Appendix E

World Climate, the Oceans, and Early Indications of Climatic Change

Definition. -"Climate" is how one characterizes the weather at a particular place as it occurs over periods of weeks, years, centuries, or millenia. The modern notion of climate includes its variation and extreme occurrences as well as its average conditions.

At the present time, there is accuracy in the detailed 3-to 5-day weather forecasts. For periods longer than that, one begins to speak in less detailed terms, to describe more general features such as mean conditions and the likelihood of various departures from the mean. Over these longer periods of time (weeks, months, seasons), the climate at a particular place seems to be influenced by progressively more distant forces, such as ocean conditions, solar radiation, and polar ice variations. Thus, we speak of an interactive climate system which includes atmospheric, oceanic, cryospheric and solar influences among other factors.

Historical Perspective

Recent dramatic advances in meteorology and climatology are due to three concurrent streams of development. First, the basic scientific understanding of atmospheric (and oceanic) behavior has grown. Physical and mathematical models have been constructed which duplicate rather well the overall behavior of the atmosphere. Detailed numerical models as used in weather forecasts show reasonable predictive skill. Climate models, though much less precise in time and space resolution, successfully duplicate the large features of the observed climate. Second, and more recently, electronic computers have enabled the development of more detailed and complex models and the solution of their associated mathematical equations. The large computing machines also enable the inclusion and effective treatment of vast amounts of actual data rather than summarized data or proxy parameters.

Third, and most recent, observations from space provide truly global data to describe global-scale climate. A pair of polar-orbiting satellites can view each point on Earth four times a day. A satellite in geosynchronous orbit can continuously monitor conditions over almost a whole hemisphere.

These advances led to the Global Atmosphere Research Program (CARP) conducted during the last decade. The objective of this program was to observe the atmosphere and produce the most comprehensive set of data ever compiled. These data were then to be used to increase understanding of the behavior of the atmosphere, to improve models, and to assess our ability to predict future behavior of the atmosphere. A second major objective was to improve our understanding of the Earth's climate.

The data from the Global Weather Experiment (GWE)–the ultimate phase of GARP–are **still being** analyzed, but already dramatic results are coming to light. For instance, through a combination of surface drifting buoys and satellite-borne data collection systems, measurements taken during the **GWE revealed a previously unobserved complexity in the atmospheric conditions over the Southern oceans.** These vast, remote areas had been largely unmonitored prior to the GWE. In addition, satellite-acquired cloud image data have revealed important interhemispheric flows which influence atmospheric conditions in the Northern Hemisphere. These findings are important because the large-scale aspects of climate are truly global in nature. This has become progressively clear over the years, as scientists such as Hadley, Rossby, Walker, Bjerknes, and many others, have described the overall features of the planetary atmospheric flow about the Earth. Now means are becoming available that demonstrate directly, through observations, the global nature of climate.

Over the last decade, we have become increasingly aware of our vulnerability to extreme climate events. The "Dust Bowl" conditions of the 1930's and their attendant impacts on agriculture and the economy have been well documented. During 1972, unanticipated drought and adverse growing conditions led to severe shortages in the world-wide supply of grains. This led to adverse domestic economic impacts including the U.S. sale of wheat to the Soviet Union at prices lower than the world prices. The effect of the 1973 Middle East oil embargo was heightened when fuel shortages occurred while there was very cold weather in New England and the Midwest. The California drought of 1976 and 1977 would have had very adverse effects had it persisted any longer.

Because modern society is vulnerable to climate occurrences, important benefits could also result from knowing climate variations in advance. jack Thomson, a noted meteorologist, has estimated that the total annual monetary loss due to poor weather conditions was approximately $13 billion (in 1971). Of that amount, about $418 million could have been saved if reliable **30-** and 90-day forecasts had been available. The larger part of the "protectable" loss required **shorter forecasts, 5 days or less. Thompson found the sectors most benefiting from climate forecasts to be: agriculture,** energy, public safety, construction, communications, and electric power. Given the large increase in energy costs since 1972, the potential savings from reliable climate forecasts should today be much greater than estimated by Thompson.

Just as the value of reliable climate forecasts is being defined, the research community is developing promising techniques for providing reliable seasonal forecasts as much as 6 months in advance. These results have come from diagnostic studies of the "Southern Oscillation." This phenomenon involves a family of climate fluctuations around the globe—including links between atmosphere and ocean conditions in the tropical Pacific and subsequent climate behavior over North America. Warming of central equatorial Pacific water typically leads to displacement of the North American jet stream northward over the West and southward over the East. This causes below normal surface temperatures in the populous eastern United States and warm temperature in the West. The severe winter of 1976-77 (following the 1976 El Nino ocean warming) was typical of this pattern.

The hope for seasonal forecasts lies in the recognition that ocean conditions oflen persist for several months. Thus, when appropriate ocean conditions develop (usually during our spring and summer) they will indicate the likelihood of subsequent anomalous winter conditions occurring in the United States.

In a more recent study, Brown-Weiss confirmed that 3-to 4-month forecasts would be very useful to public utilities for planning natural gas purchases and in planning the mix of petroleum products (e.g., the relative amounts of gasoline versus heating oil).

In addition to forecasts, there are many important uses of climate information falling under the general heading "Applied Climatology." This refers to the statistical characterization of the climate based on the data record. Examples are: the estimation of fuel and electric power demand based upon heating and cooling degree days; planting crops based on the latest data of a killing frost; designing dams based on maximum probable precipitation. Many of these statistical application techniques have been developed because reliable forecasts have not been possible. others, for instance those associated with the design of structures, would probably continue even if forecasts were available because the life of the structure is so long.

Finally, there are important applications which require "current climate" information. For example, in monitoring growing conditions in areas important to worldwide commodity trading, it is important to analyze current conditions in relation to the climate norm. Crop yield models require not only the current weather data but also the climatology for the regions. To be useful, these data must be gathered, processed and disseminated to users very quickly.

Mindful of our vulnerability to climate, our opportunities to improve our knowledge of climate, and the opportunities to make beneficial use of improved climate information, the Congress passed and the President enacted the National Climate Program Act (Public Law 95-367, dated Sept. 17, 1978).

The National Climate Program

The purpose of the National Climate Program is "to understand and respond to natural and man-induced climate processes. " In establishing the national program, the act set up mechanisms for coordinating and integrating the climate activities of the Federal agencies. In particular, the act established a National Climate Program Office as lead entity for administering the program and required the preparation of a 5-year plan to state the goals and priorities of the program and the roles of the Federal agencies in conducting the program.

The current (and first) 5-year plan emphasizes the production of useful climate information based on existing knowledge while simultaneously expanding our understanding of climate and its impact on society. The priority programs (and associated lead agencies) in each of these activity areas are as follows:

Activity category	*Principal thrust*	*Lead agency*
1. Providing climate products	Generation and dissemination of climate information	NOAA
	Climate prediction	NOAA
II. Responding to impacts and policy implications of climate	Carbon dioxide, environment, and society	DOE
	Climate and world food production	USDA
III. Understanding climate	Solar and Earth radiation	NASA
	Ocean heat transport and storage	NSF

Potential Contributions From Space Capabilities

Direct satellite measurements and satellite relay of data will make important contributions to all of the above tasks. Considering the continuing elements of the National Climate Program, space contributions and requirements on space systems are likely to be as follows:

Impact Assessment: Effects *of climate on processes and natural resources.* —This area of the program concerns direct climate effects such as the development of crop yield models and energy demand models in terms of climate variables. Demonstration programs such as the Large Area Crop Inventory Experiment (LACIE), and the snowmelt runoff project in California have provided important tests of the uses of space-acquired data. It is recommended that such activities continue with even greater end-user involvement. These demonstration projects provide for development of effective user application models.

Climate System Research: *a) Developrnent of climate simulation and prediction* models.—The main contribution to this area is likely to be from improved computer power and computation techniques. Space systems will provide better global data both as input to the models and as a check on model outputs. This will remove input data as a source for model errors and permit selection of the best modeling approaches.

b) Studies of physical climate processes.–In order progressively to extend our knowledge of the overall climate system, certain key processes are selected for detailed study. There is, for instance, a good deal of interest currently in ocean-heat transport, air-sea interactions, the oceans' role in the global carbon cycle, and stratospheric processes. Space systems, in conjunction with other measurement techniques, will contribute significantly to these process studies.

Data, Information, and Services: ***a)*** *Observation.–* The object here is to compile an accurate, objective record of climate behavior for both applications and research. It is in **this area that space capabilities will make the most important contributions** to climate activities. The observation programs are subdivided along climate regimes: atmosphere, oceans, cryosphere, stratosphere, and solar. The contributions are likely to be as follows:

1) ***Atmosphere:*** Data from the operational weather satellites are first used for weather purposes. These data are then archived and become a major contribution to the climate record. They include atmospheric temperature, moisture, cloud imagery, and sea-surface temperature.

2) ***Oceans:*** As the oceans cover three-fourths of the Earth's surface, they have a profound effect on the climate. Because the areas are so vast, satellites, in combination with in situ devices, provide an effective approach to measurements. Plans are now being formulated for progams extending into the next decade to understand the oceans' role in climate. **A** key aspect is how the oceans store, transport, and redistribute heat globally. These problems will be addressed through a progressive series of studies culminating in a global ocean circulation experiment. A typical interim experiment is the CAGE experiment to measure the fluxes of heat, mass, and momentum through "fixed" ocean and atmospheric boundaries. Satellites will be needed to give the heat balance at the top of the atmosphere and provide other supporting data (e.g., data collected from drifting buoys).

A key satellite experiment in ocean climate studies will be the TOPEX mission. As currently planned, the mission will use a satellite altimeter and radar scatterometer to measure sea-surface topography and wind fields. The aim is to provide information on surface currents and wind stress, The mission may include a microwave radiometer to provide improved sea-surface temperature data. These data, especially on a global scale, are very important to the understanding of the transport of energy from lower to higher latitudes and the exchange of energy between the ocean and the atmosphere. The TOPEX mission derives from the GOES, SEASAT family of altimetric satellites. It is planned for flight in the mid- 1980's.

3) Cryosphere; The expansion and recession of the polar ice packs are thought to be important indicators of climate. The annual variations in the extent of continental snow packs may also be an indicator. Certainly the extent of continental and polar ice cover influences the radiation balance of the planet. The ICES satellite mission is an experiment to give detailed data on the great Greenland and Antarctic ice packs.

One recent study indicates that the rise in sea level since 1940 may be related to the melting of the polar ice caps as a result of atmospheric warming due to increased CO_2 in the atmosphere. The melted ice would tend to cool the oceans and thereby the atmosphere, masking a direct thermal signal of increased CO_2. Satellite data on the oceans, polar regions and the stratosphere will be needed to gain conclusive data on these questions.

4) ***Stratosphere:*** Important progress has been made in developing satellite-borne stratospheric composition measurement techniques. Much of this effort has been stimulated by concern over changes in the stratospheric ozone layer. An ozone monitoring sensor is being developed for incorporation onto the operational weather satellite system to enable ozone monitoring.

At the present time, the precision in satellite ozone measurements is about that of Earth-based measurements. But satellite data provide a global view difficult (if not impossible) to infer from the sparse ground measurement network.

94-915 0 - 82 - 23

5) ***Solar:*** The Sun provides the energy which gives rise to atmospheric and oceanic movements. **There are attempts under way to measure variations** in solar **energy arriving at and leaving the Earth (the radiation budget) and to relate** such variations to climate variability. The Earth radiation budget experiment is part of this effort. Because of the complex nature of atmospheric absorption, it is necessary to monitor the radiation above the atmosphere. Spacecraft provide the only means for continuous solar and Earth radiation monitoring.

6) ***Diagnosis and Projection:*** Climate diagnosis is the detailed analytical and statistical study of climatic events to try to relate climate observations (temperature, pressure, winds, etc.) with the inner workings of the climate system. Diagnostic studies associated with the Southern Oscillation (SO) and other atmospheric and oceanic phenomena hold potential for developing new techniques for seasonal climate prediction.

Because ocean conditions tend to persist over several months, it may be possible to predict several months in advance when certain abnormally cold winters are likely to occur over the populous eastern United States.

However, in order to verify these hypotheses and assess the reliability of resulting predictions, much better sea-surface temperature (SST) data will be needed. The most reliable data are probably provided by ocean buoys. But these data leave wide ocean areas uncovered. Reliable satellite-acquired data, because of wide area coverage, will be a great improvement. Existing satellite-measured SST data are not sufficiently precise to meet climate requirements; improved SST sensors are required.

Requirements From the National Climate Program

Now that the program components have been introduced, it is of interest to discuss certain requirements inherent to climate monitoring. The overriding requirement is for a continuous, intercomparable data record for a span of time that is climatologically significant. In most instances, this is several years. More generally, the longer the record the more valuable it is in determining the likelihood of "extreme" occurrences. Yet, even a period of few years exceeds the life of most satellite sensors. Thus, in the planning for monitoring from space, account must be taken of the need for continuity of data, requiring intercalibration of instruments, documentation of data handling techniques, and so forth. This is referred to as the development of climatically significant data sets.

Secondly, because of the nature of the climate system and the resulting central tendencies of the data, monitoring for climate is likely to require greater precision than short-term monitoring (e.g., weather). That is, where one is measuring diurnal variations in temperature there are likely to be greater fluctuations than, say, in the annual mean temperature from year to year.

Thirdly, there must be a commitment to acquire and prepare new and existing data for climate uses. This may involve some risk. At this stage, one is not always certain that the "best" parameters are being measured. Nevertheless, in order to make useful tests, analyzable data sets covering significant time periods must be available, For example, it was planned that the Earth radiation budget should be monitored over at least one solar activity cycle (1 1 years). Yet, because of severe budget constraints, there is no activity under way to sustain the measurements beyond the initial system to be launched in 1984.

Because of the vast and remote areas involved, and because of the general hostility of the environment for measurement equipment, satellite systems (in conjunction with in-situ platforms) offer a reliable, cost-effective way to collect important ocean-climate data. This was demonstrated during the global weather experiment. During this and the next decade, efforts must be made to gain further knowledge of the processes by which the oceans transport and store heat. New satellite techniques (for measuring surface currents, wind stress, and surface temperature, interalia) have promise for playing major roles in those efforts. Stratospheric monitoring and polar ice monitoring will also contribute to early detection of climate change.

The Climate Program Impact Upon National Space Policy

OTA has outlined six principles and associated issues underlying U.S. civil space activities. The impact of the National Climate Program is analyzed in relation to each of these principles quoted below:

> 1. "Space activities maybe justified by political, as well as by social, economic, scientific, technological, or other benefits."

In the early years of the space program, national space goals were primarily engineering-oriented. The cutting edge of space technology was in learning how to successfully launch and recover space vehicles, to "put a man on the Moon by 1970." Now that much of the engineering capability is secured, it would appear that any new national space goals are more likely to be oriented toward application of space technology. Indeed, the national governmental policy challenge for the 1980's seems to be shaping up to be to make the economy stronger, in which case all programs, including space activities, will be evaluated in terms of their economic contribution.

The long-term goals of the national climate program are primarily economic—to be able to routinely predict climatic variations (weekly to seasonal) for economic payoffs in energy conservation, agricultural productivity, water resources management, and resort management as well as long-term climatic change potentially associated with, say, atmospheric CO_2 buildup. The near-term objectives of the climate programs are primarily in research aimed at improved understanding of climate on which to build climate prediction skills. Therefore, the climate program applications of space technology can be seen as economic in the long run and mainly research or scientific in the short term.

There are certain characteristics of the climate program's space requirements that must be taken into account i n the formulation of any comprehensive national space policy:

a) Remote sensing from space is essential to climate research and forecasting, For obtaining certain climatic parameters, e.g., measuring the Earth radiation budget, there are no alternatives to spaceborne sensors.

b) Climate studies require long periods (often measurable in decades) of data continuity. This is different from most other space applications (e.g., weather). Consequently, the accuracy and precision of data useful for short-term purposes may be wholly inadequate for climate.

c) Climate studies require truly global coverage. Present coverage is inadequate because data from the tropical oceans and the Southern Hemisphere, which are crucial to climate forecasts, are most sparse. Future coverage may be even less complete if the number of meteorological satellites is reduced in response to fiscal constraints.

d) Overall, **U.S.** climate program activities are more reliant upon multipurpose satellites, especially meteorological satellites, than on climate satellites. There is an open question whether this trend will be continued into the future because climate research requirements and the evolving climate forecasting skill will necessitate:

—monitoring climate-unique parameters potentially requiring unique satellite orbits or unique sensors;

—improved long-term data continuity; and

—increased data volume, possibly demanding the total payload of a given satellite.

On the other hand, if these capabilities can be obtained through reliance upon multipurpose satellites, it would seem potentially more efficient. A system of multipurpose Earth remote-sensing satellites could result in fewer space platforms carrying the same same sensing capacity.

2. "The United States should be 'a leader' (cf. Space Act of 1958) in 'aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities . . . "

Climate research and climate forecasting are inherently global, Climate activities, following the precedent set in meteorology, are characterized by a high degree of international cooperation and sharing, e.g., GARP. However, in practice most of the remote sensing in support of climate studies around the world has been done by U.S. satellites.

While the U.S. commitment to climate studies and forecasting will serve to maintain **U.S.** visibility in world climate activities, the objectives of U.S. climate activities are primarily economic and scientific. It is in the best interest of the **U.S.** climate program to maintain an atmosphere of international cooperation and participation so as to gain scientific and engineering support from other nations in the interests of efficient and rapid cooperative progress in climatology.

3. "Civilian and military space activities will be conducted in separate (and independent) institutional structures. "

Since the climate program will, for the foreseeable future, procure much data from space platforms justified primarily for other purposes, ownership of those platforms whether by military or civilian institutions will make no difference so long as data quality, quantity, and timeliness are adequate. Conversely, if the climate program requirements evolve in such a way as to necessitate dedicated climate satellites, the integration of **U.S.** military and civilian satellite systems under a common institutional structure could affect climate data acquisition, but that effect cannot now be projected.

4. "The National Aeronautics and Space Administration, established by the Space Act of 1958, is authorized to conduct research, development, construction, testing, and operation for research purposes of (aeronautical and) space vehicles. It is not authorized to have operational responsibility for space systems. "

The national climate program, as a user of multipurpose satellites owned and operated by nonclimate program entities, would be neutral on the question of the identity of the U.S. civil space system operator. However, to the degree that the climate program's data requirements necessitate a dedicated climate satellite system, the operational responsibility question will be acute.

5. "Commercialization of space technology and applications should be promoted."

From the point of view of the potential commercial supplier of climate remote-sensing data, the climate program with its requirement for long-term data continuity would appear a promising market.

From the point of view of Government climate program managers, commercialization of the satellites that supply climate observations is of concern primarily in terms of cost but also in terms of data quality and timeliness. If a large, diversified (many firms) satellite remote-sensing industry were to develop, inter-firm competition could be expected to work in the interests of the climate programs to keep data prices low and data quality, quantity and timeliness high. If, on the other hand, the private remote sensing industry were to be essentially monopolistic, the climate program managers' concerns would be justified.

On a broader commercialization question, if the entire climate program were to be commercialized, it seems obvious that the satellites supplying the climate data would also be commercial. Commercialization of the entire climate program is a possibility only in the long run after climate forecasting has been proven, and even then total commercialization seems improbable.

The evidence is strong that the core of the climate program will remain a public function for the foreseeable future and that no more than the value-added components will be commercialized. Climate forecasts, the long-term objective of the climate program, are certain to be, in part, public goods. Certain major public policy decisions, such as those potentially associated with CO_1, acid rain, or ozone, will be heavily dependent upon climate forecasts. The forecasts themselves and the capability to produce them will almost certainly be a government responsibility because the market for such global climate predictions will not be commercially viable. Hence, a core climate program capability will be governmental for the foreseeable future.

6. "The United States will engage in cooperative, international activities involving peaceful uses of outer space."

As discussed under issue B, climatology is global in nature, U.S. climate activities are rooted in international cooperation, and remotely sensed climate data are openly shared in the international community. Nonetheless, it is an open question whether the U.S. would feel comfortable being reliant upon foreign owned/operated satelites for our core climate observations.