CLIMATE VARIATION AND ITS EFFECTS ON OUR LAND AND WATER

Part C. Geological Survey Climate Plan

GEOLOGICAL SURVEY CIRCULAR 776-C

WORKSHOP ON EARTH SCIENTISTS' PERSPECTIVES OF CLIMATE CHANGE

Convened near Denver, Colorado, December 7-9, 1976

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Climate Variation and Its Effects on Our Land and Water

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By Keith A. Howard and George I. Smith, Editors

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A product of the Workshop on Earth Scientists' Perspectives of Climate Change, convened near Denver, Colorado, December 7-9, 1976

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PREFACE

The enormous impact on society of climatic variation is being recognized increasingly by both the public and government. Numerous recent publications as diverse as the public press, governmental documents, scientific journals, and special volumes of learned societies have dealt with the subject. Despite this heightened awareness of human vulnerability to shifts of climate, solutions to the political and scientific problems involved continue to be elusive.

Climate changes constantly. The reasons for climatic variability are not well understood, however, despite the formulation of many attractive and reasonable hypotheses. Perhaps of even greater concern is the growing realization that we do not yet fully understand the numerous subtle ways in which changing climate affects us. These are problems that merit more concentrated scientific attention.

Climate is generally considered primarily of interest to atmospheric scientists. Yet all scientists who have dealt with the earth, and even with other planetary bodies, have had to consider climatic problems. That past changes of climate on Earth have exceeded those measured by meteorologists is well recorded in rocks and surface features studied by earth scientists. The detailed histories of parts of the Earth's crust developed in studies of resource and environmental problems document beyond doubt that many of the differences in rocks and fossils found in local stratigraphic sequences were caused by changes in climate and their geological consequences. The rates at which geologic processes modify the landscape and impact man's use of the land are affected by climatic changes. And water supplies are obviously affected by changing climatic patterns.

In the course of their studies of the Earth and its geologic history, scientists of the Geological Survey have thus also contributed to a better understanding of past climatic changes. They are also fully aware of their obligation to help apply that knowledge of climatic history to the recognition of present and future climatic trends and to their probable future impact on human activities.

For these reasons, a workshop was convened near Denver on December 7-9, 1976, by scientists of the Geological Survey to explore the role of earth science in addressing national needs regarding information on climate. This three-part report is an outgrowth of the discussions by members of the workshop. Part A explores the roles and methods of the earth sciences in climatic research. Part B summarizes the types of climate-oriented work now being carried out by earth scientists of the Geological Survey. Part C proposes a research strategy designed to increase our understanding of the earth-science aspects of climatic variation.

V. E. McKelvey

Director
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SUMMARY

Earth-science research on climate variation can make major contributions toward understanding the causes of climate variation and estimating its impacts. Current efforts especially need to be expanded that will (1) improve the ability to estimate probabilities and impacts of future change, and (2) better document the natural variability of climate so as to explore causes of climate.

A program is proposed that will enable the Geological Survey to fulfill its national responsibilities as part of the coordinated multi-agency National Climate Program. Goals, approaches, and tasks are specified for each of five program elements:

- Consequences of climate variation on land and water resources. An understanding of geologic, hydrologic, and biologic responses to climate change is needed to estimate possible effects of droughts and cold seasons, infrequent catastrophic events (flash floods, hurricanes, accelerated erosion, landslides, mudflows, and dust storms), and slight climate shifts that affect sensitive environments. This knowledge will improve resource management.
- Recurrence of climate variations that affect land and water resources. Time-sequence data provided by the recent geologic record are needed to estimate the probability of recurrence of climate related events including droughts and hazardous floods, mudflows, and hurricane erosion. Actuarial estimates like these will probably always be the main basis for certain land and water management decisions.
- Understanding climate change. Climate history must be better defined from the recent geologic record in order to search for recurring patterns of change, to determine maximum rates of change, and to constrain climate theories, including the effects on climate of geologic events such as volcanic eruptions.
- Research related to monitoring climate. Geological Survey research will contribute to monitoring and understanding of several components of the climate system: ice, snow, and water runoff processes, improved interpretation of satellite image data; effects of land use on climate; and paleoclimate techniques.
- Data management. This program element will provide effective information transfer from scientists to users in order to maximize use of climate data in public planning.

A PROGRAM TO IMPROVE UNDERSTANDING OF CLIMATE CHANGE AND ITS IMPACTS

WHY EXPAND EARTH-SCIENCE RESEARCH ?

Climate is taking on increased importance in our national concerns and our national planning. A United States Climate Program has been recommended by the Interdepartmental Committee for Atmospheric Sciences[1] by Congressional hearings[2] and it has received Presidential endorsement. Expanded study of climate will involve many agencies and disciplines. Earth-science research is one of several vital components (fig. 1).

Now is a time of accelerating risk. As we approach the limits of our natural resources, the increasing use and misuse of resources poses the danger of major economic and political upheavals caused by climate variation. Concern is spreading that the long-term increase of carbon dioxide in the atmosphere from the burning of fossil fuel is raising global temperatures. Temporary imbalances in food production and water availability cause major economic and political disruptions. Our resources of soil, deep ground water, and forests are being reduced by misuse. If we are to reverse this trend and manage our resources intelligently for the future, we must know where climate is heading and what will be the consequences. Now is the time to embark on a program of research toward this end.

Now also is a time of scientific promise. The research capabilities of the U.S. Geological Survey and other earth-science institutions can substantially improve our knowledge of climate and its impacts on mankind.

[1]Interdepartmental Committee for Atmospheric Sciences, 1977, A United States Climate Program Plan: Federal Coordinating Council for Science, Engineering and Technology, Washington, D.C., 81 p.

[2] U.S. House of Rep., 1977, National Climate Act of 1977: Washington, D.C., 95th Congress, Rept. No. 95-266, 24 p.

Many studies of climate are already underway throughout the world (see lists of involved international organizations and Federal agencies in Part A of this report, U.S. Geological Survey Circular 776-A). Earth-science team research efforts supported by the National Science Foundation have, for example, led to recent advances in our knowledge of oceanic climates through Quaternary time[3] to global maps of ice-age conditions essential to the refinement of atmospheric circulation models[4] and to improved abilities to interpret past climate from tree rings[5] Increasingly, interdisciplinary efforts are integrating earth sciences with meteorology and other sciences, and data are emerging that hold promise of correlating climate variations with such events as volcanic eruptions, variations in earth orbit, sunspot frequency, and perhaps geomagnetic reversals. The recent "track record" of these programs offers promise of even more progress if they are supported adequately.

The Workshop on Earth Scientists' Perspective of Climate Change provided a focus for and an important step in coordinating the diverse climate-related investigation activities in the Geological Survey. Two companion reports from the workshop highlight the role of earth science in climatic research (U.S. Geological Survey Circular 776-A) and summarize current climate-related activities in the USGS (U.S. Geological Survey Circular 776-B). It became clear during the workshop that an expanded program of research on the earth-science aspects of climate is needed to help satisfy an urgent need for better information on climatic variability and its impacts. This third part of the workshop report therefore proposes such a program of research.

[3] Hays, James, Imbrie, John and Shackleton, Nicholas, 1976, Variations in Earth's Orbit: Pacemakers of the Ice-Age: Science, v. 194, no. 4270, p. 1121-1132.

[4] CLIMAP Project Members, 1976, The surface of the ice-age Earth: Science, v. 191, no. 4232, p. 1131-1144.

[5] Fritts, Harold, 1976, Tree rings and climate: New York, Academic Press, 567 p.

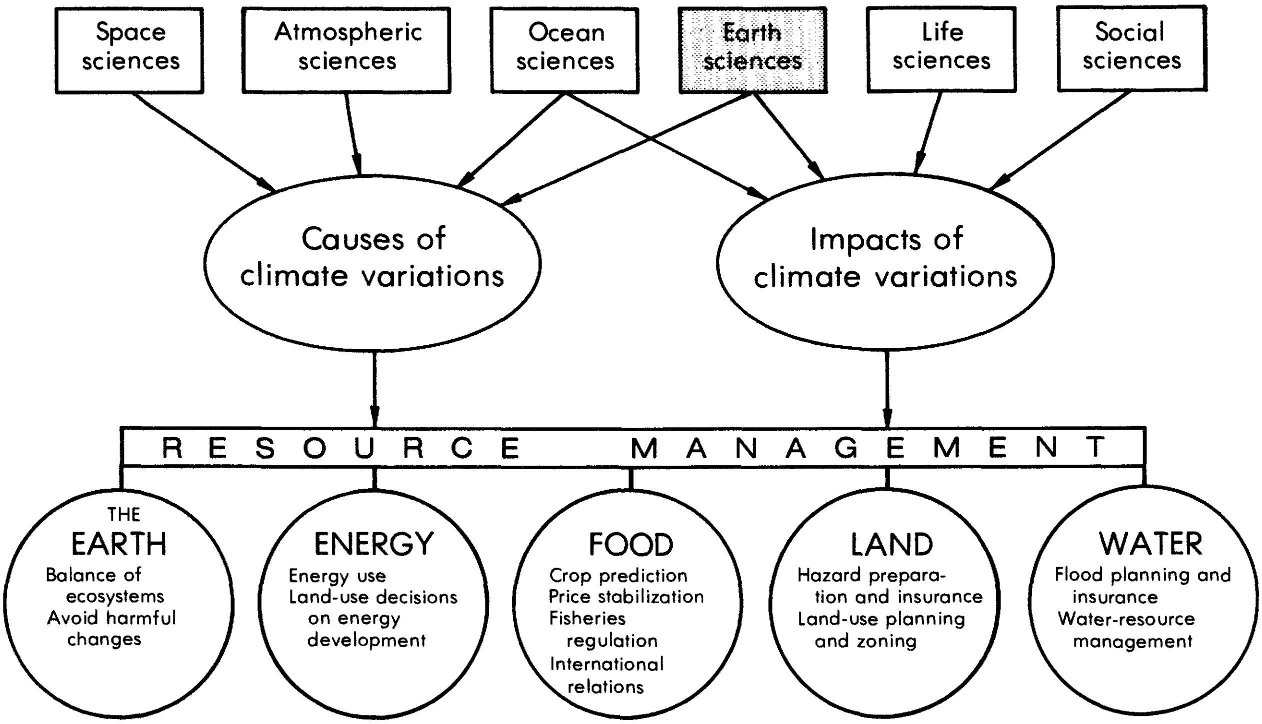


Figure 1.--Relation between scientific disciplines and users of climate data.

WHY A USGS CLIMATE PROGRAM ?

The U.S. Geological Survey functions as the Government's earth scientist. Implicit in this role is a responsibility to assure the Government and the public that earth-science information is being developed at a rate sufficient to promote understanding of climatic variability and its impacts on land and water resources.

The participants in the Geological Survey workshop, along with many other earth scientists, feel strongly that current national efforts toward this goal are insufficient. Greater research efforts are especially needed to:

- Obtain better areal and temporal records of long-term variations in climate in order to document the physical limits of the natural variability of climate and to explore possible causes of climatic change.
- Develop quantitative methods of estimating probabilities and consequences of future climate changes so that planners can adequately assess their impacts.

Climatic impacts, especially, have received far too little attention. Climatic variations and their effects on the continents, which impact man <u>most</u> directly, need particular emphasis. Only with substantially greater effort can there be hope of estimating with confidence the likelihood and consequences of adverse climatic variation.

The workshop participants therefore recommend that the Geological Survey mount a research program devoted to understanding climatic variability and its consequences on the Nation's land and water. A program plan is offered here to meet Geological Survey responsibilities to A United States Climate Program Plan. An object in presenting this plan is to seek comment and advice from the scientific community, government entities, and data users that will assist the effectiveness of the Geological Survey climate program. This expanded program will be an integral part of the United States Climate Program that is coordinated by the National Oceanic and Atmospheric Administration (NOAA). Agency roles are described in A United States Climate Program Plan and in Part A of this report (U.S. Geol. Survey Circular 776-A).

Geological Survey earth-science research to improve our understanding of climate will complement paleoclimatic research sponsored by the National Science Foundation (NSF). Much of the NSF research has been focused on records from the deep sea floor. The Geological Survey program focuses on continental records; it thus complements much of the research being carried out by the academic community and provides a source of in-house technical advice to the government on geologic aspects of climate.

MAJOR OBJECTIVE

The objective of a climate program within the Geological Survey is to provide information on past, present, and future climates and the possible responses of our land and water resources to climatic changes. As shown in figures 1 and 2, this information may be applied both directly to resource management and through climate theory to modeling and eventual prediction. The program must encourage the development of basic concepts in earth sciences and provide for an efficient flow of information both to land and water managers and to research programs in meteorology and other disciplines that need geologic information to provide boundary conditions for climate theories. Part of this information flow can be assured through close coordination with other Federal agencies (fig. 1; see Circular 776-A).

The USGS program will use Geological Survey expertise and, through grants and contracts, the abilities of universities, States, and other institutions. The Geological Survey program is outlined in figure 2 which shows how the five major program elements are related:

- Consequences of climate variation on land and water resources
- Recurrence of climate variations that affect land and water resources
- Understanding climate change
- Research related to monitoring climate
- Data management

These five program elements correspond to the program categories identified by the United States Climate Program Plan (table 1), though the correspondence is imperfect because the Survey program emphasizes the impacts of climatic variation on land and water resources. The program is designed to fulfill USGS responsibilities to the United States Climate Program (table 1). Each of the five elements of the Geological Survey Climate Plan are discussed below, along with examples of that element's goals, technical approach, and specific tasks.

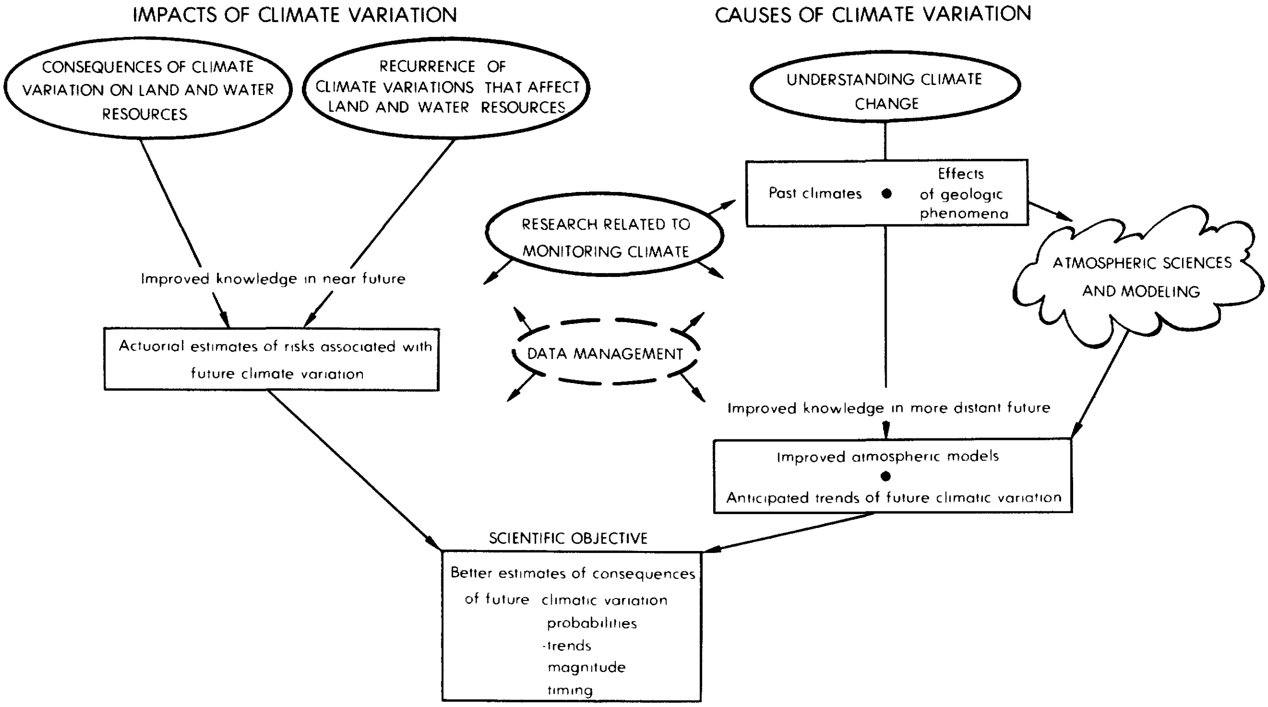


Figure 2.--Geological Survey Climate Plan showing interrelations of the major program elements (circled).

PROGRAM ELEMENTS

CONSEQUENCES OF CLIMATE VARIATION ON LAND AND WATER RESOURCES

Goals

- Develop fundamental understanding of geologic, hydrologic, and biologic response to climate conditions and climate change for different environments.
- Distinguish effects of changing land and water use from geologic and hydrologic responses to variable climate.
- Evaluate the dependency of hazards (such as landslides or mudflows) on climate and better understand the effects of catastrophic climatic events (such as hurricane-induced floods) that occur too infrequently in the historical record for adequate knowledge.
- Determine the expected reaction of sensitive and fragile environments such as arid lands, tundra, wetlands, and strip-mined lands to slight shifts in climate.
- Understand the effects of droughts and assess the interdependence of water and other resources as a basis for improved water management strategies.

Approach

Sound environmental planning in the future will include consideration of the physical consequences that would result from possible variations in climate patterns. Knowledge of the probable responses of land and water resources can be obtained from extrapolation of the changing balances between the land, water, and life systems during minor variation of our present climate, and from earth-science evidence of the past balances under different climates.

Data must be obtained on current processes, such as erosion, and intergrated with data from the past record, such as geologic evidence for

Table 1.--*USGS Responsibilities to United States Climate Program*

Category in United States Climate Program Plan	Estimate of FY 1979 funding in all agencies ($ million)	Implied USGS responsibilities in this program	Other agencies that can contribute	USGS program element	Current USGS missions FY 1978[2] ($ million)
A. Climate variability & national activities	6.3	Impacts on land, water resources & energy development (pp. 11-14)[1]	USDA (droughts, soil resources, plants), EPA (water quality), DOE (stored radioactive waste)	Consequences of climate variation on land and water resources	1.4
B. Diagnosis & projection of short-term climate variability	7.9	Estimate variability & probability of occurrence of climate events; including climate effects such as runoff (pp. 17, 18, 20-21, 29-31)	NSF (tree ring sequences), NOAA (statistical techniques), DOI/OWRT (drought sequence)	Recurrence of climate variations that affect land and water resources[3]	0.3
C. Climate research	31.0	Paleoclimatic data and analysis, especially the continental record (pp. 24-27 34, 37)	NSF (especially tree-ring and sea-floor data)	Understanding climate change	3.5
D. Observations for climate research and services	45.9	Assess climate modification due to land-use changes, research efforts related to monitoring of fresh water, snow/ice, soil moisture, albedo; paleoclimatic technique development (pp. 39-40, 47-50)	NASA (satellite monitoring and technique development), NSF and DOD (ice processes), NSF (paleoclimate)	Research related to monitoring climate	1.2
E. Climate data management	13.2	Water Resource and Landsat data banks. Data transfer. Possibly coordinate all paleoclimatic information (pp. 48, 52, 53-54, 56, 58-59, 63-67)	NOAA/EDS now investigating needs & may set up data bank for paleoclimate data	Data management	0.5
Total	104.3				6.9

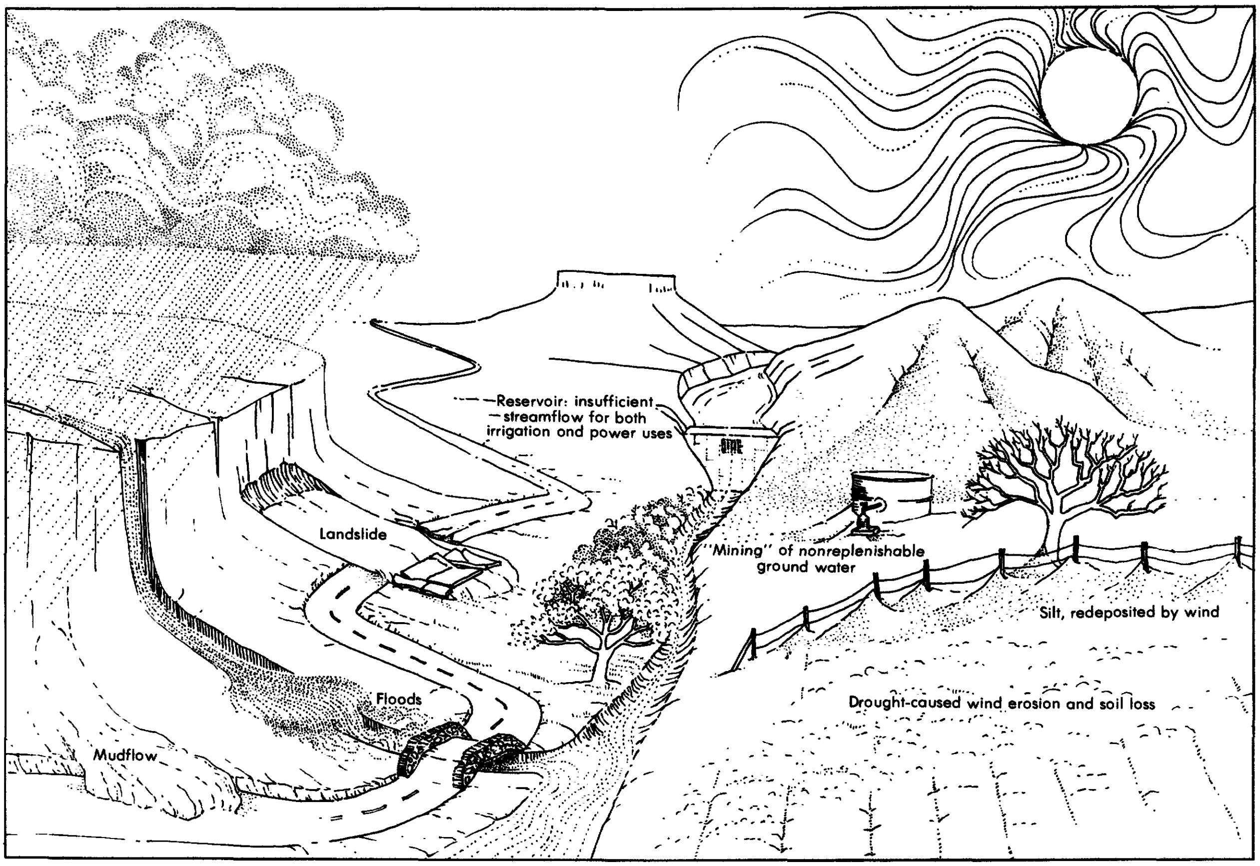
[1]Page numbers in United States Program Plan.
[2]Current USGS investigations related to climate are undertaken for missions with objectives other than climate. USGS plans to allot $1 million in FY 1979 for climate impacts (category A) and climate research (category C).
[3]This USGS program element is directed toward impacts of climate variation and could be assigned to either category A or B of the United States Climate Program Plan.

erosion, in order to develop an understanding of the physical and chemical mechanisms involved. Fundamental knowledge of such processes will improve appraisals of the response of land, water, and life to climatic variation. This will allow, for instance, an understanding of the relative importance of climate variation versus land use on desertification. Fundamental understanding of processes, furthermore, aides in interpreting paleoclimatic data from indirect evidence in the geologic record and thereby reconstructing past climates.

Priority areas for research are sensitive environments such as the arid Southwest, Alaska tundra, semi-arid Great Plains (whose agriculture is very sensitive to climate), and wetlands of the Southeast. Records of past and current changes are most pronounced in such areas and the impacts of future changes will be greatest there.

Tasks

- Relate changes in surface and underground water resources to observed climates.
- Determine the physical effects of flash floods, as examples of climatic extremes, in Appalachia, Colorado, and the Southwest.
- Determine the erosional and offshore depositional effects of infrequent catastrophic coastal storms along the Gulf and Atlantic coasts.
- Study processes and rates of natural and man-induced wind erosion and deposition in times of drought.
- Monitor the response of glaciers to varying climate in order to assess hazards from outbursts on glacier-dammed lakes and calving of icebergs into shipping lanes.
- Determine the effects of disruption of tundra and permafrost under warmer conditions.
- Prepare regional and national maps of land and water conditions at times of extreme past climates, such as the cold regime 300 years ago and the warm period about 6000 years ago, and assess how future land use could be adapted to those conditions under future climates.
- Perform an audit of the 1930's drought in order to guide in the development of drought contingency plans.
- Search for climate correlations with vegetation changes over time



Impacts of changing climate on land and water: some geologic and hydrologic consequences in monumented plots, and distinguish natural effects from changing use of water by man.

- Search for periods of extreme cold in the recent geologic record to determine the possible consequences of climates colder than those of historic times.
- Determine the effects of drought-related forest fires in Alaska and California on subsequent erosion of denuded slopes and sedimentation downstream.

RECURRENCE OF CLIMATE VARIATIONS THAT AFFECT LAND AND WATER RESOURCES

Goals

- Develop geologic and hydrologic evidence of variations in frequency, rate, duration, and magnitude of climate-related events in our present interglacial climate, including droughts, floods, mudflows, hurricanes, and cold spells.
- Improve an understanding of the statistical structure of climate processes.
- Provide estimates, based on past frequencies, of the probability of climate-related events and their geologic and hydrologic consequences.

Approach

Estimates of the occurrence probability of climate-related events are essential to good management of land and water. These estimates include the possible frequency and magnitude of extreme events that cause hazards, such as floods, landslides, and mudflows. Other estimates involve the persistence and statistical structure of a climatic sequence, such as estimates of maximum, minimum, and average streamflows needed for planning a multipurpose reservoir. These actuarial estimates will probably always be the main basis for certain land and water planning activities.

Improved knowledge of the probability of recurrence of future climate-related events will be acquired by:

- Extending historical information on climate-related events farther back in time, thus enabling improved estimates of future occurrence,
- Developing time-sequence data in areas or in regard to processes where historical data do not exist,
- Providing very long sequences of data related to climate that can be used to understand the statistical structure of climatic processes.

Knowledge of rates of possible climate variation could provide planners and policy makers with a basis for estimating lead times that might be available prior to future climate variations. The detailed knowledge of rates of change can come from the study of transitional periods in climatically sensitive records, such as erosion, deposition, glacier fluctuations, and especially tree rings, snow layers, coral layers, and varved sediments that allow resolution of individual years.

Investigations will focus on the recurrence patterns of hydrologic and geologic events caused by climate, especially in environments where the records are most sensitive to change and in environments that yield geologic records having high time resolution. Recurrence estimates must be combined with quantitative information on climate-induced geologic and hydrologic processes to provide a quantitative basis for risk assessment. This second program element then is closely related to and interdependent with the first one.

Tasks

- Develop a history of drought recurrence, magnitude, and duration in the recent geologic record of the arid Southwest and the Great Plains using evidence from tree rings, plant communities, deposition of windblown dust, lake sediments, and arroyo cutting and arroyo alluvial deposition.
- Develop long chronologies of streamflow for rivers in California, Washington, the Southwest, and the Great Plains using tree rings and other evidence in order to improve information about the persistence and frequency of low flows.
- Determine the extent to which our designed water resource systems are sufficiently resilient to cope with extreme droughts and with post-drought recovery (abandoning wells, returning to the use of surface water, and recharging the ground water supply).
- Develop methods for identifying and dating hurricane passage in nearshore sediment and fauna, and develop time sequences of hurricane recurrence along the Gulf and Atlantic coasts.
- Develop a chronology of alluviation over the past several hundred years in a variety of settings across the continent in order to establish the frequency and distribution of catastrophic flood events.
- Develop a history of flash flooding in Appalachia, the Colorado Front Range, and the Southwest by dating old flood deposits using botanical and radiocarbon techniques.
- Perform statistical analyses and seek persistent patterns in tree ring records of climate.

Goals

- Develop a basic record of past climatic patterns on the continent to identify geologic constraints to the development of climate theories and models.
- Determine whether distinctive patterns of climatic sequences have recurred in the geologic record.
- Determine the rates of past major changes in climate and whether "warning signs" of change can be identified.
- Evaluate the potential effects on climate of geologic phenomena such as volcanic eruptions.

Approach

A major challenge facing science is to develop a capacity for short- and long-range climate prediction. To approach this will require sustained long-term efforts in many scientific disciplines. An initial objective must be to understand the climatic variability of the past.

It is the earth sciences that provide long records of past climatic variation. These records allow modern climates to be viewed with a long-term perspective, and they are essential to the development of useful models of climate change.

> "In general, the record of past climate indicates that the longer the available record, the more extreme are the apparent climatic variations. An immediate consequence of this... characteristic is that the largest climatic changes are <u>not</u> revealed by the relatively short record of instrumental observation but must instead be sought through paleoclimatic

studies. The record of past climates also contains important information on the range of climatic variability, the mean recurrence interval of rare climatic events, and the tendency for systematic timewise behavior or periodicity. Such climatic characteristics are in general shown poorly, if at all, by the available instrumental records."[6]

A global shift in atmospheric circulation that initiated major climatic change would be enormously disruptive. Even though the larger consequences could require centuries to develop fully, the Earth's inhabitants and their terrestrial resources could be severely affected by adverse climate in a very short time. Some evidence suggests, for example, that persisting snow (incipient glaciers) could form over large areas in just a very few years, causing worldwide cooling and possibly an irreversible progression toward a full-blown ice age. The atmospheric behavior prior to such climatic change is unknown, but study of the geologic record of past changes offers hope that we can learn something of two aspects: (1) the nature of any warning signs that precede major change, and (2) the possible rates of major climatic changes. Some of the most complete records of global climate change through the last several glaciations are derived from analysis of ocean-bottom cores, but the very nature of these data precludes much information of rates of atmospheric change or climatic fluctuations of short duration such as 100 years or less. Short-interval information on past climatic sequences and the rates of climate change at times of maximum change can be obtained most accurately from the paleoclimatic record on land.

Evidence is mounting that climate may be markedly influenced by volcanic eruptions, dust storms, and perhaps other geologic phenomena such as geomagnetic reversals. High-altitude dust from large eruptions has been known to persist in the stratosphere for months and markedly change the radiation balance on regional and global scales. Can climate change be triggered by such events? The answer can come from geologic records of large eruptions and dust-erosion events when they are correlated precisely with a detailed climate history of the same periods. The volumes of ash from large prehistoric eruptions are indicated by the areal extent and thickness of correlative ash layers in geologic sections. Major dust storms are identified by their erosional and depositional records.

How seriously do man's activities impact the climate? The recent National Academy of Sciences book Energy and Climate raises concern that increased atmospheric carbon dioxide from the burning of fossil fuel could cause global warming, possibly to the point of eventually melting the ice caps and flooding coastal cities. Estimates of such manmade effects, which are vitally needed for policy decisions, will emerge as the controls and mechanics of our climate system become better understood. One key to possible causes comes from study of climatic responses to boundary conditions vastly different from today's; these conditions are represented both in the record of the geologic past and in the geologic record of climatic history on Mars and other planets.

[6] National Academy of Sciences, 1975, Understanding climatic change-- A program for action: Washington, D.C., National Academy of Sciences, p. 36.

Tasks

- Search the geologic record for recurring climate sequences or cycles in fragile environments where small climate changes cause large changes in ecologic balance, and in lakes and bogs where continuous rapid sedimentation has taken place.
- Determine maximum rates of climate change from detailed study of high-resolution climatically sensitive records (pollen, fossils, tree rings, chemical precipitates, glacier variations, snow layers) for times of maximum atmospheric change.
- Define a high-resolution, record of climate history through Quaternary time from sites of rapid sedimentation on the continent, and use this to refine and improve calibration of the lower resolution sea-floor records now available.
- Search for warning signs of major climate change by studying patterns of hydrologic, geologic, biologic, and chemical responses for times that preceded major change.
- Relate the stable-isotope composition of rain and snow to the meteorological processes that fractionate the isotopes, and determine which chemical processes modify those compositions as the moisture is incorporated into minerals, soil, glacier ice, ground water, and plants.
- Investigate the effects of water, plants, and geologic materials on the atmospheric flux of carbon dioxide.
- Study modern examples of possible climate alteration by volcanic eruptions and dust storms, using field and remote-sensing techniques.
- Investigate possible correlations in the geologic past between major eruptions or dust storms and climate change, and seek to measure the influence of such events on regional and global climate.
- Search for correlations between climate and changes in the geomagnetic field, and explore possible cause-and-effect relationships.
- Determine geologic evidence of the long-term climatic history of Mars and other planets in order to compare effects of grossly different boundary conditions.
- Improve our understanding of how continental glaciation begins and whether one or a few years of unmelted snow across northern North America could trigger a full-blown ice age.
- Seek isotopic means to determine the history of atmospheric carbon dioxide in the recent geologic past and whether climate has responded to natural changes in carbon dioxide content.
- Determine the climatic patterns across the continent for the warm period about 6000 years ago as a guide to the conditions that might be expected if the atmosphere warms because of increased carbon dioxide from burning fossil fuels.
- Develop time-slice maps of North American continental climate as needed by NSF's CLIMAP project and other interagency projects that are seeking to refine general circulation models of the atmosphere.

RESEARCH RELATED TO MONITORING CLIMATE

Goals

- Develop understanding of the processes governing drainage basins and snow and ice fields and the relations between precipitation, temperature, and cloudiness and runoff, glacier flow and icebergs.
- Improve techniques for determing snow cover, soil moisture and temperature, and other ground-surface characteristics.
- Evaluate land-use effects on local and regional climate.
- Improve techniques for documenting, dating, and determining climatic parameters from geologic materials.

Approach

The climate system contains three main interacting fluid components (air, sea, ice) subject to the boundary conditions of the earth's surface configuration and rotation and the sun's radiation. Primary responsibility for routine monitoring of the air and sea components lies with other agencies and institutions. Geological Survey responsibilities include improving understanding of the interactions between precipitation, snow and ice, cloudiness, and runoff. Major advances in understanding glacial processes, especially, must be made.

Support of regional and global monitoring of the present climate requires improved techniques for determining snow cover in forested areas, soil moisture and vegetative cover. Development of such techniques will enable the appropriate agencies to monitor changing land, water, and snow and ice conditions regionally and globally from satellite so as to provide data for climate models.

Land use may affect local and regional climate directly through changes such as in albedo, in evaporation of moisture, and in the atmospheric content of wind-blown dust. These effects can be properly evaluated only when we develop a thorough understanding of the interactions between solar radiation, the atmosphere, and different ground and dust characteristics. This understanding will be promoted by continued monitoring of land use and by comparison of modern effects with those indicated in the historic and geologic record.

Development of highly specialized techniques offers the promise for rapid expansion of paleoclimatic knowledge. The successful attainment of the goals of the USGS climate program will require expanded facilities and skills for documenting, dating, and determining the climatic significance of geologic materials. Some techniques, such as determining past temperature from isotopic composition, need testing and improvement. Others, such as in tree-ring research, are developed but need enhanced facilities to carry them out. Still others, such as improved dating and correlation, need to be developed so as to fill "blind spots" in the existing technology.

Tasks

- Investigate the mechanisms of growth, basal sliding and surging of glaciers in order to understand the dynamics and thermodynamics of the major ice sheets and their long-term interactions with the oceans and atmosphere.
- Develop models that can provide quantitative climate information from data on the advance and retreat of glaciers.
- Improve techniques for interpreting snow and ice data from remote sensing.
- Improve techniques for obtaining soil-moisture and temperature information from remote sensing.

- Determine the properties and potential effects on climate of wind blown dust caused by poor land use.
- Develop remote-sensing techniques to determine changes in albedo, net radiation, and radiation temperature caused by changing land use in order to evaluate possible modifications to climate.
- Develop low-cost and versatile methods of artificially exposing sediments and obtaining cores.
- Expand the known volcanic-ash chronology as a dating tool.
- Improve the ability to interpret chemical and isotopic content of tree rings.
- Establish a detailed history of the evolution of ecologically very sensitive fossil groups in Quaternary time through establishing an improved biochronology of associated rapidly evolving fossils.
- Develop radiometric age techniques for sediments too old for carbon-14 and too young for potassium-argon methods.
- Establish transfer functions by which rainfall and temperature can be better estimated from chemical, isotopic, and biologic composition of geologic materials.
- Establish a network of geologic benchmark stations where the geologic response to climate can be monitored over time.

DATA MANAGEMENT

Goals

- Assure that technical data on earth-science aspects of climate are easily available to both scientific and nonscientific users.
- Provide a focus for public and technical inquiry for information on earth-science aspects of climate.
- Promote the use in public planning of data on climatic impacts.

Approach

Management of the enormous base of data needed for climate research and services under the United States Climate Program Plan is the primary responsibility of other agencies, but they will be supported by two current USGS archive activities as well as by activities in NOAA and other agencies. The Geological Survey has primary responsibility for cataloging United States hydrologic data in the National Water Data Exchange (NAWDEX), and also for maintaining files of Landsat satellite imagery and aerial photograph data at the Earth Resources Data Center. The Survey is working with NSF and the Environmental Data Service (EDS) of NOAA to investigate needs for central data cataloging of paleoclimatic data.

A major additional need for data management is in making relevant data more readily available to users. Publication of accurate technical information in reports and maps is a USGS tradition. Transfer of information to users can be further accomplished through workshops and public-oriented products designed to be directly useful in planning and policy making for land and water use.

Tasks

- Prepare maps that show risk of various land uses to climatic variation.
- Develop dynamic models that simulate interaction of land, water, energy, and food resources in various climate scenarios.
- Develop water-management strategies that utilize the improved data on hydrologic and biologic responses to possible climate variations.
- Make regional assessments of climate-related hazards for use in land-use planning, disaster preparation, and insurance.
- Maintain close interaction with the public through workshops, nontechnical reports and through

information that can be used by local public advisors such as agents of the Soil Conservation Service.

- Encourage educational institutions to devote more attention to the specialized techniques required in earth-science investigations related to climate.

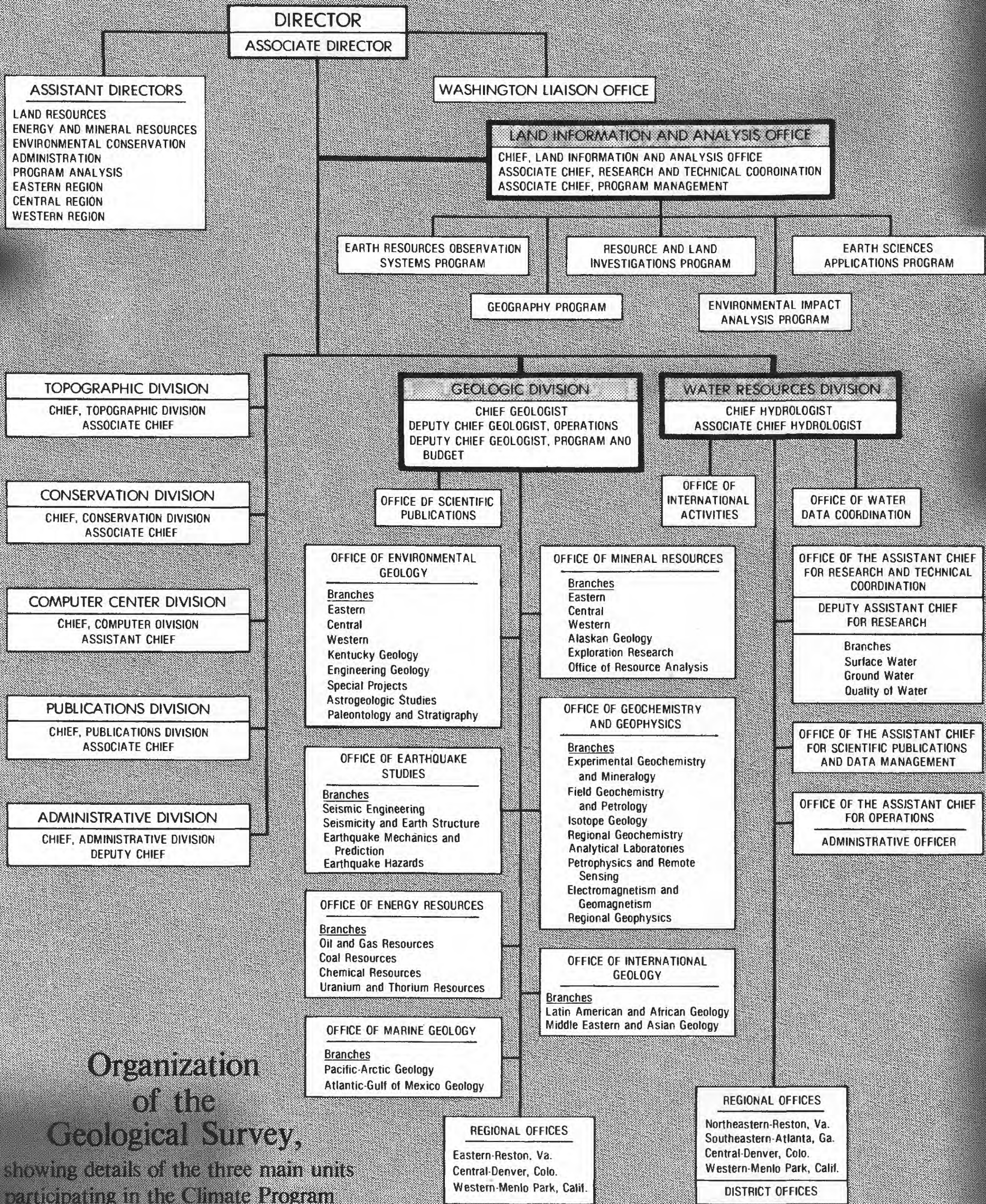
BENEFITS

Exact achievements of expanded Geological Survey research on climate of course cannot be predicted. Full implementation of the USGS Climate Plan is likely to result, however, in improvements in our capability for prediction, planning, and management of:

--food production
--surface and ground water supplies
--flood hazards
--soil resources
--wind erosion and deposition
--arroyo cutting and gullying
--fragile environments
--lake and reservoir levels
--hurricanes and catastrophic coastal storms
--landslides and mudflows
--glacier hazards
--land use and development

MANAGEMENT OF GEOLOGICAL SURVEY PROGRAM

The expanded earth-science climate program will involve the participation of many groups within the Geological Survey as well as in universities, States, and other recipients of grants and contracts. The accompanying organization chart of the USGS highlights the three active participating units of the Survey: the Geologic Division, Water Resources Division, and Office of Land Information and Analysis. An interdivision committee under the lead of the Geologic Division's Office of Environmental Geology is being established to ensure coordination of current and future climate-related research within the agency. Review of the expanded program can best be accomplished through establishment of an advisory committee. Liaison with other agencies involved in the national climate program is provided through several current biagency coordinating committees and through the Climate Program Coordinating Office recently set up in the National Oceanic and Atmospheric Administration to coordinate the climate activities of all Federal agencies. Climate is inherently a global problem and its study has many international aspects. These require that the Geological Survey coordinate with and participate in many of the international programs listed in Part A (Circular 776-A).



Organization of the Geological Survey,
showing details of the three main units participating in the Climate Program

CLIMATE VARIATION AND ITS EFFECTS ON OUR LAND AND WATER

Circular 776-A -- Earth Science in Climate Research

CONTENTS

Circular 776-B -- Current Research by the Geological Survey

CONTENTS

Names and bounding ages of geologic eras, periods, and epochs, and frequently used names of Quaternary stages.

Geologic time scale, complete

Era or Erathem	System or Period		Estimated ages of time boundaries, in millions of years ago
Cenozoic	Quaternary		
			2 - 3
	Tertiary		
			65
Mesozoic	Cretaceous		
			130
	Jurassic		
			180
	Triassic		
			225
Paleozoic	Permian		
			?280
	Carboniferous Systems	Pennsylvanian	
			310
		Mississippian	
			350
	Devonian		
			410
	Silurian		
			435
	Ordovician		
			480
	Cambrian		
			600
Proterozoic & Archeozoic	Precambrian		
			4500 ±

Cenozoic time scale

	Series or Epoch	Estimated ages of time boundaries, in millions of years ago
Quaternary	Holocene	
		0.01
	Pleistocene	
		2 - 3
Tertiary	Pliocene	
		5.5
	Miocene	
		26
	Oligocene	
		38
	Eocene	
		54
	Paleocene	
		65

Quaternary stage names

Holocene	(interglacial)
Pleistocene	Wisconsin (glacial)
	Sangamon (interglacial)
	Illinoian (glacial)
	Yarmouth (interglacial)
	Kansan (glacial)
	Aftonian (interglacial)
	Nebraskan (glacial)