and climate. Past exchanges have dealt with fundamental and new approaches to extend simulations of the climate system and to methodologies used for impact assessments of energy technologies. It is anticipated that such exchanges will continue as a mechanism to improve communication regarding research results, assessment priorities, and impact assessment needs and limitations.

The DOE will also participate, as requested, in future cooperative exchanges sponsored within the U. S. Climate Program and within the World Climate Program. The area in which cooperation may be most appropriate is the potential impacts and assessment techniques related to energy, land-use, and water resource development projects. Further, through coordinating research programs and exchanging data on an international level, more rapid progress will be made toward understanding energy-climate relationships and associated research and development expenditures will be optimized. Through the international exchange of research findings, and data on concentrations of energy-related pollutants, and climatic impact assessment techniques, the global planning process for utilization and conservation of energy resources within acceptable environmental impacts can be strengthened.

CHAPTER 6. MANAGEMENT AND IMPLEMENTATION OF THE DOE CLIMATE PLAN

A central theme in the management and implementation of the DOE Climate Program is that the data resources collected, the assessment methodologies devised, and the understanding of climate variability developed, make a vital, continuing contribution to the DOE mission of providing adequate energy to the American public within acceptable environmental constraints and social costs. Further, the applied research will be managed and conducted so as to minimize the chance that future technological developments will create environmental-impact surprises. Although not all surprises can or will be avoided in energy and environmental planning, particular attention will be devoted to identifying potential early warning signals of impacts of technologies that deserve evaluation prior to large-scale implementation. To achieve this goal, the "user" offices and administrations within the DOE will be responsible for incorporating and assessing the significant results, findings, and assessments of the National Climate Program into their research programs and planning activities as early as is feasible. Further, DOE will provide information on and undertake assessments of future energy technologies in concert with the efforts of other agencies participating in the National Climate Program.

A proposed management structure of the DOE Climate Program is shown in Fig. 6.1. As mentioned in Chapter 4, the overall coordination of the National Climate Program is the function of the National Climate Program Office (NCPO) in the Department of Commerce. Liaison and coordination with the NCPO will be important to DOE in order to ensure the transfer of results of more fundamental research and to arrange for the availability of up-to-date data bases and findings for DOE assessments.

The newly created CO_2 and Climate Research Program in the Office of Health and Environmental Research (OHER), within the Office of the Assistant Secretary for the Environment (ASEV), will coordinate DOE climate research and activities and assist the ASEV in representing the program before the OMB and congressional committees. In carrying out this function, the Manager of CO_2 and Climate Research Program will, based on input from and the concurrence of the various entities within DOE, recommend an overall DOE budget needed to implement the DOE contribution to the Climate Research Program.

An Energy-Climate Steering Committee (ECSC) will be established to advise this Program Manager on budgetary planning, focus, and priorities to be included within the overall DOE climate research program. This committee will serve on behalf of the DOE Research and Development Coordination Council (RDCC) and its chairman will be appointed by the DOE principals of divisions and organizations participating in the Energy-Climate Program. The representative of the ASEV will provide representation on the ECSC for the long-term research aspects of the DOE Climate Program and ensure that DOE provides adequate support for such research. These secretarial representatives, with the assistance of personnel of the CO_2 and Climate Research Program, will serve as the focal point for coordination of the DOE climate related activities. This coordination will assure that all DOE research is consistent with the DOE Climate Program Plan and that it is contributing to the overall U. S. Climate Program. The CO_2 and Climate Research Program personnel will prepare an annual report summarizing all energy-climate research within DOE. The Program status will be reviewed annually by the ECSC, the ASEV and the Office of Energy Research, and results will be communicated to the NCPO.

The Manager of the CO_2 and Climate Research Program, with advice from the ECSC, will also maintain a proper balance among the several human resource sectors participating in the DOE Climate Program, namely, the DOE national laboratories, the university research community, and the private sector. This division will also develop detailed research, assessment, and activity plans with the assistance of the appropriate entities within DOE, identify qualified researchers and participants for the project elements contained in the DOE Climate Program, and develop the staff necessary to implement the program. The DOE Energy-Climate Steering Committee will also be established in FY-1979 to serve in an advisory and facilitator mode during this organizational phase of the program. This committee will initiate and coordinate the elements of the DOE Climate Program based on incremental funding needed to implement the FY-1981 budget, as summarized in Table 6.1. Priorities within this preliminary DOE budget have been set to focus on the immediate needs of the DOE mission, as described earlier in this Program Plan, and to do so with a broad based program taking advantage of the many resources and capabilities of the DOE.

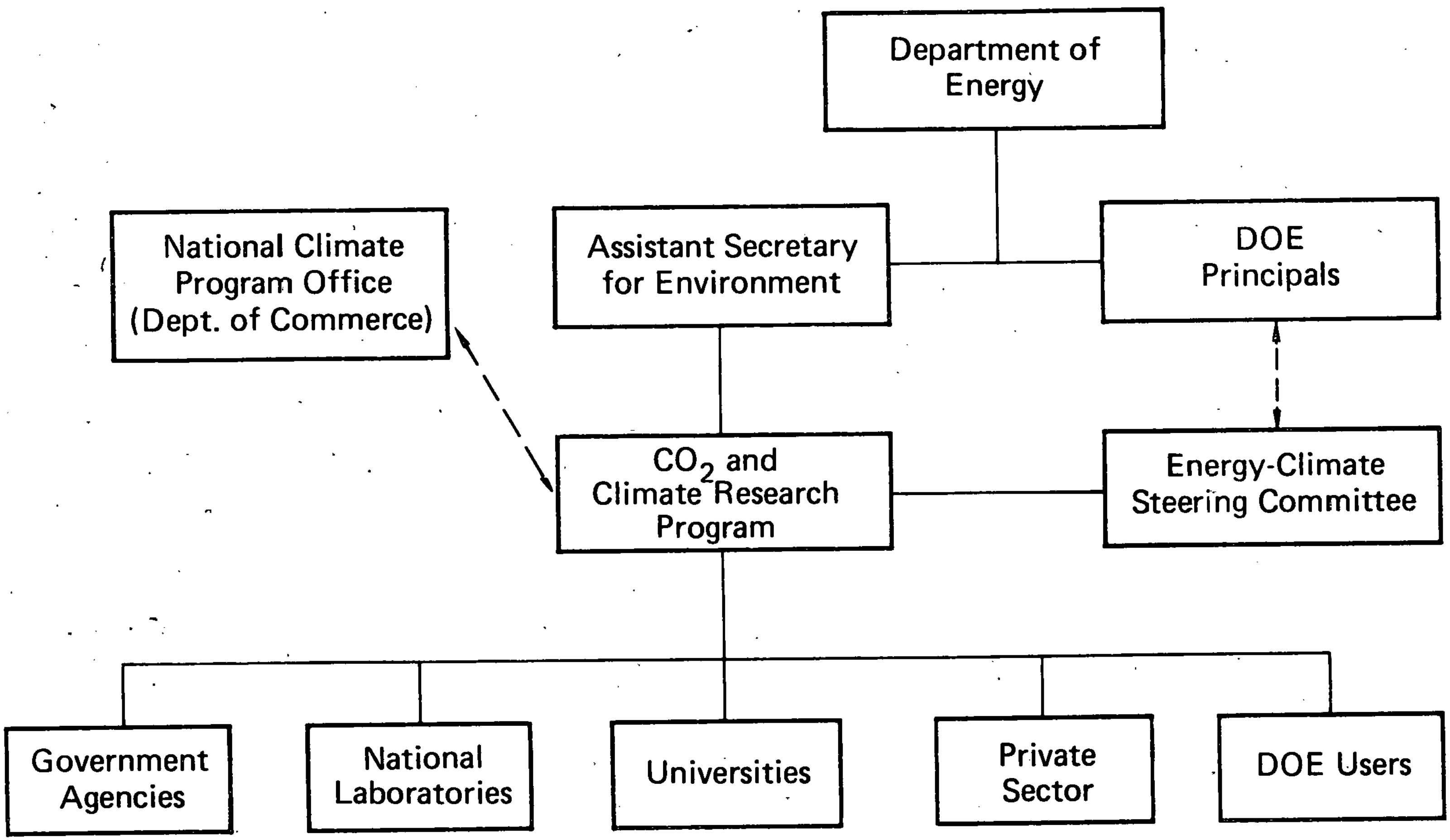

FIGURE 6.1. Proposed organizational chart for implementing the Climate Program Plan within the Department of Energy.

TABLE 6.1. Preliminary Allocation of Incremental Funding for the DOE Climate Program Proposed FY-1981 Budget (in $K).*

Activity	U. S. Climate Plan Category	Office of DOE						
		Environ. Activity (Baratz)	Environ. Data (Coblentz)	Energy Research (Bartley)	Emerg. Plan. (Allen)	Federal Energy Regul. Comm. (Moriarty)	CO_2 and Climate Research Program (Slade)	Total
Climate Data Management and Analysis	Climate Data Management		200					200
Global and Regional Assessment of Energy Technology on Climate	Impacts on Climate Variability						800	800
Process Research and Global Budgets of Nitrogen, Sulfur, etc.	Impacts on Climate Variability and Climate Research			1000				1000
Diagnostic Studies and Seasonal Climate Prediction	Diagnosis & Projection of Short-term Climate Variability		300	200			500	1000
Weather and Climatic Impacts on Energy Technology and Systems	Impacts on Climate Variability	300	200		200	400	200	1300
Development and Coordination of Personnel and Resources	Climate Research & Other Categories						1000	1000
	TOTAL	300	700	1200	200	400	2500	5300

*Estimated Incremental Funding is shown for planning purposes only; as yet, these plans have no direct relationship to actual FY-81 budget requests.

APPENDIX A. THE CLIMATE SYSTEM AND PROCESSES OF CLIMATIC CHANGE

INTRODUCTION

The atmosphere is a dynamic system powered by the sun. The differential heating caused by a surplus of solar radiation at low latitudes and a deficit at high latitudes serves as the forcing function for the varying behavior of the atmosphere. The atmosphere through its motions strives to return to a condition of static stability constrained by the requirements of conserving mass, energy and momentum. The atmospheric conditions as they vary from moment to moment and from place to place are referred to as weather. The term climate refers loosely to the weather averaged over both time and space as well as the statistical properties of the atmosphere, including weather extremes, joint frequency distributions, and many other measures of weather variability.

The climate at any location on the earth is determined by a combination of influences ranging from the global scale down to details of the local environment. The distribution of solar radiation, for example, affects climate on a global scale (the macroclimate), whereas geographic features may influence climate within smaller regions (the mesoclimate and microclimate).

THE GLOBAL CLIMATE SYSTEM

The global climate system is composed of several components: the atmosphere, oceans, land surfaces, snow and ice masses (the cryosphere), and the biosphere. These major physical components are coupled by the transport of mass, momentum, energy, and water. The coupling is further complicated by many feedback mechanisms, including the radiative effects of trace atmospheric constitutents.

The oceans are large heat storage reservoirs that absorb, store and resupply to the atmosphere vast amounts of energy through the exchange of latent and sensible heat as well as longwave radiation. The energy which is lost to the atmosphere is replenished by absorption of solar radiation. The ocean currents play an important role in affecting the spatial distribution of the energy transferred to the atmosphere. The momentum exchange between the atmosphere and ocean due to wind stress affects both atmospheric and oceanic circulation patterns. Variations in the extent of sea-ice alter the global radiation and energy balances by changing the albedo and thermal capacity of the earth's oceans. Factors affecting surface albedo include the amount of snow and ice on land surfaces, soil moisture, and the extent and type of vegetation.

The atmospheric composition, including cloudiness, affects the transfer of solar and longwave radiation. The net flux of radiative energy at the earth's surface determines the amount of energy available for evaporation or transfer as sensible heat to the atmosphere. Since cloudiness depends upon temperature, humidity and wind circulation patterns in addition to convective activity, there is a coupling between atmospheric dynamics and the radiative and hydrological processes. The biosphere affects evapotranspiration of water and release of certain other trace constitutents to the atmosphere and is itself regulated by such growth-controlling factors as wind, temperature, moisture, and the solar energy available for photosynthesis.

This complex climate system has undergone many changes in the past, as reflected in the climatic record. In addition to the natural climatic variations to be expected in the future, it is possible that man can also affect the climate by disturbing the delicate balances of heat, radiation, and water on a regional and ultimately on a global scale.

THE CLIMATIC RECORD

In interpreting and extrapolating the historical records, it is important to realize that the magnitudes of climatic averages themselves vary not only with the location but with the period and length of the record. Thus a particular 30-year period may not be representative. Indeed, the period 1931-1960, upon which many statistical analyses are based in defining "normal" climate, was abnormally warm compared to the average for the last thousand years. Further, the climatic record for the past million years shows that the climate has varied over all recorded time scales (Fig. A-1).

Figure A-1

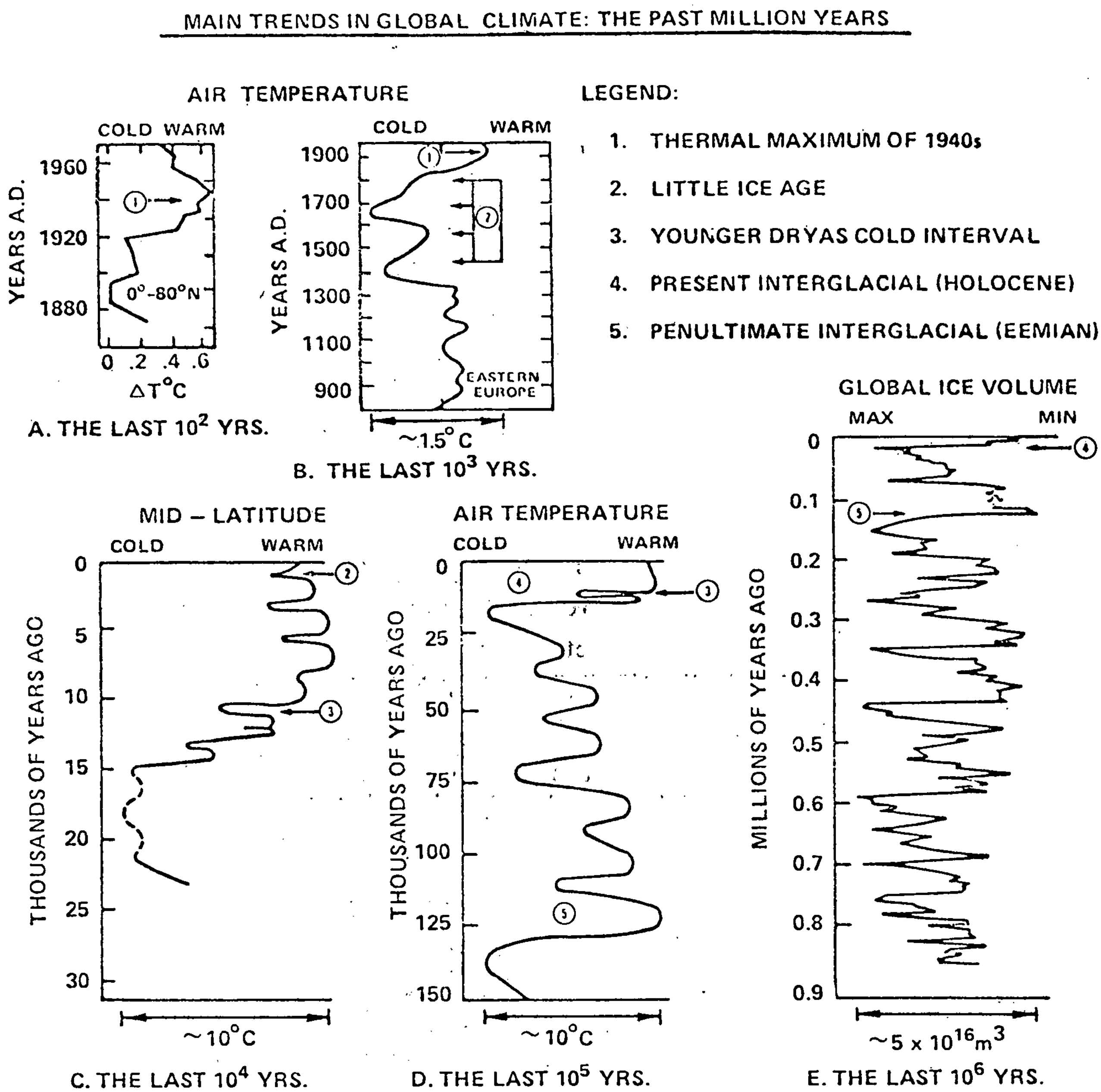

FIGURE A-1. Main trends in global climate: the past million years. (a) Changes in the five-year average surface temperatures over the region 0-80 N; (b) Winter severity index for eastern Europe; (c) Generalized northern hemisphere air-temperature trends, based on fluctuations in alpine glaciers, changes in tree-lines, marginal fluctuations in continental glaciers, and shifts in vegetation patterns recorded in pollen spectra; (d) Generalized northern hemisphere air-temperature trends based on mid-latitude sea-surface temperature, pollen records, and on worldwide sea-level records; (e) Fluctuations in global ice-volume recorded as changes in isotopic composition of fossil plankton in deep-sea core V23-233. Reproduced from Report of the GARP Panel on Climatic Variation (submitted to USC/GARP).

Figure A-2 shows the variation in global mean surface temperature over the past 100 years. From the 1890's to the mid-1940's the global air temperature increased by about 0.5°C. Since 1940 global mean temperatures have fallen by about 0.3°C and appear to have leveled off. Every summer during the 1930's in the corn belt of the United States was warmer than the average for the century. The results of the recent cooling trend can be seen in agricultural records. For example, harvests in England were completed about 9 days later on the average during 1960-1973 than during the 1940's. Food production may be affected less by cooling or warming trends than by a trend associated with greater variability of the weather and more common occurrence of droughts, floods, hot summers, and severe winters.

The instrumental record of climatic change only spans the last 200-300 years. Climatic variations over much longer time scales have been deduced by analyses of tree rings, fossil flora pollen and fauna in deep ocean sediments and their isotopic composition, fossil pollen in soil and lake sediment layers (varves), isotopic composition in ice cores from Greenland and the polar ice caps, and sea-level changes. Although these data do not give a complete global picture, they do clearly show climatic trends and periods of significant climatic variations.

Figure A-3 shows the variation of the mean temperature for central England inferred from historical data. Fluctuations in temperature of the magnitude shown in Fig. A-3 coincide with significant changes in agricultural practices that caused the migration of civilizations. Around the ninth century Norse settlers in Iceland seem to have flourished in a phase of rapid warming and were able to establish a colony in Greenland. However, within a few hundred years a deterioration in climate occurred that was a major contributing factor in the collapse of the Greenland colony. The Iceland colony barely survived through the Little Ice Age, which extended from the 15th to the 19th centuries.

MECHANISMS OF CLIMATIC CHANGE

The causes of past climatic changes have not yet been adequately explained. There are three mechanisms, however, that seem to offer the greatest insight into patterns of climatic change on various time scales over the past 400,000 years. First, there are the long-term cyclic effects produced by subtle, regular variations

FIGURE A-2

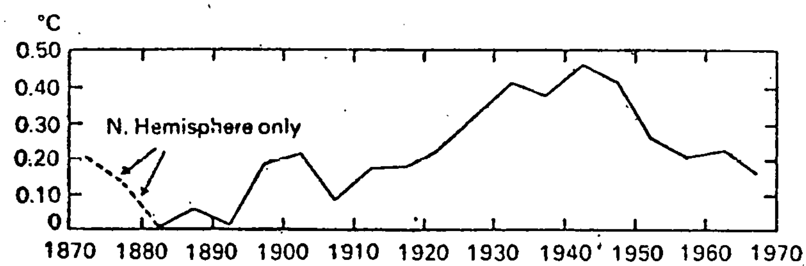

FIGURE A-2. Variation in global mean surface temperature over the past century. Five-year means from Murray Mitchell and the U.S. National Center for Atmospheric Research (NCAR). [Source: Gibbin, 1976]

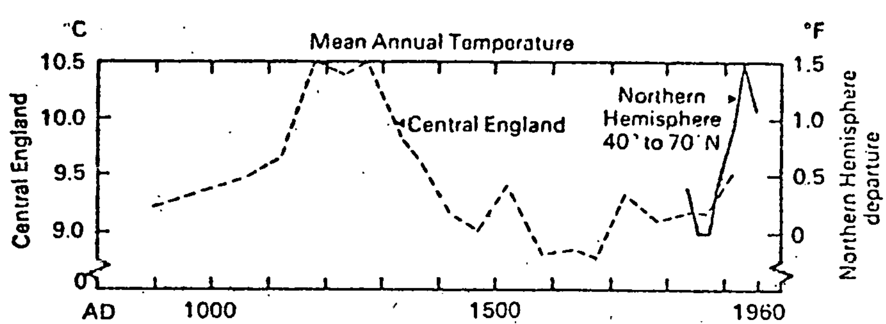

FIGURE A-3. Variation of mean temperatures over the past millenium, inferred from historical data for England by H. H. Lamb. Solid line shows 20-yr means for the Northern Hemisphere, calculated by Murray Mitchell. [Source: Gribbin, 1976] in the earth's orbital path and inclination around the sun and in the orientation of the spin axis of the earth relative to the sun. These factors induce predictable, systematic changes in the amount of solar energy reaching the top of the atmosphere for different latitudes. In a cycle of approximately 23,000 years, the earth advances in its elliptical orbit so that its closest approach to the sun occurs at different times of the year. The earth and the sun are now closest in January, but in 10,000 years they will be closest in July (a period of approximately 20,000 years). There are also orbital changes affecting climate on time scales greater than 20,000 years. In a cycle of approximately 41,000 years, the orbit tilts so that the earth's axis is sometimes more nearly perpendicular to the planetary plane than at other times (more properly, the tilt changes with respect to the moving ecliptic). In a cycle of approximately 93,000 years, the eccentricity of the earth's orbit changes from nearly circular to more noticeably elliptical.

A second mechanism, which may cause climatic changes on the time scale of a few decades, is variation in the solar output. There is still considerable debate about the link between solar activity (e.g., the 11-year sunspot cycle) and weather. Nevertheless, Schneider and Mass (1975) were able to reproduce many features of the observed record of temperature variations since 1600 with a model which incorporated an empirical dependence on solar activity as measured by the Wolf sunspot number. This dependence seems to imply that the solar output is more than 2% less when there is no sunspot activity than when there is moderate activity. More observations by either satellite or balloon-borne instrument systems are needed to confirm such a relationship.

A third mechanism for climatic change is increased atmospheric dust loading due to volcanic activity, which can affect climate on a time scale of years to decades. Intense volcanic eruptions can inject large amounts of dust into the stratosphere where the residence time may range from several months to several years. Dust produced by volcanoes can have a veiling effect that reduces the amount of solar radiation reaching the ground and scatters more incoming solar radiation back to space. The reduction in solar heating of the earth/atmosphere system results in cooler surface temperatures. Climate models including parameterization of the effect of volcanic dust have duplicated the major features of the recent climatic record, including the cool temperatures of the Little Ice Age and the decades around 1800 along with the general warming trend between the 1890's and 1940's (Oliver, 1976; Schneider and Mass, 1975). None of the above mechanisms, however, satisfactorily explains the decline in temperature observed since 1940.

Some have postulated that the cooling since 1940 is due to anthropogenic influences rather than natural climate variability. The suggestion that man has increased the amount of atmospheric dust through agricultural and industrial activities and that this is the cause of the recent cooling is not borne out in global measurements of atmospheric turbidity, although this may partially explain the observed changes in regional climates.

Climatic fluctuations involve processes on a range of spatial scales that can interact in a highly complex way so as to cause climatic anomalies affecting large geographic areas. The intermediate-term anomalies are the result of persistently recurrent weather systems of the same type. The fundamental question involves how and why particular events recur during a given season or sometimes recur for several seasons or years. To cause recurrent events like prolonged droughts or cold waves would seem to require some sort of memory. It is highly unlikely that the atmosphere alone can account for this persistent recurrence because of its highly variable nature and its relatively short thermodynamic relaxation time.

The oceans play a major role in the evolution of intermediate- and medium-term climatic fluctuations. The top three meters of the ocean contain as much heat as the entire atmosphere, and anomalies in ocean temperature have been observed to penetrate down to a few hundred meters. These temperature anomalies create vast heat reservoirs that may affect the course and behavior of storms and jet streams later on. The anomalies are in turn frequently responses to antecedent abnormal atmospheric conditions.

It appears that the abnormal winter of 1976-77 was the result of several factors that operated in a synergistic fashion so that positive nonlinear feedback processes were set up in the coupled ocean/air/land system (Namias, 1978b). Extreme cold dominated the eastern half of the United States, record drought affected the far west, and equally abnormal warmth occurred over Alaska and much of the Canadian Arctic. Namias suggests that interactions between sea surface temperature anomalies in the North Pacific and the atmospheric flow pattern resulted in storms being diverted northward to Alaska rather than coming into the West. The storms moving up to Alaska then created a southward bulge in the jet stream in the eastern United States that moved arctic air masses southward producing snow. Snow-albedo feedback then intensified the cold and the temperature difference between the continent and the Gulf Stream, setting up another set of storms along the Eastern seaboard that created more snow and more cold air (Namias, 1978b).

This simplified description illustrates the complex coupling of physical processes and events that can lead to climatic change. Understanding of these processes has not yet developed to the point, however, where accurate quantitative predictions of climatic changes can be made several months in advance.

APPENDIX B. CASE STUDIES OF PROBLEMS IMPORTANT TO DOE

Variable climate and weather extremes during the past several years in the United States have had a significant impact on our national society as a result of the effects on energy production and storage systems. There have been periodic shortages of various fuels (natural gas, coal, gasoline, and hydroelectric power) on both regional and national scales. A few case studies of how climate variations have affected the energy sector are presented to illustrate the importance of research focused on improvement of short-term (seasonal) climate prediction capabilities.

THE WESTERN DROUGHT OF 1976 and 1977

During 1976 and 1977 one of the most severe droughts in a century occurred in the western United States. The snowpacks in the Sierra-Nevada Mountains in Northern California were only about 15% of normal in February 1976, and the subsequent reduction in run-off caused hydroelectric power generation to be curtailed to approximately 55% of normal during the first half of 1977. Conservation measures were implemented for electrical power and water usage, but it was still necessary to resort to natural gas and oil-fired turbine generators to provide the needed electrical energy. The additional cost associated with providing this supplemental power amounted to $400 M, a cost that was passed along to the consumer.

Due to shortages of irrigation water from normal sources, increased pumping from ground water supplies was required. Reduced flows of fresh water into the San Francisco estuary resulted in deteriorating water quality in the upper reaches of the estuary due to increased salt content. Salt water intrusion also impacted water supplies from some local wells. The impacts of the drought on forests included reduced growth and significantly higher frequencies of infestations and blights, particularly affecting pines.

NATURAL GAS CURTAILMENTS: HEATING SEASONS 1976-77 AND 1977-78

Natural gas is used for approximately 85% of the residential space heating in the United States. Because of the high use of natural gas for residential heating and limited supply rates, it is usually necessary to curtail natural gas supplies to industrial and interruptible users for limited periods of time even during "normal" winter conditions. In addition to curtailments, supplemental natural gas supplies (including storage in underground aquifers close to the place of demand) are used to meet the space heating requirement.

Each fall the Energy Information Administration projects the natural gas demand and assesses the gas delivery capability for the coming winter. These estimates are used to project the gas curtailments. Figure B-1 shows the natural gas requirements, deliveries and curtailments for three consecutive heating seasons in the United States. The actual data are shown for the 1975-76 and 1976-77 heating seasons; projections are shown for the 1977-78 season assuming normal climate conditions. The population-weighted degree-day data are shown as a measure of the climate conditions. The winter of 1975-76 was 7% warmer than normal, and the winter of 1976-77 was 13% colder than normal.

On a regional basis, the data may differ significantly from the national average. For example, much colder than normal conditions occurred during the 1977-78 winter in the northeastern United States resulting in rather severe fuel shortages. Very high residential utility bills were reported in parts of Maryland as a result of higher energy usage coupled with the use of high-cost alternative fuels. The DOE experience in managing and regulating this energy system suggests that improved management could be achieved if accurate, regionalized, seasonal climate forecasts were available for planning purposes as an alternative to planning based upon assuming normal conditions.

OVERSUPPLY OF OIL IN CALIFORNIA

Per capita demand for oil and gasoline has declined in California since 1974. This decline is the net result of many factors including much higher prices and less available personal income caused by higher unemployment rates and overall inflationary pressures. The recent drought has made the public more

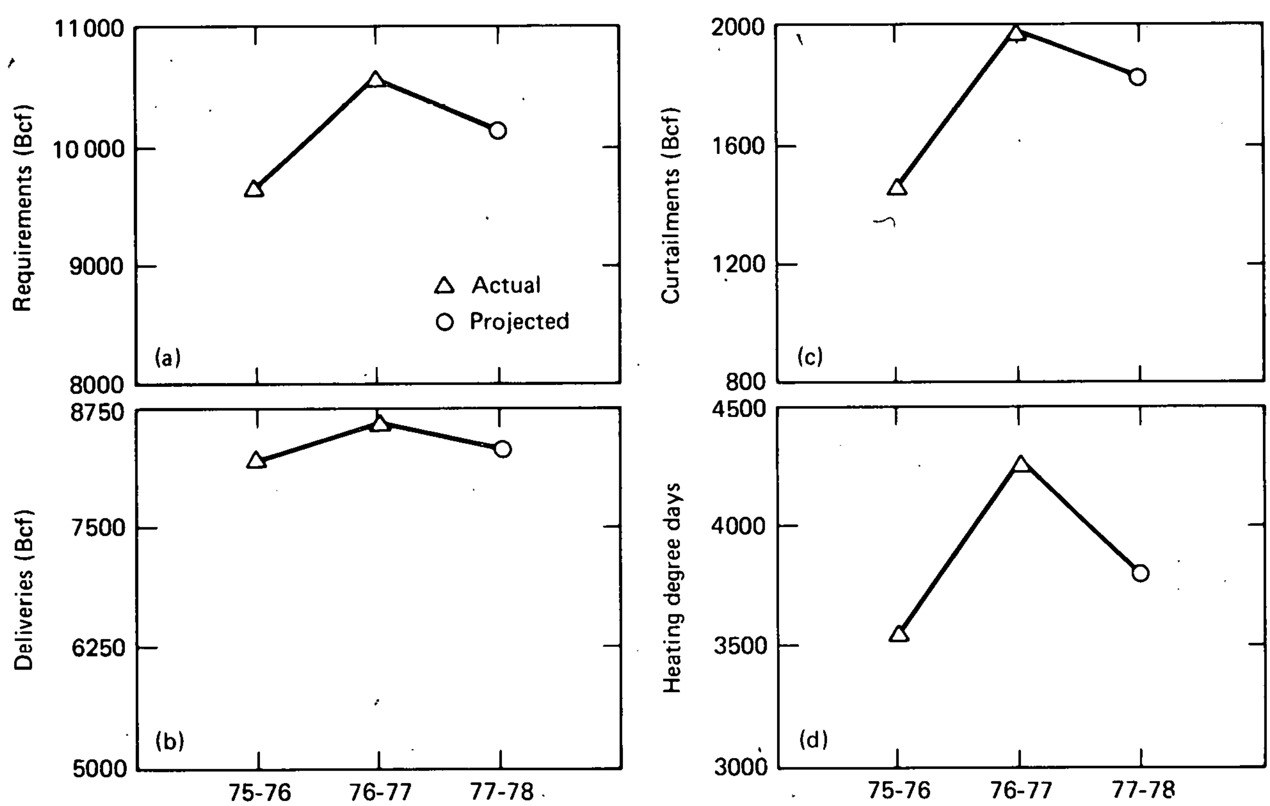

FIGURE B-1. Data showing the (a) natural gas requirements, (b) deliveries, and (c) curtailments for three consecutive heating seasons in the United States. The population-weighted degree-day data (d) show that the climate varied markedly from year to year in a pattern similar to natural gas requirements and curtailments. Deliveries, however, remained essentially constant. [Source: Bass, 1977] conservation-minded, and this has influenced the consumer's attitude against wasteful usage of gasoline, oil, and natural gas (in addition to water). The opening of the Alaska pipeline introduced a new large source of crude oil into the California marketplace. Crude oil and refinery products cannot now be piped out of the state to areas of the country where there are shortages. Because California oil has too high a sulfur content, most of the oil used by the utilities is higher-grade oil imported from Indonesia. The energy industry probably favored the "swapping barrel for barrel" of California produced oil for that from Japan (low sulfur); however, this solution was not implemented in 1977-78 for political reasons.

The amount of gasoline used for transportation is highly dependent upon the weather. The prolonged rainy periods during the 1977-78 winter reduced the demand for gasoline. The winter was also warmer than normal, which reduced the demand for heating oil (used principally by commercial buildings). Planned deliveries of oil from Alaska to the Long Beach facilities far outran the demand, resulting in a backup of tankers at Long Beach waiting to unload. This situation increased the cost of oil delivery by keeping ships idle. The availability of accurate regional seasonal climate predictions may in the future assist energy planners in avoiding situations of oversupply such as occurred in California.

PEAK LOAD PLANNING FOR SOLAR POWER APPLICATIONS

It is anticipated that solar options will supply a gradually increasing fraction of the nation's energy needs, perhaps as much as 10% by the year 2000. Solar energy systems may contribute significantly to the electrical and residential space heating requirements in several geographic regions, but these systems are weather and climate dependent. That is, the residential heating requirement, which is climate dependent, will be partially met by a weather-dependent energy system. Improved weather and climate predictions will be required in order to effectively plan for the requirements on a blend of various energy sources. Of particular concern is the planning for peak energy demand on a regional basis. Load switching programs may be needed that are operated in realtime based on weather data.

EMISSIONS OF CARBONYL SULFIDE

A cornerstone of the National Energy Plan 1977 is the increased use of coal in the U. S. Later a directive indicated that new coal burning plants, or those converted to coal, need use only the best available control technology in regard to SO_2 emissions, independent of the content of sulfur in the fuel. It was recognized by Crutzen (1976), that the incomplete combustion of sulfur in a fuel or control process could lead to increased emissions of the gas carbonyl sulfide (COS). COS has only weak tropospheric sinks; thus, over extended periods of time COS can be transported upward into the stratosphere where it can be chemically converted to sulfate aerosols, that in turn can affect atmospheric temperatures by reducing atmospheric transmission. Very new estimates indicate that a major fraction of the background stratospheric sulfate may be generated by such conversion. It is clear that with such feedback processes acting in the atmosphere, proposed control options applied to the increasing variety of energy technologies should be examined periodically for adverse effects using the best available assessment information and methodologies.

APPENDIX C. CARBON DIOXIDE RESEARCH PROGRAM

A recent analysis of the potential climatic effects of the by-products of energy production and consumption (heat, particulate matter, and gases) showed that the combustion product carbon dioxide has the greatest apparent potential for disturbing the global climate over the next few centuries (National Research Council, 1977). The perception that there might be a serious CO_2 problem stems from the following:

- There has been a well-documented world-wide increase in atmospheric CO_2 concentrations since 1958; this growth has probably been occurring since the middle of the last century.
- An amount equivalent to about fifty percent of the CO_2 released from fossil-fuel burning has been accumulating in the atmosphere.
- CO_2 transmits solar radiation but absorbs some of the outgoing long-wave radiation from the earth; which is the so-called "greenhouse" effect. Thus, qualitatively, CO_2 should act to warm the lower atmosphere and, by radiating more outgoing energy, cool the stratosphere.
- Different calculations of the "greenhouse" warming indicate that doubling of the CO_2 content of the air could result in a 1.5-3^{o}C warming of the lower atmosphere. This global warming is sufficient to cause significant alteration of the present climate.
- While the climatic effects would be world-wide, they will likely not be uniform: some regions of the globe would experience greater changes from the present climate; others less.
- The doubling of atmospheric CO_2 could take place within the next 75 years. There are sufficient fossil-fuel reserves to raise the atmospheric CO_2 many-fold if they are consumed rapidly enough.
- Natural rates of removal of CO_2 from the air are calculated to be so slow that it might take many centuries before atmospheric CO_2 levels returned to "normal" after emissions ceased.

After determining the extent of the problem and assessing the adequacy of current research programs addressing the problem, the Office of Carbon Dioxide

Effects Research and Assessment was formed in 1977 within DOE to provide a focus for a coordinated research program so that answers can be furnished in a timely manner. The crucial questions to be answered include:

1. What will be the potential future atmospheric concentrations of carbon dioxide?
2. What will be the climatic effects of these concentrations?
3. What will be the effect on the biological and physical environment of these changes?
4. What, if any, will be the effects on human societies?
5. What, if any, actions can be taken in order to diminish the climatic changes or mitigate their consequences?

Research within this long-term program will initially be addressed toward answering the first two questions.

SOURCES OF ATMOSPHERIC CARBON DIOXIDE

The main source of the observed increase in CO_2 is thought to be combustion of fossil fuels. Recently, however, the possibility has been raised that world-wide land-use practices, particularly deforestation and oxidation of humus, could also be contributing to the buildup. It is not thought likely that natural sources, while important over the long history of the earth, are a significant factor in the recent rise.

Volcanoes and other natural venting of CO_2 from the earth's interior, as well as weathering of terrestrial carbonates, is thought to be only a very small fraction of the current annual net input. Recent suggestions that venting of methane along fault lines, and subsequent oxidation, could represent an additional source may need to be checked. No specific study of natural sources is now planned but it should be borne in mind that no comprehensive theory exists to explain the natural cycle of CO_2 over the billions of years of the earth's history - or in fact what atmospheric concentrations of CO_2 actually occurred during this time.

There are three aspects to the problem that should be considered: estimation of the carbon content of fossil fuel reserves in the ground; determination of the annual rate at which these reserves are converted to fuel and used (also other industrial sources such as cement production); and projection of future demand for these fuels.

The available reserves are well enough known today to argue that, if burned rapidly enough, atmospheric CO_2 will continue to increase to several times its present value. Nevertheless, better assessment on a country-by-country basis will be needed to keep track of the potential supply.

A controversy exists whether the carbon in the atmosphere is increasing partly because of deforestation and other land-use practices, or whether the biosphere now acts as a net sink, absorbing a fraction of the fossil fuel CO_2. Current models of oceanic uptake of CO_2 allow, at most, only a small amount of extra non-fossil fuel CO_2 to come from the biosphere. Other investigators have claimed that amounts as great as the fossil-fuel contribution itself could be coming to the air from deforestation. If the latter is the case, then the understanding of the various sinks for atmospheric CO_2 must currently be seriously in error.

Regardless of current and past biospheric trends, it is clear that future levels of atmospheric CO_2 could be substantially increased by large-scale clearing of tropical rain forests followed by oxidation and associated disturbances of the soils. There are reasonably good estimates of past and current fossil fuel usage, but there is very poor knowledge of the current rate of conversion of one type of vegetation to another or to nonvegetated areas like cities, and what this means in terms of the total biospheric mass of fixed carbon. These conversions can be deliberate, as with conversion of forest to agriculture or incidental to other activities, or they may be natural as a result of local climatic shifts. It is desirable to estimate the current changes in the biosphere both to formulate and calibrate models of the carbon cycle as well as to determine the effects of future land-use changes on CO_2 levels.

SINKS FOR ATMOSPHERIC CO_2

The ocean is currently believed to be the major sink for atmospheric CO_2. To provide reliable predictions of future atmospheric CO_2 levels, one must thoroughly understand the dynamics of this CO_2 uptake and the transfer of CO_2 from the surface waters to deeper waters. Several important aspects are involved. The exchange rate of CO_2 between air and sea must be known as a function of temperature, sea state, and possibly wind speed and water chemistry. The thermodynamic distribution coefficient of CO_2 gas between air and sea water (the CO_2 buffer factor) must be known as a function of temperature, alkalinity and total dissolved inorganic carbon concentration. The patterns and rates of vertical transfer within the sea must be determined. The impact of climate changes on these rates must also be anticipated. The vertical flux of particles and organisms transporting carbon downward through the sea should be assessed. The possible influence of environmental changes induced by man's activities on these fluxes must be determined. The role of $CaCO_3$ in determining the uptake of CO_2 from the air should be examined. The dissolution of $CaCO_3$ in marine sediments enhances the capability of the ocean to absorb fossil fuel CO_2 from the air. For the shallow sediments, the critical mineral is high-magnesium calcite; for the deep sea sediments, the critical mineral is calcite.

Most scientists now believe that transfer of CO_2 from the surface waters to deeper waters will constitute the rate-limiting step for oceanic uptake of CO_2 for the next several hundred years. This transfer takes place both by turbulent mixing through the main thermocline and by organized circulations where water previously in contact with the air sinks, mainly at high latitudes. Much of our knowledge of the penetrations of CO_2 into the oceans stems from observations of man-made tracers, notably tritium and ^{14}C, produced in nuclear weapons tests. Continued surveys of these and other transient tracers are likely to be our main tool to provide an understanding of oceanic circulation and mixing.

The rate of future increases in CO_2 concentrations are dependent on how much higher CO_2 levels would enhance the primary production potential of the vegetation and so increase the rate of carbon fixation by the biota. Such fixation would reduce the rate of increase in atmospheric CO_2 from new sources.

To acquire information on the plants' responses to higher CO_2 levels, it will be necessary to consider the effects of increased CO_2 on photosynthesis, nitrogen fixation, water-use efficiency of plants and, of course, actual growth. Photosynthesis is the central process governing the primary productivity of all green plants. The availability of nutrients and water are generally considered to be the major limiting factors to plant productivity, and it is not clear to what extent enhancement of photosynthesis by increased CO_2 will increase carbon fixation. Water use by plants is controlled largely by the stomata, which in turn may be influenced by the ambient CO_2 concentration. It is possible that increased atmospheric CO_2 could result in increased water-use efficiency by allowing the photosynthesis rate to remain unchanged while reducing the demand for water. On the other hand, plants may increase photosynthesis for the same water usage at elevated CO_2 concentrations. Note that increased primary productivity by itself is not sufficient to slow down the atmospheric CO_2 growth. Only if this increased productivity results in a year to year increase in stored biomass or detritus will it increase the strength of the sink for excess CO_2.

MODELS OF THE CARBON CYCLE

All the major components of the carbon dioxide research program involve model development as part of their efforts, but an additional component will be devoted to integrating the results of these studies into a global carbon cycle model. Its goal will be to predict the future atmospheric CO_2 concentrations from scenarios of fossil fuel use and land-use changes. To be valid, these models must be able to reproduce not only the currently available data on atmospheric CO_2 growth, but be compatible with the distribution of the isotopes of carbon in the atmosphere, oceans and biosphere.

Progress in this area will depend upon progress in determining the components of the carbon cycle and their reactions to increased atmospheric CO_2 coupled with any attendant climate changes. Attempts to model the carbon cycle will also likely disclose areas needing particular research emphasis in the other components. This effort must proceed, as with all modeling efforts, in close association with data gathering and analysis.

Some modeling of the carbon cycle is now going on both in the U.S. and abroad. Cooperation among the groups is essential. There is marked similarity in the assumptions and transfer rates among carbon reservoirs, but this may indicate the paucity of information upon which all of the modeled processes are based.

CLIMATE EFFECTS OF INCREASED CO_2

The consequences to the climate of increased atmospheric CO_2 have been estimated from computer simulations. These simulations, which indicate that a doubling of CO_2 concentrations would increase the global mean temperature of the lower atmosphere by between 1.5 and 3°C, are crude even though they employ the most sophisticated techniques and machines available. Several factors not now included in simulation models are thought to be important and others not now known could also prove to be significant. In addition, none of the climate models applied to the CO_2 problem have contained a realistic topography or distribution of land and water. Thus, regional climatic changes cannot now be predicted, yet regional modifications of precipitation may be the most crucial consequence of CO_2 increases in the atmosphere.

Knowledge of the climatic history of the earth is important both to anticipate what might happen and to provide data to help validate the computer simulations. Emphasis will be put on periods where the earth was warmer than it is now - such as the hypsithermal. Abnormally warm years within the period when instruments were available will also be considered.

EFFECTS OF CLIMATE CHANGE

It is necessary to translate the anticipated climate changes due to increased CO_2 into effects on the biosphere as well as on the cryosphere and ocean circulation. It is likely that some of these effects will feed back to the climate system itself and to the carbon cycle. In addition to the effects already mentioned, the following effects are also possible and in need of further study.

- Marine organisms could be affected by increases in dissolved CO_2. The slow lowering of oceanic pH and lowering of the super-saturation with respect to $CaCO_3$ of surface waters could affect the ability of organisms to form carbonate shells and skeletal structures.
- Changes in atmospheric circulation could produce changes in oceanic circulation. Marine productivity could be reduced if the rate of upwelling were decreased since the latter controls the supply of nutrients to certain surface waters.
- Greatly elevated CO_2 concentrations in the air may have effects on non-photosynthesizing organisms. It is unlikely that mammals would suffer, but possibly invertebrates and microorganisms would be affected.
- Ecosystem stability and the geographic distribution of plants, and the animals associated with them, could be affected. Shifts of temperature

and precipitation patterns could rearrange the location of major biomes; some species could suffer, others might prosper.

- o Special attention should be given to agricultural effects of climate changes. This, of course, is of current concern because climate changes occur naturally. The reaction of the world's food and fiber producing regions to the CO_2-induced climate changes warrants special consideration, however.
- o Much concern has been expressed that warming would cause the polar ice sheets to melt and the sea level to rise. It is quite unlikely that this would happen in the next few centuries and the likelihood of its occurrance may have been overstressed. Climatically-induced surges of the ice sheets are possible, but the causes of surges are not well understood. It has been asserted, however, that West Antarctica could deglaciate if the ocean should warm. Because this could produce a 5 meter sea level rise, this possibility deserves some special attention. The recession of mountain glaciers also should be examined although total melting of them would only raise sea level about 1 m.

SOCIETAL IMPACTS

The ultimate issue is, of course, the impact of increased CO_2 on society. It must be stressed that impacts of climate change will not fall equally on all segments of the world's society despite their global nature. Indeed some regions or countries may find benefits in the altered climate, others may be relatively unaffected, while some could be harmed significantly. Such disparity of effects may make international agreements very difficult to achieve if they are ever needed.

Among the more obvious things to explore are the impacts of shifting agricultural regions and productivity, water availability due to changing precipitation regimes (e.g., can inter-basin transfer of water alleviate the problems of local drought), and impacts on energy demand itself (is there a positive or negative feedback on CO_2 production?).

The decision to curtail fossil fuel will be made only if and when society's costs are believed to exceed the benefits to continued fossil fuel combustion.

World-wide agreement on reduced consumption of fossil fuel will present very serious international problems. Thus, it seems worthwhile to explore how societies might cope with the climatic consequences of increased CO_2.

MITIGATING STRATEGIES

Besides reducing fossil-fuel use, one may consider other technological "solutions" should CO_2 increases be seen as undesirable. Certainly both more efficient use of energy and the development of non-fossil energy sources would help reduce the CO_2 growth and could conceivably delay the onset or even solve the problem.

No technical solution has been proposed so far that seems practicable, but this should not deter the search. One should still explore the possibilities of removing CO_2 from effluent streams or from the air, sequestering it in permanent or quasi-permanent reservoirs. Even if such studies fail to uncover a feasible method for doing so, they will serve to demonstrate that technological optimism will not be a substitute for a realistic assessment of the problem.

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