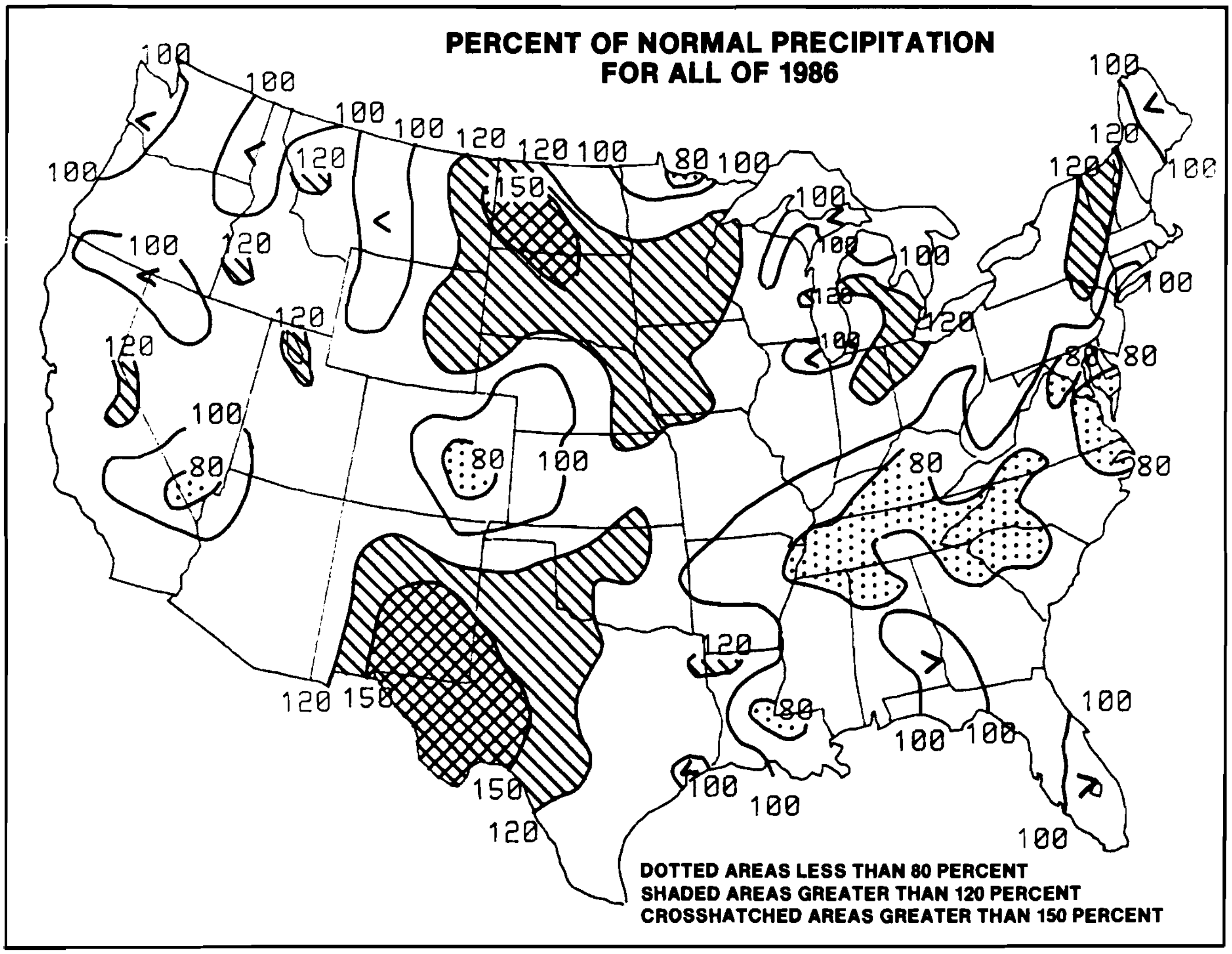
PN-ABJ-445

1986 Annual Report

National Climate Program



1986 WAS RELATIVELY WET IN CENTRAL STATES, DRY IN SOUTHEAST

COVER: Annual precipitation was well above normal in the northern and southern Great Plains in 1986. Much of the Southeast was unusually dry, especially during the first half of the year. *(Weekly Climate Bulletin,* January 10, 1987. NOAA/Climate Analysis Center.)

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NATIONAL CLIMATE PROGRAM ANNUAL REPORT 1986

January 1988

PARTICIPATING AGENCIES:

Department of Agriculture
Department of Commerce
Department of Defense
Department of Energy
Department of Health and Human Services
Department of Housing and Urban Development
Department of the Interior
Department of Justice
Department of State
Department of Transportation
Department of the Treasury
Agency for International Development
Council on Environmental Quality
Environmental Protection Agency
Federal Emergency Management Agency
National Aeronautics and Space Administration
National Science Foundation

Compiled by the National Climate Program Office
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
11400 Rockville Pike
Rockville, Maryland 20852
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ACRONYMS

ACRIM .... Active cavity radiometer irradiance monitor
AID .... Agency for International Development
AISC .... Assessment and Information Services Center
AVHRR .... Advanced very high resolution radiometer
AWDN .... Automated Weather Data Network

BASC .... Board on Atmospheric Sciences and Climate
BP .... Before present

CAC .... Climate Analysis Center
CCM .... Community climate model
CCCO .... Committee on Climate Change in the Ocean
CFC .... Chlorofluorocarbons
CIAM .... Cooperative Institute for Applied Meteorology
CIRES .... Cooperative Institute for Research in Environmental Sciences
CLICOM .... Climate Computer System
COADS .... Comprehensive Oceans Atmosphere Data Set
COHMAP .... Cooperative Holocene Mapping Project

DERF .... Dynamical extended range forecasting
DOC .... Department of Commerce
DOD .... Department of Defense
DOE .... Department of Energy
DOI .... Department of the Interior
DOS .... Department of State

ECMWF .... European Center for Medium-Range Weather Forecasts
ENSO .... El Nino-Southern Oscillation
EPA .... Environmental Protection Agency
ERBE .... Earth Radiation Budget Experiment
ERBS .... Earth Radiation Budget Satellite
ERS-1 .... ESA Remote Sensing Satellite
ESA .... European Space Agency
ETAC .... Environmental Technical Applications Center

FIFE .... First ISLSCP Field Experiment
FIRE .... First ISCCP Regional Experiment
FNOC .... Fleet Numerical Oceanography Center
FSU .... Florida State University
FY .... Fiscal year

GAO .... General Accounting Office
GARP .... Global Atmospheric Research Program
GCM .... Global circulation model
GEOSAT .... Geodetic satellite
GFDL .... Geophysical Fluid Dynamics Laboratory
GISS .... Goddard Institute for Space Studies
GLA .... Goddard Laboratory for Atmospheres

ACRONYMS—Continued

GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GTS	Global telecommunications system
HCS	Historical climatological series
ICP	Intergovernmental Climate Program
IOC	Intergovernmental Oceanographic Commission
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IGOSS	Integrated Global Ocean Station System
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land-Surface Climatology Project
JPS	Joint Planning Staff (WCP)
JSC	Joint Scientific Committee (WCP)
MIT	Massachusetts Institute of Technology
METEOSAT	European Meteorological Satellite
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCP	National Climate Program
NCPO	National Climate Program Office
NESDIS	National Environmental Satellite, Data, and Information Service
NIMBUS	Meteorological Satellite System
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NRC	National Research Council
N-ROSS	Navy-Remote Ocean Sensing System
NSF	National Science Foundation
NWS	National Weather Service
OMB	Office of Management and Budget
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
PLCD	Preliminary Local Climatological Data
PRC	Peoples Republic of China
RFC	River Forecast Center
RFF	Resources for the Future
RITS	Radiatively important trace species

ACRONYMS—Continued

SOA	State-of-the-art
SBUV	Solar backscatter ultraviolet radiometer
SEAS	Shipboard environmental (data) acquisition system
SEASAT	Meteorological and oceanographic research satellite
SIO	Scripps Institution of Oceanography
SMM	Solar Maximum Mission
SPS	Strategic planning seminar
SRB	Surface radiation budget
SSG	Science Steering Group
SST	Sea surface temperature
SWERB	Simulator for water resources in rural basins
THIR	Temperature/humidity infrared radiometer
TIROS	Television infrared observation satellite
TOGA	Tropical Oceans and Global Atmosphere
TOMS	Total ozone mapping spectrometer
TOPEX	Topographic Experiment
TOVS	TIOS operational vertical sounder
UARS	Upper atmosphere research satellite
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
UNEP	United Nations Environmental Program
US	United States
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USSR	Union of Soviet Socialist Republics
VLBI	Very long baseline interferometry
WCDP	World Climate Data Program
WCRP	World Climate Program
WCP	World Climate Research Program
WG VIII	Working Group 8
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WRCC	Western Regional Climate Center
WWW	World Weather Watch
XBT	Expendable bathythermograph

CONTENTS

OVERVIEW

Potential climatic effects of increased concentrations of atmospheric carbon dioxide and other greenhouse gases, a possible El Nino-Southern Oscillation (ENSO) event, ozone depletion, and drought in the southeastern United States were major scientific issues in the National Climate Program in 1986.

Concern about greenhouse gases and their effect on climate stood out among these issues.

- Congressional hearings, held in June 1986, focused on the scientific evidence for global climate change and on the potential policy and economic impacts that might occur as a result of this change. Senator John Chafee of Rhode Island, who chaired the hearing, said "Ozone depletion and the greenhouse effect can no longer be treated solely as important scientific questions. They must be seen as critical problems facing the nations of the world. These are problems that demand solutions."
- Congress enacted legislation (PL 99-383) calling for increased study of greenhouse effects and designated 1990 as the International Greenhouse Year.
- Congress requested the EPA to prepare a report by 1988 on the potential impacts of climate change caused by increased levels of CO_2 and other trace gases and on stratospheric ozone depletion.
- DOE published state-of-the-art reports on what is known and what remains uncertain about the greenhouse effect and changing climate. Among their general conclusions were that, although scientifically sound tools are available for estimating global change over the next 50-100 years or longer, estimating climate change on smaller, regional scales will require improved monitoring and model development.
- The discovery of decreasing ozone concentrations over Antarctica (the "ozone hole") prompted the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Chemical Manufacturers Association to organize an expedition to the Antarctic to investigate the source for these observations. By November 1986, initial experiments had been conducted but understanding of the phenomenon remains incomplete.
- In Geneva, negotiations began under the auspices of the United Nations Environmental Program (UNEP) on a protocol to regulate the production of chlorofluorocarbons (CFC).

The international dimensions of climate were especially pronounced in 1986. The World Meteorological Organization (WMO), in coordination with ICSU and the Intergovernmental Oceanographic Commission (IOC), is leading the implementation of the World Climate Research Program (WCRP). In 1986 the WMO convened the first informal governmental commitments meeting for WCRP. At this meeting the United States indicated its intent to support the WCRP and identified areas where it will provide resources and technical support.

Although the effects of greenhouse gases dominated public attention, the scope of the National Climate Program (NCP) includes many areas of climate research, forecasting, and applied climatology. Major events in 1986 included the following:

- An ENSO event began to develop in 1986. By the end of the year, NOAA had issued an advisory that Pacific atmospheric and oceanic indices indicted that a warm episode was in progress. However, as the area of highest sea surface temperature shifted toward the central and western Pacific, it became apparent that the intensity of the event was significantly less than the 1982-83 ENSO event.

The development of this important atmospheric-oceanic phenomenon is being monitored by an international program called Tropical Ocean Global Atmosphere (TOGA), which is using satellite- and sea-based observational systems to study the evolution of this climatic event. Extensive data management systems are in place to record and archive the data collected during the TOGA experiment. One of the most important precursors of an emerging ENSO event is changes in sea level, which can now be measured from satellites.

- The launch of the U.S. Navy altimeter satellite, GEOSAT, in March 1985 ushered in a new era for physical oceanography. By measuring the shape of the ocean surface, an altimeter provides information on surface circulation and sea level variability that can be obtained in no other way. In October 1986, some GEOSAT data were declassified and preliminary data now released have been used to monitor sea level changes in the Pacific Ocean.

- Research on the causes of large-scale changes in the atmosphere and ocean has progressed to the point where university-based researchers were able to predict, in March 1986, development of an ENSO event. Later in the year it was determined that it was not a severe event. These techniques are experimental and skill must be greatly improved before they can demonstrate potential capabilities for seasonal and long-term climate forecasting.

- The potential availability of long-range climate forecasts was the subject of a strategic planning seminar convened by the National Climate Program Office (NCPO). The seminar, jointly organized with Resources for the Future (RFF), focused on the economic and political consequences of applying long-range forecasts.

- A major drought occurred in the southeastern United States during 1986, covering all or part of eleven states. Unusually dry conditions began developing in December 1985 and continued through the summer. This marked the most severe drought condition in the region in over 100 years.

The year 1986 marked the publication of a major study by the National Academy of Sciences (NAS), *Atmospheric Climate Data: Problems and Promises.* The study urged a greater commitment by the federal government to collect, archive, and disseminate climate data, and to promote broader interactions with the user communities. "What is most critical," the report said, "is that the Federal Government seriously examine its handling of weather and climate data from a broad, long-term perspective, and that it establish mechanisms to ensure sensible, government-wide planning and implementation of data management."

The National Climate Program was conceived and planned primarily to address climate variability and change. It is now apparent that changes in biological productivity and diversity and changes in the chemical composition of the atmosphere play important roles in climate change and in the entire environment. This evolution in understanding has focused the attention of much of the geoscience community on issues of "global change." In 1986, the General Assembly of the International Council of Scientific Unions established the International Geosphere-Biosphere Program (IGBP). In separate but related actions taken in 1987, NSF has established a Global Geosciences Program, and NASA's Earth System Scientific Committee has proposed a national program to study global climate change. In both of these evolving activities, climate change remains a crucial focus.

Amendments to the National Climate Program Act made important changes in program administration. An interagency Climate Program Policy Board was formally established and given broad responsibilities for program planning and review. Functions and responsibilities of the National Climate Program Office were increased by the amendments. Section 6, Intergovernmental Climate Programs (ICP), was repealed; however, authority to carry out intergovernmental climate-related studies and services remains as an element of the program.

Finally, activities of the NCP since its beginning were reviewed by a panel of the NAS. Their report, *The National Climate Program: Early Achievements and Future Directions* (NAS, 1986a), reviews past accomplishments and provides a blueprint for the future. Major recommendations of the report will be addressed in the second 5 year-plan for 1988-1992.

"The National Climate Program Act was meant to be an experimental prototype for the organization of research that crosses agency and interdisciplinary boundaries. The Conference report to the 1978 Act stated that

> **The entire point of making climate the focus of a national program is to emphasize that it is a subject which cannot be confined in ordinary organi zational boundaries and that it must be considered as a critical element of strategic planning in almost all areas of human endeavor.**

Judging by the progress which has been made in the last seven years, I would say that the intent of the 1978 act has been carried out."

George E. Brown
Member of Congress, 1986

INTRODUCTION

The strategy of the National Climate Program is to stress the early production of useful data and information based on current knowledge of climate while simultaneously expanding the understanding of climate and its relationship to society. General guidance for the program is provided by a 5-year plan as required by the National Climate Program Act. The plan is updated periodically to reflect current needs and program changes. The first revisions were reported in an interim plan for 1984-1986. A new 5-year plan is being written for 1988-1992. The new plan will increase the emphasis on climate services, risk assessment, and application of climate information in decision-making.

The National Climate Program is organized into three areas with the following objectives:

Data and Services. Develop an improved knowledge base of climate data and scientific information on natural and man-induced climate change, and make climate data and information more readily available through improved climate services.

Research and Development. Advance the basic understanding of the climate system on all time scales, and coordinate the National Climate Program with international programs on global climate change.

Impact Assessment and Response Strategies. Improve climate impact and risk assessment methodologies and information for decision making, and organize federal responses to national priority issues in climate.

In compliance with the Act, this annual report for 1986 describes the year's major activities, including an evaluation of progress toward program objectives. Information in this report was provided by the federal agencies involved. Persons listed below can provide details on specific areas of the program.

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Department of Energy (DOE)
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Department of State (DOS)
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Environmental Protection Agency (EPA)
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The annual report was prepared under the direction of Alan D. Hecht, Director, National Climate Program Office, National Oceanic and Atmospheric Administration, (301) 443-8646.

SUMMARY OF SIGNIFICANT ACHIEVEMENTS AND EVALUATION

CLIMATE DATA AND SERVICES

HIGHLIGHTS

- National Academy of Sciences review of climate data published
- User services at NCDC set new record
- Improvements made in *Weekly Climate Bulletin*
- Climate computer (CLICOM) system becomes operational
- River forecast center data base developed
- Comprehensive Oceans Atmosphere Data Set (COADS) available
- Historical ocean data files available for climate research
- Sea level monitoring increased
- Ocean data delivered in real time
- Historical climate records assembled

National Academy of Sciences Review of Climate Data Published

In 1984, the National Climate Program Office requested that the National Academy of Sciences' Board on Atmospheric Sciences and Climate (BASC) review the national system for acquiring, archiving, and disseminating climate data. The Panel on Climate-Related Data was created by BASC to carry out and report the results of the review.

The panel met five times between March 1984 and January 1986 to observe climate data management systems and to assemble information bearing on technological and institutional aspects of future climate data management. The panel's recommendations were that (NAS, 1986b):

- The federal government should articulate a need for an integrated national policy covering all aspects of weather and climate information services;
- The federal government should improve the coordination of weather and climate data activities;
- NOAA should establish a central data officer with broad responsibility to plan and coordinate weather and climate data management activities throughout NOAA; and
- The federal government should actively promote the use of both weather and climate data.

Copies of the panel's report, *Atmospheric Climate Data: Problems and Promises,* are available from:

Board on Atmospheric Sciences and Climate
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, DC 20418

User Services at NCDC Set New Record

The National Climatic Data Center (NCDC) is the nation's archive for climate data. During 1986, NCDC answered over 95,000 requests for climate data, a record number, and about 7,000 more than last year.

Examples of some of the requests received and answered:

Shuttle Disaster: Numerous media calls were received after the announcement that cold temperatures may have contributed to the explosion of the space shuttle on January 28, 1986. The Orlando *Sentinel* apparently broke the story using data obtained from NCDC.

Southeast U.S. Drought: Numerous requests for data related to the southeast U.S. drought were received from the news media, research organizations, local and state governments, and consultants.

Dallas-Fort Worth Aircraft Accident: NCDC received many requests for data relating to the August 2, 1985 accident involving Delta Flight 191 at Dallas-Fort Worth Airport. These data were used for a variety of purposes, ranging from studies of microbursts to defending Delta Airlines in lawsuits.

Nuclear Waste Storage Facilities: Several requests for data were received from state and local governments and environmentalists from areas of the United States that were being considered for potential nuclear waste storage facilities.

NCDC began using a commercial electronic mail service to deliver data to customers. Preliminary local climatological data (PLCD) information is delivered to approximately 100 customers monthly via MCI Mail, MCI Corporation's electronic mail service. Several customers also use this service to request data and information from NCDC.

Improvements Made in Weekly Climate Bulletin

Improvements to the *Weekly Climate Bulletin* include a global "events" map (figure 1) and accompanying descriptions which summarize the most important surface climate anomalies. Special climatic summaries of regional temperature and precipitation anomalies also appeared in the bulletin. The summaries focused on long-term drought in the southeastern United States, Africa, South America, and China, and on the Indian monsoon. Twelve special summaries on the drought situation in the southeastern states appeared in the bulletin between March 29 and September 20. The early stages of the developing drought were first reported in the January 4, 1986 issue of the bulletin. The special summaries included percent of normal precipitation charts, time series of cumulative precipitation, and a 100-year index of precipitation for the region (figure 2).

Climate Computer (CLICOM) System Becomes Operational

In 1986, the CLICOM (climate computer) microcomputer system moved from a design prototype to operation. CLICOM was developed at the National Climatic Data Center (NCDC) under the sponsorship of the World Meteorological Organization.

The system was developed primarily as a data rescue and management tool for developing countries (McGuirk, 1986), but the potential for other applications has generated widespread interest in the United States and other developed nations. The U.S. Department of Agriculture (USDA), for example, has successfully demonstrated that CLICOM data formats can be used as input to the SWERB water management model (simulator for water resources in rural areas). CLICOM also is being used by the University of Reading, U.K. to manage data for statistical rainfall studies. Proprietary and in-house software have been requested by fourteen countries. It is expected that CLICOM will be established in 50 developing countries by the end of 1987. Twenty state climatologists and regional climate centers have received or requested copies of NCDC programs, system documentation, and hardware requirement lists for CLICOM.

Building on proprietary data management software, NCDC has written over 100 additional CLICOM programs. The total integrated package uses a menu system to lead the user through data entry, station history, station physical and climatological limits, quality control, retrospective editing, archiving, and basic applications such as statistical summaries or data plotting.

River Forecast Center Data Base Developed

A new product from the Climate Analysis Center (CAC) of the National Weather Service is the weekly totals of supplemental high-density precipitation data from selected River Forecast Center (RFC) stations. The eight most recent individual weekly totals by station are stored and updated on CAC's request/reply system. A graphics package was completed that will be used in selecting RFC stations for computing average precipitation amounts. Several state climatologists are helping CAC by comparing RFC data with preliminary cooperative reports in order to determine the reliability of RFC stations data for climate applications.

Comprehensive Oceans Atmosphere Data Set (COADS) Available

COADS was developed as a cooperative effort among the Environmental Research Laboratories (ERL), the National Climatic Data Center of NOAA, the National Center for Atmospheric Research (NCAR), and the Cooperative Institute for Research in Environmental Sciences (CIRES) to bring together and analyze for global climatic research marine data from several dozen sources covering a period of over 120 years. In 1986 the data set was used to refine global temperature variations between 1861 and 1964 (Jones et al., 1986) and for many other research applications (e.g., U.S./USSR conference on climate and carbon dioxide, Leningrad 1986). Data for the 1970's were updated to 18.5 million observations and the 1980-1985 period, containing over 3.6 million observations, was added. Many retrospective data sources are used (e.g., delayed data from over forty countries), and historic data holdings continue to grow.

Preparation of the COADS data set was facilitated by special agreements with the USSR to obtain earlier data, by an agreement with India to process data from the Maury Collection for the 1800s, and other data-sparse periods, such as during World Wars I and II.

Historical Ocean Data Files Available for Climate Research

NOAA's National Ocean Data Center (NODC) provided data management support for the Tropical Ocean Global Atmosphere Program, while continuing to enlarge its archive files of historical ocean data. NODC has also compiled a preliminary inventory of available time-series ocean sections and fixed stations in the North Pacific Ocean. The inventory describes oceanographic station data (temperature-salinity) held either by World Data Center A, Oceanography (in manuscript form) or, for most cruises, by NODC (in digital form) from repetitively occupied sections and stations that have compiled time series of data for at least 5 years.

NODC's routine data management activities support climate programs through continued growth of its

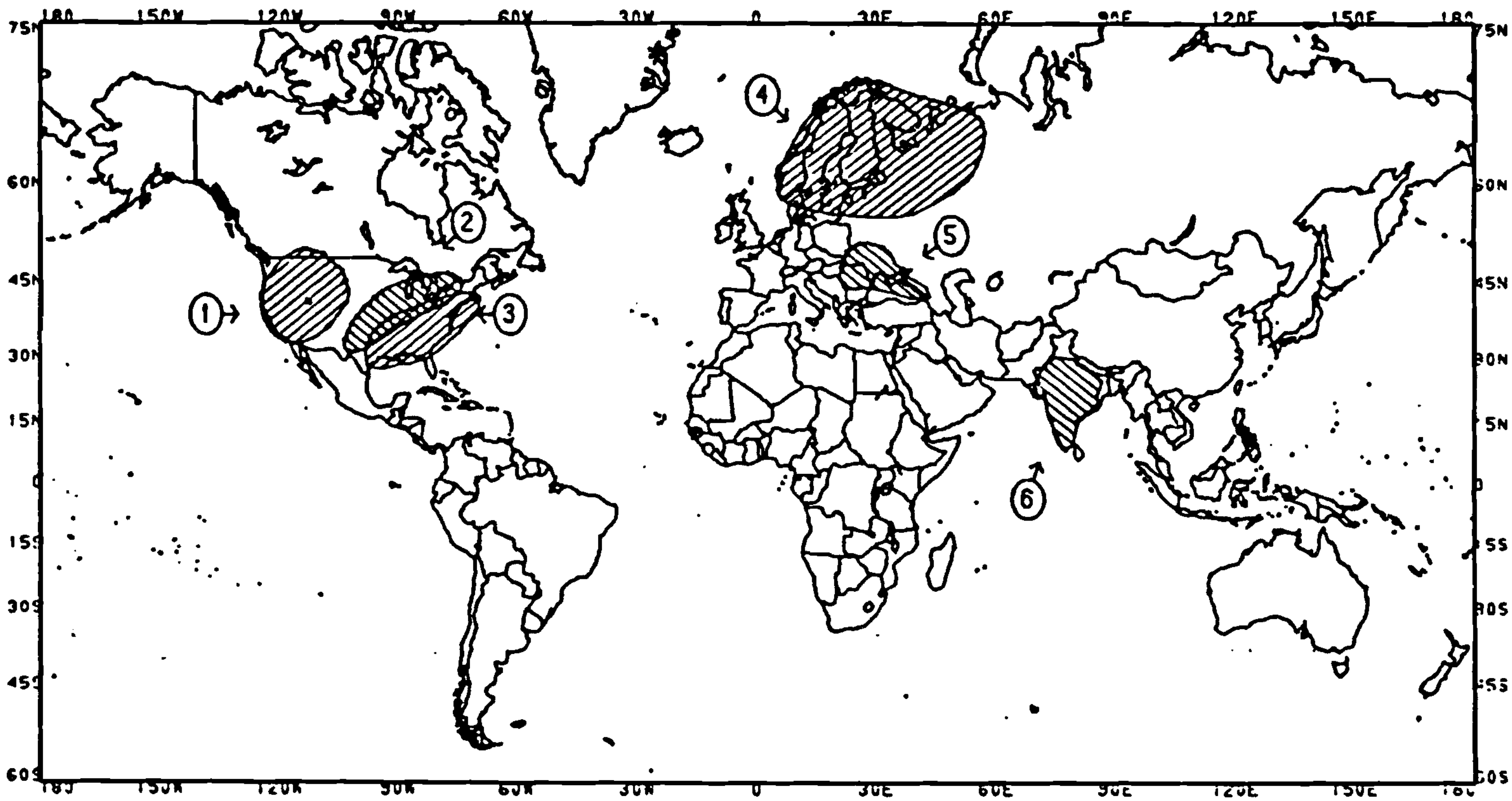


Figure 1. Map of major climatic events for week ending October 4, 1986. (1) Early season cold continues in western United States; (2) heavy rains and flooding continue in central United States; (3) high temperatures exacerbate drought in southeast United States; (4) temperatures moderate in northern Europe; (5) rains ease dryness in eastern Ukraine and Bulgaria; and (6) most of India remains unseasonably dry. *(Weekly Climate Bulletin,* NOAA/ Climate Analysis Center.)

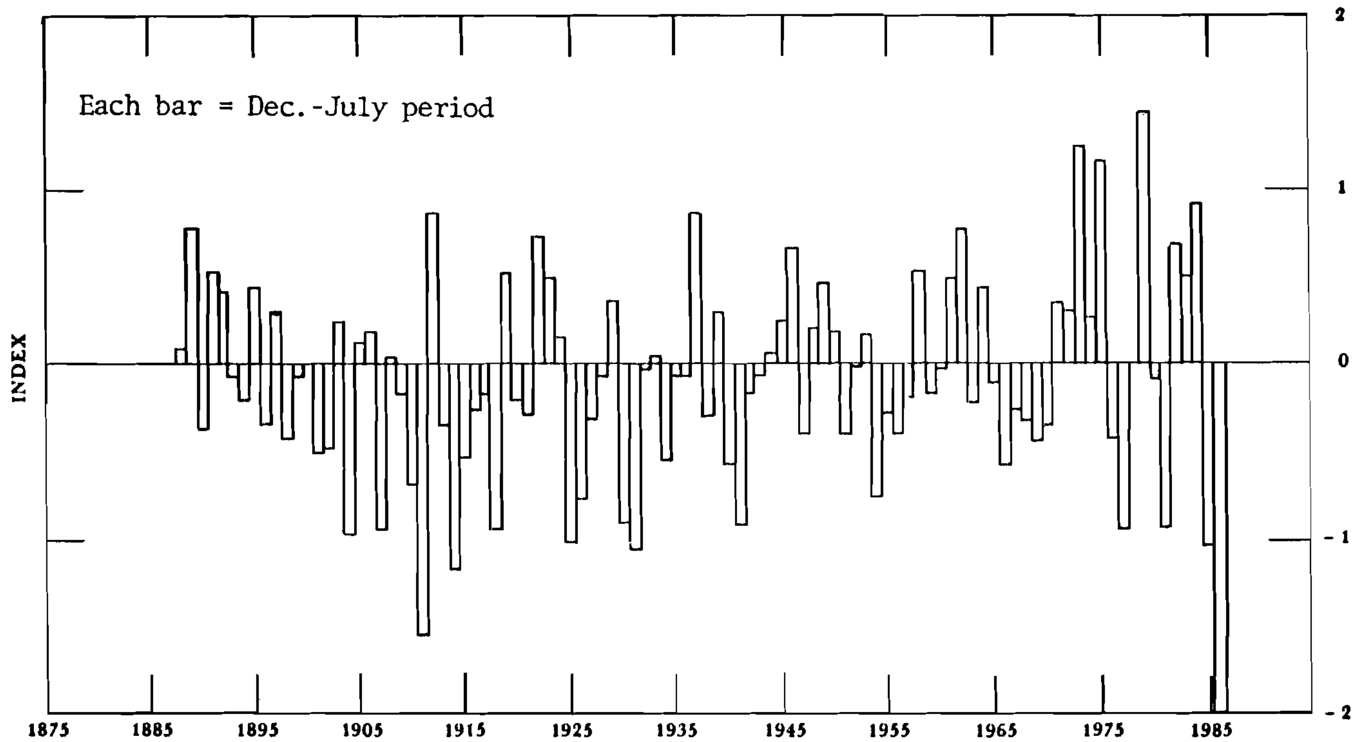


Figure 2. Precipitation index for the southeastern United States (based on up to 30 stations with long periods of record). The zero line is the mean value for the period of record. The year refers to the last 7 of the 8 months in the period, i.e. "1887" refers to December 1886 through July 1887. (NOAA/Climate Analysis Center.)

historical ocean files and provision of data and data products to individual researchers. NODC's archive files now have nearly 750,000 oceanographic stations dating to the early 1900s and 1.7 million bathythermograph temperature profiles from 1941 onward. During the year, NODC responded to more than 4,000 user requests. Among its products, NODC publishes the quarterly *Mariner Weather Log*. As a comprehensive source of global tropical cyclone tracks and related data, this publication is a unique resource for climate researchers.

Sea Level Monitoring Increased

Tide gauge stations along the Atlantic, Gulf, and Pacific coasts, and in Hawaii and Bermuda were selected for inclusion in the global mean sea level monitoring program. Global positioning system (GPS) surveys were made at seven tide gauge stations located near the Richmond, FL; Maryland Point, MD; and Westford, MA very long baseline interferometry (VLBI) observatories. A mobile VLBI unit was used to establish a station at the NOAA Pacific Marine Environmental Research Laboratory in Seattle, which will be used as a reference station for GPS surveys of tide gauges in the northwest region. An interagency plan was developed jointly with the Department of Energy for VLBI, GPS, and absolute gravity surveys in 1987 in Bermuda and Hawaii.

Ocean Data Delivered in Real Time

The Shipboard Environmental [Data] Acquisition System (SEAS) Program has made it possible to deliver data to users accurately and quickly, from platforms operating in selected areas of the oceans. Meteorological observations (winds, temperature, pressure, waves/swell, and ice) and expendable bathythermograph (XBT) measurements, which are collected by SEAS units, are automatically transmitted through the GOES satellite system. Only seconds elapse between the time of the shipboard transmission and the arrival of data at national processing centers.

The U.S. Navy and NOAA jointly operate a growing number of shipboard observing platforms, largely in cooperation with commercial shipping lines whose officers volunteer their ships and their time in ensuring that observations are taken and data transmitted. These measurements are vital to international research efforts such as the Tropical Ocean Global Atmosphere Program. These observations provide international climate researchers with the opportunity to monitor the marine atmosphere and ocean thermal structure to investigate air-sea interactions that affect global climate. SEAS observations and measurements will also be useful for calibrating and validating global ocean data derived from satellite-based observations. Approximately eighty SEAS units are deployed on government and voluntary ships operating world-wide, including ships from Australia, Canada, China, Japan, and Portugal. An additional fifty units will be deployed during 1987.

Historical Climate Records Assembled

NCDC, supported by the Department of Energy's Carbon Dioxide Research Division, has assembled a historical data base of monthly temperature and precipitation data for over 1,200 stations in the contiguous United States. The network (figure 3) was established to detect changes in climate over the past 100-200 years. All available observed monthly temperature and precipitation data are included and corrected for nonclimatic factors. The network contains a significant number of locations with data for over 100 years. The earliest data begin in 1783. Most stations have serially complete data beginning in 1900.

The data base for the network will be maintained by the Carbon Dioxide Information Center and the National Climatic Data Center. The data will be updated annually.

NCDC has extended its historical climatology series with maps of monthly and seasonal precipitation departures for the period 1895-1985. The publication, which is available in four seasonal volumes (HCS 3-12, 13, 14, 15), complements earlier atlases of temperature departures, hydrological drought indices, drought severity indices, and moisture anomaly indices (Karl et al., 1986a). Another publication in the series (HCS 3-16), *Probabilities and Precipitation Required to End/Ameliorate Droughts* (Karl et al., 1986b), provides estimates of the precipitation required to end or ameliorate an ongoing drought of specified intensity and the probability of receiving the required amount in the ensuing 2, 3, or 6 months (figure 4).

Evaluation

Steady progress has been made in improving management and accessibility of climate data. Orders for climate data and information at the National Climatic Data Center increased by more than 7 percent over 1985.

For several years, climate and ocean data centers have increased efforts to assemble data bases and achieve near real-time access to current weather and ocean data. Several of these efforts are now showing success. A related effort, the CLICOM data management system, became operational during the year. CLICOM was originally planned as a climate data management system for use in developing countries, and it is beginning to be used for state and regional climate data management in the United States.

A comprehensive review of climate data acquisition, archiving, and dissemination was reported during the year by the National Academy of Sciences' Board on Atmospheric Sciences and Climate. The study panel that conducted the review made a detailed examination of current systems of climate data management to assess future problems and needs. Several factors contributing to data management problems were identi-

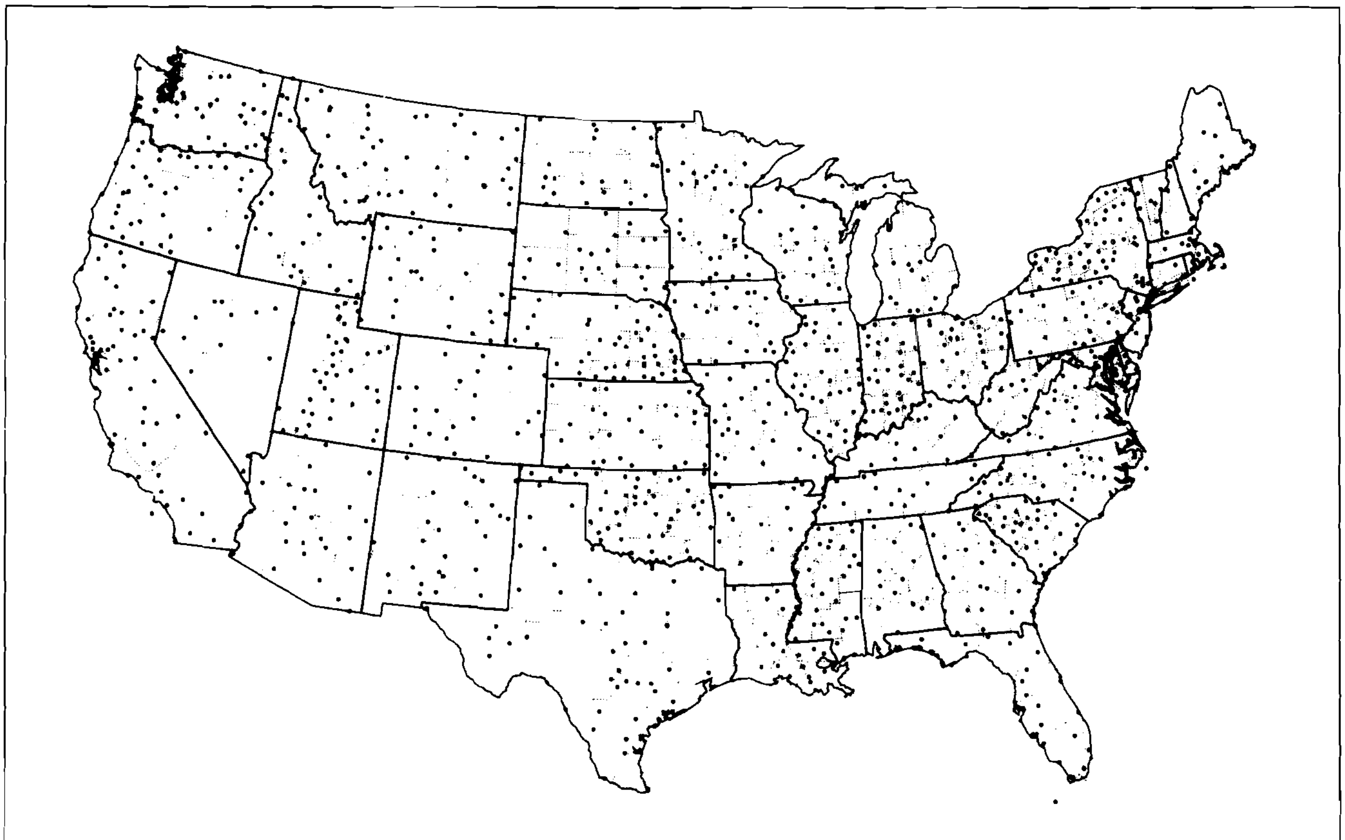
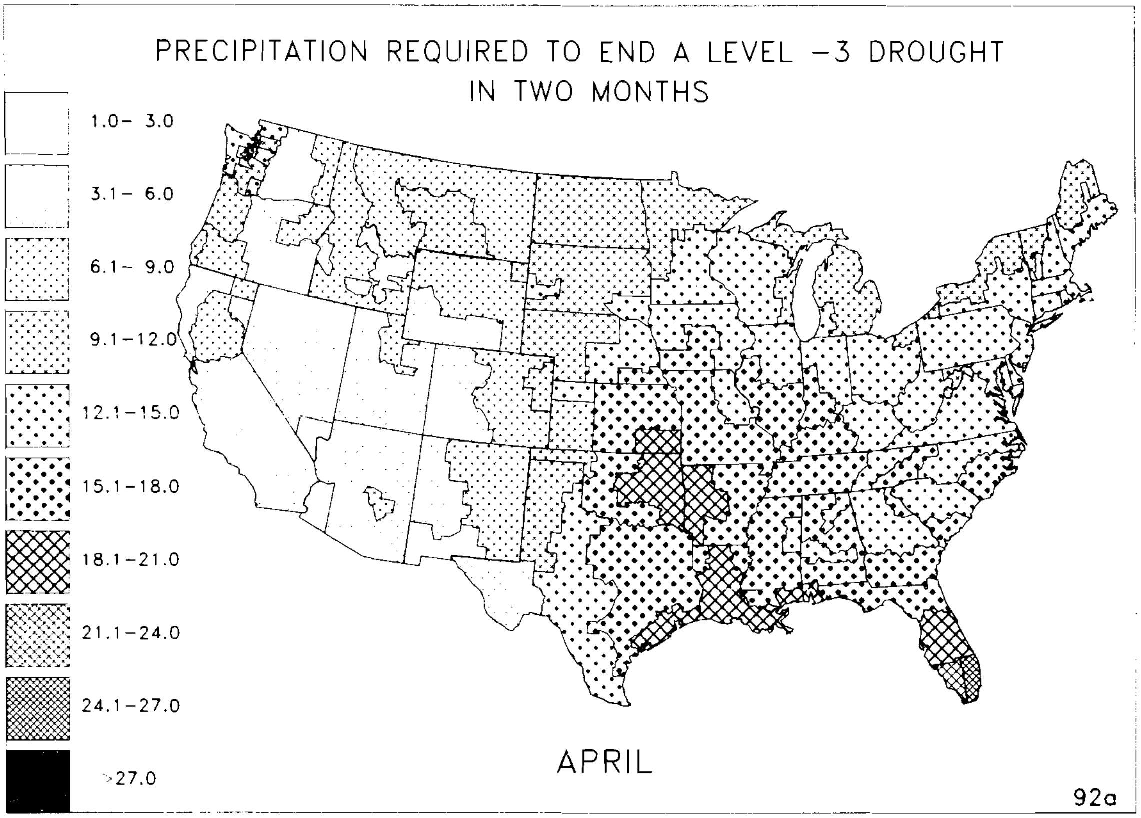


Figure 3. The historical climatological record (HCN) consists of more than 1,200 weather stations for which monthly temperature and precipitation data are available. Most stations have complete data from 1900. (NOAA/Climate Analysis Center.)



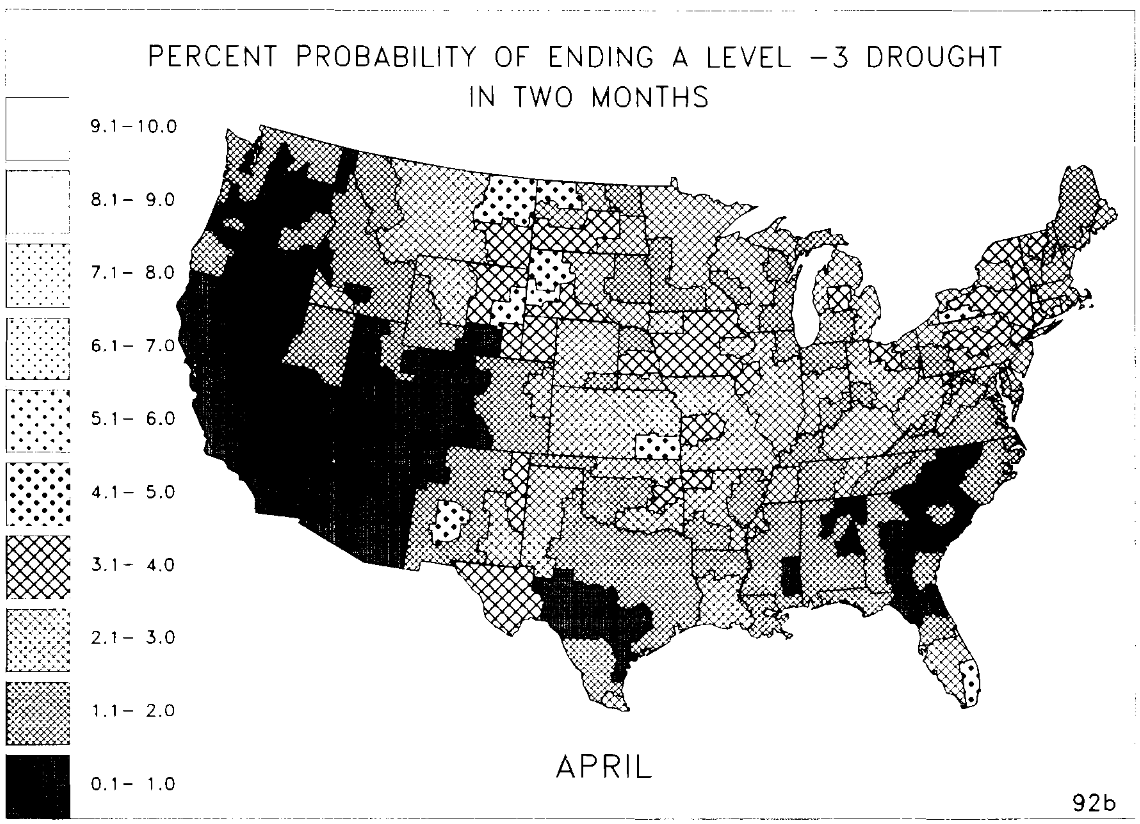


Figure 4. Example of drought analysis based on climatological data and the Palmer drought severity index (PDSI) which ranks drought on a scale of +4 (extreme wetness) to -4 (extreme drought). In April, the precipitation required to end severe drought (-3) varies from 12 to 18 inches over most of the Corn Belt, and the probability of receiving that much precipitation in the next 2 months is only 4 percent or less. (Karl et al., 1986b.)

fied. Foremost among these are problems arising from technology improvements that are leading to an *"explosive growth in the quantity and diversity of weather and climate data,* growth that could overwhelm the capabilities of current data systems in the United States." The study panel recommended steps to provide an institutional structure for climate data management that can meet the challenges of rapidly changing technology and growing national needs for climate data and services.

CLIMATE RESEARCH AND DEVELOPMENT

HIGHLIGHTS

Climate Observation and Prediction
- Depletion in Antarctic ozone monitored
- Satellite altimetry data available
- Extended range forecast models evaluated
- ENSO monitoring assisted with ocean forecast model
- El Nino and Southern Oscillation (ENSO) analyzed
- African rainfall record analyzed

Tropical Oceans and Global Atmosphere (TOGA)
- TOGA status
- TOGA data management system in operation

Earth Radiation Budget (ERB)
- ERBE observes global cloud cover
- Surface radiation budget project started
- International Satellite Cloud Climatology Project (ISCCP) nears end of data collection phase
- Time series of Nimbus-7 monthly mean total cloud amount analyzed
- Project FIRE measures cloud properties over the United States

Paleoclimate
- Climate record from Dunde Ice Cap recovered
- Cooperative Holocene Mapping Project (COHMAP) compiles global scale paleoclimate maps

Carbon Dioxide and Climate Change
- North Pacific Ocean a winter source of CO_2
- Global temperature trend documented
- Greenhouse effect: Projections of global temperature

Climate Observation and Prediction

Depletion in Antarctic Ozone Monitored

Significant decreases in ozone concentration in the stratosphere have been observed over Antarctica during the austral spring (figure 5). This finding is especially interesting because, while global decreases in stratospheric ozone due to anthropogenic chlorine compounds have been predicted by atmospheric chemists, the Antarctic ozone loss was completely unanticipated. The ozone loss is considerable. Half the ozone over Antarctica disappears before concentrations partially recover. The pronounced spatial characteristic of the decrease has led to its popular description as an "ozone hole." The agreement among ground-based, satellite, and balloon-borne ozone data for that region leave no doubt about the reality of the loss.

Shortly after the announcement, by the British Antarctic Survey, of the discovery of the ozone hole, researchers sought to explain the phenomenon in terms of man-made chemical perturbations, natural dynamical changes in the atmosphere, and the solar cycle. The paucity of chemical data for Antarctica made evaluation of these theories difficult. In an effort to gather more complete data on the Antarctic ozone hole, NOAA, NASA, NSF, and the Chemical Manufacturers Association jointly sponsored a National Ozone Expedition to Antarctica during August-November 1986. Analysis of these and other data is ongoing.

Satellite Altimetry Data Available

The launch of the U.S. Navy altimeter satellite, GEOSAT, in March 1986 ushered in a new era of physical oceanography. Satellite altimetry has been shown to be one of the most versatile and useful data types for ocean remote sensing and is considered to be a critical part of global oceanographic research programs. By measuring the shape of the ocean surface, an altimeter provides information on surface circulation and sea level variability that can be obtained in no other way. GEOSAT represents the first altimeter satellite since the abbreviated SEASAT mission in 1978 and the only such satellite launched during this decade.

Because the GEOSAT data are classified, NOAA has established a dedicated processing facility at the Johns Hopkins Applied Physics Laboratory where the raw data are received and analyzed to produce unclassified sea level and wave height data and to derive information on ocean currents. An example of GEOSAT-derived sea level data is illustrated in figure 6, which compares the satellite altimeter data with tide gauge data in the vicinity of Christmas Island (1.9°N, 157.5°W) in the Pacific.

In October 1986, GEOSAT was maneuvered into an orbit coinciding with SEASAT's. The new phase of the mission is expected to last for 2 years. The ground track will repeat every 17 days, yielding a data set useful for sea level and other studies. These unclassified data will be processed by NOAA in Rockville,

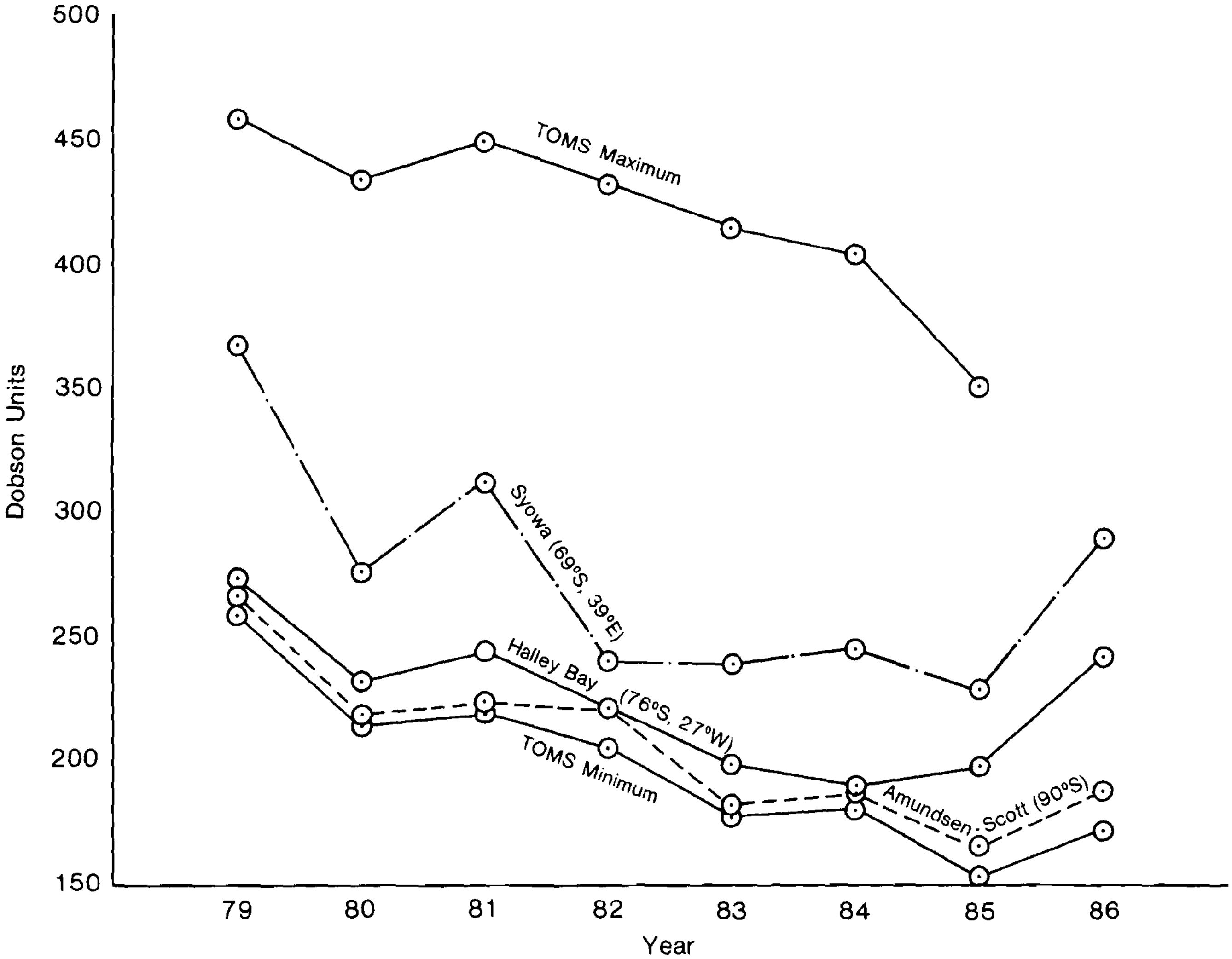


Figure 5. Mean October total ozone (Dobson units) for 1979-1986 from Nimbus 7 TOMS over thirteen Antarctic stations, plus TOMS minimum and maximum monthly mean. (Stolarski and Krueger, 1987. Personal communication.)

MD, and released through the National Oceanographic Data Center.

Extended Range Forecast Models Evaluated

The National Meteorological Center's (NMC) Climate Analysis Center and Development Division are cooperating in assessing the feasibility of operationally useful monthly climate predictions based on dynamical models. Assessment began with the Workshop on Dynamical Extended Range Forecasting (DERF), held at NMC in October 1985, to consider experimental strategy and design, and model requirements. Collaboration with the European Center for Medium Range Forecasts (ECMWF), the United Kingdom Meteorological Office (UKMO), the National Center for Atmospheric Research (NCAR), NOAA'a Geophysical Fluid Dynamics Laboratory (GFDL), and NASA's Goddard Laboratory for Atmospheres (GLA) was also planned. The experiment depends on a good numerical model. The one selected is derived from the NWS operational medium-range forecast model.

One outcome of the workshop was a coordinated experiment for DERF activities at NMC. Nine exploratory 30-day forecasts were produced: three winter cases, three summer cases, and one ensemble of three forecasts. Overall objectives were to gain experience in generating and evaluating 30-day predictions, and to improve concepts for continued medium-range forecasting. Specific objectives were to develop and apply tools and procedures for assessing the operational use of dynamical models, and guide strategies for comprehensive tests for climate-range forecasts.

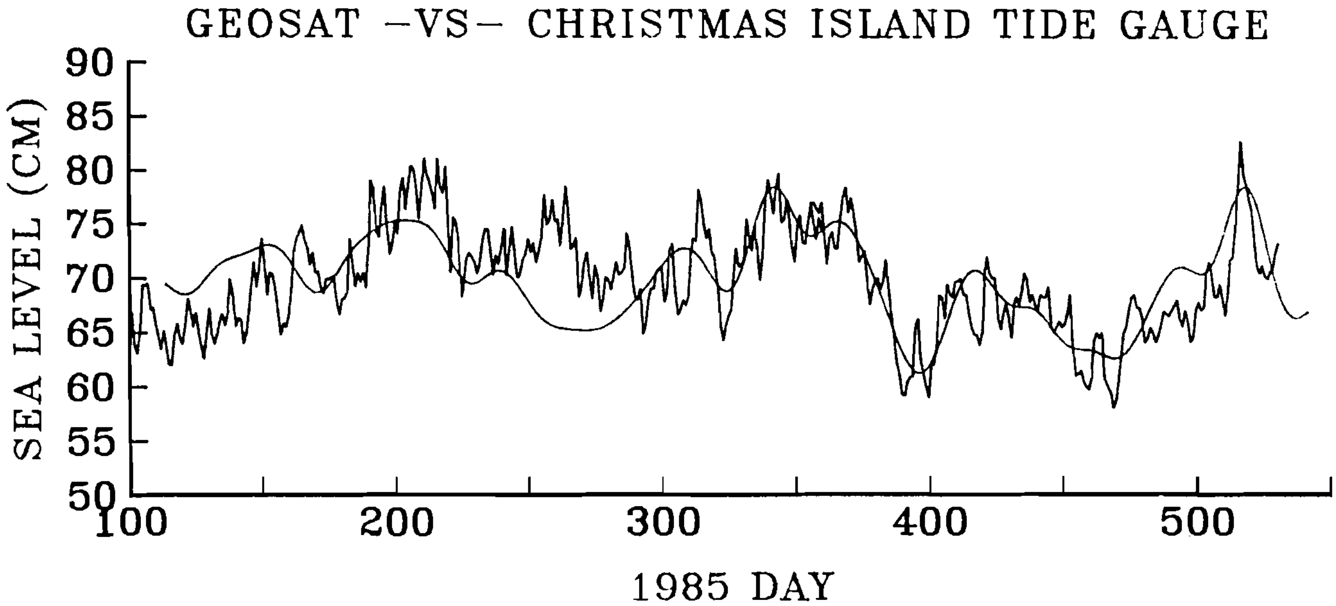


Figure 6. Comparison of GEOSAT-derived sea level data with tide gauge data in the vicinity of Christmas Island (1.9°N, 202.5° E). (Cheney et al., 1986.)

Overall evaluation results are encouraging. In a majority of cases, the DERF 30-day mean surface temperature forecasts over the United States verified as well or better than NWS's operational monthly surface temperature outlooks (figure 7).

The anomaly correlations for the 30-day average, 500-mb height fields over the Northern Hemisphere (as well as subjective appraisal charts) are similar to NMC forecasts and the corresponding predictions produced by ECMWF. The medium-range forecast model in both NMC and ECMWF typically fails to capture major blocking events that develop more than several days into the forecast period. Persistent features are handled much better. The ensemble of March cases shows that the disparity between successive forecasts can be quite large.

ENSO Monitoring Assisted with Ocean Forecast Model

An ocean forecast model is now operational at NMC. Average monthly surface winds are used to force the model, which estimates parameters used by CAC to monitor El Nino-Southern Oscillation (ENSO) development. Comparisons against observations indicate that the model is doing a good job of hindcasting the thermal and velocity fields. Improvements in the heat flux formulation and in the treatment of mixing in the near surface layers have led to good sea surface temperature (SST) simulations (figure 8). Some problems still remain in the western Pacific and off the coast of Central America, where the model SSTs are slightly high. With continued improvements in mixed layer physics and in estimates of the heat fluxes, uncertainties in SST can probably be brought down to about 1 °C or so. Further improvements will be made by assimilating in situ and satellite data directly into the model. This should result in an SST product for the tropical Pacific of greater spatial and temporal resolution than the present TOGA SST product, and at least equal accuracy.

El Nino-Southern Oscillation Analyzed

The Climate Analysis Center has completed a worldwide analysis of ENSO-related precipitation. The results of the analysis are shown in figure 9, which identifies the regions most often showing ENSO effects, and an ENSO calendar (table 1). CAC has extended the Tahiti-Darwin Southern Oscillation Index (SOI) back to 1882 in a joint effort with P. Jones of the Climate Research Unit, University of East Anglia (Ropelewski and Jones, 1987).

African Rainfall Record Analyzed

The annual cycle of African rainfall and its interannual variability were investigated by the Climate Analysis Center using monthly observations from over 1,000 stations for the period 1901-1973. Average seasonal rainfall ranges from less than 50 mm in the desert regions to over 2 meters in portions of coastal West Africa (figure 10). These analyses add detail to general observations that extratropical regions of Africa (the extreme northern and southern parts of the continent) experience maximum rainfall during the winter season. Subtropical regions experience maximum rainfall in summer, and two rainfall maxima, roughly 6 months apart, occur in the equatorial regions.

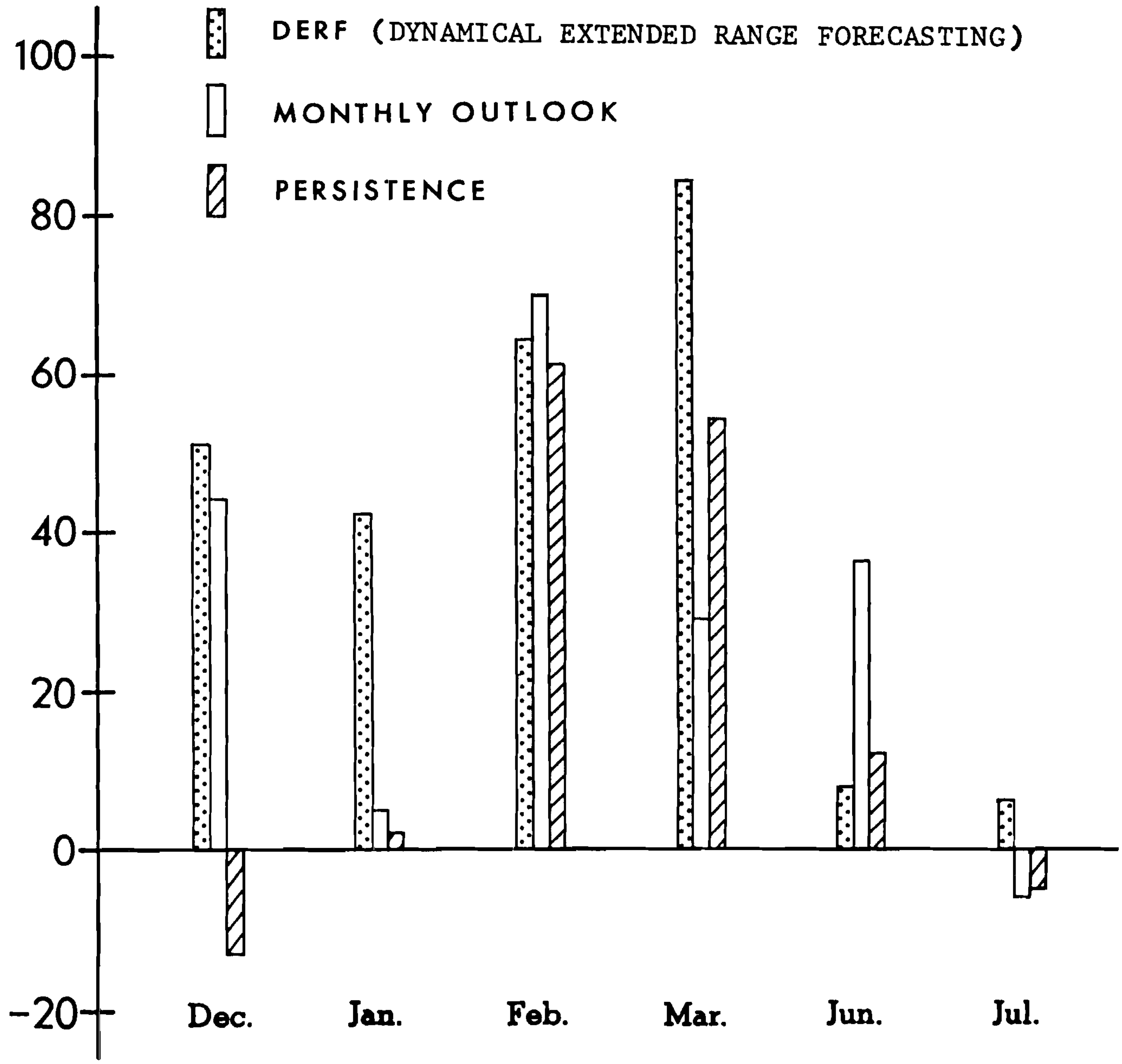


Figure 7. Skill scores (relative to chance) for monthly mean 3-class temperature forecasts verified at 100 U.S. stations. DERF RUN forecasts are generated objectively by regression from 700-mb 30-day mean model output. Initial dates are several days later than MONTHLY OUTLOOK issue dates, rendering comparisons only approximate. PERSISTENCE scores are generated from observed 30-day mean temperature classes just preceding the date of issuing the MONTHLY OUTLOOK. (NOAA/Climate Analysis Center.)

Interannual rainfall was analyzed to detect systemic regional rainfall anomalies. Seasonal and annual rainfall tends to vary systemically among broad regions of Africa. Rainfall anomalies of opposite sign tend to be observed on either side of latitude 8°N in West Africa during northern summer, and either side of 12°S in Southeast Africa in southern summer. It was determined that the dipole pattern in southern summer was observed during 7 of the 11 ENSO years that occurred during the period of this investigation. During those years, 15-30 percent more rainfall was observed between the equator and 10°S, and 15-30 percent less rainfall between 15°S and 30°S was observed. A composite rainfall anomaly map (figure 11), constructed by averaging the rainfall anomalies for the 11 ENSO years in the period of investigation, shows this distinct pattern (Janowiak, 1987).

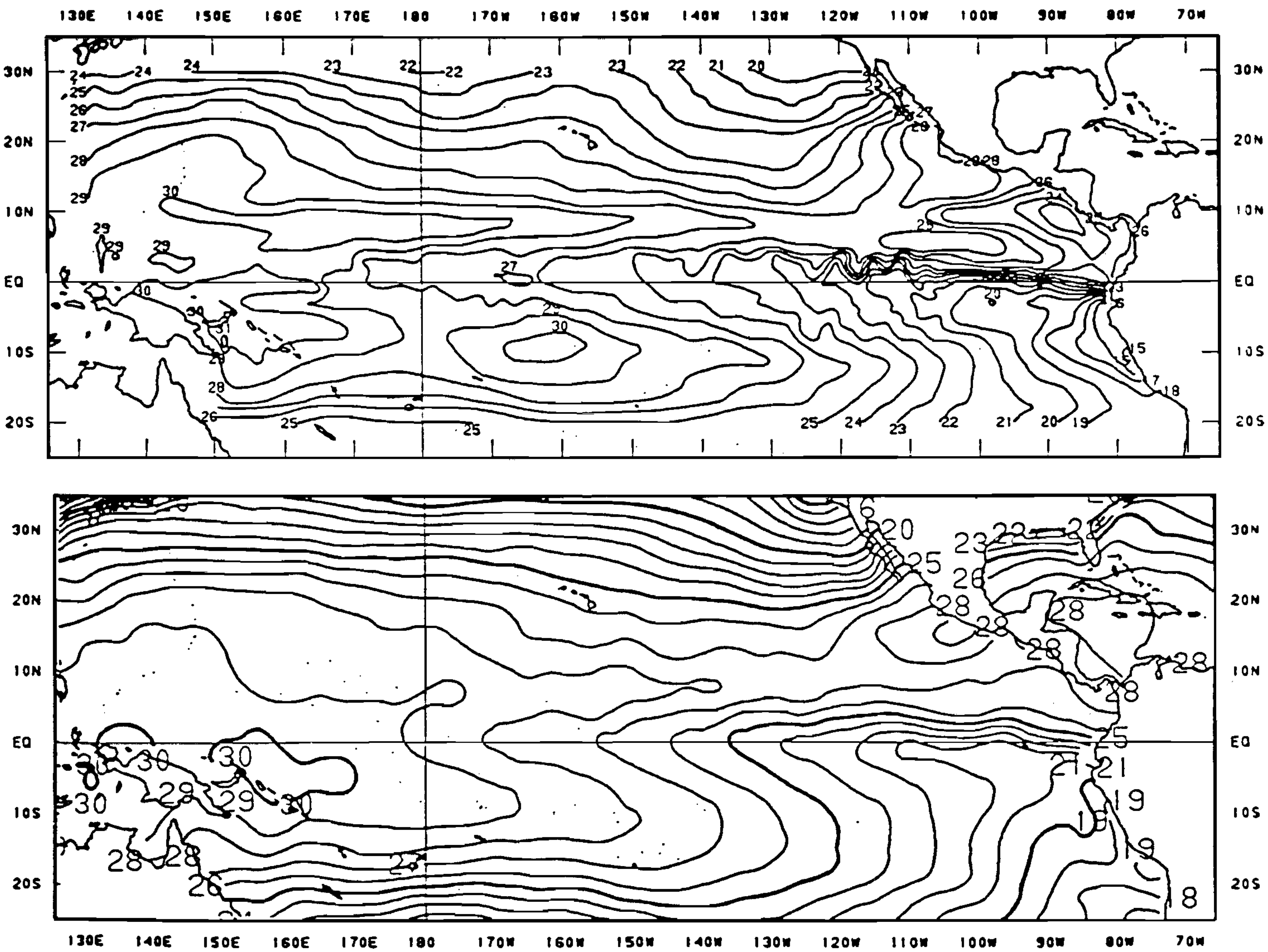


Figure 8. Sea surface temperature analyses for November 1985. The upper panel shows a "snapshot" of the SST for November 15, 1985 derived from the ocean model. The lower panel shows the CAC/NMC monthly averaged blended SST analyses, adjusted by drifting buoy data. (NOAA/Climate Analysis Center.)

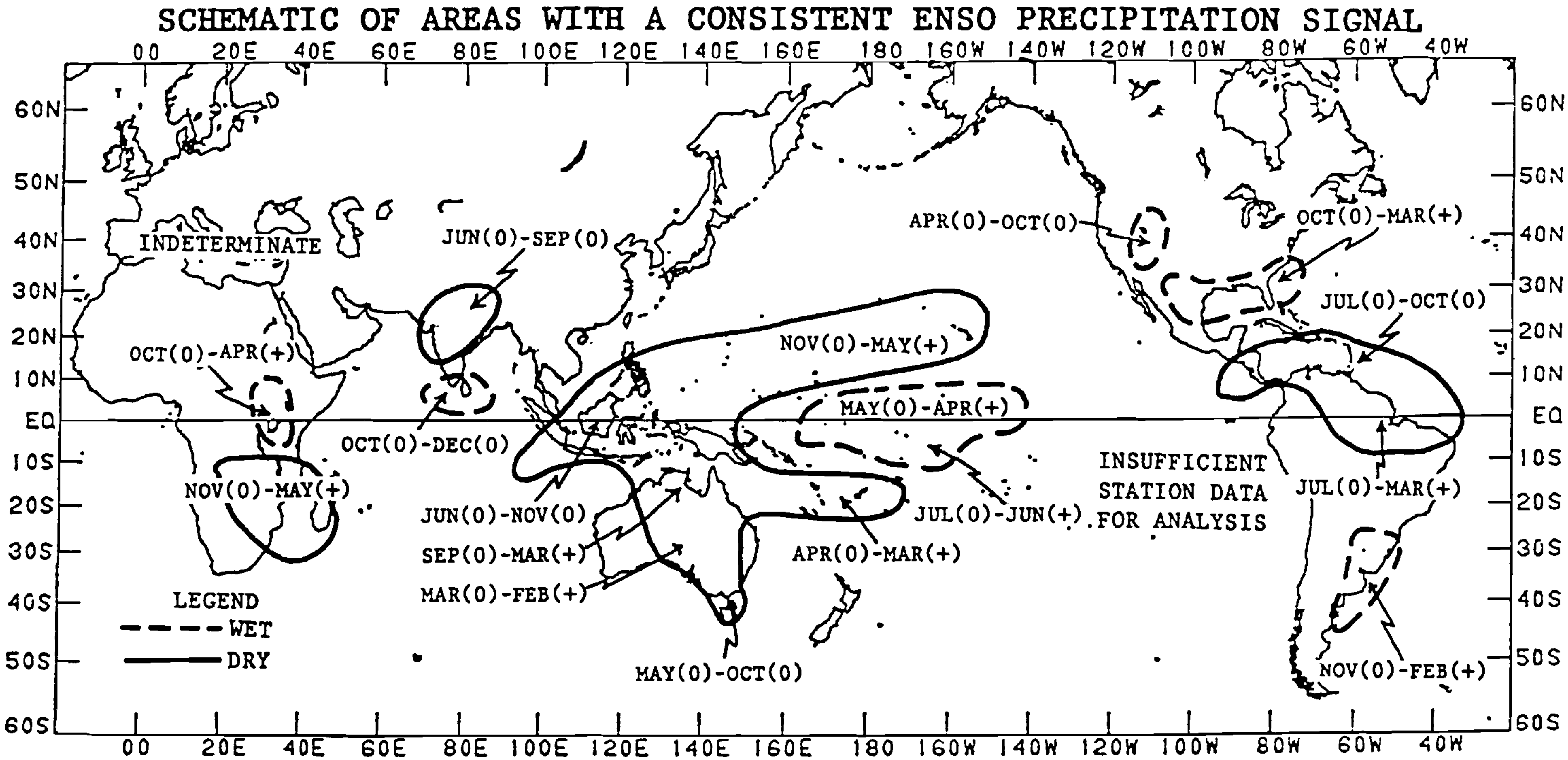


Figure 9. Schematic representation of the principal ENSO-related precipitation based on the detailed analyses for core regions. (Ropelewski and Halpert, submitted for publication.) (NOAA/Climate Analysis Center.)

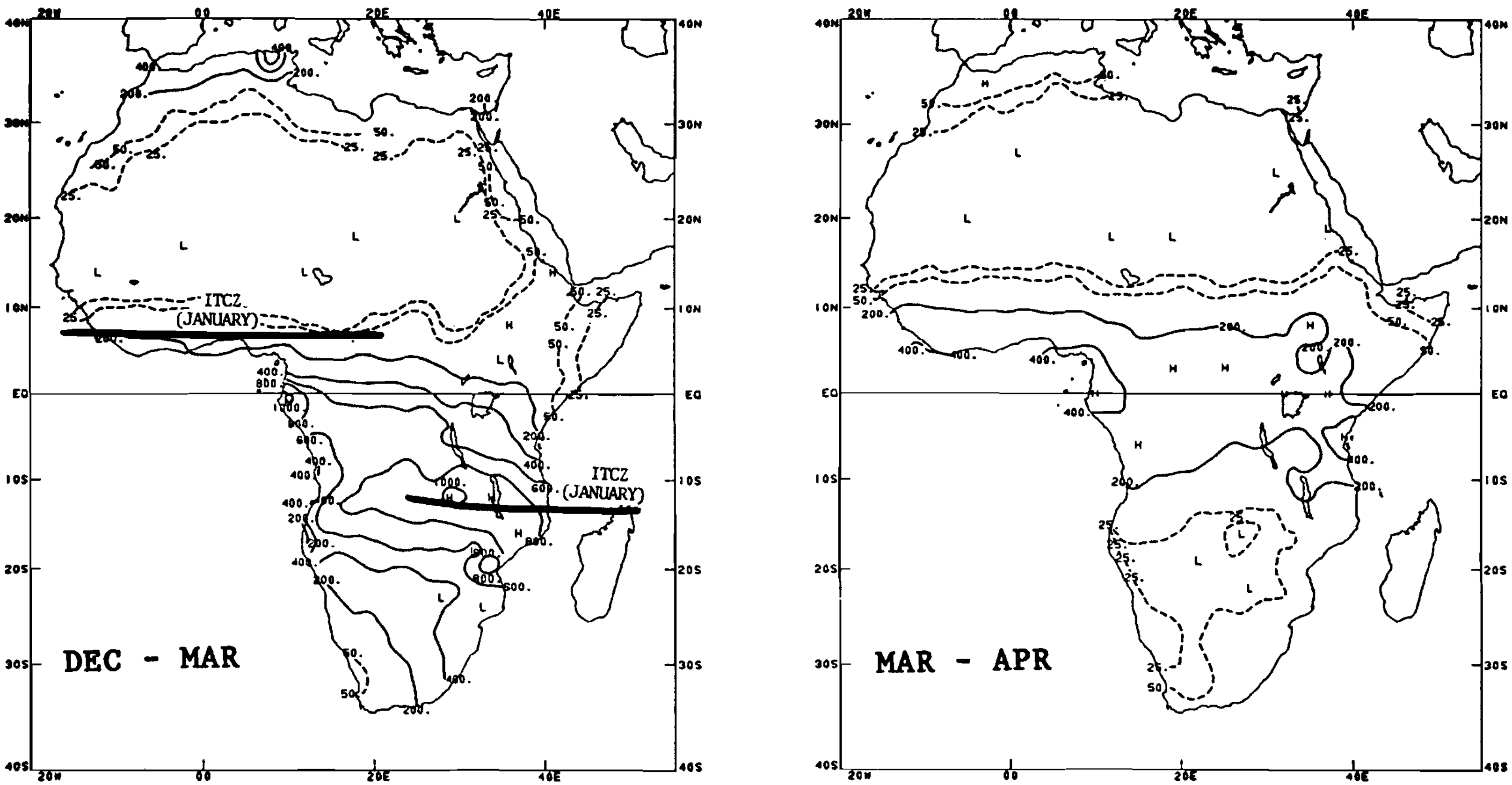


Figure 10. Annual cycle of African rainfall (mm) for austral summer (Dec.-Mar.), boreal summer (June-Sept.), and transition seasons (April-May and Oct.-Nov.). (NOAA/Climate Analysis Center.)—Continued

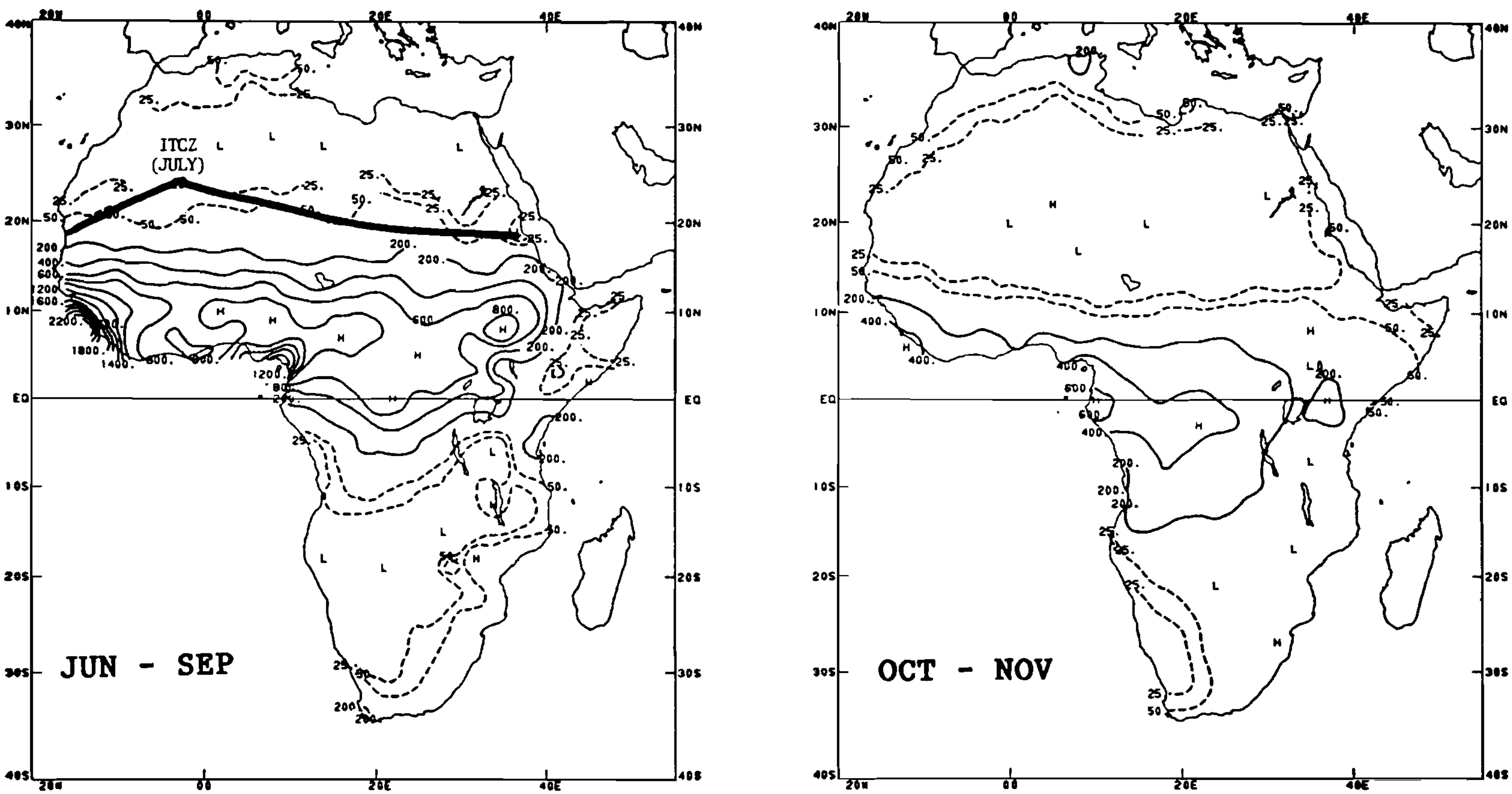


Figure 10. Annual cycle of African rainfall (mm) for austral summer (Dec.-Mar.), boreal summer (June-Sept.), and transition seasons (April-May and Oct.-Nov.). (NOAA/Climate Analysis Center.)

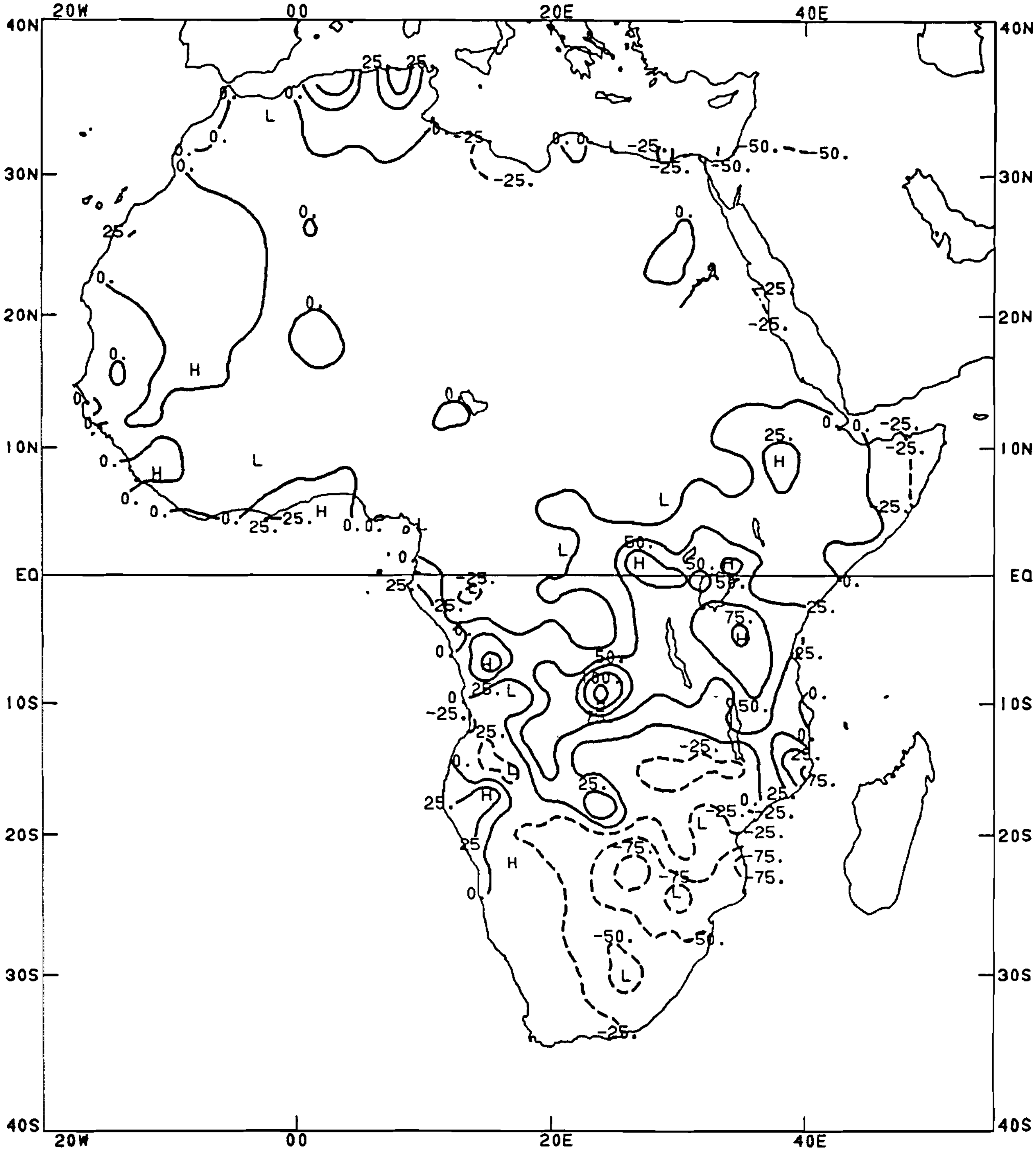


Figure 11. Composite rainfall anomaly (mm) during austral summer for ENSO years. Regions between the equator and 10°S tend to be wetter than normal, and regions between 15°S and 30°S tend to be drier than normal in Africa during an ENSO year. These anomalies range between 10 percent and 30 percent of normal in these regions. (NOAA/Climate Analysis Center.)

Table 1. Summary of ENSO-Related Precipitation for Selected Regions of the World

Region	Season	Number of Episodes* Total	Wet	Dry
PACIFIC BASIN				
entral Pacific	May-Apr.	8	7	1
.Central Pacific	July-June	8	8	0
ndonesia-New Guinea	June-Nov.	25	5	20
'iji-New Caledonia	Oct.-Mar.	11	2	9
Aicronesia-W. Pacific	Oct.-May	13	1	12
Iawaii	Nov.-May	11	2	9
AUSTRALIA				
Northern Australia	Sept.-Mar.	26	4	22
Eastern Australia	Sept.-Feb.	26	6	20
S.Australia-Tasmania	May-Oct.	24	6	18
Central Australia	Mar.-Feb.	26	7	19
INDIAN SUBCONTINENT				
India	June-Sept.	26	5	21
Minicoy-Sri Lanka	Oct.-Dec.	26	1	5
TOPICAL AND SOUTHERN AFRICA				
East Equatorial Africa	Oct.-Apr.	13	1	2
Southeast Africa	Nov.-May	22	5	17
SOUTH AMERICA				
Northeastern SA	July-Mar.	17	1	16
Southeastern SA	Nov.-Feb.	19	8	1
CENTRAL AMERICA				
C. America-Carib.	July-Oct.	19	5	14
NORTH AMERICA				
Great Basin	Apr.-Oct.	11	9	2
Gulf and North Mexico	Oct.-Mar.	22	84	

* Total number of episodes is determined by data available for analysis; for example, eight episodes span the period 1950 to 1983 and twenty-six episodes cover the period beginning in 1880. Source: Ropelewski and Halpert, 1987. Global and regional scale precipitation patterns associated with the El Nino-Southern Oscillation. *Monthly Weather Review*, Vol. 115 (in press).

During northern summer, no apparent association with El Nino was detected, However, evidence of an association between the rainfall anomaly dipole pattern in West Africa and the northern summer Atlantic sea surface temperature anomaly pattern corresponding to sub Saharan dry episodes was discovered.

Tropical Oceans and Global Atmosphere (TOGA)

TOGA Status

TOGA, a 10-year international study of the interannual variability of the tropical oceans and global atmosphere, officially began on January 1, 1986. The scientific objectives of the TOGA program are:

1. To determine the predictability of the tropical oceans and related planetary-scale atmospheric circulation patterns on time scales ranging from several weeks to a few years.
2. To explore the potential of coupled atmosphere-ocean system models for climate prediction.

Activities during preliminary TOGA studies (1984-85) focused on augmenting the observation network and initiating analysis and modeling. With the measurement program reasonably well established in the Pacific, TOGA has begun to shift emphasis toward the Indian Ocean. During 1986, tide gauge stations were installed at Mombasa, Kenya; Dar es Salaam, Tanzania; Port Louis, Mauritius; and Diego Garcia in the Indian Ocean. Australia has placed a sea level gauge at Cocos Island. Applications have been made for installation of gauges at other locations in the Indian Ocean and at several sites along the Indonesian coast.

Significant progress was made toward completing the TOGA ship-of-opportunity XBT network in the Pacific and Atlantic oceans. In the Pacific, new lines were added between northern Australia and Japan, Peru and Japan, and Alaska and the Strait of Magellan, while in the Atlantic, new lines were added between French Guiana and Europe and South America and Europe. This essentially completes the required TOGA XBT network in those two oceans. In the Indian Ocean, new lines were added between western Australia and the Persian Gulf. While it is expected that more lines will be added in 1987, the Indian Ocean remains undersampled.

Fifteen nations have signified readiness to participate in the international TOGA program. The Federal Republic of Germany will assume responsibility for the Global Precipitation Center; France will operate the Subsurface Ocean Thermal Center beginning in January 1987; India will sponsor an upper air wind center; and the United Kingdom expressed an interest in operating a Marine Climatology Data Center that would merge all of the data and produce a single surface set. The United States operates the Sea Level Data Center at the University of Hawaii and the Sea Surface Temperature Data Center at NOAA's Climate Analysis Center (CAC). In 1987, CAC will begin operating the Precipitation Data Center.

The United States is a major contributor to TOGA. Data are provided from a number of atmospheric and ocean networks, and modeling studies for TOGA are carried out at several NOAA centers (CAC, GFDL, and PMEL), Lamont-Doherty Observatory of Columbia University, Florida State University, and at the National Center for Atmospheric Research.

TOGA Data Management System in Operation

The National Oceanographic Data Center (NODC) has begun routine tracking and processing of subsurface ocean temperature data from the TOGA Pacific area. The system enables NODC to track, acquire, quality control, and merge all available XBT data in this area. The data include telecommunicated XBT data received by the National Meteorological Center and the Fleet Numerical Oceanography Center (FNOC), plus delayed data from NOAA, Navy, and other U.S. and foreign ships.

NODC now produces a monthly TOGA data tape that is transferred to the Scripps Institution of Oceanography (SIO), which performs further data quality control and generates analytical ocean data products for TOGA investigators. These data are available within 15 days of the end of each month. NODC and SIO have formalized this cooperation through a Joint Environmental Data (Thermal) Analysis Center.

On October 1, 1986, the TOGA Pacific thermal data set contained 12,762 XBT temperature profiles. Of these, 9,297 (73 percent) were from NMC and 2,500 (20 percent) were from FNOC. The remainder were delayed data and from other sources. Using its microprocessor-based data tracking system, NODC can provide inventory products showing the spatial and temporal distribution of XBT data in the TOGA Pacific database.

Earth Radiation Budget

ERBE Observes Global Cloud Cover

The Earth Radiation Budget Experiment (ERBE) continued observations of the earth from satellite-borne instruments. These were on the earth radiation budget satellite (ERBS), launched in October 1984 from space shuttle Challenger, and NOAA-9, launched in December 1984. NOAA-10, launched in September 1986, also carries a set of ERBE instruments.

The solar constant measured by an ERBE instrument is 1364.8 W/m^2, with a certainty of better than 0.2 percent. This is in close agreement with measurements from Nimbus-7 and the active cavity radiometer irradiance monitor (ACRIM) measurements from the Solar Max Mission. ERBE also observes the fluxes of reflected sunlight and thermal energy emitted from the earth and atmosphere. These fluxes are fundamental climate parameters of the sources and sinks of energy that drive the climate system.

In its observations of the earth's energy budget, ERBE is separating clear-sky fluxes from the fluxes which include clouds. This allows ERBE to estimate cloud forcing, i.e., the change in the energy budget attributed to clouds. Cloud forcing is fundamental to studies of climate and climate change because it includes the increased reflection caused by low clouds, as well as the decreased emission to space, particularly for high clouds. Because of the difficulty in understanding clouds, the precise nature of their impact has been a subject of considerable controversy in climate modeling over the last decade.

Figure 12 shows ERBE estimates of net cloud forcing for April 1985. Dark areas indicate observations in which the greenhouse effect of clouds dominates. In these regions, clouds are more effective at impeding outgoing emissions than at reflecting, resulting in a net heating of the earth-atmosphere system. The light areas are those areas where clouds seem to have a small cooling effect. The intermediate shaded areas indicate where clouds have a strong, net cooling effect. In these areas, clouds reflect more incoming solar energy than they block from emission. The cooling areas are particularly noticeable in regions of persistent, low stratus clouds, such as off the western coasts of South America and Africa. Cooling is also important in the Northern Hemisphere storm tracks in the Pacific and Atlantic.

Surface Radiation Budget Project Started

NASA recently established a Surface Radiation Budget (SRB) Satellite Data Analysis Project at the Langley Research Center. The first task for the project is to define and validate appropriate data reduction algorithms and then to process multiyear global data sets using those algorithms. The data set will be designed to describe the spatial and temporal variations of SRB components and meet accuracy requirements for SRB data in the World Climate Research Program. The components of interest are incoming and outgoing shortwave and longwave radiation fluxes at the surface. Due to the requirement for global coverage and the demonstrated feasibility of satellite techniques, emphasis is being placed on determining the SRB from satellite measurements and using surface-based measurements for validation studies.

Initially, satellite and surface measurements will be taken for pilot validation studies using algorithms. Satellite data covering a broad range of spatial and spectral resolutions are available from such systems as the ISCCP and ERBE. Except for shortwave measurements for some midlatitude land areas, the surface radiation measurements required are virtually nonexistent. The SRB project will obtain these data from ongoing studies such as First ISLSCP Field Experiment (FIFE) and the First ISCCP Regional Experiment (FIRE), and various oceanographic studies.

The first field work of the SRB Satellite Data Analysis Project was completed in 1986. The work was done in cooperation with the FIRE cirrus cloud experiment in Wisconsin. Both shortwave and longwave measurements were taken for investigating shortwave sampling. These ground-based measurements are being combined with satellite data for the initial pilot study using algorithms.

International Satellite Cloud Climatology Project Nears End of Data Collection Phase

ISCCP entered the fourth year of its 5-year data collection phase in July 1986. The objective is to pro-

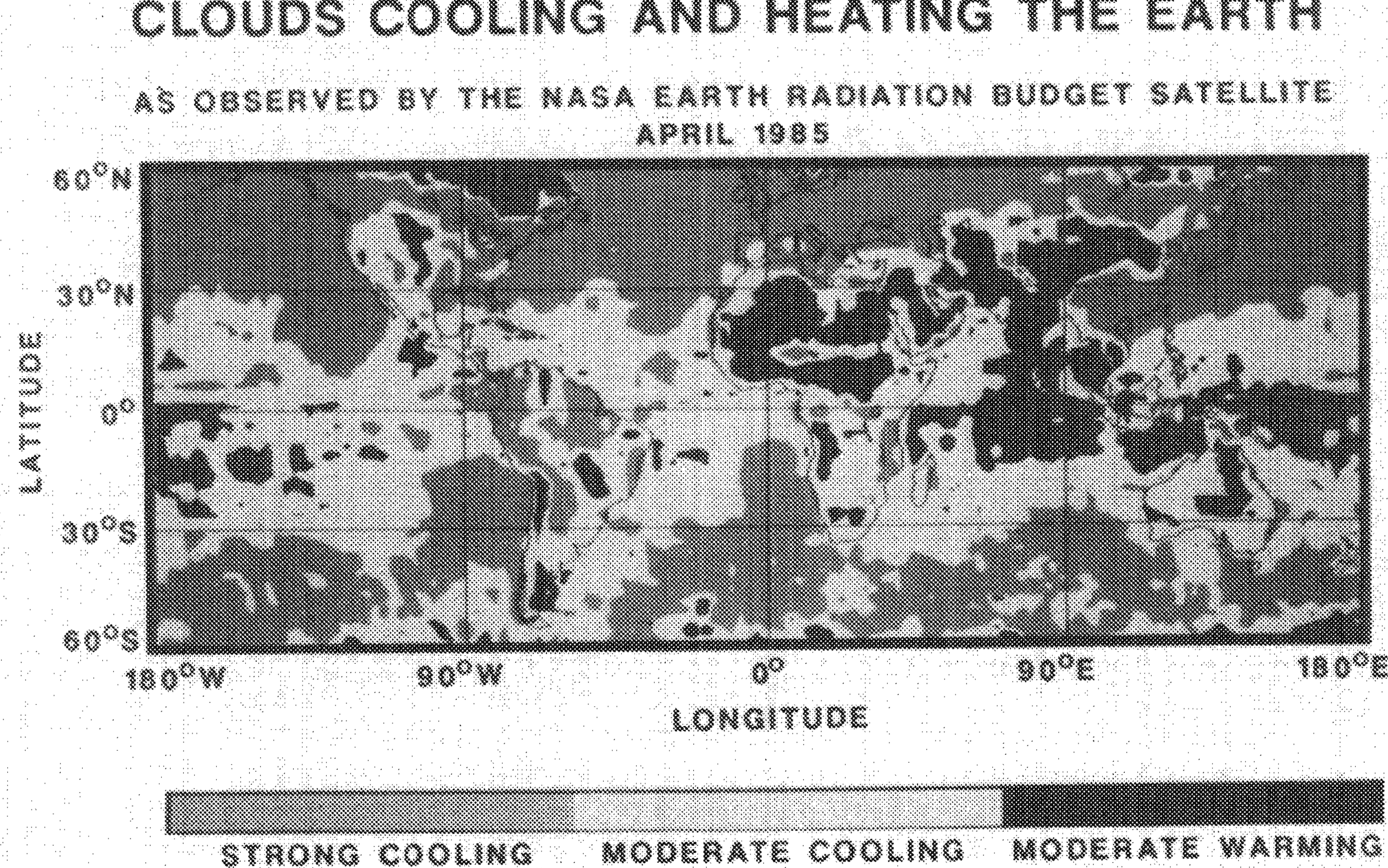


Figure 12. Clouds cooling and heating the earth. From the NASA Earth Radiation Budget Satellite, April 1985. (NASA, ERBE Project.)

duce a globally uniform satellite radiance data set from the different imaging data available (Schiffer and Rossow, 1985). The data are collected at 3-hour intervals from an international network of operational geostationary and polar-orbiting meteorological satellites. The radiances are further processed by NASA into a global cloud data set categorized by cloud type. Parameters archived include cloud amount, cloud height, cloud top temperature, and cloud optical thickness. These data will be essential for improving the parameterization of clouds in climate models. These data will also prove beneficial in improving the understanding of the impact of clouds on the earth's radiation budget and hydrological cycle. Data are collected from geostationary satellites GOES (U.S.), METEOSAT (Europe), and Geostationary Meteorological Satellite (GMS) Japan, and from the NOAA-7 polar orbiting satellites. A central archive of all ISCCP products is maintained by NOAA/National Environmental Satellite, Data, and Information Service (NESDIS).

Test production of the cloud climatology products from analysis of the radiance data started at the beginning of the year. One month of METEOSAT and GOES results and 2 months of NOAA-7 results were produced for testing and to support two pilot studies. The pilot study on polar cloudiness had its first workshop in August 1986, and the pilot study on the uses of ISCCP data in climate research held its second workshop in October 1986. The workshops provide guidance on the implementation of the cloud analysis algorithm and help define the format and contents of the climatology for research. First delivery of cloud results is expected in 1987.

Time Series of Nimbus-7 Monthly Mean Total Cloud Amount Analyzed

The time series of monthly mean total cloud amount from April 1979 to October 1984 is shown in figure 13 for hemispheric and global averages. These cloud estimates are derived from radiation measurements of instruments on the Nimbus-7 satellite, temperature/humidity infrared radiometer (THIR) and total ozone mapping spectrometer (TOMS).

The principal features apparent from the figure are that the annual average of total cloud amount in the Southern Hemisphere is greater than in the Northern Hemisphere and, globally, total cloud amount is gradually decreasing over the 5 1/2 year period. The decrease is partly explained by changes in calibration of the TOMS instrument during the first 2 years and, in the fifth year, by changes in atmospheric circulation resulting from the 1982/83 ENSO event, which is consistent with changes in the earth's radiation budget (Ardanuy and Kyle, 1986).

Hemispheric cloud amount has an annual cycle, with the maximum in the respective summer season and a minimum in the winter season, suggesting that convective processes are more effective at producing extended cloud fields than advective (polar front) processes. The Southern Hemisphere time variations are more uniform than in the Northern Hemisphere, which is probably the result of differences in the proportion of land and ocean areas and the resulting radiative heating differences between the two hemispheres. These differences in the two hemispheric time variations in cloud amount explain the semiannual cycle of globally averaged cloud amount evident in the figure; there is an amplitude of 2 to 3 percent, with maxima at the solstices and minima at the equinoxes (Stowe et al., 1986).

Project FIRE Measures Cloud Properties Over the United States

Project FIRE is a 5-year study of the role of clouds in the earth's climate. Specifically, FIRE will measure the radiative and physical properties of cirrus and marine stratocumulus clouds over the continental United States. Measurements will be made from satellite, airborne, and surface platforms.

FIRE is supported by five federal agencies. NASA is the lead agency and is supported by the National Science Foundation (NSF), NOAA, Department of Defense (DOD), and the Department of Energy (DOE). A series of observational and modeling strategies are designed to meet the goals of FIRE. The objective of the first strategy, intensive field operations, is to produce detailed observations of cirrus and marine stratocumulus clouds from a number of platforms and instruments. The objective of the second strategy, extended time observations, is to compare long-term observations of cirrus and marine stratocumulus clouds. The third strategy will compare predicted results from a range of radiative and physical processes and modeled results with the multiscale observations.

Intensive field operations were conducted in 1986 in central Wisconsin and will be made off the coast of southern California in 1987. Both operations will be repeated in 2 years. Extended time observations also began in 1986 and will continue through 1989. Coordinated surface and satellite observations will be made over the continental United States. Lidar, radiometric, and meteorological measurements will be made at sites in Utah, Colorado, and Wisconsin at times of satellite overpass and during periods of cirrus cloud activity.

Paleoclimate

Climate Records from the Dunde Ice Cap Recovered

U.S. scientists led by Dr. L.G. Thompson of the Ohio State University and Chinese scientists from the Lanzhou Institute of Glaciology and Geocryology have completed the first year of a 3-year cooperative glacioclimatology program on the Dunde ice cap located in the northeastern section of the Tibetan highlands in the Qilian Shan region of China (38° 05'N; 96° 24.5'E at 5400 m elevation). The objective is to extract ice

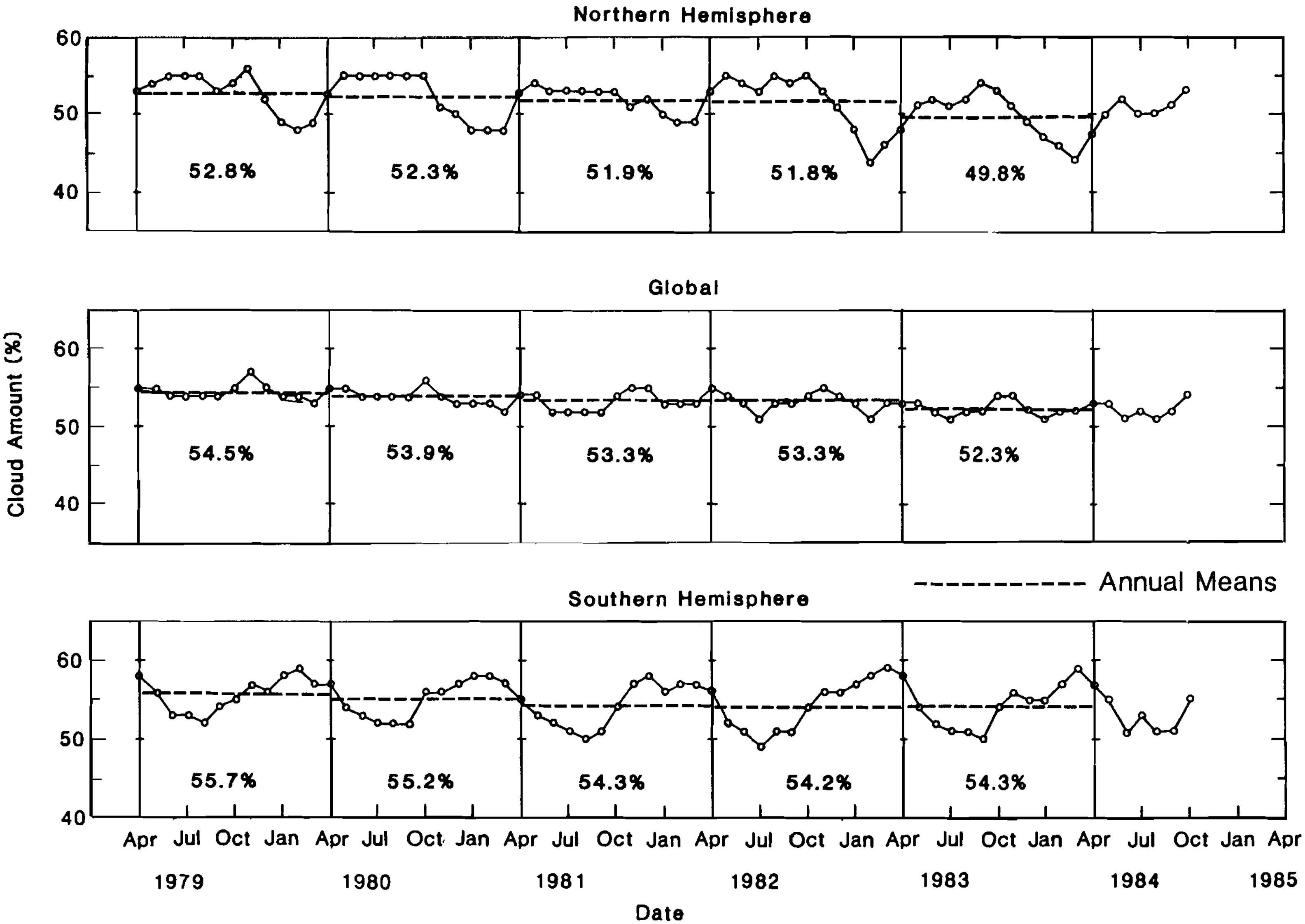


Figure 13. Time series of monthly mean total cloud cover, averaged hemispherically and globally, as derived from Nimbus-7 satellite THIR/TOMS data. (NOAA unpublished.)

core paleoclimatic records of the general environmental conditions, including drought, volcanic activity, moisture sources, glacier net balance, and possible temperature for the past 3,000 years. The project is supported jointly by the National Science Foundation and the National Geographic Society.

Results from the 1986 field program (July to September) confirm preliminary findings from the 1984 National Academy of Sciences and Academia Sinica expedition that the Dunde ice cap exhibits the characteristics of polar ice caps. The climatic record which potentially could be recovered from ice cores taken at Dunde would cover at least the past 3,000 years, thus providing an opportunity to obtain a history of the "Little Ice Age" in the Tibetan Highlands.

The Dunde ice cap has similarities with the Quelccaya ice cap in southern Peru, from which a 1,500-year ice core proxy record of tropical climate is being constructed. Over 80 percent of the snowfall at each site occurs in summer, resulting in annual dust layers that are visible in the snow-pit stratigraphy, ice cores, and vertical margins of both ice caps. Annual precipitation at Quelccaya is strongly modulated during ENSO episodes, while annual precipitation at Dunde is affected by the intensity and duration of the monsoon season over the Tibetan Highlands.

The precipitation record at the two sites offers a unique opportunity for investigating the strong link (observed in modern instrumental records) between monsoon intensity and ENSO episodes in the equatorial Pacific Ocean. In addition, the long and well-documented historical records from central and eastern China will allow the upper 2,000 years of the climatic record in the Dunde ice cap to be calibrated and will provide independent dating checks on the ice core chronology.

Cooperative Holocene Mapping Project (COHMAP) Compiles Global Scale Paleoclimate Maps

COHMAP is an international, interdisciplinary research project supported by NSF and carried out by climatologists, paleoecologists, geographers, and geologists. Its primary focus is the evolution of the climate system since the late Quaternary period (150,000 years ago), through the most recent glaciation (18,000 years ago), and over the Holocene period (last 10,000 years).

The COHMAP project has compiled global-scale maps of paleoclimatic conditions which are being compared with the climate simulations obtained from the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR). The observations and model simulations are for the past 18,000 years at 3,000-year intervals.

Simulations of both January and July conditions for 18,000, 15,000, 12,000, 9,000, 6,000, and 3,000 years before the present (yr BP), and for modern conditions have now been completed. At 18,000 yr BP, experiments include the effect of lowered atmospheric CO_2 concentrations, in addition to the effects of the ice sheets and more extensive sea ice.

Ongoing studies are comparing the model results with the observations. The agreement is good when one takes into account such factors as the horizontal resolution of the model and known model deficiencies. Documentation of the entire set of experiments has been published (Kutzbach and Guetter, 1986), and an overview of results for all of North America has also been completed (Kutzbach, 1986). In addition, the project has completed an experiment for 9,000 yr BP using a coupled atmosphere-ocean model in order to study climate response to coupled atmosphere-ocean processes. Simulation of oceanic conditions for 18,000 yr BP is in progress in collaboration with NCAR. The U.S. Geological Survey and NCAR are also collaborating to use high-resolution models that would allow COHMAP to study regional details of climate over the United States.

Carbon Dioxide and Climate Change

North Pacific Ocean a Winter Source of Carbon Dioxide

Investigators at the Lamont-Doherty Geological Observatory of Columbia University observed CO_2 concentrations in the North Pacific Ocean that seemed to contradict a major premise in the general understanding of the global carbon cycle. Data obtained during the winter showed this region acting as an intense source of CO_2 for the atmosphere; previous data, which were collected during the summer, indicated that the region acted as a sink. Further investigation has confirmed the new findings, creating a need to reassess the ocean's dynamics in taking up CO_2.

Since the beginning of the industrial era, concentrations of CO_2 in the atmosphere have increased from about 280 parts per million (ppm) to about 345 ppm; they have been projected to double possibly by 2075. Atmospheric monitoring since 1958 shows, however, an annual gap of about 50 percent between industrial emissions of CO_2 and the atmospheric increase. These findings suggest that some other reservoirs must take up the missing CO_2.

The oceans exchange CO_2 with the atmosphere through their surface layer, which in turn mixes with the deep ocean. A global survey conducted in 1972-78 has largely shaped current understanding of the patterns that characterize CO_2 exchange between the surface layer and the atmosphere. The equatorial zone in the Pacific and Atlantic oceans is regarded as a strong source of atmospheric CO_2, while the high latitude oceans are generally considered sinks.

In the past, oceanic measurements of CO_2 were made mostly during the summer. Since small oeanographic vessels rarely ventured into freezing waters, winter concentrations in the high latitudes were virtually unknown. Yet this is the important season for CO_2 dynamics in these regions. Due to the intense cooling, surface water becomes dense and is transported by convection into the deep ocean. In the process, CO_2 moves from the atmosphere into the deep ocean for storage. Because CO_2 becomes more soluble in sea water at lower temperatures, it has long been assumed that oceanic sinks located at high latitudes would become more intense during winter.

The present study contradicts these expectations. Winter observations taken by two shipping lines show that water of the northwestern Pacific Ocean becomes a strong source of CO_2 (denoted by an increase in partial pressure of CO_2 in the sea water) during the winter when cooling enhances a deep convective mixing of surface water. The region becomes a weak to moderate sink for CO_2 (denoted by reduced partial pressure of CO_2 in the sea water) during summer when the water is warmest (figure 14).

The deep convective mixing of the ocean, when surface water is coldest, accounts for the winter observations. Besides transporting surface waters into the deep ocean, it also brings to the surface deep water rich in CO_2 and nutrients. According to the observations, nutrients are indeed most concentrated in surface water during winter. The upwelling of deep water with its CO_2 more than compensates for the CO_2 lost to the atmosphere as surface water sinks.

As waters warm, convective mixing subsides. This transition and the increased use of CO_2 for photosynthesis account for the region's conversion into a CO_2 sink in the summer. On average over a year, the northwestern Pacific acts as a moderate source of CO_2 and appears to give off an amount of CO_2 equivalent to about 5 percent of the current annual industrial CO_2 emmission.

The seasonal variability of CO_2 chemistry in other regions of the world's oceans has not been investigated (Takahashi et al., 1986).

Global Temperature Trend Documented

The first comprehensive estimate of the trend in global mean surface temperature over the last 120 to 130 years has been developed by scientists at the University of East Anglia (Jones et al., 1986b). To generate this estimate, they compiled and corrected data over land and oceans for both hemispheres.

The global mean surface air temperature is the measure most commonly used to indicate the state of the earth's climate system. Variations in global mean temperature show the climate system's response to natural changes and to possible influences such as increased atmospheric concentrations of carbon dioxide and other greenhouse gases. Previous estimates of the temperature reflect data primarily from Northern Hemisphere land surfaces, and it was uncertain how well this record represented the global trend. Last year, representative data were compiled for the Southern Hemisphere land surface. This year, two ocean data sets were released, and the Carbon Dioxide Research Program at DOE sponsored the analysis of the global data set. Figure 15 shows annual mean surface air temperatures for each hemisphere and for the entire globe. There are obvious differences between the hemispheres, and data may not have been fully corrected to allow for the magnitude of the heating exerted by urban centers, especially in the Northern Hemisphere. Nevertheless, the Southern Hemisphere record clearly confirms the upward trend in global temperature.

Globally, the increase in temperature over the time period is about 0.5°C (about 0.9°F). The upward direction of the trend is consistent with global temperature perturbation due to atmospheric greenhouse gases, but this correspondence does not show a definitive cause-and-effect relationship (Jones et al., 1986b).

Greenhouse Effect: Projections of Global Temperature

The climate modeling group at the NASA Goddard Institute for Space Studies (GISS) has carried out the first global climate model (GCM) simulations of temperature trends caused by the time-dependent growth of CO_2 and other trace gases (Hansen et al., 1986). Two scenarios depict trace gas growth rates and project changes in global temperature (figure 16). A conservative scenario, B, includes only greenhouse gases which have been measured reasonably well (CO_2, $CClF_3$, CCl_2F_2, CH_4, N_2O). It assumes that their growth rates will decrease in the next few decades, and that stratospheric aerosols (which cool the earth's surface) will continue to be present at the mean level which existed during the volcanically active period, 1960-1985. Scenario A includes several additional trace gas changes which are less well documented; it allows present trace gas growth rates to continue, and it assumes negligible volcanic aerosols, as was the case for the period 1910-1960.

Global mean temperatures computed by the model are compared with observations in the figure. The observations and model results are consistent, but the natural variability of temperature is sufficiently large compared with the temperature trends to date to make it impossible to confirm or refute the modeled greenhouse effect.

Evaluation

Over the past few years, major advances have been made in our knowledge of the processes that govern climate, and there has been progress in predicting climate on different time scales (monthly, interannually, and decadal). Part of the reason for this progress is due

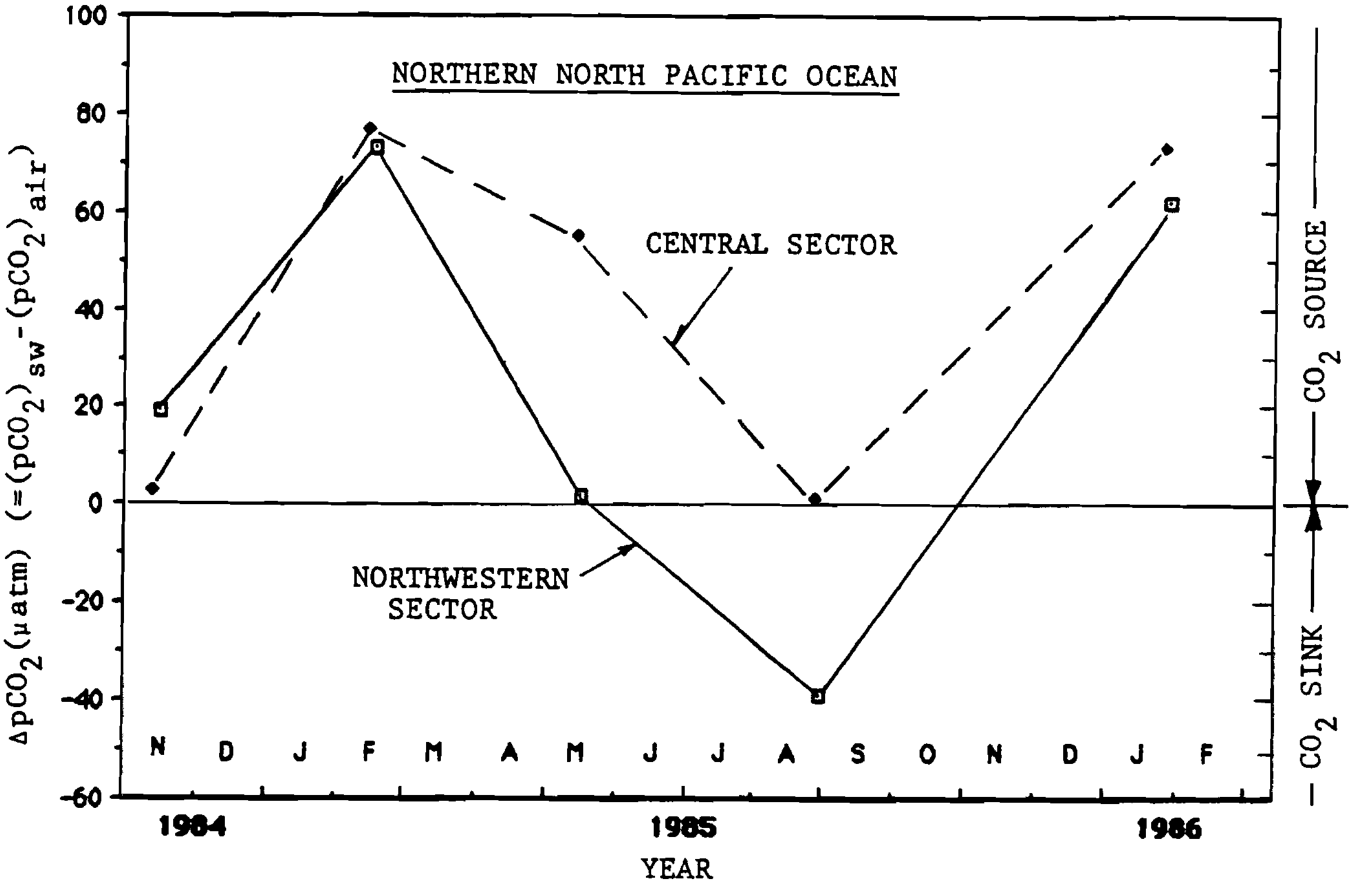


Figure 14. Time variability of air-sea difference in percent CO_2 over the northern North Pacific, 41°N-54°N. Central sector includes the Bering Sea. Northwestern sector represents the area east of the Kuril Islands and Kamchatka Peninsula. Note that the ocean becomes a strong CO_2 source in winter, and a neutral to moderate CO_2 sink in summer. (Takahashi et al., 1986.)

to the World Climate Program and the various national climate programs. Through them, it is possible to undertake the global observational experiments and data management efforts so essential for climate modeling. In addition, these programs have helped focus attention on urgent research problems, and have led to more efficient use of resources available for climate research.

Perhaps the most important event in 1986 was initiation of the 10-year operational phase of the international TOGA. Although there is no hard evidence that climate can be predicted with the accuracy of theoretical 1- to 2-week deterministic weather forecasts, considerable expectations are attached to this large-scale observational and modeling experiment. It is believed that at least part of the variability of the coupled ocean-atmosphere system can be predicted. This view is based on theoretical studies carried out during the past few years. Understanding of the mechanisms governing ocean-atmosphere interaction has improved radically, and the chain of ENSO-related events taking place over several years has been the subject of recent studies and documentation. These are (1) the occurrence of anomalies in the intensity of tropical weather patterns, (2) their impact on the southern ocean circulation and its sea surface temperature distribution (El Nino), and (3) subsequent atmospheric manifestations, such as droughts in India and Indonesia, and extreme wintertime temperatures in the southeastern United States.

Considerable effort has been devoted to evaluating the consequences of increasing concentrations of radiatively active gases in the atmosphere. If present trends continue over the next few decades, the radiative effects of the combined concentrations of carbon dioxide and other greenhouse gases (e.g., CFCs, CH_4, N_2O) would be equivalent to a doubling of the atmospheric concentration of carbon dioxide before the middle of the next century. The most advanced experiments with climate models show that this would lead to a global average warming in the range of 1.5°C to 4.5°C. The warming will be most pronounced in high latitude winter. It must be recognized, however, that the present models do not provide regional details of expected climatic change nor is this likely to be possible in the near future.

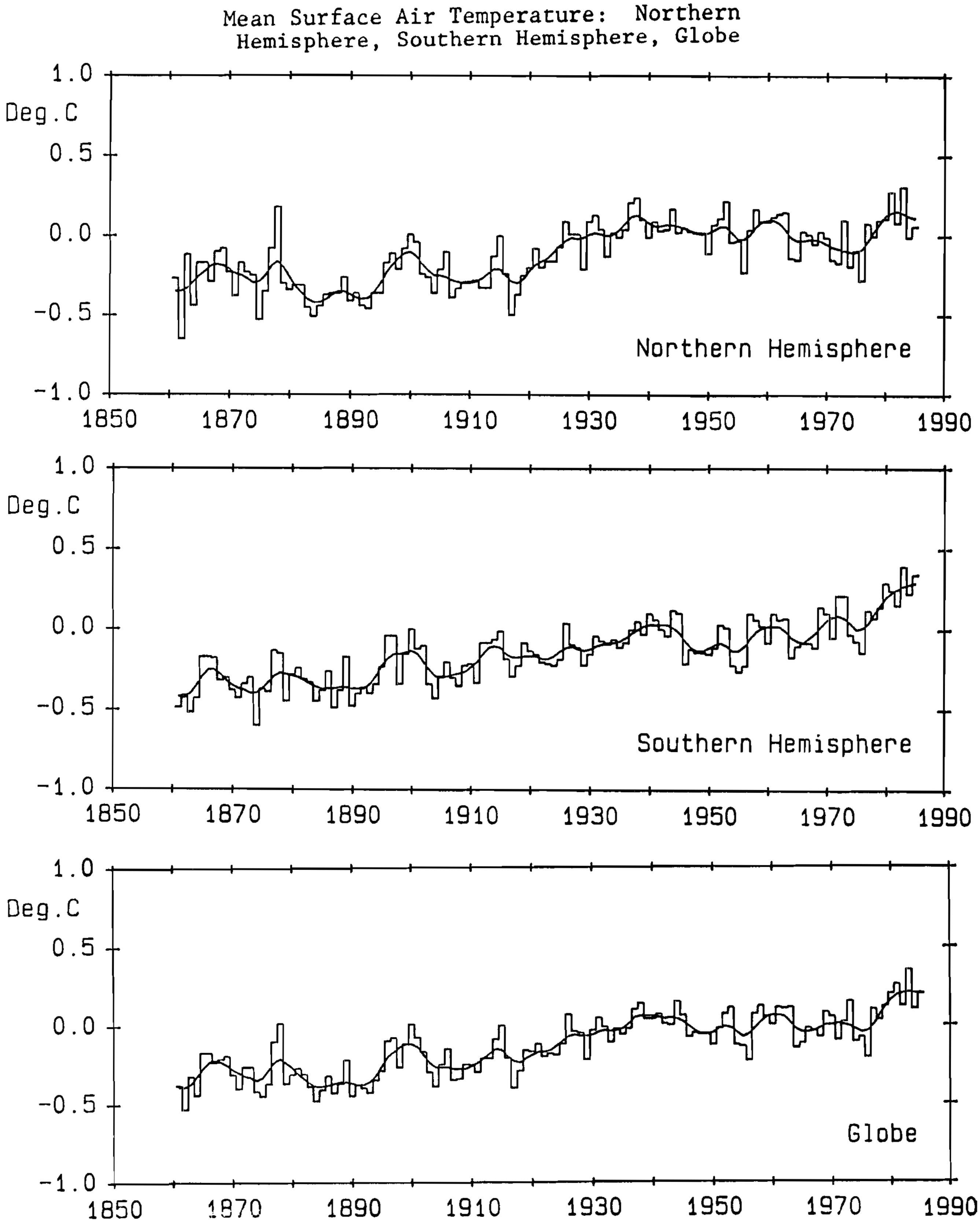


Figure 15. Annual mean surface air temperature for each hemisphere and entire globe, 1860 to present. (Takahashi et al., 1986.)

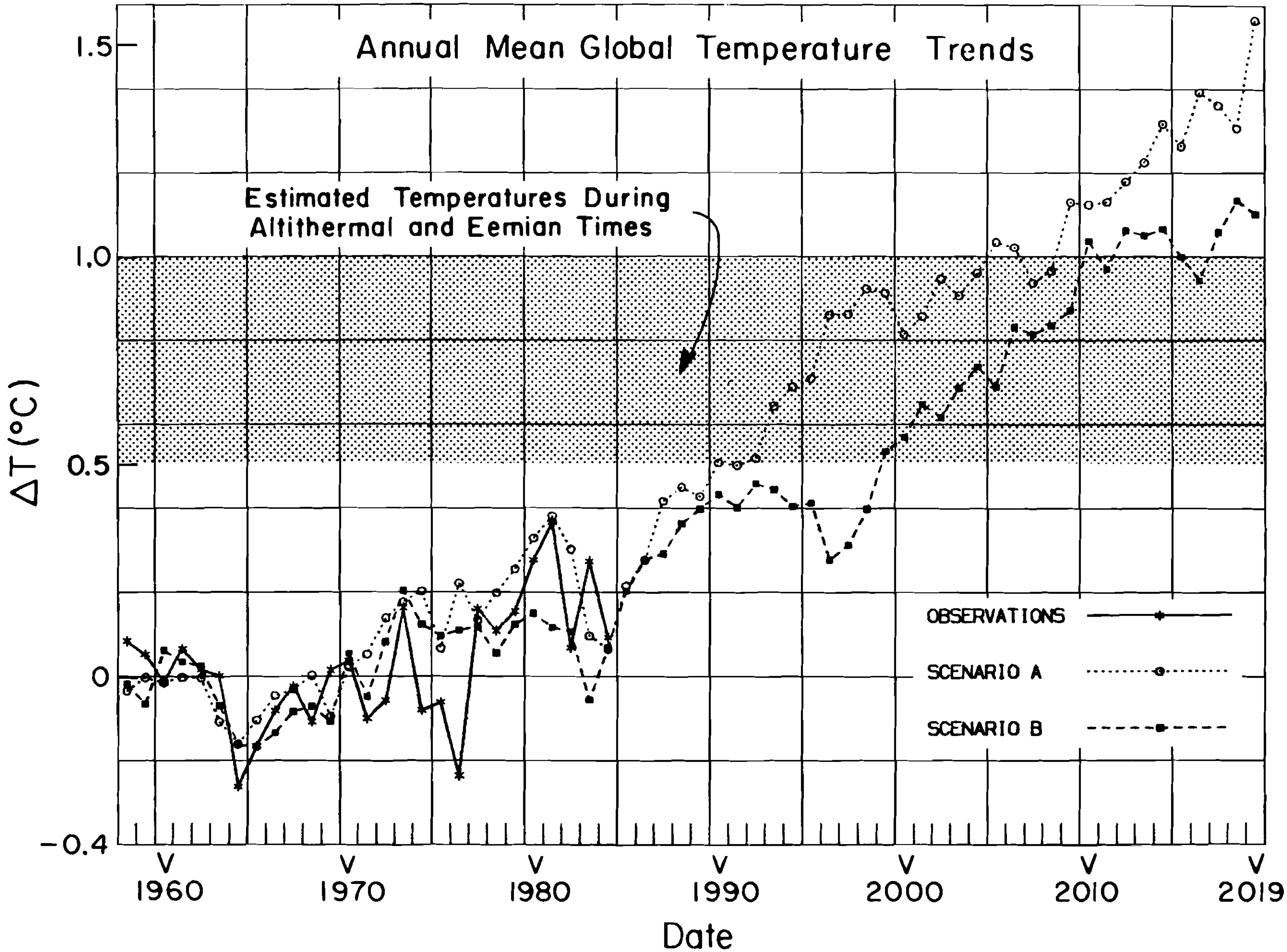


Figure 16. Global temperature trends for observations (solid line) and from calculations with the GISS global climate model. (NASA.)

IMPACT ASSESSMENT AND RESPONSE STRATEGIES

HIGHLIGHTS

- Senate hearings address greenhouse effect and ozone depletion
- DOE completes analysis of greenhouse effects and climate change
- Congress requests the Environmental Protection Agency (EPA) to undertake assessment studies
- EPA estimates impact of sea level rise on coastal United States
- Record drought in southeast United States
- Satellite technology aids assessment of African drought
- Marine assessment technology transferred to developing countries

Senate Hearings Address Greenhouse Effect and Ozone Depletion

Two days of congressional hearings in June focused on the scientific evidence of ozone depletion and atmospheric warming, and on actions being taken by the federal government to improve understanding of these changes and respond to them. The hearings were held by the Senate Subcommittee on Environmental Pollution of the Committee on Environment and Public Works (U.S. Senate, 1986). Testimony was taken from scientists engaged in atmospheric research, officials of federal agencies, and public interest and industry representatives.

Senator John Chafee of Rhode Island, who presided over the hearings, said "Ozone depletion and the greenhouse effect can no longer be treated solely as important scientific questions. They must be seen as critical problems facing the nations of the world. These are problems that demand solutions." Senator Chafee proposed several actions be taken, including studies by EPA and the Office of Science and Technology Policy (OSTP) of energy policy options for alternatives to fossil fuel and ways to reduce use of other trace gases; a review of scientific knowledge of these problems by the National Academy of Sciences; study of the environmental effects of climate changes; and other actions to bring the issues of ozone depletion, greenhouse effects, and climate change to the attention of other nations and international agencies.

DOE Completes Analysis of Greenhouse Effects and Climate Change

The DOE Carbon Dioxide Research Division completed its analysis of detailed findings reported in the four state-of-the-art (SOA) reports and two companion volumes on what is known and what remains uncertain about the greenhouse effect and changing climate. An analysis of the SOAs will be published in 1987. Four general conclusions were gleaned during the analysis:

1. Although scientifically sound analytical tools are available for estimating global climate change over the next 50-100 years or longer, regional and subcontinental estimates are not consistent with observational data. Estimating climate change on smaller, regional scales will require improved monitoring and model development.
2. Estimating the rate of climate change requires better understanding of the earth's natural cycling of carbon and its long-term stability as well as polar ice dynamics. It requires improved global monitoring of current climate and human changes in land use, and forecasts of future societal trends (e.g., population, energy source, and consumption rates).
3. Changing climate and increased atmospheric CO_2 may affect the world's principal agricultural regions, major forests and hydrological systems, and coastal lands.
4. Increased international education and collaborative research are needed to develop the knowledge base for policy decisions. Data and methodologies must be developed for managing, using, and conserving the earth's life-sustaining natural resources under changing climatic conditions.

Congress Requests EPA to Undertake Assessment Studies

Congress has substantially expanded EPA's role in studies of climate change caused by the release of greenhouse gases. The EPA has been directed to conduct two studies on the effects of climate change and report to Congress by March 1988. The first study will examine health and environmental consequences, including effects on agriculture, forests, wetlands, human health, rivers, lakes, and estuaries, as well as other ecosystem and societal impacts. The second study will examine policy options to stabilize and reduce emissions of greenhouse gases, addressing energy efficiency, alternatives to fossil fuels, reduced uses of chlorofluorocarbons, deforestation and reforestation, and ways to reduce emissions of other greenhouse gases such as methane and nitrous oxide. Congress has appropriated $3.6 million for the studies.

EPA Estimates Impact of Sea Level Rise in Coastal United States

An EPA study estimated that a 1-to 1.5-meter rise in sea level by 2075 (theoretically possible under current projections of global warming) would destroy 50 to 90

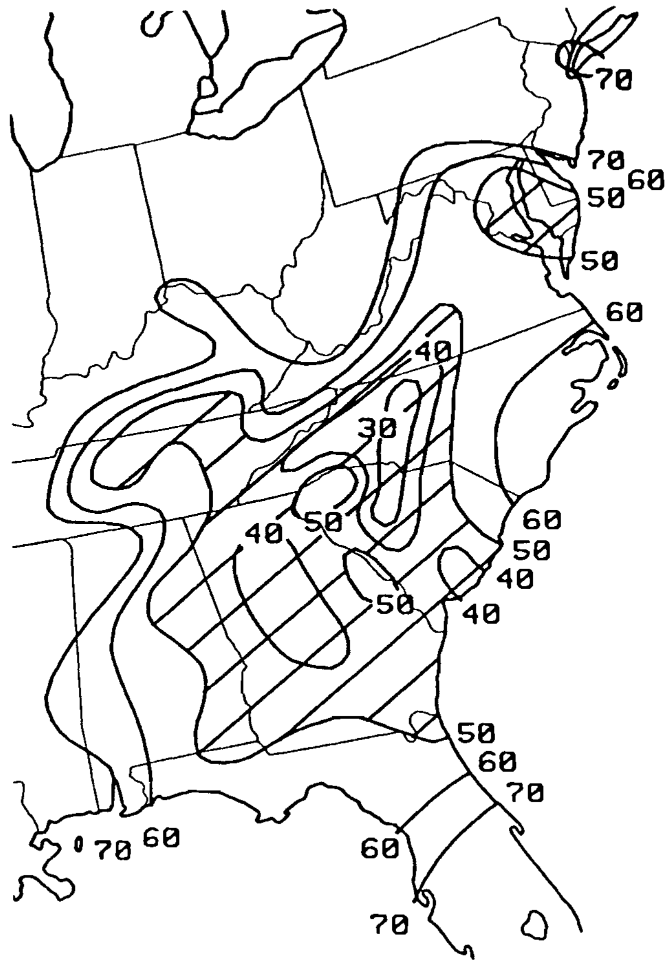


Figure 17. Percent of normal precipitation in the southeastern United States, March 30 to July 19, 1986. (NOAA/ Climate Analysis Center.)

percent of the marsh in the area of Charleston, South Carolina (Kane et al., 1986). Another EPA study, conducted jointly with the Delaware River Basin Commission, concluded that a 60-centimeter rise in global sea level would introduce excessive salt concentrations into Philadelphia's drinking water intake, as well as in aquifers in suburban New Jersey (Hull and Titus, 1986). An EPA beach erosion study (Titus et al., 1986) led the state of Maryland to shift its coastal protection strategy from groins (jetties) to pumping sand onto the beach because the latter strategy can more successfully accommodate a rise in sea level (Associated Press, 1985).

Record Drought in Southeast United States

Unusually dry conditions began in the southeast United States in December 1985, and the region grew increasingly drier, exceeding previous records over several climatic divisions. Severity of the drought by mid-July is shown in figure 17. Rain showers that covered the region during the second and third weeks of August allowed some crops to partially recover. This was the first general rain over the Southeast since mid-March.

The 1986 drought was unusual. Except for local impacts, it had essentially no effect on food prices nationally due to a large carryover from record 1985 crops and near ideal conditions for 1986 crops in the Corn Belt and West Coast states. Based on the November 10, 1986 USDA *Crop Production Report*, national corn yields for 1986 set a record of 119.3 bushels per acre compared with 118 bushels per acre in 1985, while soybean yields were only 0.3 bushels below the 1985 record of 33.8 bushels per acre.

The first hay crop was less than half the 1985 crop in Georgia and South Carolina. This, combined with the loss of summer pastures, caused farmers to face the choice of selling herds or buying and importing hay from other regions. As the shortage worsened, farmers from other regions of the United States donated hay, and railroads and private trucking lines offered to transport it to southeastern states.

Crop losses for the two hardest-hit states, South Carolina and Georgia, varied by crop, with the percent reduction in yield in the two states from 1985 to 1986 as follows: peanuts, 30 percent and 34 percent; soybeans, 20 percent and 33 percent; corn 51 percent and 29 percent; and cotton, 42 percent and 34 percent;

respectively. Tobacco yields were reduced only 9 percent. Because of acreage reductions mandated by law, total production of field crops in the southeast states was down by 50 percent.

In contrast, the broiler industry appears to have benefited from the severe drought. The region produces 53 percent of the nation's broilers, and reduced production caused by drought-related losses led to higher prices and profits for the industry as a whole.

Satellite Technology Aids Assessment of African Drought

Recent drought in Africa and its subsequent impact on food supply led to increased U.S. participation in the development of a famine early warning system (FEWS). The NOAA Assessment and Information Services Center (AISC), in support of the Agency for International Development (AID), has developed satellite technology to assist in field enumeration of yields of major grain and cash crops in the Sahel region of Africa. Results for 1985 and 1986 show useful products. Previous qualitative assessments by AISC demonstrated that the system can provide lead times of 30 days before harvest and as much as 60 to 90 days before food shortages are detected in developing countries. Regular operational cables and special assessments have been prepared for U.S. embassies and AID missions.

AISC, in cooperation with the Cooperative Institute for Applied Meteorology (CIAM) at the University of Missouri-Columbia, developed a process for transferring climate impact assessment technology to scientists in developing countries. The technology includes methods for using conventional meteorological, agricultural, and hydrological data with other information, such as remote sensing data, to produce a comprehensive assessment. Use of microcomputers enhances the development and preparation of the assessments. Training in the United States and in regional centers operated by developing countries was followed by technical assistance to individual countries. After technical seminars were presented, seminars for decision makers were provided to acquaint them with the system and its applications. The objective of the training program was to produce an assessment bulletin in each country.

Marine Assessment Technology Transferred to Developing Countries

Marine specialists in AISC developed satellite imagery for the west African shelf region to determine the feasibility of applying NOAA advanced very high resolution radiometer (AVHR) imagery to the management of west African fisheries. The fishery of that region is dependent on upwelling cells for nutrition and for life-cycle timing for reproduction. These upwelling cells can be easily identified and tracked using the AVHR data. By alerting fishermen to where the fish are feeding, fuel costs are reduced, catch per unit effort is optimized, spoilage is decreased, and fisheries managers can intervene to prevent overfishing.

Evaluation

Since the NCP began, resources committed to climate impact assessments and response planning have not changed significantly. What is significant, however, is the shift in emphasis from studies of specific effects of climate variation (e.g., on crop yields), to broader assessments of climate variation, for example, the impact of a major drought on regional crop production and, ultimately, on the regional and national economy. Satellite technology has proven practical in monitoring and assessing climate for large areas. Approaches for using this information are being tested worldwide.

At the forefront of current interest in climate and its impacts are the growing awareness and concern about future climate change caused by atmospheric warming. The quest for solutions or, more realistically, for alternative ways to respond to future climate warming, has just begun.

NATIONAL CLIMATE PROGRAM OFFICE ACTIVITIES

HIGHLIGHTS

- National Climate Program Act amended
- Western Regional Climate Center started
- Experimental climate forecast centers conduct diverse programs
- Industry use of climate forecasts studied
- Policy considerations of using climate forecasts discussed at seminar

The National Climate Program Office plans and coordinates the National Climate Program under the direction of the Climate Program Policy Board, and is assisted by an interagency working group representing federal agencies. NCPO provides funding for experimental climate forecast centers, and for regional climate centers, including the Western Regional Climate Center (WRCC), discussed below, which the President's budget has recommended for termination because they are not a core responsibility of the federal government. NCPO also cooperates with the U.S. Department of State and other federal agencies in coordinating climate-related international meetings and conferences in which the United States participates.

National Climate Program Act Amended

Amendments to the National Climate Program Act in 1986 (P.L.99-272) provide important changes in the administration of the Act. An interagency Climate Program Policy Board was established and given broad responsibilities for program planning and review. The board is directed to review all agency and department climate budget requests; to submit a report to the Office of Management and Budget (OMB) concerning these requests; and to seek the advice of users and producers of climate data, information, and services. The NCPO director is to represent the board and to serve as spokesperson for the program.

The functions of NCPO were increased by the amendments. In addition to its role as lead entity responsible for administering the program, the NCPO is directed to provide staff services for the board, review agency budget requests, and submit an analysis of the climate budget to the board. The NCPO is to coordinate interagency participation in international climate-related activities, and work with the National Academy of Sciences and other private, academic, state, and local groups in preparing and implementing the 5-year plan and the program. Section 6 of the Act, Intergovernmental Climate Programs (ICP), was repealed; however, ICP functions were retained. The effect of repealing Section 6 is to remove the requirement that states must match federal grants, and that states prepare climate plans as a condition for receiving grants for climate services and studies. (See the appendix for more information about the amendments.)

Western Regional Climate Center Started

The Western Regional Climate Center (WRCC) was officially started August 1, 1986 at the Desert Research Institute, Reno, Nevada. The service area of the center includes Arizona, California, Idaho, Nevada, New Mexico, Oregon, Utah, and Washington. Detailed planning of the center's program began with a meeting of western state climatologists. The WCC will cooperate with NOAA climate centers (NCDC and CAC) to improve dissemination of climate data to users in the West. Contacts have been made with private sector users of climate data in the West and arrangements for sharing data have been discussed.

Climate centers in the North Central and Northeast regions have developed systems to demonstrate and test the dissemination of climate data in near real-time. Research completed at the centers includes development of a method to correct mean temperature data for time-of-observation bias (Head, 1985, 1987; Karl et al.,1986c), and definition of winter temperature regimes for the Northeast (figure 18).

A regional automated weather data network (AWDN) begun in Nebraska with a grant from NCPO has been expanded to 51 stations over a 6-state area. More than 80 percent of the stations were purchased by state agencies and universities, local governments, and private sector firms. The AWDN system was queried more than 12,000 times in 1986 for climate and weather data needed by irrigators, and for crop and livestock

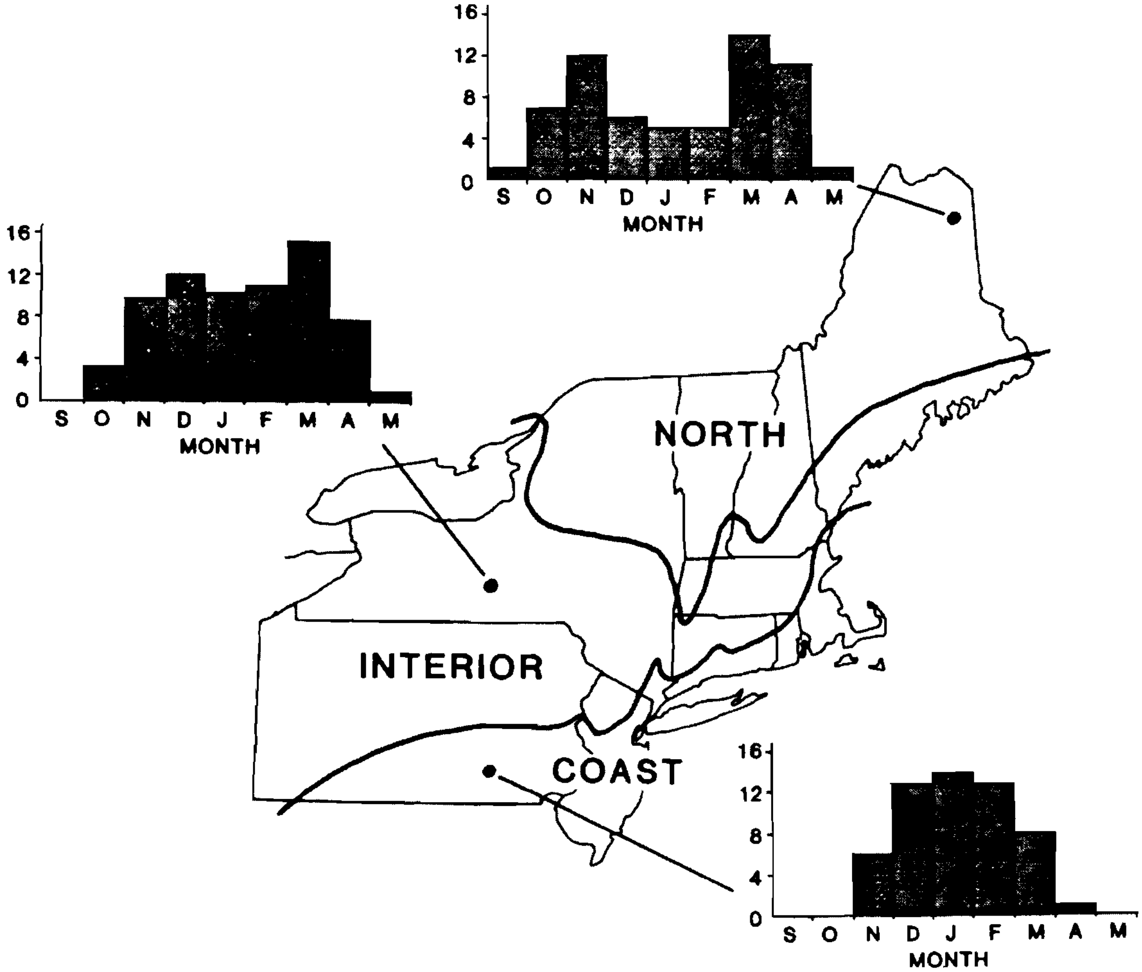


Figure 18. Three regimes of the monthly distribution of freeze-thaw days in the northeast United States. The coastal area has a single peak in January or February, the interior has double peaks in December and March, and the north has double peaks in November and March. (Schmidlin et al., 1987.)

production and marketing. Additions and improvements in the AWDN data products were made with the assistance of information obtained from users (Meyer et al., 1986).

Experimental Climate Forecasting Centers Conduct Diverse Programs

Important gains were made at the *NASA/GSFC Experimental Climate Forecast Center* in statistical-dynamical monthly prediction, diagnosis of slowly changing planetary circulation, and studies of the predictability of major weather anomalies. The most significant achievement involves analyses of forecast skill and a clear demonstration that monthly forecast skill can be obtained in practice as well as in theory. The result is important because users can realize considerable advantage if they know in advance which predictions are reliable. Several GCM experiments shed new light on the relation of boundary processes, such as surface hydrology and anomalous sea temperatures, to major heat wave and drought episodes. In particular, it was found that soil moisture processes contributed to a modest strengthening of the continental high pressure cell in a simulation of the 1980 summer heat wave in the United States. Anomalous sea surface temperatures had the opposite effect. The possible use of GCMs to forecast these events continues to be explored at the forecast center.

The *Scripps Experimental Climate Forecast Center* pursues a diverse program employing synoptic, statistical, and dynamical approaches to extend the range and accuracy of weather and climate forecasts and to better identify the reliability associated with them.

Winter air temperatures have been related to two different large-scale coherent structures in the atmospheric flow field. These features appear as alternating areas of high and low pressure over the Pacific Ocean, North America, and the Atlantic Ocean, and have typical lifetimes of 2-4 months. These atmospheric features occur with unusual strength in about 1 of 3 years. At such times the probability of making a successful forecast for much of the East and West coasts exceeds 70 percent, compared with less than 40 percent success in forecasting January temperatures for the continental United States (figure 19).

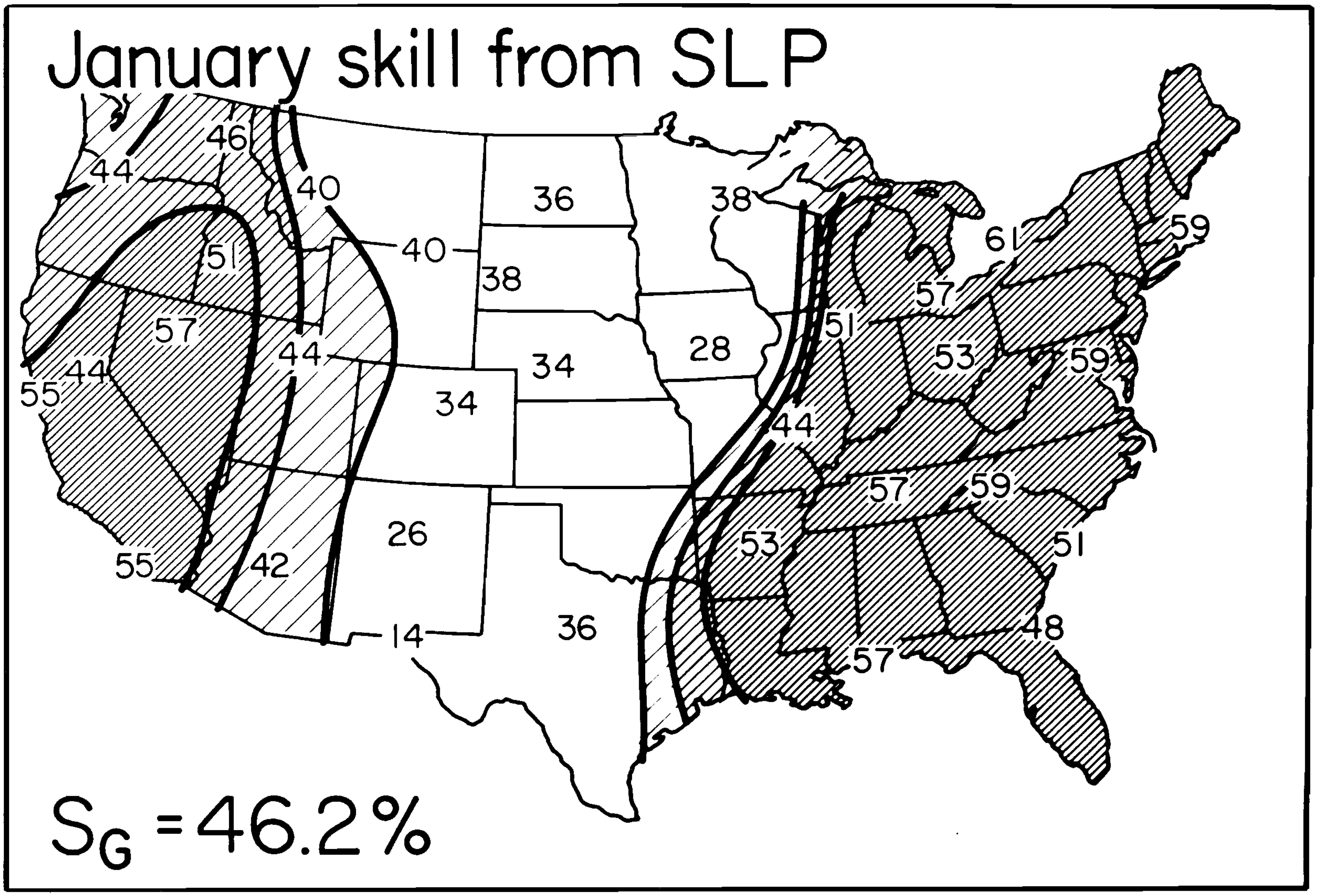


Figure 19. Skill in forecasting January air temperatures for the contiguous United States, 1930-1980 average. (Barnett and Preisendorfer, 1986.)

The study of persistence (when weather patterns tend to remain the same) lies at the heart of long-range forecasting. Preliminary studies at the Scripps Institution of Oceanography indicate that some of this persistence in the Northern Hemisphere may be related to El Nino (figure 20). In these cases, the subtropical westerlies were unusually strong over a large portion of the Northern Hemisphere, with a greatly expanded circumpolar vortex.

The past 5 years have seen a phenomenal tendency for heavy precipitation over the Western Plateau (figure 21). Among other effects, this has led to heavy springtime river runoff and very high water levels in Great Salt Lake. Researchers at the Scripps Center are exploring possibilities that these persistent regimes may result from (1) specific anomalous surface boundary conditions, as seen from sea surface temperature patterns, or (2) anomalous wind patterns. This diagnostic work will use the longest available historical surface data sets, including COADS.

Scientific activity at the *University of Washington Experimental Climate Forecast Center* focused on preparing on an optical disc a reformatted version of weather data analyzed by the National Meteorological Center. The data are NMC's twice-daily weather data from 1962 onwards. They are available to research groups through the NCAR library at cost.

Industry Use of Climate Forecasts Studied

The thermodynamic model under development at Lamont-Doherty Geological Observatory was used to make experimental monthly mean temperature forecasts for 10 months in 1986. Forecasts were then given to New York gas utility affiliates participating in the experiment so the data could be evaluated for potential use in utility operations.

Utilities use climate forecasts mainly to estimate fuel loads or needs. The forecast is used to plan for gas storage and transmission, refine spot purchase contracts, maximize sales to interruptible customers, and forecast revenues. However, at present, it is risky to use climate forecasts to plan gas distribution in response to a load forecast. If the public service agency regulating the utility does not reward the utility for taking the risk or in some manner require that the utility use climate forecasts to reduce consumer costs, there is little incentive for the utility to take the risk.

Particular applications require forecasts on different time scales. For monthly forecasts, the main concern is abnormal weather that would upset short-term load decisions. Seasonal forecasts are useful for planning the whole heating season, and to refine storage and transmission requirements.

In order to gain widespread acceptance, a climate model will have to establish a credible record and include confidence information. It is unlikely that utilities will cease to rely on climatic normals in the near future. However, a forecast that includes confidence data and is in the format requested by the utilities stands a reasonable chance of being used, along with climatic normals. The conclusions from this study are applicable to all climate models used to forecast temperature summaries a month in advance.

Policy Considerations of Using Climate Forecasts Discussed at Seminar

NCPO's 1986 Strategic Planning Seminar (SPS), "Policy Aspects of Climate Forecasting" (Krasnow, 1986), was jointly sponsored by Resources for the Future (RFF). The purpose of the seminar was to assess public policy issues arising from the prospect of usable climate forecasts (on the scale of 30 to 90 days), and their impact on agriculture, the environment, and national resource management. The seminar was timely because conditions in the Pacific Ocean were favorable for the development of an ENSO event. Progress made in understanding ENSO, especially since the 1982-83 episode, is the main source of optimism about early prospects for long-range forecasts of weather fluctuations. Less has been achieved or even attempted, however, in using knowledge about ENSO conditions or other long-range forecasts to guide planning and decision making. Potential applications can be cited, but the economic value of these forecasts is far from certain, particularly when weighed against the risk of using wrong forecasts.

The purpose of these seminars is to serve as a forum to discuss major climate issues in a policy-related context, thereby helping to improve understanding of climate processes and their impacts, and contributing to long-term plans of the climate program. The next seminar is tentatively planned to address policy issues of global climate change.

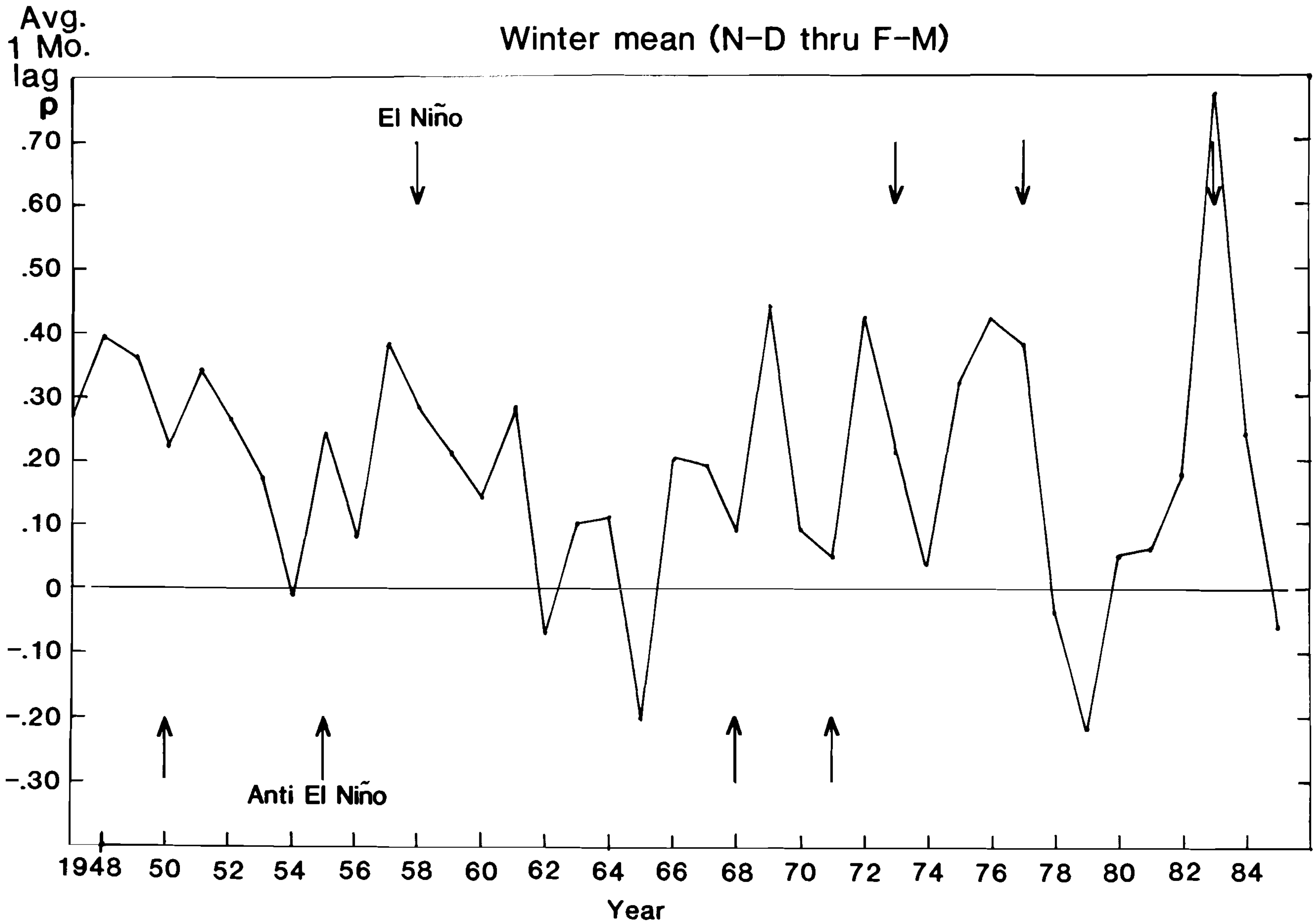


Figure 20. Correlations (p) at one-month lag of 700-mb height anomaly pattern in the North American and adjacent oceans region (30°-60°N, 30°-150°W). These are averages for the four pairs of months: November-December, December-January, January-February, and February-March. 700-mb height anomalies indicate the anomalous wind pattern at about 3 kilometers altitude, which largely determines surface weather. Major El Ninos are indicated by arrows pointing downward (on top), while anti-El Ninos are indicated by upward-pointing arrows (on bottom). These pattern correlations yield a quantitative measure of similarity between one month's wind pattern and that of the next month; a value exceeding .34 (absolute value) is statistically significant. (Namias, 1986.)

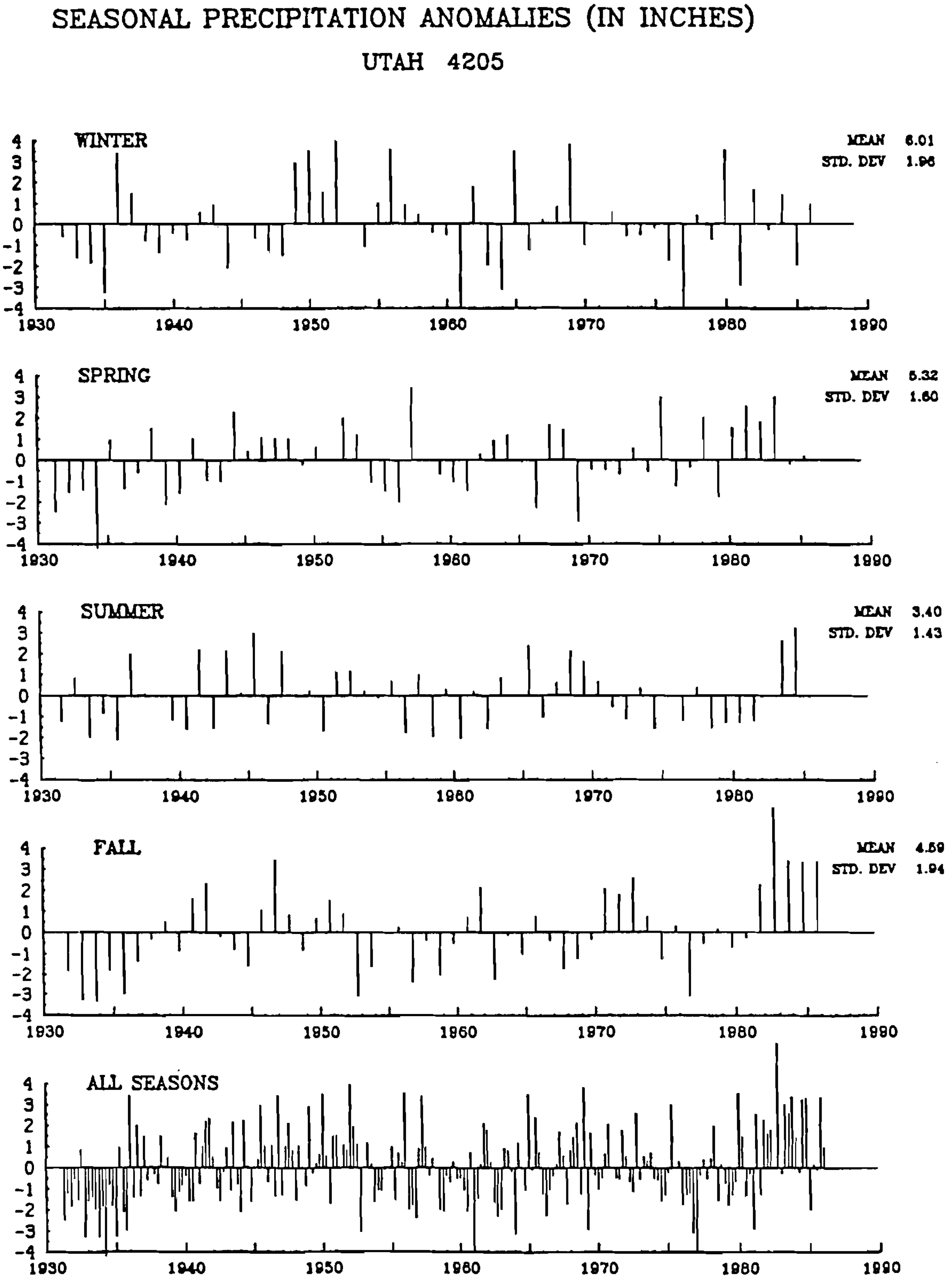


Figure 21. Seasonal precipitation anomalies for the Utah northern mountain climatological division, derived from NCDC records. Note the succession of heavy seasonal precipitation over the past 5 years and the extended dry period in the early 1930s. (Namias and Cayan, 1986.)

INTERNATIONAL ACTIVITIES

HIGHLIGHTS

- U.S. commitment to WCRP established
- EPA and UNEP hold international conference on ozone and climate
- EPA prepares ozone risk assessment
- UNEP begins negotiations to protect the ozone layer
- Research on African drought proposed
- U.S. and USSR cooperate in research on environmental change
- U.S. and PRC cooperate in atmospheric research

U.S. Commitment to WCRP Established

Three international organizations, WMO, IOC, and ICSU, convened an informal meeting in Geneva to obtain indications of commitments to the World Climate Research Program. At that meeting, the U.S. representative expressed support for the WCP goals and the U.S. intention to continue its participation in planning and carrying out global-scale climate projects, including TOGA, the International Satellite Cloud Climatology Project (ISCCP), the International Satellite Land-Surface Climatology Project (ISLCP), and WOCE. (See Appendix B for a full statement of U.S. commitments.)

EPA and UNEP Hold International Conference on Ozone and Climate

In June, EPA and the United Nations Environmental Program (UNEP) sponsored a week-long "International Conference on the Health and Environmental Effects of Ozone Modification and Climate Change." The four-volume proceedings that resulted from the conference contain 73 papers on topics ranging from the impacts of increased ultraviolet-B radiation on skin cancer, the human eye, crops and aquatic organisms; to the impacts of sea level rise on Bangladesh, Africa, and South America; to the impacts of climate change on Great Lake levels, agriculture, and mortality related to heat stress (Titus, 1986).

EPA Prepares Ozone Risk Assessment

EPA released a draft five-volume risk assessment that provides a comprehensive literature review on the expected causes and effects of ozone depletion and global climate change. The agency is on a timetable to decide by November 1987 whether to regulate emissions of chlorofluorocarbons and other substances that may deplete stratospheric ozone.

UNEP Begins Negotiations to Protect the Ozone Layer

In August 1986, the United States ratified the Vienna Convention for the Protection of the Ozone Layer. In December, negotiations began under UNEP auspices on a protocol to the Convention which would establish internationally agreed-upon measures to control ozone-depleting chemicals, principally chlorofluorocarbons. The Department of State leads the U. S. delegation to the negotiations, with the support of EPA, NASA, NOAA, and other federal agencies.

Research on African Drought Proposed

In 1979, African drought was one of the motivations for establishing climate programs here and abroad. Except for brief respites and near return to acceptable conditions in 1975 and 1978, drought has continued across much of Africa's Sahel through nearly two decades (figure 22). Today, much more is known about drought in Africa than in 1979. The World Climate Program and the supporting activities of member nations have progressed to the point where it is now possible to identify the major research and monitoring strategies needed to address critical needs for climate information.

Drought as a climatological phenomenon has been highlighted by the National Academy of Sciences as needing special attention, particularly in Africa. (See *The National Climate Program, Early Achievements and Future Directions,* NAS, 1986b.) The NCPO has called upon the expertise of a large interdisciplinary community (from the Massachussetts Institute of Technology, Illinois State Water Survey, NCAR, Florida

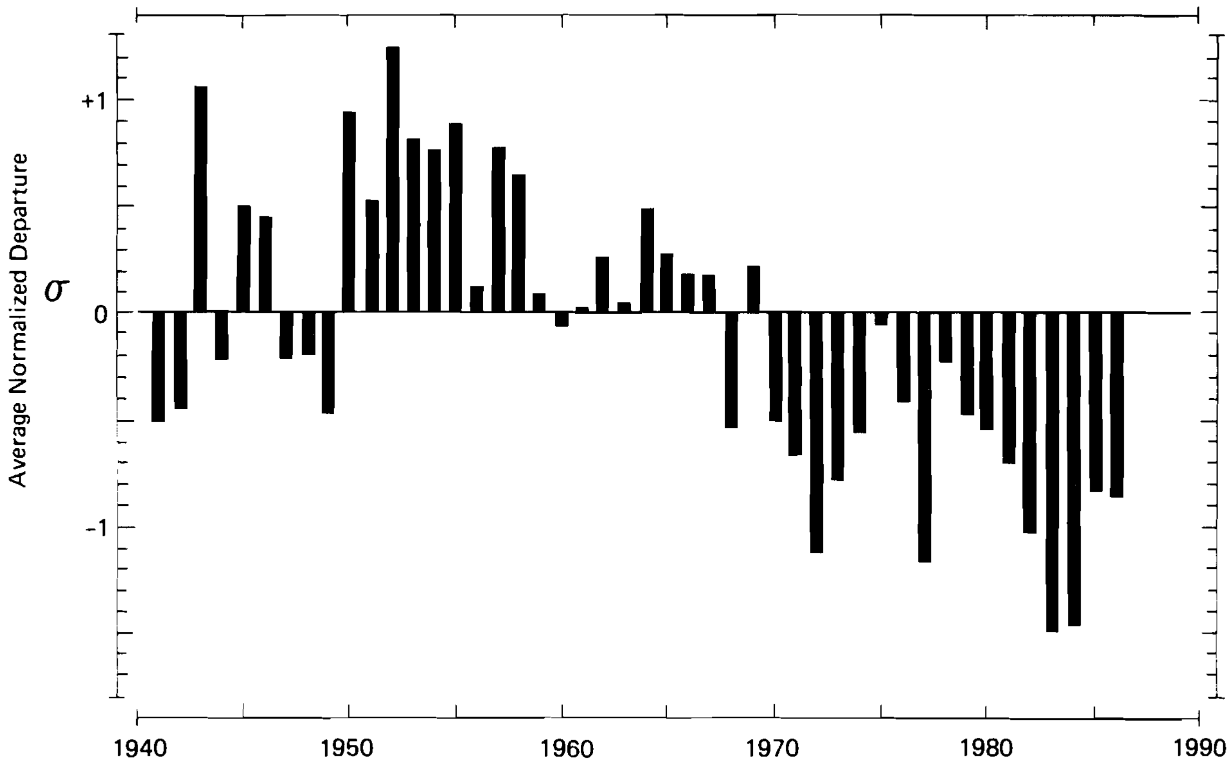


Figure 22. Rainfall index from 1941 through 1985, computed by averaging rainfall departures from normal for twenty stations in the West African Sahel. Note the downward trend in rainfall from the early and mid-1950s to the present. (Lamb 1982, 1985, 1987.)

State University and WMO; and federal agencies including NOAA, NASA, U.S. Geological Survey, Corps of Engineers, and NSF to propose a study of the River Nile catchment area, which would improve the ability to measure rainfall and river flow and develop improved hydrological forecasting methods.

A strategy for African drought research has been recommended (Sprigg et al.,1985) by a workshop organized by the NCPO and sponsored by AID. These recommendations have become the basis for steps now under way to develop joint research activities among U.S., U.K., and African scientists. Other steps being taken include proposals to bring African researchers into active participation in the WCP International Satellite Land Surface Climatology Project and to establish an international network of scientists engaged in monitoring, assessment, and prediction research relevant to African drought.

The goal of these efforts is to monitor and forecast precipitation across Africa, especially to identify drought conditions in time to assist government efforts to avoid and relieve costly socioeconomic impacts. These steps, while focusing on Africa's problems with drought, mark the start of serious efforts in the NCPO to enhance the program's ability to address drought monitoring, assessment, and prediction, including U.S. drought, more effectively.

U.S. and USSR Cooperate in Research on Environmental Change

The United States and the Soviet Union conduct cooperative research on "the influence of environmental change on climate" as part of a long-standing "Bilateral Agreement in the Field of Environmental Protection." Both the United States and the USSR recognize the importance of long- and short-term climatic variations on national economies and international trade. Future climate change caused by increasing concentrations of anthropogenic gases raises important questions regarding the environmental and societal changes that will be created. There is broad agreement that increases in global temperatures are likely to continue in the future and to exceed the normal range of natural variability over the next several decades. An important problem that must still be addressed is the prediction of regional and seasonal climate change. U.S.-USSR cooperation in the area of climate is formally conducted under four distinct projects, including: 02.08-11 (climate change); 02.08-12 (atmospheric composition and stratospheric ozone); 02.08-13 (radiative fluxes); and 02.08-14 (data management). The joint working group (WG VIII) of U.S. and Soviet scientists which conducts this research met in November 1986 in Leningrad under the co-chairmanship of A.D. Hecht (U.S.) and M.I. Budyko (USSR) and proposed significant new activities. These include the initiation of cooperative studies of stratospheric ozone depletion in Antarctica, a joint oceanographic cruise in 1987 of U.S. and USSR scientists aboard the Soviet research ship *Akademician Korolev* in the western Pacific, a workshop in 1987 in the Soviet Union on Arctic aerosols, a symposium in 1987 in the Soviet Union on solar variations and climate, and a symposium in 1988 on the "Climatic Conditions at the End of the 20th Century and the Beginning of the 21st Century."

U.S. and PRC Cooperate in Atmospheric Research

The United States and the People's Republic of China (PRC) cooperate in five areas of atmospheric research: (1) comparative studies of climates and agriculture of the North China Plain and the North American Great Plains, (2) monsoon research, (3) Tibetan plateau and mountain meteorology, (4) climate studies, and (5) torrential rains over the Yangtze River. Both countries also have exchange programs for training and education. The major participants are NOAA and NSF for the United States, and the State Meteorological Administration (SMA) for the PRC.

Activities in 1986 included joint workshops, and short- and long-term visits for cooperative research, training, and education. A cooperative summer field program, the Tibetan Plateau Meteorological Experiment-86, was carried out jointly by scientists from Colorado State University, Florida State University, and SMA near Lhasa and Naggu in Tibet. The objective was to collect data for analysis of large terrain effects on heating and subsequent air motions.

New projects on mesoscale meteorology and satellite data impacts will be added to the program in 1987. The PRC will begin by hosting seven U.S. scientists for an extended series of lectures on research, operations, and field-related aspects of the weather systems of both countries that most affect human activities.

BUDGET SUMMARY, 1980-1987

The National Climate Program Act established NCPO as the lead entity responsible for administering the program. Management functions of NCPO include planning, oversight, coordination, budgeting, program evaluation, and reporting to the Executive Branch and the U.S. Congress. NCPO compiles climate budget data from federal agencies prior to their submission to the U.S. Office of Management and Budget and prepares an analysis of the budget in terms of base programs and initiatives.

The amount and distribution, by agency, of annual program funding since the program began in 1979 is shown in table 2. Total program funding for FY 1979-1987 is shown in figure 23. In FY 1986 and 1987, spending is reduced from peak levels of FY 1984 and 1985.

A few agencies have had significant changes in their climate budgets. NASA expenditures dropped after FY 1983 as instrument acquisition for the ERBE mission was completed. DOD showed an increase of almost $6 million in FY 1986, reflecting one-time equipment upgrades at the Air Force Environmental Technical Applications Center (ETAC), NCDC, and at Global Weather Central. DOE, lead agency for carbon dioxide research, has an increase of approximately $1 million in FY 1987. EPA's budget was increased to $3.6 million for greenhouse gas assessment studies.

Table 2. National Climate Program Budget History, FY 1979-1987, by agency

($ millions)

Agency	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87 (est)
USDA	15.0	17.3	17.4	15.8	16.4	16.1	16.1	15.4	15.4
DOC	18.2	18.3	25.2	29.2	28.6	36.2	39.7	33.0	30.1
DOD	8.0	9.2	9.4	10.2	10.7	12.5	12.7	18.5	13.0
DOE	4.4	10.0	12.2	13.5	9.1	13.6	14.1	13.3	14.6
EPA	–	–	–	–	–	0.2	0.3	0.3	3.6
DOI	4.2	6.1	6.5	4.8	3.4	3.1	2.0	1.0	1.0
NASA	12.0	23.5	30.0	31.9	33.6	25.2	18.0	18.3	18.9
NSF	25.3	36.4	32.1	34.7	37.2	37.3	40.4	38.5	44.5
NCPO	*	*	*	1.0	1.1	1.1	1.1	1.9	2.1
TOTAL	88.0	120.8	133.7	141.1	140.0	145.3	144.4	140.2	143.2

* Included in DOC totals

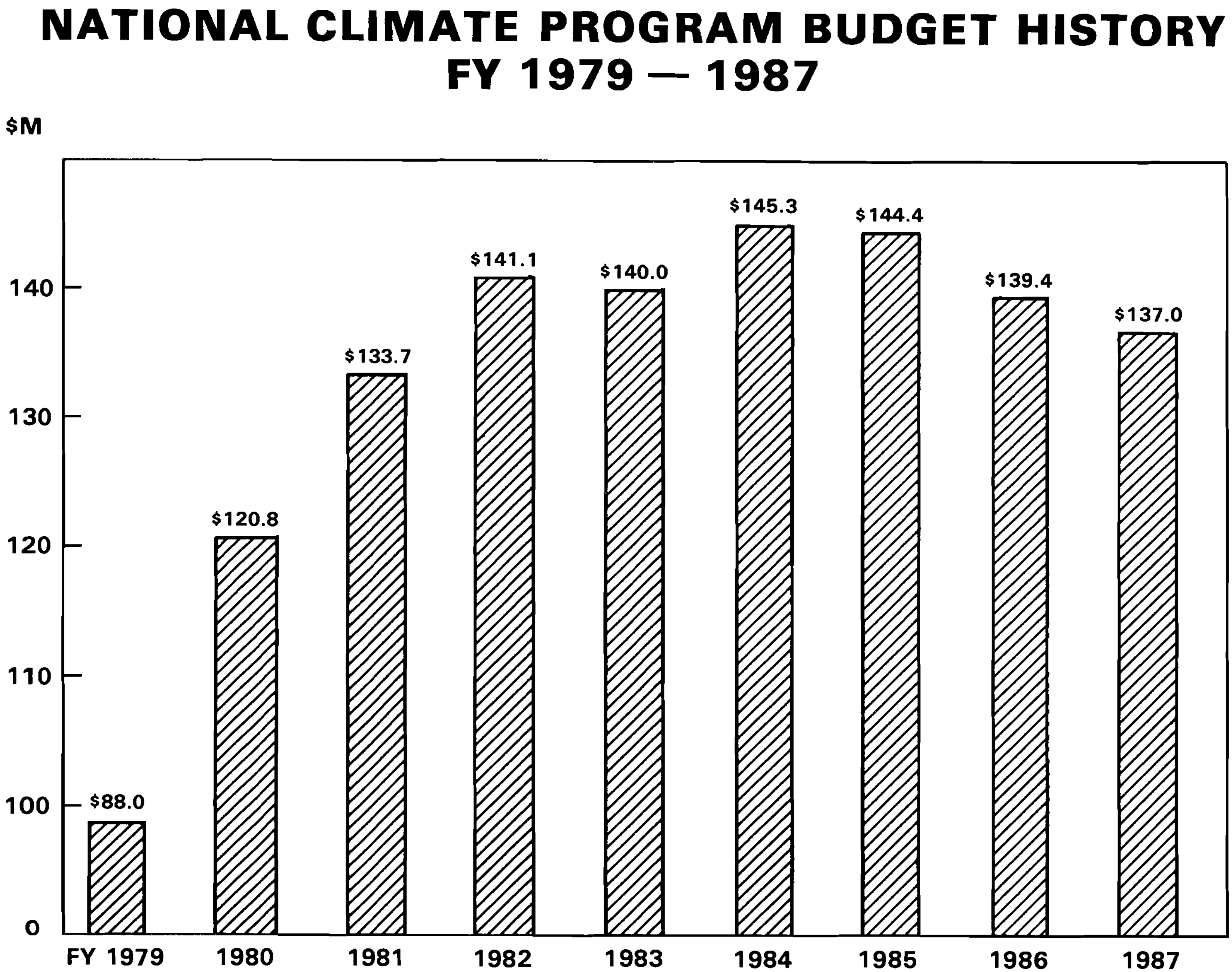


Figure 23. National Climate Program funding FY 1979 to FY 1987 (National Climate Program Office, 1987.)

REFERENCES

Ardanuy. P. E. and H. L. Kyle, 1986. El Nino and outgoing long wave radiation: observations from NIMBUS 7, ERB. *Monthly Weather Review,* Vol. 114, No. 2. pp. 415-433.

Associated Press, 1985. Doubled Erosion Seen for Ocean City, *Washington Post,* Nov. 14, 1985.

Barnett, T. P. and R. Preisendorfer, 1987. Origins and levels of monthly and seasonal forecast skills for United States surface air temperatures determined by canonical correlation analysis. *Monthly Weather Review.* In press.

Cheney, R., B. Douglas, R. Agreen, L. Miller, D. Milbert, and D. Porter, 1986. The GEOSAT altimeter mission: a milestone in satellite oceanography. EOS Transactions, Amer. Geophys. Union, Vol. 167, No. 48. (Dec. 2, 1986). pp. 1354-1355.

Hansen, J., A. Lacis, D. Rind, G. Russell, I. Fung, T. Ashcraft, S. Lebedeff, R. Ruedy, and P. Stone, 1986. The greenhouse effect: projections of global climate change. In *Effects of Changes in Stratospheric Ozone and Global Climate,* Vol. 1: *Overview.* J. G. Titus, ed., Environmental Protection Agency and United Nations Environment Program, Washington, D.C., pp. 199-218.

Head, D. E., 1985. *Mean Temperature Biases as a Function of the Time of Observation.* NCRCC Paper 6., North Central Regional Climate Center. Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL.

Head, D. E., 1987. Mean temperature biases as a function of time of observation. *Trans., Il. Acad. Sci.* In press.

Hull, C. H. J. and J. G. Titus, 1986. *Greenhouse Effect, Sea Level Rise, and Salinity in the Delaware Estuary.* Environmental Protection Agency and Delaware River Commission, Washington, D.C.

Janowiak, J. E., 1987. An investigation of annual and interannual rainfall variability in Africa. *Monthly Weather Review.* In press.

Jones, P. D., T. M. L. Wigley, and P. B. Wright, 1986. Global temperature variations, 1861 and 1984. *Nature* Vol. 332, pp. 430-434.

Kane, T. W., B. J. Baca, and M. L. Williams, 1986. *Potential Impacts of Sea Level Rise on Wetlands Around Charleston, South Carolina.* Environmental Protection Agency. Washington, D.C.

Karl, T. R. and R. W. Knight, 1986a. *Atlas of Monthly and Seasonal Precipitation Departures from Normal (1895-1984) for the Contiguous United States.* Historical Climatology Series 3-12, 13, 14, 15, National Climatic Data Center, Asheville, NC 28801.

Karl, T. R., R. W. Knight, D. S. Ezell, and F. T. Quinlan, 1986b. *Probabilities and Precipitation Required to End/Ameliorate Droughts.* Historical Climatology Series, 2-16, National Climatic Data Center, Asheville, NC 22801.

Karl, T. R., C. N. Williams, Jr., P. Y. Young, and W. M. Wendland, 1986c. A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperature for United States locations. *J. Clim. Appl. Meteor.,* Vol. 25, pp. 145-160.

Krasnow, K. (eds), 1986. *Policy Aspects of Climate Forecasting.* Proceedings of a Seminar, March 4, 1986. Resources for the Future. Washington, D.C.

Kutzbach, J. E., 1986. Model simulations of the climatic patterns during the deglaciation of North America. To appear in: *North America and Adjacent Oceans During the Deglaciations,* H. E. Wright, Jr. and W. F. Ruddiman, eds. Geology of North America publication series, Geol. Soc. Amer.

Kutzbach, J. E. and P. J. Guetter, 1986. The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18,000 years. *J. Atmos. Sci.,* Vol. 15 (Aug), pp. 1726-1759.

Lamb, P. J., 1982. Persistence of sub-Saharan drought. *Nature,* Vol. 299, pp. 46-48.

Lamb, P. J., 1985. *Zeischrift fur Gletscherkunde und Glazialgeologie,* Vol. 21, pp. 131-139.

Lamb, P. J., 1987. An essay on the development of regional climatic scenarios for policy-oriented climatic impact assessment. *Bull. Amer. Meteor. Soc.* (accepted).

McGuirk, D. E., 1986. CLICOM. A climate data management system for developing countries. Preprints, *2nd International Conference on Interactive Information and Processing Systems for Meteorolgy, Oceanography, and Hydrology,* Miami. Amer. Meteor. Soc., pp. 118-123.

Meyer, S. J., K. G. Hubbard and D.A. Wilhite, 1986. *Improving Nebraska's Near Real-Time Weather-Based Products Through User Interaction.* CAMaC Progress Report 86-4. University of Nebraska-Lincoln.

Namias, J., 1986. Persistence of flow patterns over North America and adjacent ocean sectors. *Monthly Weather Review,* Vol. 114, pp. 1368-1383.

Namias, J. and D. Cayan, 1986. Seasonal Precipitation Anomalies (fig.). Scripps Institution of Oceanography. Unpublished.

National Academy of Sciences, 1986a. *Atmospheric Climate Data. Problems and Promises.* National Academy Press. Washington, D.C.

National Academy of Sciences, 1986b. *The National Climate Program. Early Achievements and Future Directions.* National Academy Press. Washington, D.C.

Ropelewski, C. F. and M. S. Halpert, 1987. Global and regional scale precipitation patterns associated with the El Nino-Southern Oscillation (ENSO). *Monthly Weather Review.* In press.

Ropelewski, C. F. and P. D. Jones, 1987. An extension of the Tahiti-Darwin Southern Oscillation Index. *Monthly Weather Review.* In press.

Schiffer, R. A. and W. B. Rossow, 1985. ISCCP global radiance data set: a new resource for climate research. *Bul. Amer. Meteor. Soc.,* Vol. 66, pp. 1498-1505.

Schmidlin, T. W., B. E. Dethier, K. L. Eggleston, 1987. Freeze-thaw days in the Northeastern United States. *J. Clim. Appl. Meteor.,* Vol. 26, No. 1, p.5.

Sprigg, W. A. (ed.), S. Nicholson, E. Rasmusson, C. Rooth, P. Sellers, J. Shukla, and T. M. L. Wigley, 1985. *African Drought: Monitoring and Prediction.* A Report of a Workshop. University Corporation for Atmospheric Research, Boulder, CO.

Stolarkski, R. S. and A. J. Kruger, 1987. Personal communication. NASA/GSFC, Washington, D.C.

Stowe, L. L., P. P. Pellegrino, P. H. Hwang, P. K. Bhertia, T. F. Eck, C. S. Long, C. G. Wellmeyer and H-Y Mike Yeh, 1986. Spatial and temporal characteristics of global cloud cover as observed from the Nimbus-7 satellite. *Proceedings of 6th AMS Conf. on Atmos. Radiation,* Williamsburg, VA, pp. 99-102.

Takahashi, T., J. Goddard, S. Sutherland, D. W. Chipman, and C. C. Breeze, 1986. *Seasonal and Geographic Variability of Carbon Dioxide Sink/Source in the Oceanic Areas: Observations in the North and Equatorial Pacific Ocean, 1984-1986 and Global Summary.* Final Technical Report for Contract, MRETTA 19x-89675C, submitted to the Carbon Dioxide Research Division, Office of Energy Research, U.S. Department of Energy, Washington, D.C.

Titus, J. G. (ed), 1986. *Effects of Changes in Stratospheric Ozone and Global Climate.* Vol. 1: *Overview.* Vol. 2: *Stratospheric Ozone.* Vol. 3: *Climate Change.* Vol. 4: *Sea Level Rise. Proceedings of the International Conference on Health and Environmental Effects of Ozone Modification and Climate Change.* Environmental Protection Agency and United Nations Environment Program. Washington, D.C.

Titus, J. G., S. P. Leatherman, C. Everts, D. L. Kriebel, and R. E. Dean, 1986. *Impact of Sea Level Rise on the Beach at Ocean City, Maryland.* Environmental Protection Agency. Washington, D.C.

U.S. Department of Agriculture, 1986. *Crop Production Report,* November 10, 1986. U.S. Department of Agriculture, Washington, D.C.

U.S. Senate, 1986. *Ozone Depletion, The Greenhouse Effect, and Climate Change.* Hearings before the Subcommittee on Environmental Pollution, Committee on Environment and Public Works. U.S. Government Printing Office. Washington, D.C.

APPENDIX A

Summary of Amendments to the National Climate Program Act

The following are the principal amendments to the National Climate Program Act enacted in the Consolidated Omnibus Budget Reconciliation Act of 1985 (PL 99-272), Sec. 6084:

Establishment of a Climate Program Policy Board and its duties

(1) The Secretary shall establish and maintain an interagency Climate Program Policy Board, consisting of representatives of the Federal agencies specified in (the Act) and any other agencies which the Secretary determines should participate in the Program.

(2) The Board shall—

(A) be responsible for coordinated planning and progress review for the Program;

(B) review all agency and department budget requests related to climate transmitted under subsection (g)(1) and submit a report to the Office of Management and Budget concerning such budget requests;

(C) establish and maintain such interagency groups as the Board determines to be necessary to carry out its activities; and

(D) consult with and seek the advice of users and producers of climate data, information, and services to guide the Board's efforts, keeping the Director and the Congress advised of such contacts.

(3) The Board biennially shall select a Chair from among its members."

Duties of the National Climate Program Office

The Office shall—

(A) serve as the lead entity responsible for administering the program;

(B) be headed by a Director who shall represent the Climate Program Policy Board and shall be spokesperson for the program;

(C) serve as the staff for the Board and its supporting committees and working groups;

(D) review each agency budget request transmitted under subsection (g)(1) and submit an analysis of the requests to the Board for its review;

(E) be responsible for coordinating interagency participation in international climate-related activities; and

(F) work with the National Academy of Sciences and other private, academic, State, and local groups in preparing and implementing the 5-year plan [(described in subsection (d)(9)] and the program.

The analysis described in subparagraph (D) shall include an analysis of how each agency's budget request relates to the priorities and goals of the program established pursuant to this Act."

Grants and Contracts

(3) The Secretary may provide, through the Office, financial assistance, in the form of contracts or grants or cooperative agreements, for climate-related activities which are needed to meet the goals and priorities of the program set forth in the 5-year plan...if such goals and priorities are not being adequately addressed by any Federal department, agency, or instrumentality."

Intergovernmental Climate Programs (sec. 6)

"Section 5(d) (elements of NCP) is amended by... inserting...the following (from sec. 6): Such mechanisms may provide, among others, for the following State and regional services and functions: (A) studies relating to and analyses of climatic effects on agricultural production, water resources, energy needs, and other critical sectors of the economy; (B) atmospheric data collection and monitoring on a statewide and regional basis; (C) advice to regional, State, and local government agencies regarding climate-related issues; (D) information to users within the State regarding climate and climatic effects; and (E) information to the Secretary regarding the needs of persons within the States for climate-related services, information, and data. The Secretary may make annual grants to any State or group of States, which grants shall be made available to public and private educational institutions, to State agencies, and to other persons or institutions qualified to conduct climate-related studies or provide climate-related services."

'Section 6 of the National Climate Program Act is repealed."

The 5-Year Plan

The 5-Year Plan shall be revised "at least once every four years."

APPENDIX B

Contributions of the United States of America to the World Climate Research Program [1]

The United States of America fully supports the goals and objectives of WCRP and has in fact restructured its own National Climate Program to parallel the three-stream structure of the WCRP. The USA is prepared to support major elements of the program and, in fact, is focusing much of its climate-related resources on studies closely related to WCRP objectives. Current work emphasizes radiation processes, including the effects of clouds and a number of trace constituents related to human activities, a broad range of TOGA studies, and an active program of climate model development and model-based climate sensitivity studies. In addition, a substantial effort has been devoted to the planning of WOCE.

In March 1986, the USA National Weather Service and the Australian Bureau of Meteorology broke historical ground by calling attention, officially, to signs of a possible El Nino-Southern Oscillation (ENSO) episode. The fact that government agencies in two countries decided independently to issue ENSO advisories so early in a presumed cycle reflects a growing confidence that a lot has been learned about the phenomenon in recent years, yet the cautious language underscores the fact that many uncertainties in our understanding still remain. These developments are based on contributions from many countries to the observation and understanding of atmospheric and oceanic phenomena in the tropics. What brings the participants to this meeting together is the prospect of major additional advances in this as well as other aspects of the study of climate variations, and the realization that further progress will require a truly international effort.

Significant progress has been made in several areas of climate research since the beginning of the Global Atmospheric Research Program, including:

- **Climate modeling,** where a broad hierarchy of models, which range all the way to coupled general circulation models, albeit in simplified geometries, for the atmosphere and oceans, have been developed (these models are essential tools for exploring the complex interplay of feedback effects which modify the response to any direct external influence on the climate system), and
- **Radiative transfer modeling,** where a deeper understanding of the role and function of trace gases, clouds, and aerosol layers is developing, with a strong impetus from concerns about the effects of CO_2 increases and the growing realization that a number of other man-made trace gases may jointly exert a comparable influence.

These developments in modeling have been supported by:

—the measurement of significant upward trends in greenhouse trace gases, other than CO_2, as well as new data and models for tropospheric and stratospheric ozone chemical reactions.

—the development of the ERBE satellite and the ISCCP, which are providing the basis for a critical evaluation of how we can and do handle radiative transfer processes in climate models, and

—paleoclimate diagnostics, where increasingly powerful techniques are brought to bear on the question of past climates and the causes of their variability.

These and other advances provide a solid foundation for the development of the WCRP. The directions for future climate research have been laid out in the Scientific Plan for the WCRP and the WCRP Implementation Plan. The plan defines a broad scientific direction to follow. However, additional steps are required to develop a timetable of implementation, to further assess priorities, and to identify those programs which are ready for implementation and those which require further development.

One of the programs ready for implementation is TOGA. At its Seventh Session in Lisbon (March 1986), the JSC took a significant step forward in providing a framework for the international organization of TOGA by giving a clear definition of the roles of the various scientific and management bodies related to TOGA. The terms of the agreements between the JSC, JPS, and the TOGA SSG offer a workable formula for the imple-

[1] Statement by U.S. representative at the first informal commitments meeting of the World Climate Research Program, Geneva, Switzerland, May 1986.

mentation of this program. However, in order to implement the program, we see a need for the establishment of an international board, to be made up of representatives of countries and multinational organizations which intend to make substantial contributions to the program. We invite this meeting to consider the possible terms of reference for this board and recommend that it be established by the WMO Executive Council. It is essential that this board meet as soon as possible to establish national commitments to this program.

In addition, the USA is prepared to continue its support of the ISCCP and planning for the land surface climatology project. We also plan to work with other countries to continue the scientific and implementation planning for WOCE. In particular, activities for the next year will include close cooperation with the WOCE International Planning Office in designing management and engineering activities for float measurements, preparing specifications for the implementation of a global tracer and hydrographic survey for WOCE (including the possible use of a dedicated ship), and planning for air-sea interaction and gyre dynamics observations.

In contrast to the GARP experiments, which were organized around special observing periods of limited duration, the WCRP gives highest priority to consistent long time series of global data. For this reason, the program relies heavily on existing operational programs, such as WWW and IGOSS, which provide systematic observations of the atmosphere and ocean. The USA is prepared to do its part to support the long-term maintenance and upgrading of these basic systems, which are essential for the success of all elements of the WCRP.

I would like to draw attention to a recent meeting on global warming, held in Villach, Austria, and in particular to the consensus that the problem of climatic response to changes in CO_2 must be broadened to include a range of radiatively important trace gases. The emitting of trace gases such as chlorofluoromethanes, which are greenhouse gases but also chemically active, introduces a new dimension for climate change. The projection of future climate now depends on information on the sources of these other trace gases and their potential chemical reactions in the atmosphere. This suggests that WCRP should pay increased attention to the interaction of atmospheric chemistry and climate.

The full implementation of WCRP is possible only with broad international cooperation. It depends on significant contributions of resources from many WMO and IOC member states. Much needs to be done and no nation can do it alone. Yet, the potential benefit for all participating countries could be enormous, as we learn to use climate information and prediction for societal purposes.

Ongoing work towards cooperative efforts with other countries includes the following:

—maintenance of observational systems in the tropical Pacific for TOGA, including specific items requested in the implementation plan,

—maintenance of the Global Sea Surface Temperature Data Center at the Climate Analysis Center of the National Weather Service,

—maintenance of the Tropical Sea Level Center at the University of Hawaii,

—creation of a Geostationary Satellite Precipitation Data Center at the Climate Analysis Center of the National Weather Service.

—prediction of climate events on weekly to monthly time scales at the National Meteorological Center and the Geophysical Fluid Dynamics Laboratory,

—continuation of ISCCP data collection and processing and publication of the 5-year cloud data atlas. (Furthermore, a strong research program in cloud-radiation processes will be supported to assist in interpreting and using ISCCP data sets for climate model development and validation; the First ISCCP Regional Experiment began in April 1986 and will run for 15 years.),

—maintenance of the observational network for measuring ozone and greenhouse gases in the atmosphere and initiation of research and modeling of chemical changes of radiatively important trace species,

—continued participation in the scientific planning for WOCE and launch of the TOPEX/POSEIDON satellite in the early 1990s (subject to final approval),

—conduct of research on land-climate interactions, as outlined by ISLCCP, in order to establish the basis for assembling appropriate global data sets [including the First ISLCCP Field Experiment (FIRE), analysis of existing data sets, and development of the requisite theoretical basis],

—continued development of a hierarchy of climate models, including coupled atmosphere-land-ocean models.

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