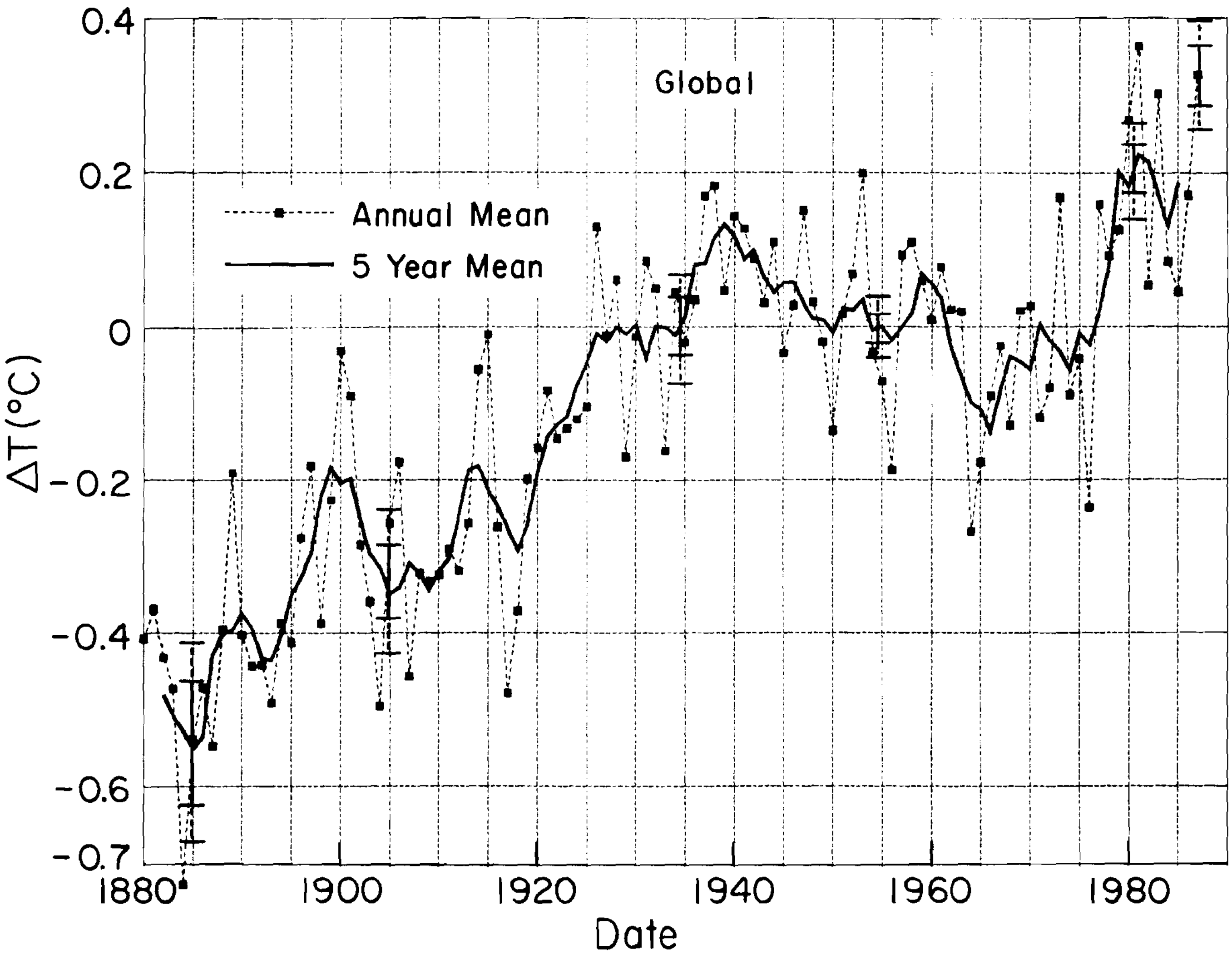
PN-ABJ-444

1987 Annual Report

National Climate Program



1980's WARMEST DECADE OF RECORD

Cover: The record of global surface air temperature for the past century shows that the decade of the 1980's was significantly warmer than any previous period of record (Hansen and Lebedeff, 1988). The dots are the annual mean temperatures. The thick line shows the running mean temperature, averaged for 5 years centered on the plotted year. Uncertainty bars (95 percent confidence limits) are shown for both the annual mean (outer bars) and the 5-year mean (inner bars).

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NATIONAL CLIMATE PROGRAM ANNUAL REPORT 1987

December 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 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
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ACRONYMS

ACRIM	Active cavity radiometer irradiance monitor
AFOS	Automation of field operations and services
AID	Agency for International Development
ARL	Air Resources Laboratory
AVHRR	Advanced very high resolution radiometer
CAC	Climate Analysis Center
CCM	Community climate model
CD	Climate Division
CLICOM	Climate computer system
CME	Community modeling effort
CRF	Cloud radiative forcing
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
EEC	European Economic Community
ENSO	El Nino-Southern Oscillation
EPA	Environmental Protection Agency
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
FIFE	First ISLSCP Field Experiment
FIRE	First ISCCP Regional Experiment
FNOC	Fleet Numerical Oceanography Center
FY	Fiscal year
GCM	Global circulation model
GEOSAT	Geodetic satellite
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
GLA	Goddard Laboratory for Atmospheres
GMS	Japanese Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
HCN	Historical climatology network
HIRS2	High resolution infrared sounder, second generation
ICMSSR	Interdepartmental Committee for Meteorological Services and Supporting Research
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IR	Infrared
INSAT	Indian Satellite
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land-Surface Climatology Project
ITPO	International TOGA Project Office

ACRONYMS—Continued

JAWF	Joint Agricultural Weather Facility
MCSST	Multi-channel sea surface temperature
METEOSAT	European Meteorological Satellite
MSU	Microwave scanning unit
NAE	National Academy of Engineering
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
NRC	National Research Council
NSF	National Science Foundation
NWS	National Weather Service
OECD	Organization for Economic Cooperation and Development
OLR	Outgoing longwave radiation
PMEL	Pacific Marine Environmental Laboratory
PNA	Pacific North America
PRC	Peoples Republic of China
QBO	Quasibiannual oscillation
SAGE	Stratospheric and Aerosol Gas Experiment
SBUV	Solar backscatter ultraviolet
SEASAT	Meteorological and oceanographic research satellite
SMM	Solar Maximum Mission
SO	Southern Oscillation
SOI	Southern Oscillation index
SOLRAD	Surface solar radiation network
SSC	Science steering committee
SST	Sea surface temperature
TOGA	Tropical Oceans and Global Atmosphere
TOMS	Total ozone mapping spectrometer
TOPEX	Topographic Experiment
UCLA	University of California, Los Angeles
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
UN	United Nations
UNEP	United Nations Environmental Program
US	United States

ACRONYMS—Continued

USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USSR	Union of Soviet Socialist Republics
WAOB	World Agriculture Outlook Board
WCB	Weekly Climate Bulletin
WCP	World Climate Program
WCRP	World Climate Research Program
WHP	WOCE Hydrographic Program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WRI	World Resources Institute
XBT	Expendable bathythermograph

CONTENTS

INTRODUCTION

The strategy of the National Climate Program (NCP) 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 of 1978. 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 prepared for 1988-1992. The new plan increases the emphasis on climate services, risk assessment, and application of climate information in decision-making. The NCP is organized into three areas with the following objectives:

Climate Data, Analysis 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.

Climate Modeling and Prediction. Advance the basic understanding of the climate system on the time scale of months to decades, and coordinate the National Climate Program with international programs on global climate change.

Climate Change and Environmental Impacts. Improve understanding of climate impact on society and identification of response strategies to climate change.

In compliance with the Act, this annual report for 1987 describes the year's major activities, including an evaluation of progress toward program objectives. Information for 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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I ADMINISTRATIVE REPORT

State of the Climate, 1987

Global average surface temperatures for the 1980's were the warmest for the entire historic record (see cover). Three separate investigating teams reported similar results (Angell, 1988; Hansen, 1988; Jones, 1988). The strength of the warming seems largely driven by above-average temperatures in the southern oceans. In fact, southern ocean temperatures were the warmest for the past 100 years.

Although 1987 was also an El Nino year, in which tropical surface waters were warmer than average, investigators studying surface temperature change suggest that the El Nino warming was in itself insufficient to cause a global warming. Perhaps of greater significance is the observation that surface temperature warming was greater in polar regions than in low latitudes, a result predicted by numerical and theoretical models of greenhouse warming.

1987 was also a year in which continued measurement of ozone thickness over Antarctica showed significant further decreases. The stratospheric ozone layer, i.e., the so-called ozone "hole," which appears each year during the austral spring (Sept.-Nov.), dropped to its lowest level since recording began in 1984.

Global Climate Protection Act Passed

The Global Climate Protection Act of 1987 (P.L. 100-367) stipulates U.S. goals for climate protection and creates a process to establish U.S. policy in conjunction with the United Nations (UN) and other international organizations.

The Environmental Protection Agency (EPA) is charged with responsibility for implementing provisions of the Act, including preparation of a report to Congress. The State Department (DOS) must estimate the extent of international understanding of the greenhouse effect and its consequences, assess international cooperation to limit global climate change, and prepare strategies necessary for further international cooperation for limiting global climate change.

The report must be submitted to Congress 24 months after enactment (December 1989). The Act further directs the President to give the problem of climate protection a high priority on the agenda of United States-USSR relations.

International Activities

International Meetings Related to Greenhouse Gas-Induced Climatic Change

Numerous international meetings focusing on the greenhouse gas issue were held in 1987. Major meetings include:

Development of Policies to Respond to Climate Change, A two-stage workshop organized by the International Seijer Institute, cosponsored by UNEP and the Rockefeller Brothers Foundation. The first workshop was held in Villach, Austria, October 1987 to discuss technically feasible options for averting or adapting to climate change. The second workshop was held in Bellagio, Italy, November 1987, to map out a new management option.

European Workshop on Bioclimatic and Land Use Changes, Organized by the Netherlands and cosponsored by UNEP and the European Economic Community (EEC), Netherlands, October 1987. As a follow-up to this workshop, UNEP is planning a series of workshops on the implications of future climate change in Africa.

First North American Conference on Preparing for Climatic Change, organized by the Climate Institute and the U.S. National Climate Program Office, Washington, DC, October 1987 (Climate Institute, 1988).

The Montreal Protocol on Ozone. In September 1987, representatives of twenty-three nations meeting in Montreal, Canada, signed an agreement to reduce the consumption of chlorofluorocarbons to 50 percent of 1986 levels by 1999, and to freeze the consumption of certain halons at 1986 levels starting 3 years after the treaty is in force. The treaty will take effect in 1988 if at least 11 nations ratify it. As of March 1988, thirty-one nations have signed the treaty, and two have ratified it. By the end of 1988, it is expected that enough nations will have ratified the treaty to put it into effect. The signing of the Montreal Protocol was a major historical event, being the first time an international agreement has been reached on reducing harmful environmental effects caused by anthropogenic activities.

WMO and UNEP Establish Intergovernmental Panel to Deal With Greenhouse-Climate Issues

Both the WMO and UNEP have agreed to establish an intergovernmental panel to coordinate and oversee international assessment of climate change and its impact on society. These activities represent the first step toward consideration of possible international responses to future climate change. This important decision lays the foundation for an international review of climate change and its impact on environmental and social systems. The United States, through the National Climate Program, will coordinate U.S. participation in these international reviews.

WMO Congress Adopts Resolution on Climate Change

Both WMO and UNEP have identified the issue of global change as having major priority in their long-term plans. UNEP is committed to taking the lead in assessing the impact of climate change on society. The WMO at their Congress in June 1987 approved a resolution on Global Climate Change which states that the WMO, through the World Climate Research Program (WCRP), has the mandate and "responsibility to provide Members (of WMO) with state of the art projections of long-term changes in the global climate."

The combined activities of WMO and UNEP, in focusing the existing World Climate Program (WCP) on global climate change and in creating an intergovernmental panel, are laying the foundation for an orderly intergovernmental process to understand and assess the impact of future climate change. The organization of the U.S. National Climate Program in accord with the WCP ensures the maximum coordination of national and international efforts.

Second World Climate Conference Planned

At the tenth WMO Congress (1987) and the subsequent meeting of the WMO Executive Council, it was agreed that the time is ripe for WMO to organize, in cooperation with UNEP, ICSU, and other international organizations, a Second World Climate Conference. It was also agreed that this conference, tentatively being planned to be held in 1990, should review all aspects of the World Climate Program, with emphasis on climate applications, especially in developing countries, and also provide a status report on the scientific understanding of climatic change. Further, it was suggested that the organizing committee for the conference should examine the feasibility of inviting ministers to the conference and study the benefits of holding the conference on an integovernmental level.

US-USSR Agreement on Climate and Ozone Protection

The President of the United States and the General Secretary of the USSR agreed at their summit meeting in December 1987 to highlight joint studies of climate and ozone changes. The joint communique said:

"The two leaders approved a bilateral initiative to pursue joint studies in global climate and environmental change through cooperation in areas of mutual concern, such as protection and conservation of stratospheric ozone and through increased data exchanges, pursuant to the U.S.-Soviet Environmental Protection Agreement and the Agreement Between the U.S. and the USSR Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes. In this context, there will be a detailed study of the climate of the future. The two sides will continue to promote broad international and bilateral cooperation in the increasingly important area of global climate and environmental change."

U.S.-USSR activities in 1987 and in 1988 will be focused to implement the specific protocol for 1987 and to begin the joint climate report in 1988.

Organization for Economic Cooperation and Development (OECD) Begins Study of Response Strategies to Climatic Change

In December 1987, a workshop on global climate change was held in Washington, D.C. with representatives from the following OECD members: Australia, Canada, the Netherlands, Norway, Sweden, Switzerland, United Kingdom, United States, and the European Economic Community (EEC).

The workshop was based on the concern that OECD member countries are likely to be affected economically, politically, and environmentally by greenhouse-gas induced climatic change. These countries are important energy users and develop advanced technologies for energy production thereby having a strong influence on future emissions of carbon dioxide. OECD countries also influence future economic development and the environmental character of developing countries.

The workshop concluded that the OECD could contribute to the World Climate Program and to the process of developing information on the climate change issue. Two classes of activities were identified for consideration by the OECD environment committee:

- Environmental and socioeconomic impacts of global change on OECD countries.
- Analysis of energy programs, environmental consequences, and economic policy.

Specific work plans will be developed in 1988.

New Bilateral Agreements With the People's Republic of China (PRC)

On August 19, 1987, the Department of Energy and the Academia Sinica of the PRC signed an agreement for joint research on carbon dioxide and climate change. An agreement for the study of environmental pollution and climate change also was signed between the EPA and its counterpart PRC agency. Both agreements complement the agreement between NOAA and the State Meteorological Agency of China (PRC) which has been in existence for a number of years.

U.S.-Canada Climate Programs Agree to Study Impact of Climate Change on Great Lakes

Formal cooperation between the United States and Canadian climate programs will begin with a joint workshop on climate change and its impact on the Great Lakes, September 27-29, in Chicago, Illinois. The workshop is being coordinated with a regional EPA study and with other ongoing Great Lakes activities. The workshop also will serve as a basis for defining future U.S.-Canada cooperation in climate research.

International TOGA Project Office (ITPO) Moves to Geneva

In August 1987 the ITPO was relocated from Boulder, Colorado to WMO headquarters in Geneva, Switzerland. The ITPO was established in 1984 as part of the U.S. contribution to the International Tropical Oceans and Global Atmospheres (TOGA) Program. John Marsh, of the UK, is the new Director of ITPO.

International TOGA Data Centers Established

The extensive data collecting activities of the TOGA program have been organized into a number of centers. International contributors to this activity are summarized below:

Center	Status	Location
Tropical Upper Air Wind Climatology	Planned	India
Global Precipitation Climatology	Planned	United States, Federal Republic of Germany
TOGA Marine Climatology	Operational	United Kingdom
Global Sea Surface Temperature	Operational	United States
Tropical Sea Level	Operational	United States
Tropical Ocean Subsurface	Operational	France

The centers are required to provide complete, quality-controlled data sets to meet the needs of TOGA researchers.

Climate and Global Change: Evolving U.S. and International Programs

Two areas of scientific interest in the United States, climate and global change, have international counterparts in, respectively, the World Climate Program (WCP) and the International Geosphere-Biosphere Program (IGBP). Although the two scientific areas address different problems, opportunities have begun to appear for close and mutually beneficial cooperation between them, both nationally and internationally.

Climate Programs

The World Climate Program (WCP) was established jointly in 1978 by the World Meteorological Organization (WMO), the United Nations Environmental Program (UNEP), and the International Council of Scientific Unions (ICSU). U.S. scientists participated in the development of the WCP in order to ensure that the program would take into account the requirements of the United States, not least with regard to the planning of global observational experiments and climate monitoring.

Since its establishment, the WCP has undergone a rapid development. Well-defined objectives and plans of action for their implementation were formulated at an early stage, and activities have been initiated within four areas: data, research, applications, and impact studies.

The U.S. National Climate Program (NCP) also was established in 1978. The NCP has been structured around three areas of work—data, climate research, and applied studies and impacts. Coordination of the NCP is vested in one body, the interagency Climate Program Policy Board.

Global Change Programs

The IGBP - A Study of Global Change, was established 1986 by ICSU, a nongovernmental international organization. IGBP aims at describing and understanding the interaction of physical, chemical, and biological processes that regulate the earth systems. It is much broader in scope than the WCP. However, it has been stated that the IGBP will be focused on processes which are not addressed by other existing programs.

In 1987, the ICSU Special Committee in IGBP decided on a number of initial priority problem areas that need further study to help develop the future research program, namely:

- Terrestrial biospheric-atmospheric chemistry interactions
- Marine biospheric-atmospheric interactions
- Biospheric aspects of the hydrological cycle
- Effects of climate change on terrestrial ecosystems

United States participation in the IGBP is coordinated by the National Academy of Sciences (NAS) through its Committee on Global Change which also will serve as the National Committee in IGBP. In addition, three federal agencies are planning research and observational programs related to the IGBP.

- NSF has initiated a multidisciplinary program called Global Geosciences. Its central goal is to understand how the earth functions as a system of interrelated processes, and to establish major cause- and -effect relationships within and between the climate system, biogeochemical cycles, and tectonic activity, all operating within the atmosphere, oceans, biosphere, and solid earth.
- NASA's Scientific Advisory Council developed a proposal for a national program to study global change called The Earth Science System. Its goal is to obtain a scientific understanding of the entire earth system by describing how its component parts and their interactions have evolved, how they function, and how they are expected to continue to evolve.
- NOAA is examining opportunities to establish a national information service based on reliable assessments, and quantitative predictions of changing global climate.

Precise definition of the U.S. Global Change Program and its interactions with the U.S. National Climate Program and the World Climate Program are being addressed by the NAS Committee on Global Change and relevant federal agencies.

Summary of NCPO Activities

Preparation of New 5-Year Plan

NCPO staff, working with the principal agencies involved in the program, has drafted a proposed new 5-year plan for the National Climate Program. During the course of the year, NCPO staff visited each agency and integrated planned agency activities into the new plan. The final plan will be issued shortly.

WMO-UNEP Intergovernmental Panel

NCPO reviewed the WMO-UNEP long-term plan for climate studies and helped formulate the concept of an intergovernmental panel. Both WMO and UNEP approved the creation of this panel at their executive committee and governing council meetings. U.S. government review was coordinated by the State Department.

US-USSR Bilateral on Environmental Protection

The NCPO led an interagency delegation to the 12th meeting of Working Group VIII of the Environmental Agreement, at the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey. The meeting resulted in plans for cooperating in climate, ozone studies, and atmospheric chemistry for 1988. Activities of the Environmental Agreement were recognized in the joint communique of President Reagan and General Secretary Gorbachev, in December 1987 (see page 4).

Congressional Hearings on National Climate Program

The Director of NCPO reported on NCP activities to the House Subcommittee on Science and Technology, July 23, 1987. The chairman of the Climate Program Policy Board, Dr. E.W. Bierly (NSF), testified at the same hearings.

Summary of NCP Climate Policy Board Activities

The board met in March, July, and October. Major items brought before the Board included:

Review of On-Going Climate Impact Analyses Activities and Discussion of the Second 5-Year Plan

At the March meeting, Dr. Alan Malinauskas, Acting Head of the Canadian Climate Program, Jesse Ausubel of the Rockefeller Foundation and the National Academy of Engineering (NAE), and Dr. Pierre Crosson of Resources for the Future (RFF) discussed the role of impact assessment studies in the NCP.

Organization of NCP Activities Related to Greenhouse Climate Change (June and October Meetings)

The board debated and approved the formulation of the U.S. position on the WMO-UNEP intergovernmental panel, approved by the two organizations in May and June, 1987. The board also discussed organization of the Second World Climate Conference, to be held in 1990. Board Chairman, Dr. E.W. Bierly, represented the United States at an intergovernmental meeting to discuss this conference. An ad hoc working group chaired by the NCPO director was organized to assist in planning the conference.

II TECHNICAL REPORT AND HIGHLIGHTS OF NCP ACTIVITIES

Climate Data, Analysis and Services

Earth Radiation Budget Experiment Aids Climate Studies

The Earth Radiation Budget Experiment (ERBE) continued observations of the earth from instruments on three satellites. The first of these is the earth radiation budget satellite (ERBS), launched October 5, 1984, by space shuttle Challenger. The second is the NOAA-9 satellite, launched December 12, 1984. A third satellite, NOAA-10, launched September 12, 1986, also carries a set of ERBE instruments.

ERBE observations have been useful to climate studies for several reasons. Most important is the solar constant measured by an ERBE instrument. This irradiance is measured to be 1365 W/m^2 with a certainty of better than 0.2 percent. This is in close agreement with other satellite measurements, such as those on the Nimbus-7 , and ACRIM measurements from the solar maximum mission (SMM). The scientific community has been interested in the possible decline in solar output since 1978. The ERBE measurements are consistent with this suggestion from Nimbus-7 ERB and from SMM. In addition, there appears to be a suggestion that the solar output may have begun an upturn.

ERBE also provides observations of the fluxes of reflected sunlight and emitted thermal energy from the earth and the atmosphere. These fluxes are fundamental climate parameters, since they determine the sources and sinks of energy that drive the climate system. The multisatellite ERBE is nearing the end of validation. Archiving of the instantaneous calibrated measurements and the top-of-the-atmosphere fluxes began in December 1987, with ERBS data for April 1985. Archiving of monthly averaged fluxes is expected to begin in the spring of 1988.

Global Earth-Observing System Close to Being Realized

The International Satellite Cloud Climatology Project (ISCCP) entered its fifth year of operational data collection in July 1987. Significant achievements in the analysis of these data were the resolution of radiometer calibration problems, final testing and refinement of the analysis methods, initiation of operational production of cloud analyses, and the beginning of research using the cloud analyses.

Data quality was significantly improved by the launch of a replacement GOES-WEST and a second polar orbiting satellite during the year. The former restores the four-satellite coverage of lower latitudes and the latter can provide additional coverage over the Indian sector.

Monitoring the calibration of the polar orbiting radiometers has become crucial to climate research, since continuous, long-term (almost 10 years) global data sets obtained from this series of satellites are now being analyzed. The ISCCP now performs a set of data comparisons that provides a reference calibration over the whole ISCCP data record (since 1983). This calibration was transferred from one polar orbiter to another in the series for the first time, enabling the extension of global climate analyses, based on these data, to much longer time periods.

Final tests of the cloud analysis method were conducted by initiating operational cloud data production, examining the internal consistency of the results, and comparing the retrieved parameter values to measurements from other systems. The first 2 months of operational results, July 1983 and January 1984, were distributed to over sixty scientists, worldwide. Research using these data was reported at three international meetings.

With all of the components of the ISCCP processing now operational, it represents the first comprehensive, global, multisatellite data collection, processing, and quantitative analysis system ever established. The system uses correlative data sets (some from satellites and some from surface observations) in addition to the satellite images.

Figure 1 shows monthly mean cloud amount distribution over the globe for July 1983 and January 1984. It illustrates that global cloud cover is formed over extensive regions of very high and very low cloud amount, with intermediate cloud transitions between the two. The largest seasonal variations of cloud amount are associated with shifts in latitude of the tropical and midlatitude storm zones (regions of high cloud amount). The close association of the midlatitude storms with the oceans is also apparent.

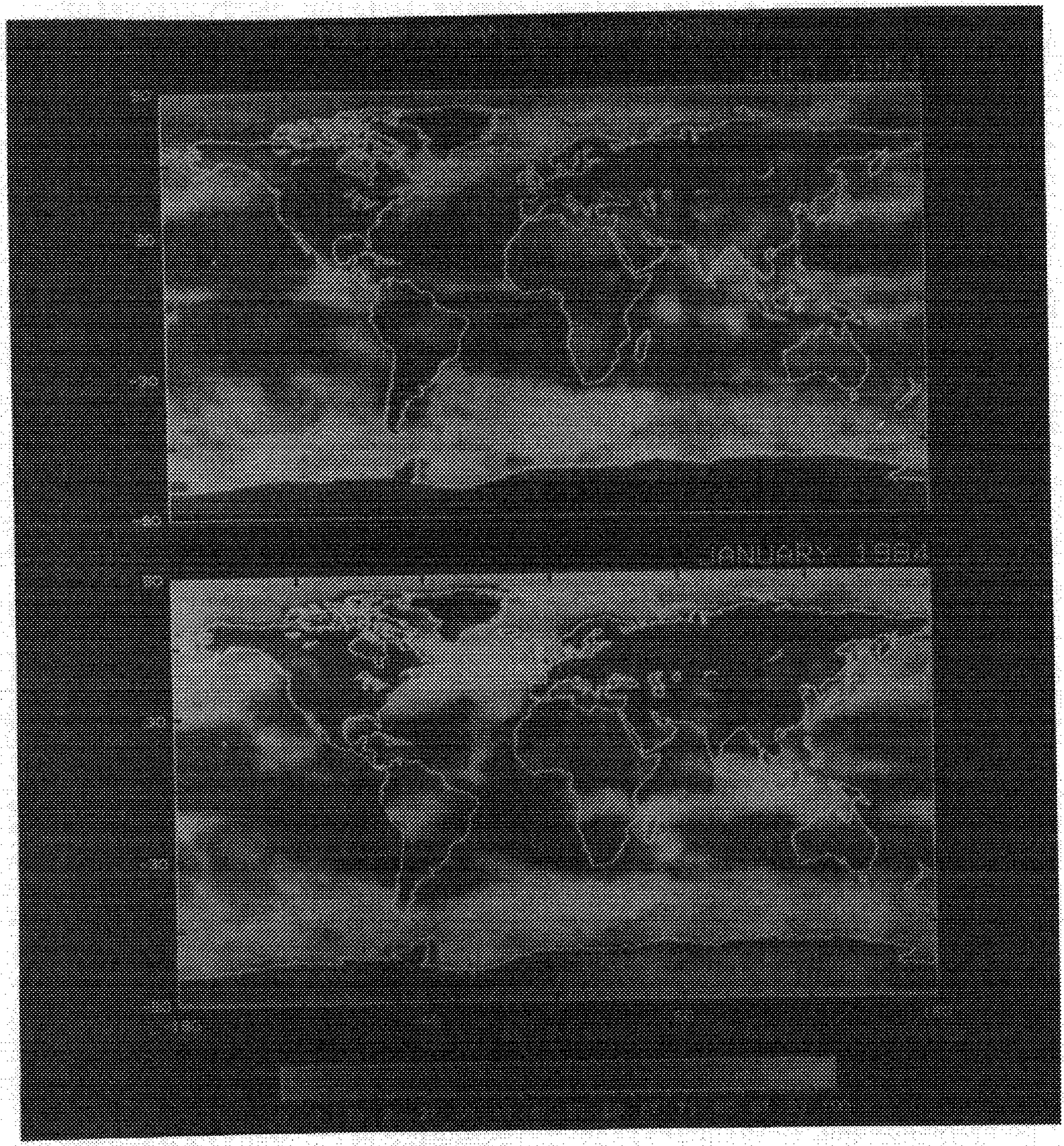


Figure 1. Monthly mean cloud amount distribution over the globe for July 1983 and January 1984. (NASA/GISS.)

Several important findings from these studies are: (1) The cloud cover over the oceans is about 10 percent greater than inferred from earlier observations (this has been confirmed by a more recent analysis of surface observations), giving a somewhat higher global mean cloud amount. The change results from better observations of remote locations, particularly the southern oceans, providing a direct illustration of the value of satellite observations of the Earth. (2) Much of the "extra" oceanic cloud cover is very low altitude cloudiness; however, the amount of thin, high cloudiness (cirrus), over both land and ocean, seems to be higher than implied by most earlier data (early FIRE results seem consistent with this). (3) Although clouds are highly variable on small scales, the larger variation of cloudiness, seen in the figure, is associated with variations on spatial scales greater than 30-100 km and time scales of 1-3 days.

Comparisons of the ISCCP with several other data sets have begun. These include comparisons with other cloud climatologies obtained from surface observations and from NASA experimental satellites (Nimbus-7 and ERBE). The intercomparison and combination of these climatologies should lead to a significantly improved global cloud climatology. Another key set of comparisons are those between the ISCCP and FIRE observations and analyses; they will provide a much more detailed understanding of cloud behavior. (See Climate Research, Physical Processes, for additional information on satellite-based research).

Ozone Measurement

During 1987, an ozone trends panel of over 100 scientists organized under the auspices of NASA, NOAA, FAA, WMO, and UNEP carefully reevaluated ozone data derived from both ground-based and satellite measurements taken between 1969 and 1986.

Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and quasi-biennial oscillation) showed decreases from 1969 to 1986 in the annual average of total column ozone ranging from 1.7 percent to 3.0 percent, at latitudes between 30° and 64° in the northern hemisphere. The decreases were most pronounced during the winter months (December through March) when they ranged from 2.3 percent to 6.2 percent.

Satellite measurements from the solar backscatter ultraviolet (SBUV) and total ozone mapping spectrometer (TOMS) aboard the Nimbus-7 taken between 1978 and 1985 were also re-analyzed. The SBUV and TOMS data normalized by comparison with nearly coincident Dobson data, showed a decrease of about 2.5 percent in total column ozone (averages between 53°S and 53°N latitudes) from October 1978 to October 1985.

Analyses of satellite (SAGE) and ground-based data taken since 1979 also show decreases in ozone concentrations which peak at around 40 km altitude, with mean values of 3 percent and 9 percent, respectively.

Stratospheric temperatures between 45 and 55 km altitude have decreased globally by about 1.7°K since 1979, consistent with decreases of upper stratospheric ozone of less than 10 percent.

In the Antarctic, there has been a large and unexpected ozone decrease over the past decade during the austral spring. Ozone decreases of more than 50 percent in the total column and 95 percent locally between 15 and 20 km altitude have been observed. The total column of ozone during the austral spring of 1987 at all latitudes south of 60°S was the lowest since measurements began 30 years ago, and the period of low concentration persisted until early December, which is the longest since the ozone "hole" was first detected. While ozone depletion is greatest in the Antarctic in spring, since 1979, ozone has decreased by 5 percent or more at all latitudes south of 60°S throughout the year.

Ocean Surface Measured by Satellite Altimetry

Observations of ocean surface winds and sea state are by-products of the satellite altimetry data collected to map the shape of the ocean surface. By analyzing the return of each transmitted pulse for intensity and wave form shape, both surface wind speed and significant wave height can be determined once each second at a resolution of 7 km. GEOSAT has produced more than 2 years of global wind speed and wave height data with verified accuracies of ±1.8 m/sec. for wind and ±0.5 m for wave height. These data, available through the National Ocean Data Center under agreement with the U.S. Navy, provide scientists with the most complete global data set of its kind ever collected (Dobson et al., 1987).

Remote Sensing Techniques Developed to Monitor Aerosols

NOAA scientists in the National Environmental Satellite, Data and Information Service (NESDIS) have developed techniques to measure aerosols over the oceans using the visible (0.58 to 0.68 micrometers) radiances measured in Channel 1 of the advanced very high resolution radiometer (AVHRR) on board the NOAA environmental satellites.

Figure 2 depicts portions of the analyzed aerosol optical thickness field over the tropical Atlantic and the Arabian Sea for the period June 18-25, 1987. The presence of the Saharan dust cloud and the monsoon-borne dust over the Arabian sea is obvious. Available surface-based observations of dust, haze, and smoke, meteorological data on surface and upper level winds,

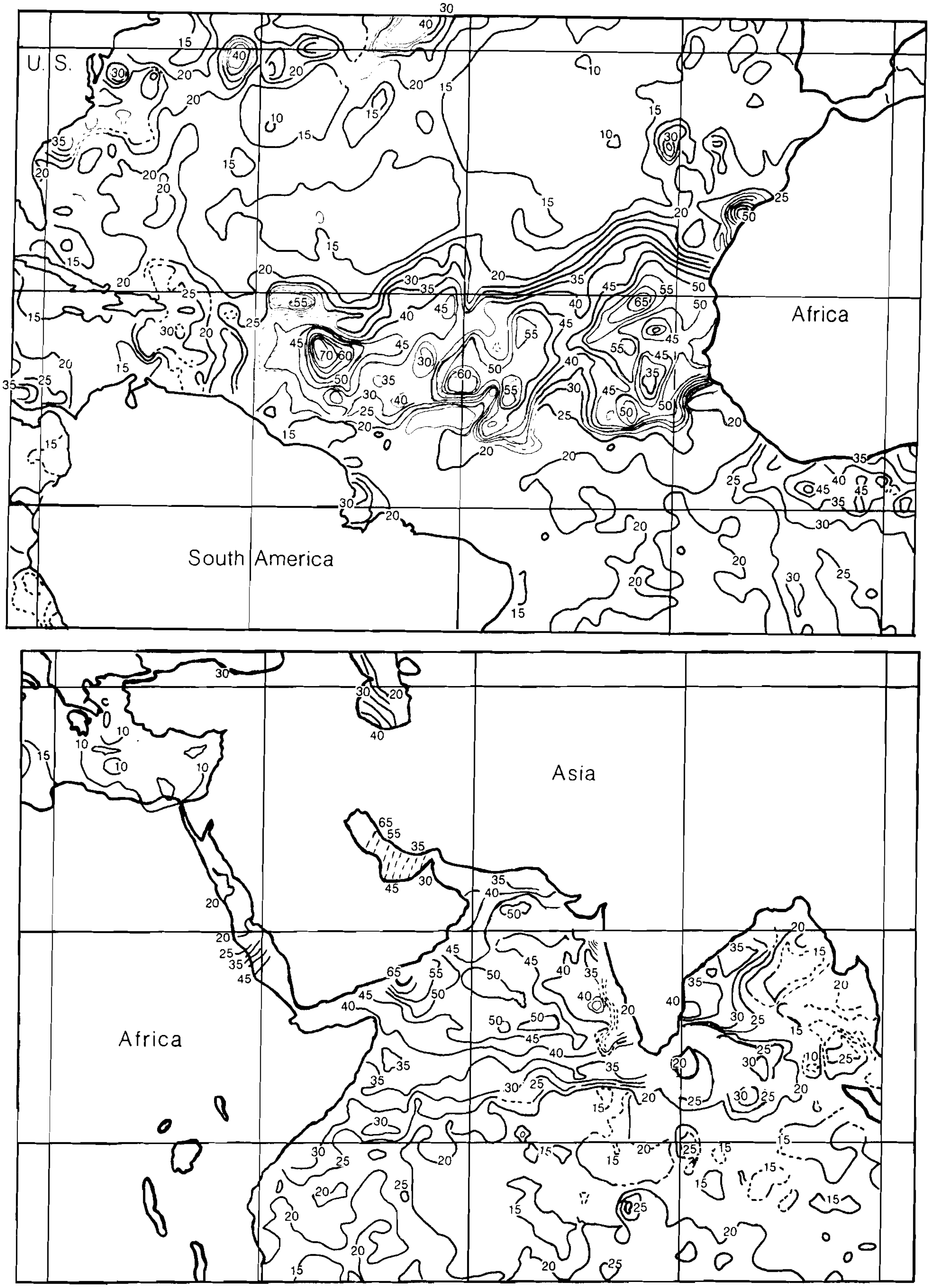


Figure 2. Analyzed aerosol field for the period 18-25 June 1987. The Saharan dust cloud is seen over the Atlantic in the diagram at the top, and monsoon-borne dust over the Arabian Sea is seen in the diagram at the bottom.

and analysis of AVHRR and GOES imagery support these findings. The smoke clouds resulting from the forest fires in China (May 1987) and California-Oregon (late summer of 1987), and episodes of air pollution off the east coasts of the United States and South America have also been detected.

An immediate application of the work done to date is the theoretical and empirical determination of effects of aerosols on the radiances measured in AVHRR channels 3, 4, and 5 and correcting for the same in the NESDIS multi-channel sea surface temperature (MCSST) procedures. Preliminary theoretical computations have indicated appreciable (about 4°K) depressions in the brightness temperatures in channels 3, 4, and 5 due to tropospheric aerosols in an extremely turbid atmosphere.

Climate Data Management Gets Priority Attention

Significant steps were taken in 1987 to improve management of climate data needed to support new climate research programs. Federal agencies formed the Interagency Working Group on Data Management for Global Change. Its goal is a consistent national data and information system for global change research by 1995. Agencies represented in the working group include NASA, NOAA, NSF, USGS, DOD, Navy, and DOE. Working group activities will include studies leading to interconnection between existing agency data systems, assembling requirements for data and information, developing standards for quality control and confidence limits, and providing technical requirements for data providers.

The Federal Coordinator for Meteorology established a working group for meteorological information management under the auspices of the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR). This group, led by the National Climatic Data Center (NCDC), will develop a plan for meteorological information management from a retrospective viewpoint. The group is also reviewing agency plans and recommending actions to ICMSSR, establishing a data reference system, and recommending standards to the National Institute of Standards and Technology (formerly National Bureau of Standards).

Data management working groups have been established between NOAA and NASA, and between NOAA and the U.S. Geological Survey (USGS). Within NESDIS, a data management council has been formed to coordinate work of the three environmental data centers, and to provide an interface with the satellite programs.

CLICOM Use Grows

The CLICOM (climate communication) system has completed its second year as an operational system for climate data management. Seventeen countries have installed the system with the assistance of the National Weather Service (NWS) and the WMO. CLICOM's acceptance in the United States has grown also, largely as a result of its adoption by regional climate centers as a standard climate data system for use by the centers and state climatologists.

CLICOM is a user-friendly, menu-driven software system developed at the National Climatic Data Center (NCDC) that provides many functions of value to those who work with meteorological data. CLICOM functions include facilities for entry, quality control, inventory, and storage of meteorological observations, a meteorological station history subsystem, and interfaces to products and models. Utilities are provided to maintain an off-line archive of data on a mass storage medium such as optical disc or magnetic tape.

The system can be adapted to work in any language, measurement system, and climatological region—features that are attractive to users in other countries. CLICOM is attractive to domestic users for its technical features and because it provides, for the first time, a single system that can economically handle climate data locally, or at a state, regional, or national level. Further information on CLICOM is available in the CLICOM users manual (NCDC, 1987).

Urban Effects on Temperature Trends Analyzed

Using the historical climatology network (HCN) of 1219 stations across the United States, the NCDC has developed several equations which relate the effect of increasing urbanization to mean seasonal and annual maximum, minimum, average, and diurnal temperature ranges (Karl et al., 1987b). These changes had not been documented before this study.

Urban effects on temperature are important even for small cities (population 10,000). For example, stations with populations near 10,000 show an average 0.01°C higher mean annual temperature than would a station located in a rural area with little or no population. Using these equations, the effect of urbanization in the twentieth century for the U.S. historical climatology network (which consists of mostly cooperative weather stations) is on the order of 0.06°C. Heat islands seem to have little effect on maximum temperatures compared with minimum temperatures. The temperature effect of urbanization, as shown by the mostly rural HCN, is approximately +0.06°C for average temperature, +0.13°C for minimum temperature, −0.01°C for maximum temperature, and −0.14°C for the temperature range over the 1901 to 1984 time period. One of the most interesting characteristics is the decrease of the diurnal temperature range since the 1940s and the lack of any noticeable trend prior to this time. Karl et al. (1984, 1986, 1987a) discuss this decrease as it may relate to greenhouse effects or aerosol loading.

USDA and NOAA Assess Drought in India

The Joint Agricultural Weather Facility (JAWF), a cooperative effort between USDA and NOAA's National Weather Service prepared a special assessment of India's 1987 drought. The Indian drought was associated with the failure of the monsoon to reach into major agricultural regions of northwestern India while producing persistent excessive rainfall and flooding in the Northeast areas. In many areas of the Northwest, monsoonal rains were a half to a quarter of normally expected totals while Gujarat (western India) averaged only 15 percent of normal rain through August. Some June and July rainfall totals were as low as 2 to 5 percent of normal monthly amounts. The severe dryness was compounded when average temperatures were the highest on record for parts of Northwest India. Because of the irrigated crop areas, national crop yields were not as sharply reduced, but the decreases were significant for many crops.

Handbook of World Crop Areas and Climate Published

Major World Crop Areas and Climatic Profiles, Agricultural Handbook No. 664, was completed and published by USDA. This is a revision and enlargement of a document published by the World Agricultural Outlook Board (WAOB) in 1981 which identified major crop areas of the world and showed production statistics and climate profiles in relation to growth stages of major crops (figure 3). The revision includes data for more crops and crop producing areas around the world. Maps show the production areas of major crops in the United States and other regions of the world. The handbook can be purchased from the Government Printing Office, Washington, DC 20402.

Weekly Climate Bulletin Improved, Circulation Grows

Several changes have been made in the ***Weekly Climate Bulletin*** (WCB) to make it more informative and attractive. A new format and cover displays the most interesting climate event of each week. Greater emphasis is placed on climate in the United States, and special climate summaries are frequently featured. Also, the quality of graphics has been improved. Consequently, the number of recipients has increased from 329 to 526.

National Solar Radiation Network Started

NOAA has been constructing a new surface solar radiation network (SOLRAD), in recognition of the important effects that surface solar radiation has on agriculture, electric power, gas consumption, and food production planning. This network (figure 4) is being implemented with state-of-the-art instrumentation and a signal quality assurance system. The first phase of the network has been completed with thirteen stations reporting data routinely. The number of stations is expected to increase to 31. The data, which include direct radiation, global radiation, and atmospheric turbidity, are transmitted on AFOS (automation of field operations and services) and can be transferred to the National Meteorological Center (NMC) computer system. The Climate Analysis Center (CAC)/NMC is operationally testing the distribution of the near real-time users via the CAC's Climate Dial-Up Service. These data will be provided to the National Climatic Data Center, Asheville, NC, and to the International Radiation Data Center, Leningrad, for permanent archiving.

Climate Research

Physical Processes in Climate Modeling

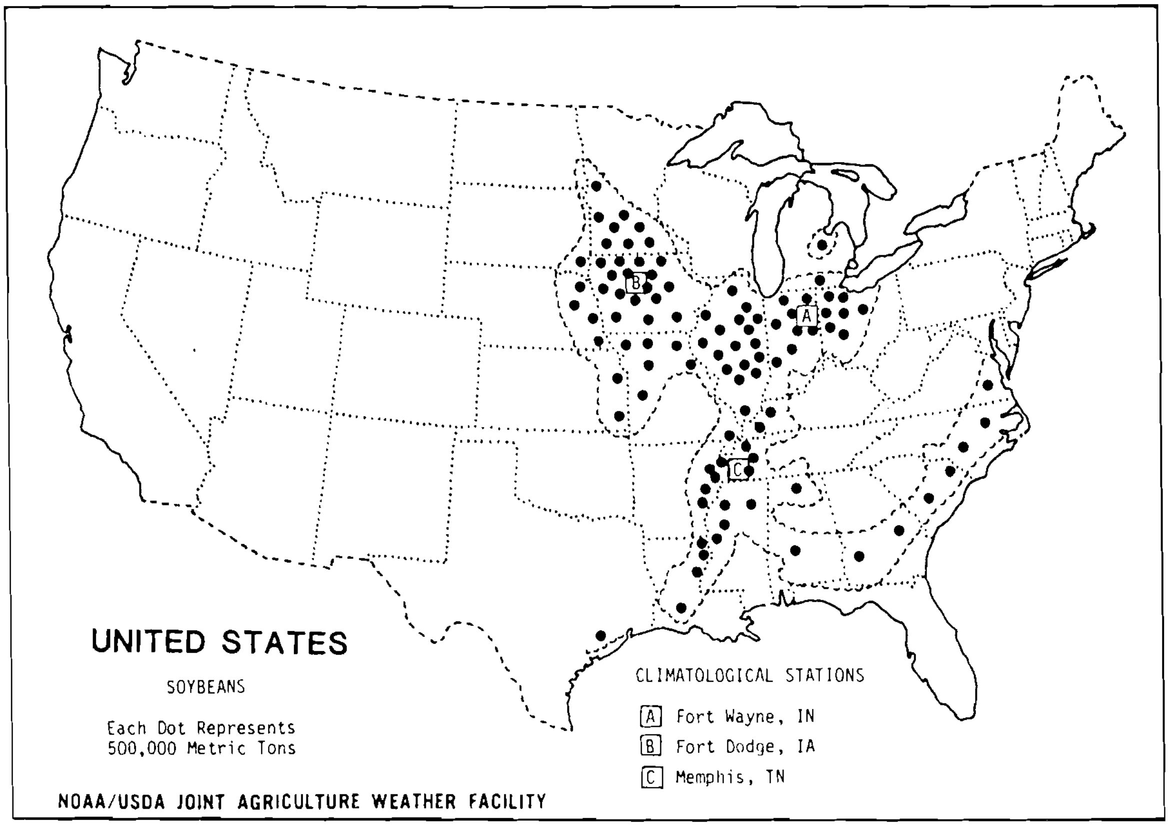
A key problem in climate dynamics is to determine the role of cloudiness in climate change. Clouds are a reflecting blanket; they cool the planet by reflecting sunlight back to space and warm it by trapping terrestrial radiation. It is not clear a priori whether there occurs a net cooling or warming.

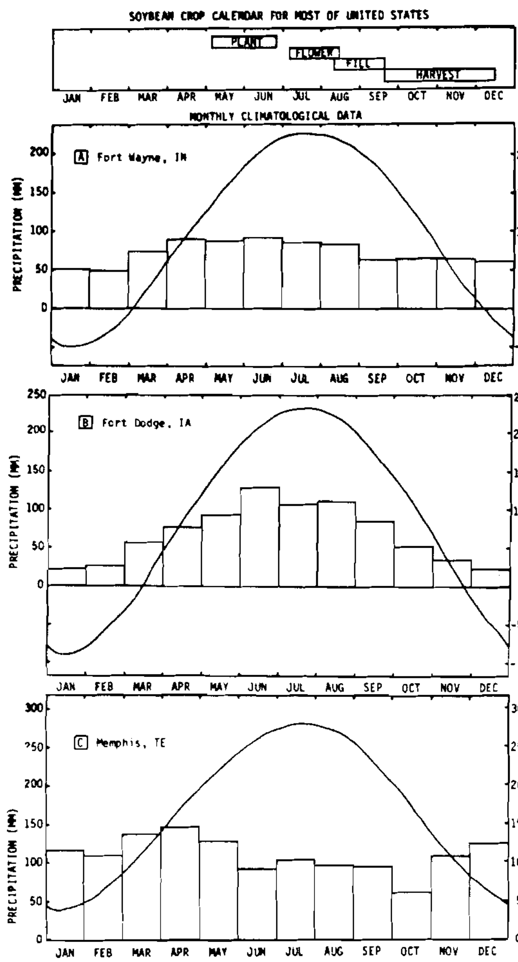
Important new observational data sets that can shed light on this question are being produced through the International Satellite Cloud Climatology Project (ISCCP), the First ISCCP Regional Experiment (FIRE), and the Earth Radiation Budget Experiment (ERBE).

Cloud and Climate Modeling

Simulated studies of global cloudiness and its effects on climate have been carried out with the University of California at Los Angeles/Goddard Laboratory for Atmospheres Global Circulation Model (UCLA/GLA GCM). Results from the GCM are being analyzed to determine the simulated global distribution of cloudiness, the interactions of the clouds with large-scale circulations, and the hydrologic cycle and sensitivity to aspects of the model's formulation. Data from ISCCP, HIRS2/MSU (2nd generation high resolution infrared sounder microwave scanning unit), Nimbus 7, and conventional sources are being used to validate model results. Particular attention is being given to cloud radiative forcing (CRF), which is the difference between a radiation flux in the presence of clouds and that which would occur in the absence of clouds with all other conditions unchanged.

Model simulations for average July test sets are in good agreement with satellite observations, thus increasing confidence in the model's capability for simulating radiation fluxes. For July, the terrestrial CRF has broad regions of intense positive and negative values, which nearly cancel in the global mean (figure 5).





United States: Soybean Statistics by State 1/
(1980/81-84/85 Crop-Year Average)

State	Area Harvested 2/	Yield	Production 3/	
	1,000 ha.	T/ha.	1,000 T	Pct.
Illinois	3,706	2.31	8,550	20
Iowa	3,326	2.44	8,111	19
Minnesota	1,926	2.21	4,261	10
Indiana	1,764	2.33	4,111	10
Missouri	2,160	1.68	3,637	8
Ohio	1,454	2.27	3,317	8
Arkansas	1,696	1.42	2,403	6
Mississippi	1,409	1.43	1,999	5
Louisiana	1,156	1.61	1,842	4
Nebraska	867	2.10	1,814	4
Tennessee	892	1.50	1,335	3
North Carolina	755	1.53	1,160	3
Total	21,111	2.02	42,540	100

1/ These States produce about 95 percent of total U.S. soybeans.
2/ 1 hectare = 2.471 acres.
3/ 1 ton of soybeans = 36.7437 bushels.

United States: Historical Crop-Year Soybean Statistics

Crop Year	Area Harvested	Yield	Production	Ending Stocks	Exports
	1,000 ha	T/ha.	1,000 T	1,000 T	1,000 T
1964/65	12,462	1.53	19,076	808	5,774
1965/66	13,941	1.65	23,014	970	6,820
1966/67	14,790	1.71	25,269	2,453	7,119
1967/68	16,109	1.65	26,575	4,527	7,255
1968/69	16,751	1.80	30,127	8,895	7,805
1969/70	16,729	1.84	30,839	6,255	11,773
1970/71	17,098	1.79	30,675	2,688	11,806
1971/72	17,282	1.85	32,009	1,958	11,344
1972/73	18,488	1.87	34,581	1,623	13,048
1973/74	22,528	1.87	42,118	4,647	14,673
1974/75	20,777	1.59	33,102	5,121	11,450
1975/76	21,698	1.94	42,139	6,666	15,107
1976/77	19,992	1.75	35,070	2,801	15,351
1977/78	23,403	2.06	48,097	4,386	19,061
1978/79	25,764	1.97	50,859	4,779	20,117
1979/80	28,467	2.16	61,525	9,756	23,818
1980/81	27,443	1.78	48,921	8,519	19,712
1981/82	26,776	2.02	54,135	6,926	25,285
1982/83	28,097	2.12	59,610	9,379	24,634
1983/84	25,304	1.76	44,518	4,784	20,221
1984/85	26,750	1.89	50,644	8,603	16,265
1985/86 1/	24,929	2.29	57,113	14,549	20,139
1976/77-85/86 Avg.	25,693	1.99	51,049	7,448	20,460

1/ Preliminary.

Figure 3. Sample of information on the normal stage of soybean development through the growing season. (USDA 1987.)

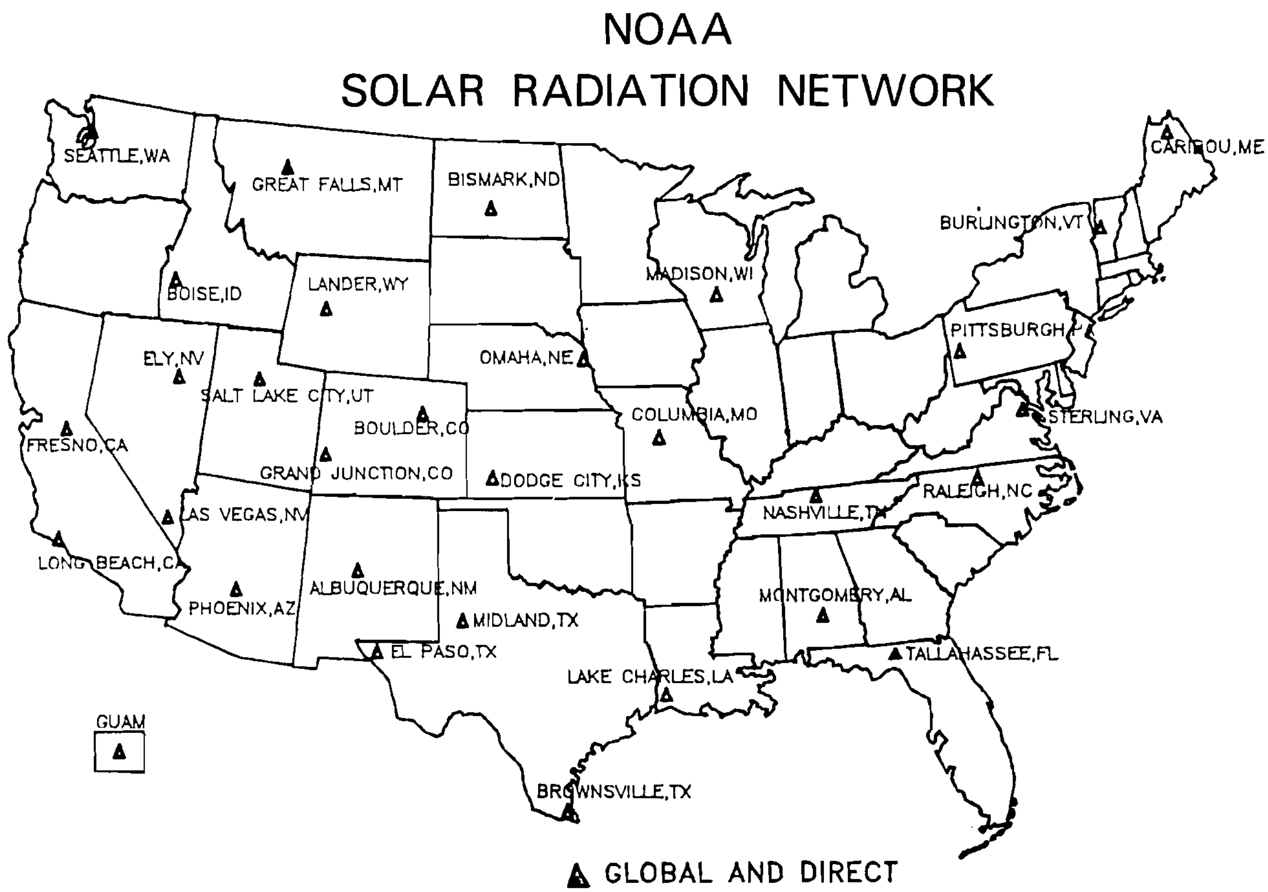


Figure 4. United States solar radiation network (SOLRAD). (NOAA/Climate Analysis Center.)

Clouds warm or cool the atmosphere, depending on their altitude. A high cold cloud tends to warm the atmosphere, because it absorbs intense radiation from the earth's surface, while emitting only weakly. In contrast, a low warm cloud tends to cool the atmosphere because it emits strongly both upward and downward, while strong absorption occurs only on its lower side. Since high clouds are common in the tropics, while low clouds occur frequently near the poles, the zonally average atmospheric CRF is a warming in the tropics and a cooling in high latitudes, thus requiring a poleward heat transport by the atmosphere, in addition to that required by latent heating. The zonal structure of the atmosphere CRF is also very strong, with warming at longitudes of rising motion, where high clouds occur, and cooling at longitudes of sinking motions, where low clouds occur. The vertical motion field induced by the atmospheric CRF thus tends to be a positive feedback on the clouds. This tantalizing result suggests the possibility of radiative-dynamic instabilities.

Sensitivity tests with the GCM show that the high cloudiness associated with cumulus convection tends to suppress convection over the land. This negative feedback is due to cloud shadow, which leads to a reduction in the surface evaporation. A similar negative feedback, with a longer time scale, may be operative over the oceans. A coupled ocean-atmosphere model is needed to investigate this phenomenon.

The diurnal variability of cloudiness and precipitation simulated by the UCLA/ GLA GCM is very pronounced, even for the oceans, and has an orderly geographic structure. The reasons for diurnal cycles of precipitation over the ocean have long been a controversial subject. Among possible overlapping explanations are:

- Absorption of solar radiation by clouds in the upper atmosphere tends to stabilize the lapse rate and so inhibits moist convection during the day but not at night.
- Solar warming induces diurnally varying, large-scale vertical motions that in turn modulate the moist convection.
- Diurnal heating of the continents forces varying circulations that extend over the oceans, influencing oceanic moist convection.

A series of model experiments aimed at testing the above hypotheses have yielded the following results:

- A diurnal cycle of precipitation does occur even in the absence of continents, but its amplitude is only about half that obtained from the oceans.
- A diurnal cycle of precipitation occurs with phase and amplitude qualitatively similar to observations.

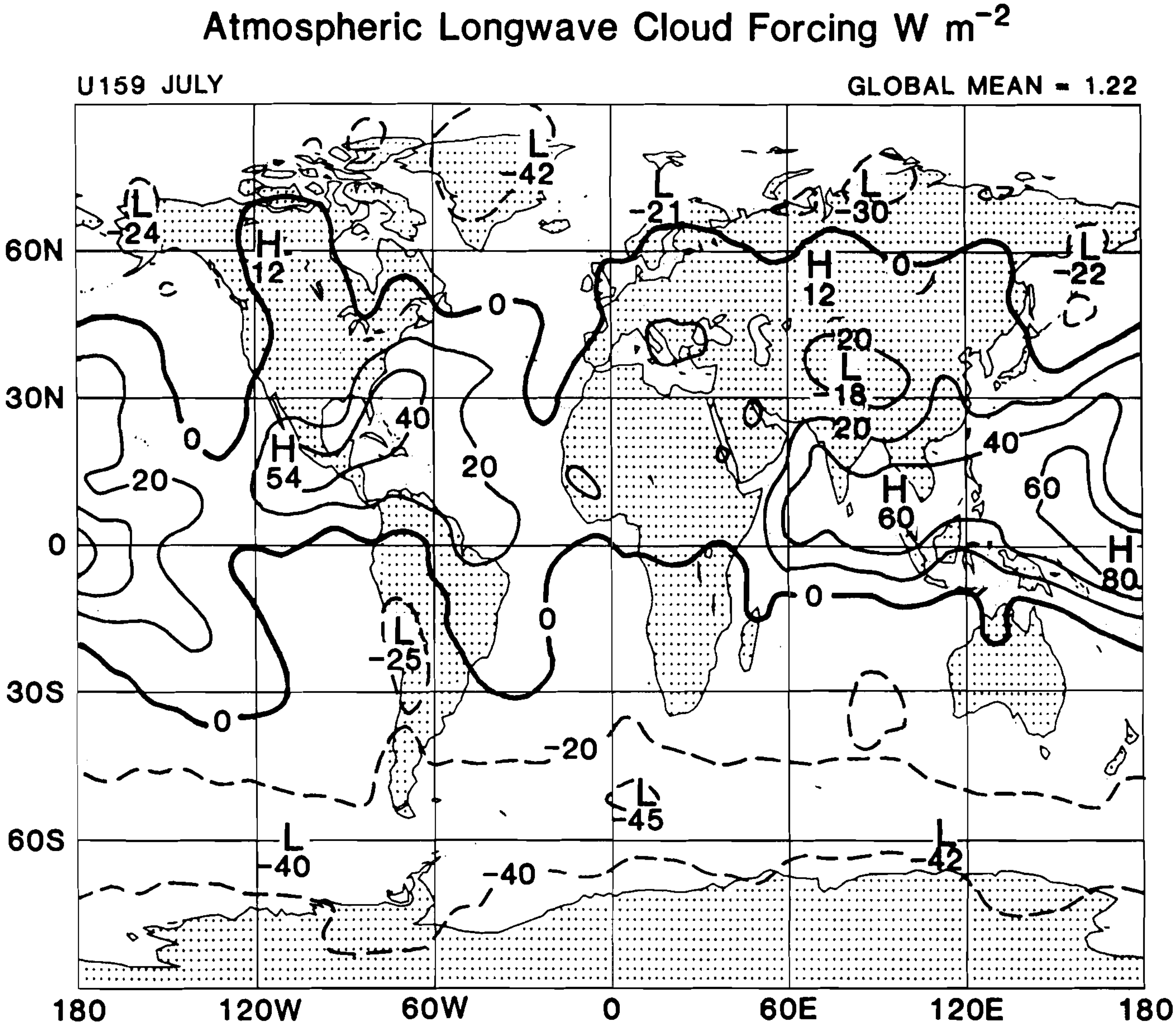


Figure 5. July atmospheric longwave cloud radiative forcing simulated by the UCLA/GLA general circulation model. (NASA.)

This shows that direct coupling between radiation and convection does play a role in forcing the diurnal cycle of precipitation over the oceans.

- Diurnal variations in vertical motions (in an all ocean experiment) show minimum rising motions at the time and place of maximum rainfall, ruling out any possibility that vertical motions drive the diurnal cycle of rainfall.

These results tend to support the hypothesis that absorption of solar radiation by clouds in the upper atmosphere tends to stabilize the lapse rate and so inhibits moist convection during the day but not at night.

In 1988, FIRE data (see below) will be used to develop improved parameterizations of marine stratocumulus clouds, and their effect on global climate.

The First ISCCP Regional Experiment (FIRE)

FIRE is the U.S. cloud climatology research program to study those clouds which play important roles in the earth's global climate. FIRE has measured the radiative and physical properties of cirrus and marine stratocumulus clouds over the continental U.S. These observations are being used to verify and improve the satellite retrieval techniques of ISCCP and to develop realistic cloud parameterization for climate modeling.

FIRE is supported by NSF, DOD, DOE, NOAA, and NASA, which is the lead agency. The project began in 1984 and will continue until 1990.

FIRE Experiments. The First Cirrus Intensive Field Observation Program was conducted in central Wisconsin, October 13- November 2, 1986. The experiment included coordinated surface, aircraft, and satellite observations of cirrus clouds in and around central Wisconsin (figure 6). The principal targets of

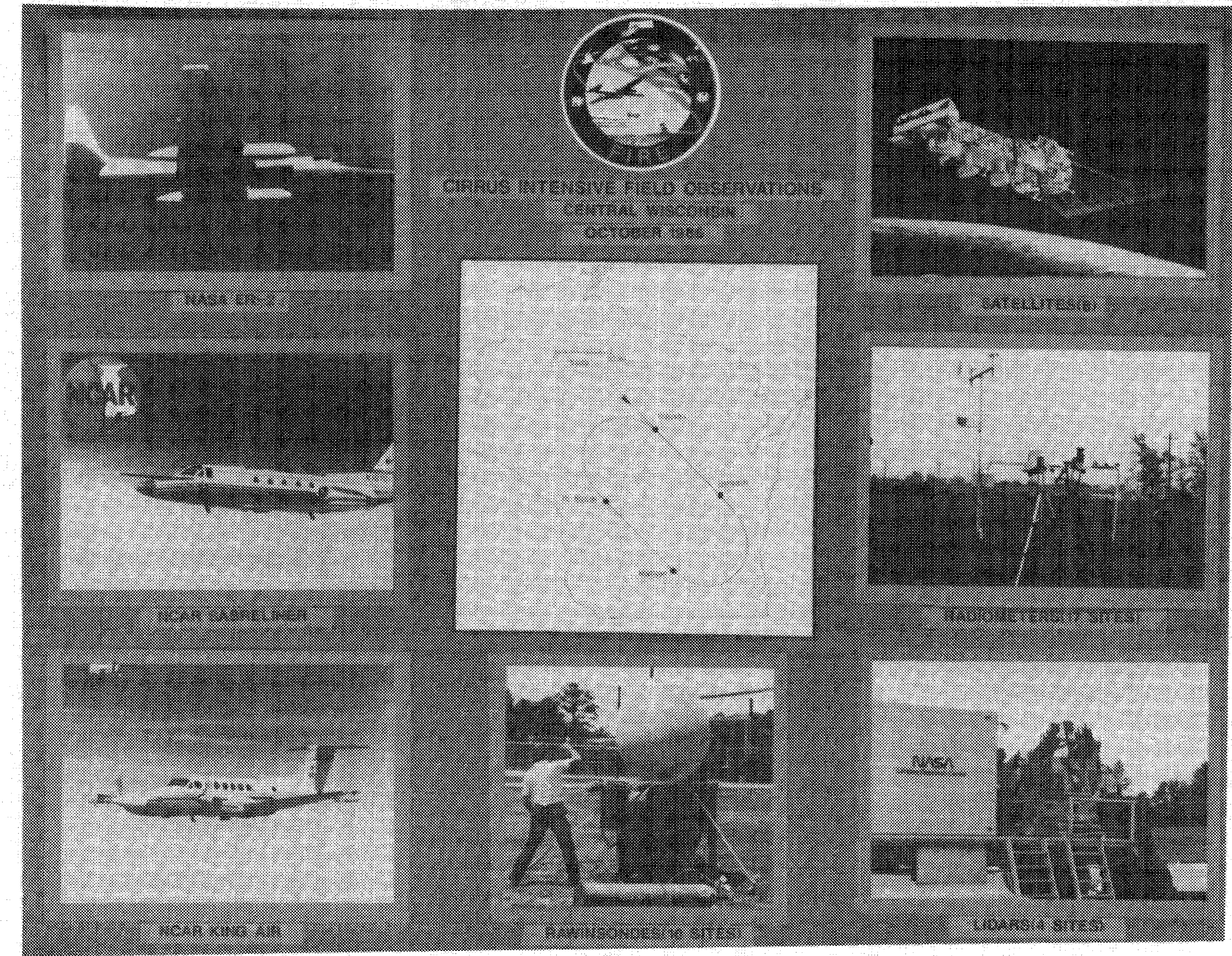


Figure 6. Activities associated with the First Cirrus Intensive Field Observation Program under Project FIRE. (NASA.)

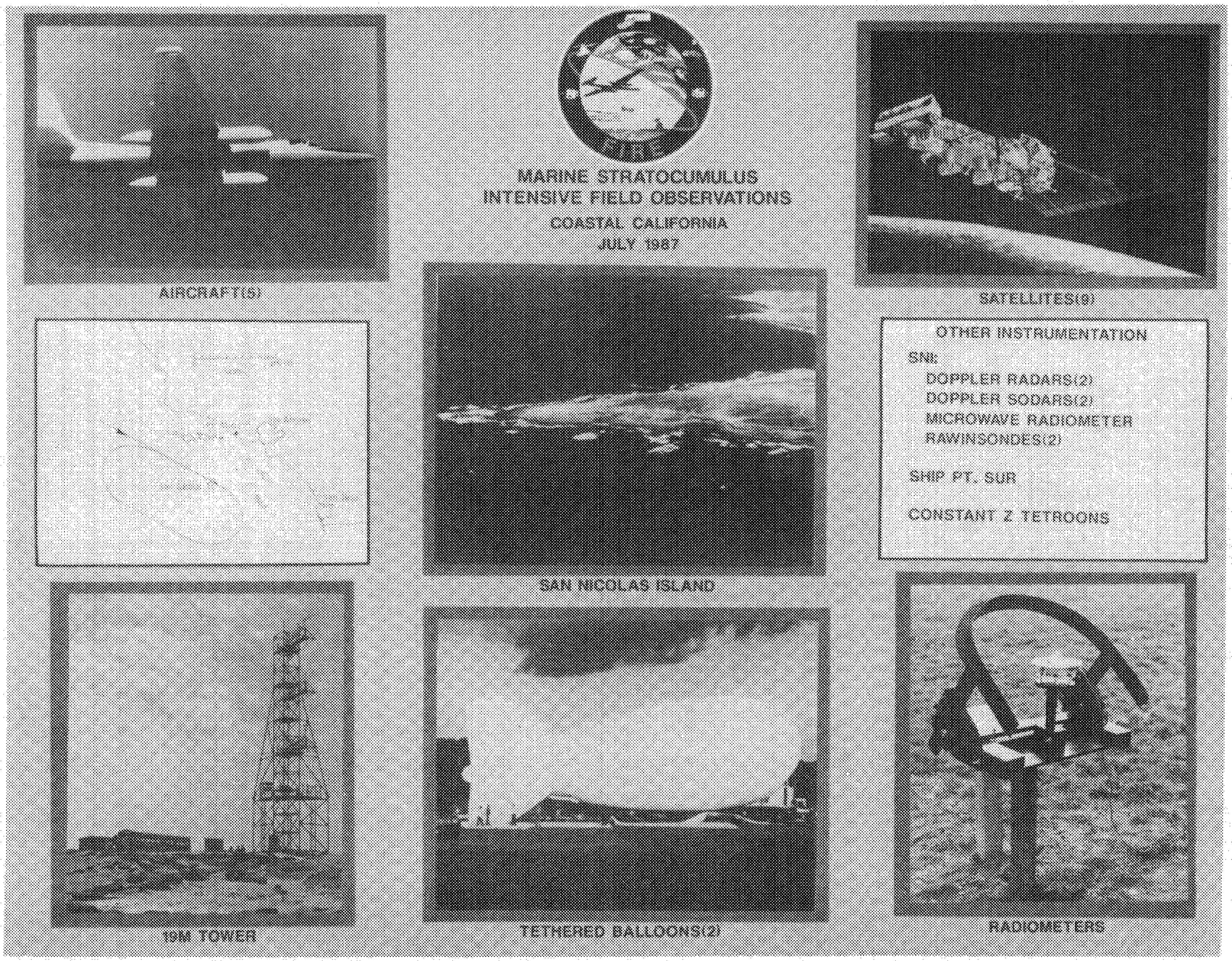


Figure 7. Activities associated with the First Marine Stratocumulus Intensive Field Observation Project under Project FIRE. (NASA.)

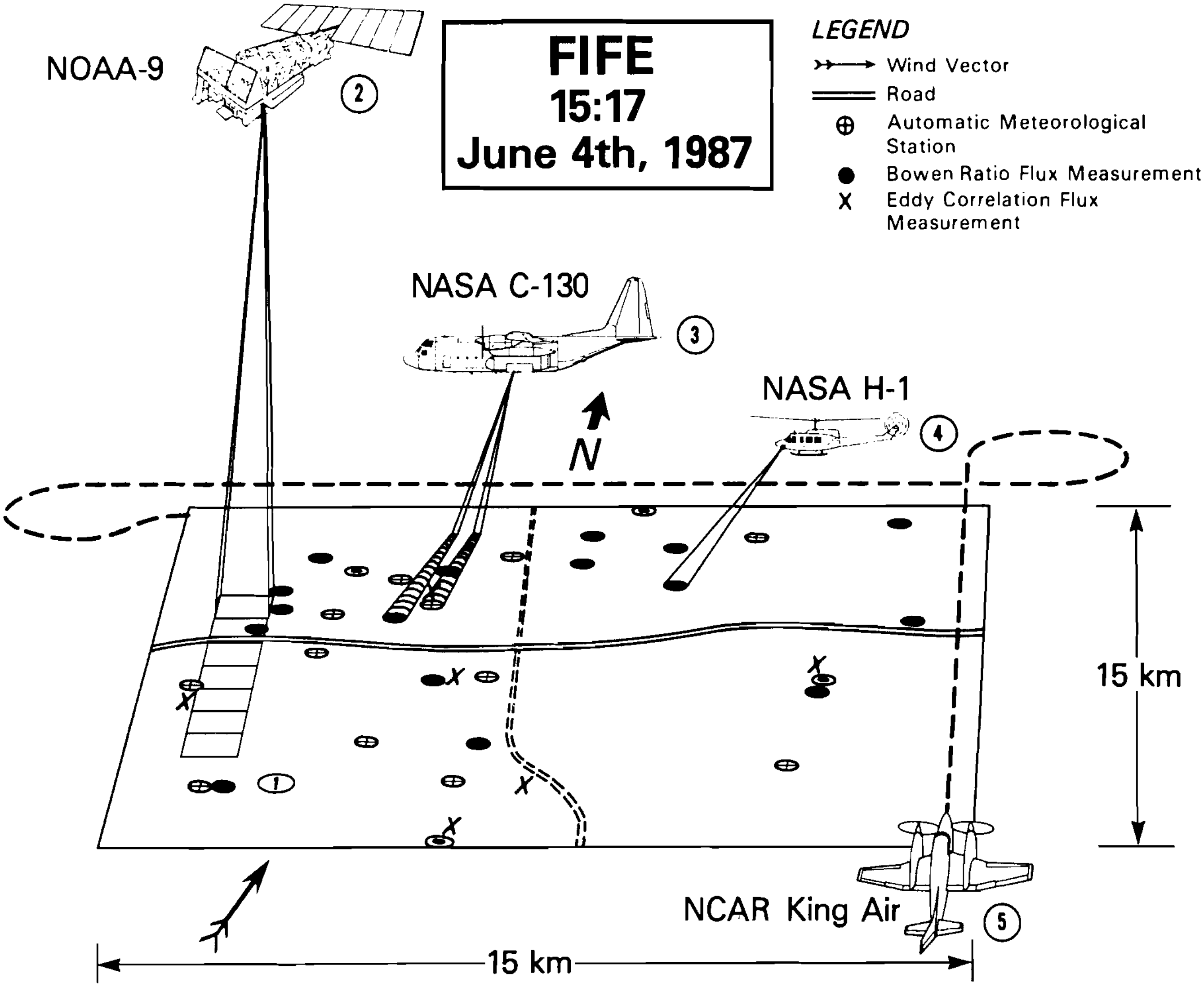


Figure 8. Coordinated data acquisition activities for First ISLSCP Field Experiment (FIFE) near Manhattan, KS. (NASA.)

the experiment were cirrus clouds associated with pre-warm frontal systems and jet streams.

The First Marine Stratocumulus Intensive Field Observation Program was performed over the eastern Pacific Ocean off the southern coast of California from June 29 to July 19, 1987. Combined aircraft and satellite observations were made of marine stratocumulus clouds upwind of and in the vicinity of San Nicholas Island (figure 7).

An additional program of extended observations of cirrus and marine stratocumulus clouds began in April 1986 and will continue to 1989. For this study, daily coordinated surface and satellite observations over the continental U.S. and Western Hemisphere are being made. At four surface sites, Salt Lake City, Utah; Boulder, Colorado; Madison, Wisconsin; and Hampton, Virgina, lidar, radiometric and meteorological measurements will be made at times of overpassing satellites and during period of cirrus cloud activity.

FIRE data are made available to the scientific community through the FIRE data archive located at the Pilot Climate Data System, Goddard Space Flight Center, Greenbelt, Maryland. Data are available to FIRE researchers 18-24 months after acquisition.

The First ISLSCP Field Experiment (FIFE)

The first field experiment of the International Satellite Land-Surface Climatology Program took place at and around the Konza Prairie Long Term Ecological Research site near Manhattan, Kansas (figure 8). The goal of FIFE is to better understand the role of biology in controlling the interactions between the atmosphere and vegetated land surfaces. The program is designed to investigate the use of satellite observations to infer climatologically significant land-surface parameters.

A number of foreign institutes and universities, NSF, NOAA, the U.S. Army Corps of Engineers, the National Research Council of Canada, and NASA are participating in this program, with NASA acting as lead agency.

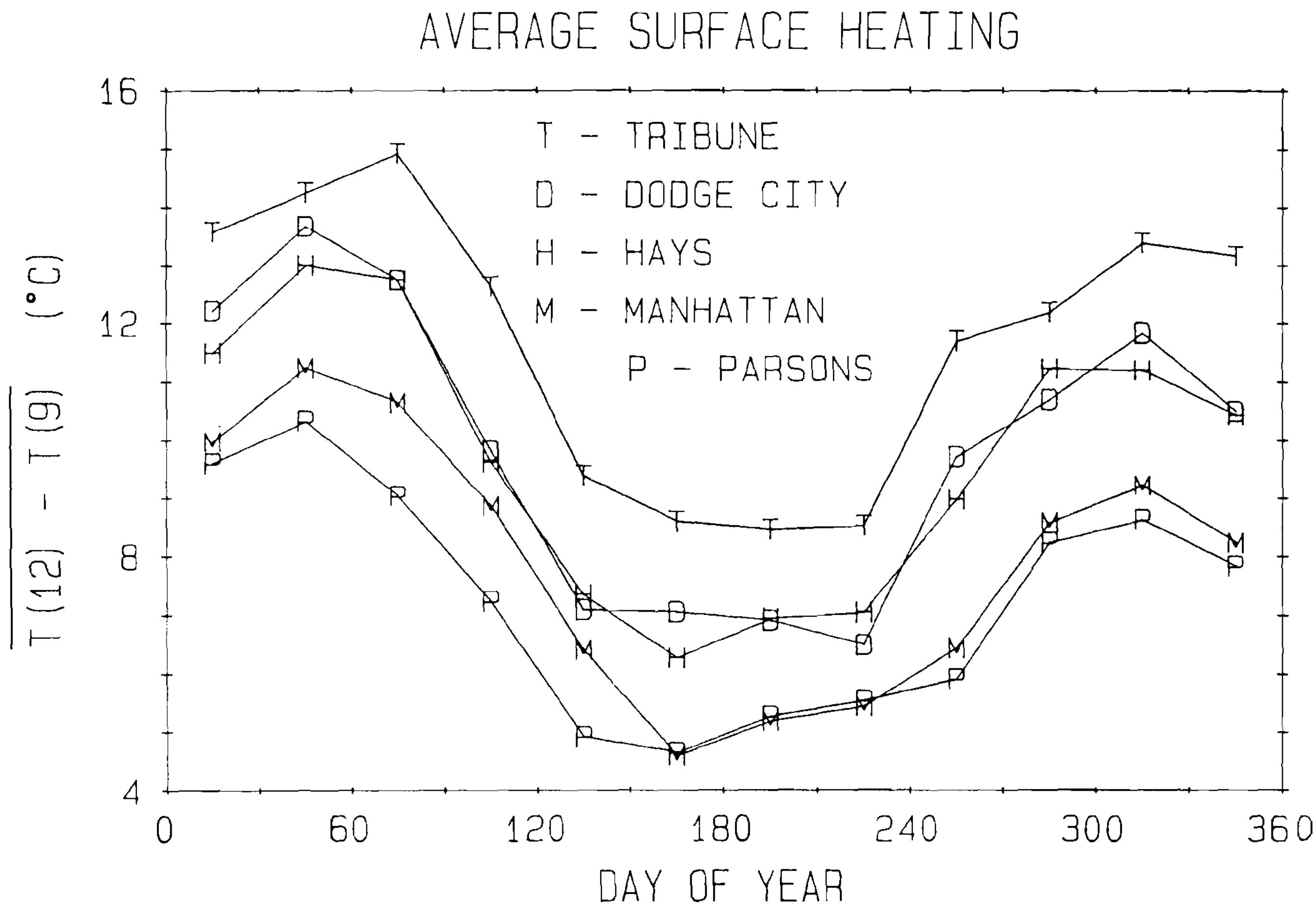


Figure 9. Average surface heating for 6 sites derived from GOES data covering 1980-85. (NOAA.)

Results of the FIFE experiment will be analyzed over the next 2 years. This program addresses important gaps in knowledge of how characteristics of the land surface interact with the atmosphere. Little is known about the global distribution of energy, moisture, CO_2, and momentum over the land; how these factors vary seasonally and interannually; how they affect the atmospheric component of the climate system; and how they can best be measured from space. FIFE is an important first step to a better understanding of these questions.

Satellite-Observed Surface Heating

Studies of the surface energy balance indicate that changes in surface temperature are determined by the amount of incident energy and its partitioning between evaporation and surface heating. Surfaces with high evapotranspiration due to active vegetation and/or moist soil will heat more slowly during the morning hours than will dry surfaces.

A 6-year (1980-85) set of GOES data for selected sites in the state of Kansas was used to study surface heating and its relationship to precipitation. Average surface heating for each site is shown in figure 9.

There is a distinct seasonal variation in heating at the measured sites. The rate of heating is high during the winter season, but declines to a lower value during summer. The decline is attributed to increased evapotranspiration associated with active vegetation and the warm season precipitation maximum that occurs in Kansas.

Results suggest that the observed surface temperature increase between 0900 and 1200 local time is related to precipitation. The physical relationship is through the surface energy balance. Increased precipitation causes increased soil moisture, with resulting larger evaporation and subsequent reduced heating.

Global Precipitation Climatology Project Begins

NOAA's Climate Analysis Center (CAC) has begun archiving satellite infrared imagery for each 2.5 degree latitude-longitude area in 5-day averages from GOES West and GOES East. These data will be used to produce monthly rainfall estimates for the tropics, where few ground stations exist. CAC has been designated to be the International Geostationary Satellite Precipitation Data Center in support of the WMO World Climate Research Program.

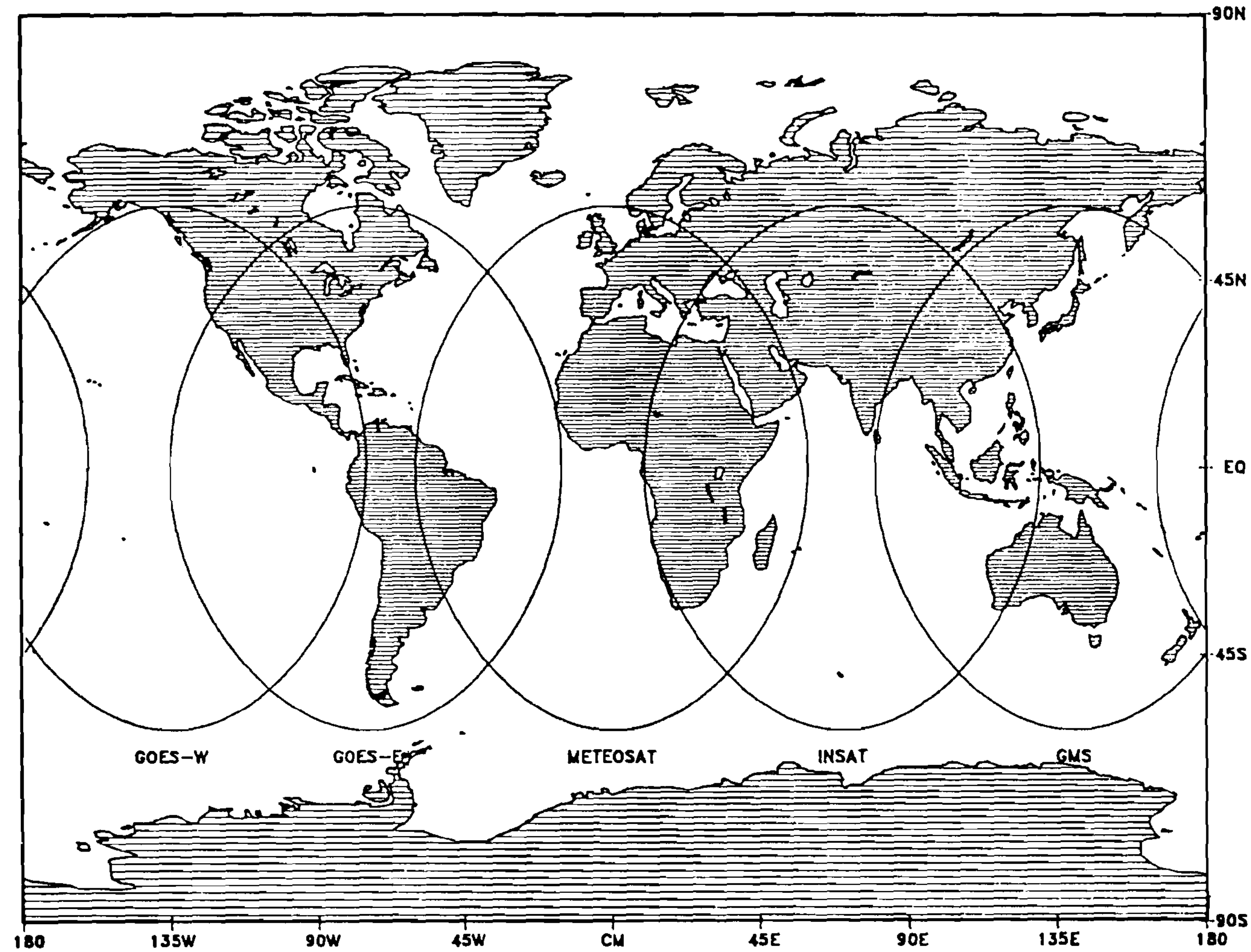


Figure 10. Areal coverage by the geostationary satellites used in the Global Precipitation Climatology Project. (NOAA/ Climate Analysis Center.)

CAC will also prepare estimates of monthly accumulated global precipitation for the period 1986-1995 from GOES (U.S.), METEOSAT (Europe), INSAT (India) and GMS (Japan) goestationary satellites IR data (figure 10).

Validating Satellite Measures of Rainfall

Estimates of tropical rainfall derived from geostationary satellites have been used to study annual, interannual, and diurnal variability of precipitation.

However, validation of these estimates is extremely difficult over the oceans, so an attempt has been made by CAC researchers to use the U.S. Climate Division (CD) rainfall data archived at the National Climate Data Center.

During the warm season, when a large fraction of the rainfall in the United States is due to convection, linear correlations between monthly CD rainfall and the satellite estimates of more than 0.7 have been calculated for large areas of the southeastern and central U.S. (figure 11, top). However, the bias in the estimate is quite large; 50 percent of the mean in the upper Midwest.

During the cold season, high correlations and low bias are still found the Southeast, but the correlations in the upper Midwest are very small (figure 11, bottom).

These results will be used to interpret geostationary satellite data when surface data are either sparse or missing.

Climate Research

Climate Modeling and Prediction

First Phase of Dynamical Extended Range Forecast (DERF) Experiments Complete

The National Meteorological Center (NMC) finished the first phase of the DERF experiments consisting of 107 30-day forecasts. Analysis of these experiments is

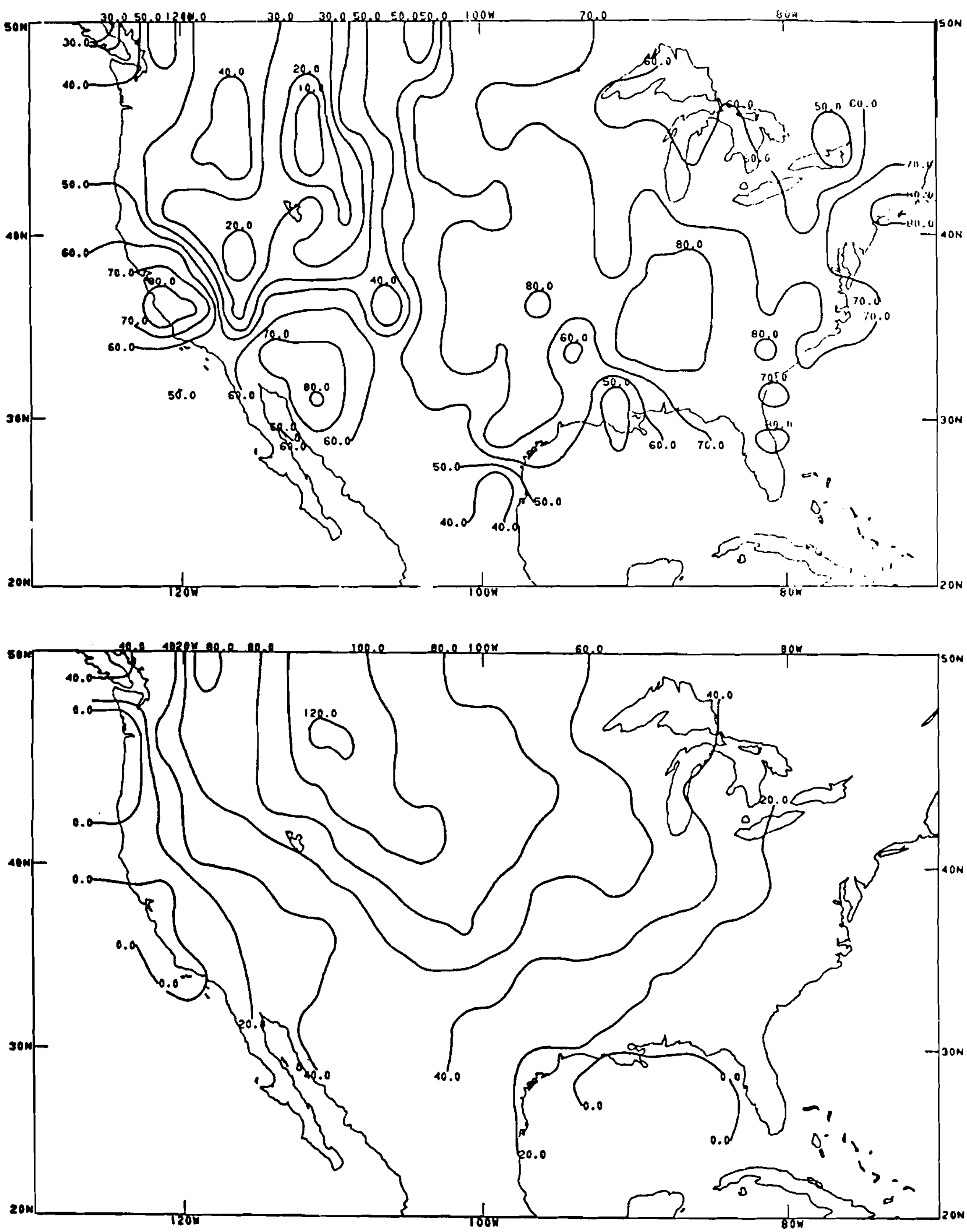


Figure 11. Correlation (top) and bias (bottom) between Climate Division rainfall and GOES estimates for the 5 warm seasons (April-September) from 1982-1986. Values have been multiplied by 100; contour interval is 10 (mm for the bias). (NOAA/Climate Analysis Center.)

under way in cooperation with the the Scripps Experimental Climate Forecast Center. [1]

Preliminary analysis by Roads (1987) indicates that most of the skill in present-day forecasts is in the initial part of the period and thus the medium-range forecasts currently used by the CAC for their monthly outlooks should continue to have considerable value. Predictability experiments performed with the same model, however, indicate that the model is potentially able to predict on a monthly time scale as well.

1987 El Nino Southern Oscillation (ENSO) Event Summary

A general weakening of the low level easterlies began during the northern hemisphere spring season and continued into the fall (October-November) of 1986. At the same time, sea surface temperature (SST) anomalies increased in the central and eastern equatorial Pacific, and temperatures near 30°C developed in equatorial waters near the international date line.

During the September-November period, enhanced convection, induced by negative outgoing longwave radiation (OLR), spread into the central equatorial Pacific near the region of warmest equatorial water.

At the same time, atmospheric pressure changes normally associated with the warm phase of the Southern Oscillation (SO) became evident. Sea level pressure rose to above normal at Darwin, Australia and fell to below normal at Tahiti, which resulted in a drop of the Southern Oscillation index (SOI).

By November all the major indices used in monitoring the SO indicated that a warm event was under way. However, classic El Nino conditions, characterized by anomalously warm sea surface temperatures (SST) along the west coast of South America, had not appeared.

During the northern winter season (December 1986-February 1987) atmospheric circulation, precipitation, air temperature and SST anomaly patterns resembled those usually associated with the mature phase of an ENSO episode. The positive SST anomalies and warmest equatorial water in the central Pacific were associated with persistent enhanced equatorial convection near the date line. The atmospheric circulation anomalies were consistent with the presence of the enhanced convection in the central equatorial Pacific.

During the same time, greater than normal rainfall occurred over the central equatorial Pacific, southern Brazil, the northern Gulf of Mexico, and eastern equatorial Africa. Drier than normal conditions occurred over southern Africa, northeastern South America, and from northeast Australia eastward to near the date line. Although northern Australia experienced wetter than normal conditions during January and February 1987, both December 1986 and March 1987 were drier than normal, resulting in a substantial shortening of the rainy season for that region. These results are consistent with the general sequence of expected atmospheric changes resulting from an ENSO event.

In January 1987, classic El Nino conditions began to develop along the west coast of South America. Maximum temperature anomalies along the west coast of South America occurred in March and heavier than normal rainfall was reported in Ecuador and northern Peru. SST decreased during April and May along the coast of Ecuador and Peru. Waters along the equator in the eastern Pacific also began to cool during April and May. The SO reached its lowest values in April and slowly increased to near zero by December (Ropelewski and Halpert, 1986, 1987; Ropelewski and Jones, 1987).

Sea Level Variations Measured by GEOSAT Altimeter

Sea level time series along the equator in the Pacific reveal a lengthy recovery to the 1986-87 El Nino, with significant differences in behavior between the eastern, western, and central regions (figure 12).

Following the build-up of 20-25-cm positive anomalies in November-December 1986, sea level in the western Pacific (166°E to 178°W) dropped abruptly to about −10 cm and remained at this level for most of 1987. The central Pacific (170°W to 122°W) underwent a similar rise and fall; however, it returned more rapidly (by June-August 1987) to the zero anomaly level. In contrast, sea level in the eastern Pacific (114°W to 98°W) remained positive through at least November 1987.

ENSO Prediction

A number of university researchers advanced climate predictions for the timing and magnitude of the 1987 ENSO event. A series of real-time predictions were started at the Scripps center in January 1986 and continue to date. These predictions were successful in identifying the 1986-87 El Nino a full 9 months before it occurred. The Scripps Center has combined their predictions with those of other El Nino forecasters for an analysis of prediction techniques and skill to be published in Science in 1988 (Barnett et al., 1988).

[1] The NCPO has established three experimental forecast centers to focus on seasonal and interannual long-range forecasting. These centers work closely with NOAA's CAC, which is the official agency in the United States responsible for making long-range forecasts. The three centers are located at the Scripps Institution of Oceanography, NASA's Goddard Space Flight Center and the University of Washington.

The first experimental forecast center workshop was held at the Goddard Space Flight Center on May 5-6, 1987. The workshop brought together participants in the program at the three centers, researchers at CAC and NMC's Development Division, and representatives of other centers and universities The purpose of the meeting was to review current plans for an integrated national program and suggest directions for the future. During 1988, NCPO will review and assess the current experimental forecast program.

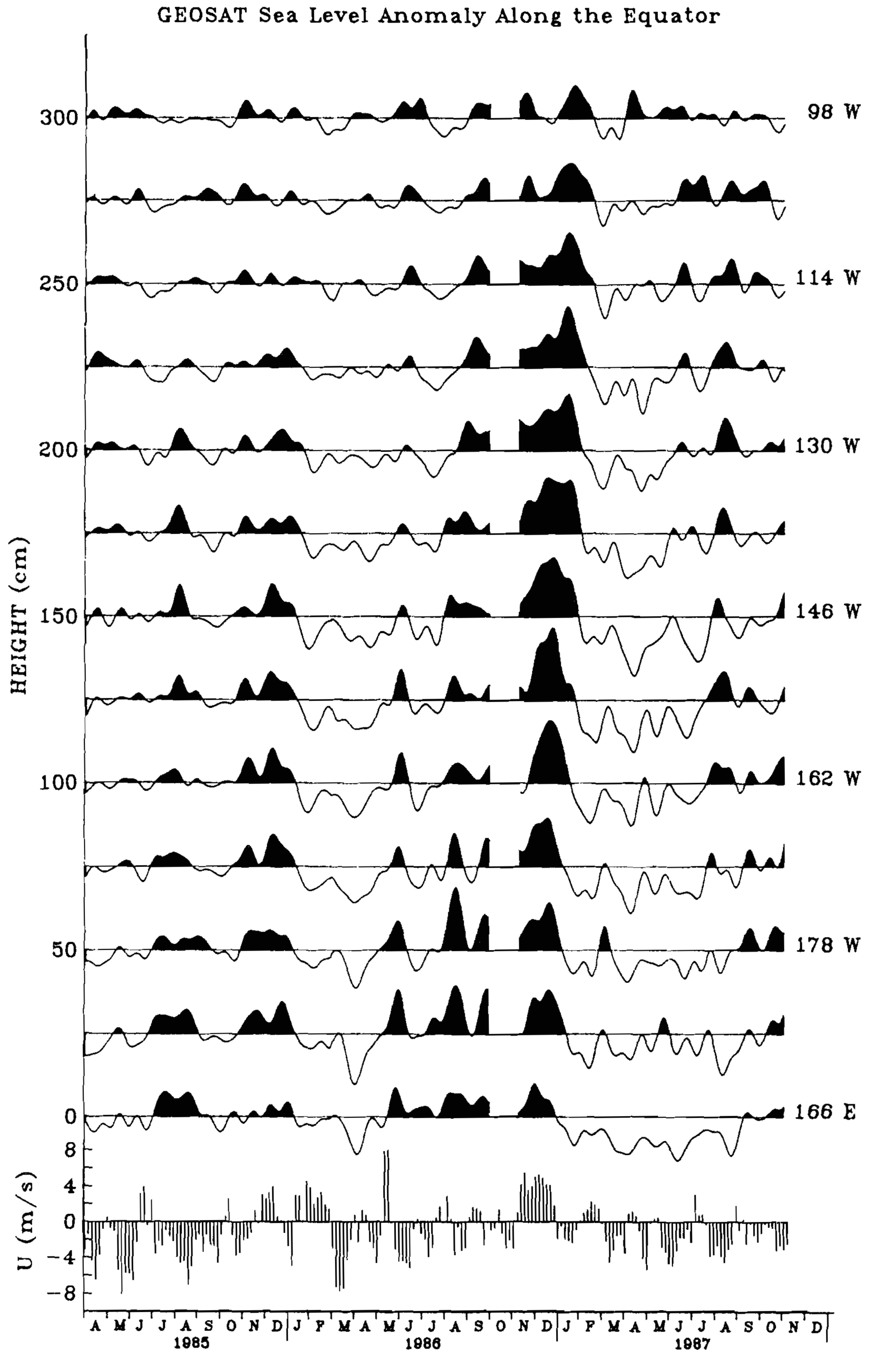


Figure 12. GEOSAT-derived sea level time series at 13 locations along the equator (8° intervals between 166°E and 90°W), April 1985 through April 1987. Horizontal lines indicate zero mean values for the first 12 months with 20 cm offset between pairs of series. Zonal wind record at bottom (U component at 850 mbar averaged between 5°S-5°N and 120°E-160°E) indicates times when westerly wind bursts were persistently observed in the far western equatorial Pacific. Westerly winds are well correlated with positive sea level anomalies which propagate eastward across the Pacific as downwelling Kelvin waves. Sustained westerlies in November-December 1986 resulted in large-scale redistribution of water and marked the onset of the 1986-1987 *El Nino*. (Cheney and Miller, 1988.)

ENSO Simulation: Ocean Hindcasting

Significant steps have been made in improving tropical ocean models for predicting ocean responses to changing atmospheric winds. Efforts at the CAC have resulted in a more accurate description of the SST anomalies in the tropical Pacific. Model output and observed data were routinely used by NOAA to monitor ENSO conditions during 1986/87.

Coupled Ocean-Atmosphere Simulation of ENSO

Model results of a coupled ocean-atmosphere GCM to study ENSO events exhibit self-sustained ENSO-like low frequency oscillations through positive feedback coupled mechanisms postulated by Lau (1981), Philander et al., (1984), and others.

This study suggests that the finite size of the ocean basin is crucial in leading to wave reflections which, through nonlinear processes, are many times greater than initial wave conditions. The essential features of the observed oscillations can be represented by a simple nonlinear delayed action oscillator.

A new ocean model capable of simulating details of the upper ocean thermal and dynamical structure is being developed by NASA scientists. Future work will include use of near real-time wind stress data obtained from NMC to allow reconstruction of the state of the ocean for rapid comparison with satellite and *in situ* data. Simulation schemes for incorporating observations of surface height with GEOSAT and TOPEX altimeters and scatterometer data are underway.

Tropical Variations and North American Climate

The hypothesis that sea surface temperature variations in the tropics may affect the climate over North America has been challenged by recent model studies. Recent studies suggest that the warm tropical Pacific Ocean temperatures of the ENSO events may not affect the average atmospheric conditions in the United States and other midlatitude continents. Results are based on improved computation methods for the community climate model (CCM) at NCAR.

Improvements in the CCM were undertaken to take advantage of the Cray computer's X-MP's four multiple processors in a highly parallel mode, thereby making possible the numerical investigation of longer time scale climatic phenomena.

Extended integrations of the CCM were run for 30 model years to assess the impact of observed inter-annually varying global ocean surface temperatures on the interannual variability of time averaged atmospheric states. The results suggest that warm tropical Pacific Ocean temperatures of the ENSO events may not affect average atmospheric conditions, unlike previous conclusions drawn from model runs based on sequential model shorter integrations. This very important result is under further investigation.

Predicting Tropical Winds—International Comparison Shows Need for Model Improvement

Surface winds from three forecast and analysis systems (ECMWF, UKMO and NMC [2]) were compared with independent wind observations from six buoys during February-July 1987. All buoys were located within 8 degrees of the equator in the Pacific Ocean (figure 13). Generally the analyses agree more with each other than with observations. In most cases the zonal winds showed better agreement than the meridional winds. Cross-spectral comparison clearly showed that the analysis systems and the buoy data were almost uncorrelated at periods shorter than 3 days.

These results underscore the urgent need to improve model prediction in tropical regions of the world, a topic being addressed by the TOGA program.

Accuracy of Sea Surface Temperature Data Sets Assessed

The CAC and the UK Meteorological Office completed a joint study to assess the accuracy of existing SST data used in climate forecasting. Comparison was made between six different monthly average SST analyses that were computed from the 1982-1986 period. These analyses include:

UKMO *in situ* (ship and buoy)
CAC *in situ*
CAC satellite
CAC blend (*in situ* and satellite)
FNOC [3] *in situ* and satellite
USSR *in situ*

Figure 14 shows SST anomalies for all six analyses for the extratropical North Pacific. Three analyses—UKMO, CAC *in situ* and CAC blend—are in close agreement, while the remaining analyses show important differences which vary with time. The figure also shows important differences between the CAC satellite analysis and the other data. The negative difference from the second half of 1982 to early 1983 is probably due to the effect of volcanic (El Chichon) aerosols on the satellite retrieval algorithms. However, differences that occur

[2] European Center for Medium-Range Forecasting, United Kingdom Meteorological Office, and National Meteorological Center (United States), respectively.

[3] Fleet Numerical Oceanography Center

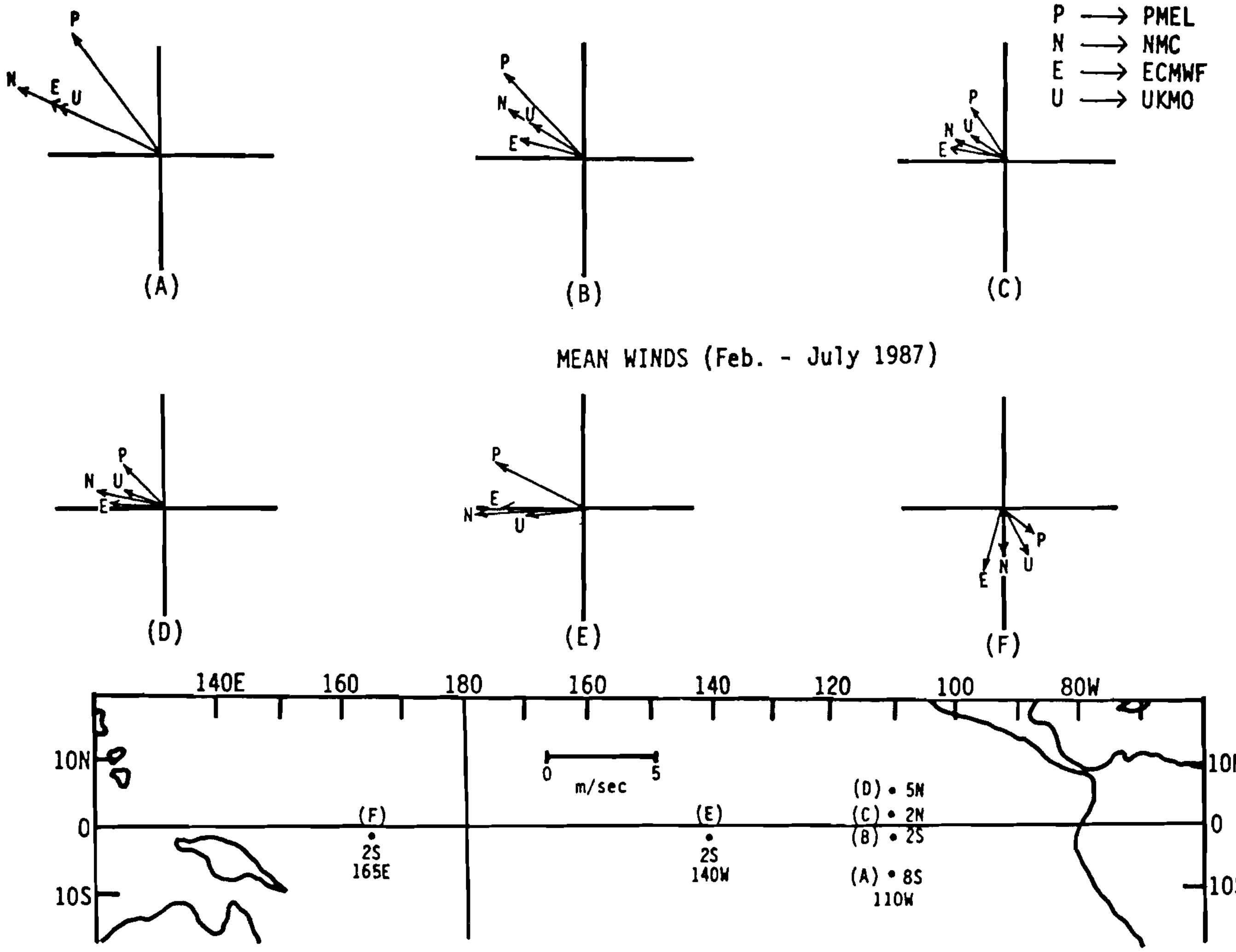


Figure 13. The six month (February to July 1987) mean surface wind vector at six locations in the tropical Pacific. The wind vectors were obtained from daily averages for PMEL buoy anemometer (labeled P) and the three forecast/analysis systems: NMC (labeled N), ECMWF (labeled E), and UKMO (labeled U).

in other periods cannot be explained as easily. The same data sets were compared to independent bathythermograph (XBT) data. Results show that monthly differences among the UKMO, CAC *in situ*, and CAC blend are not significant from XBT data. Remaining data sets from the CAC satellite, FNOC, and USSR seem to have differences and biases that are significantly different from the XBT data.

Extratropical Sea Surface Temperatures Have A Significant Influence on Wintertime Weather Patterns Over North America

The hypothesis that variations in extratropical sea surface temperatures affect the climate over the United States has been advanced by Namias for the past 20 years (J. Roads, 1987). Research at the National Climate Program's Experimental Forecast Center at the University of Washington sheds new light on this idea.

Figure 15 shows contrasting wintertime hemispheric 500 mb height correlation patterns for equatorial Pacific SSTs averaged over the region from 6°N to 6°S and from the international dateline eastward to the South American coast (left panel). SSTs in the extratropical North Pacific are averaged over a region near 32°N and 165°W (right pattern). The results are based on 6-month averages (November-April) for each winter during the 30-year period 1950-1979. The right panel consists of closed isotherms concentric about northern Canada, with strongest tropical and extratropical teleconnections over the western Pacific sector. The left pattern is notably stronger and resembles the Pacific North America (PNA) teleconnection pattern, which appears to be a natural mode of variability of the Northern Hemisphere winter circulation.

Recent general circulation model experiments indicate that this pattern could be the reflection of an atmospheric response to the extratropical sea surface temperature anomalies. It is not clear why the atmosphere is more strongly correlated with extratropical SST or why the correlation patterns for extratropical SST more clearly resemble the PNA pattern, but in any case these results

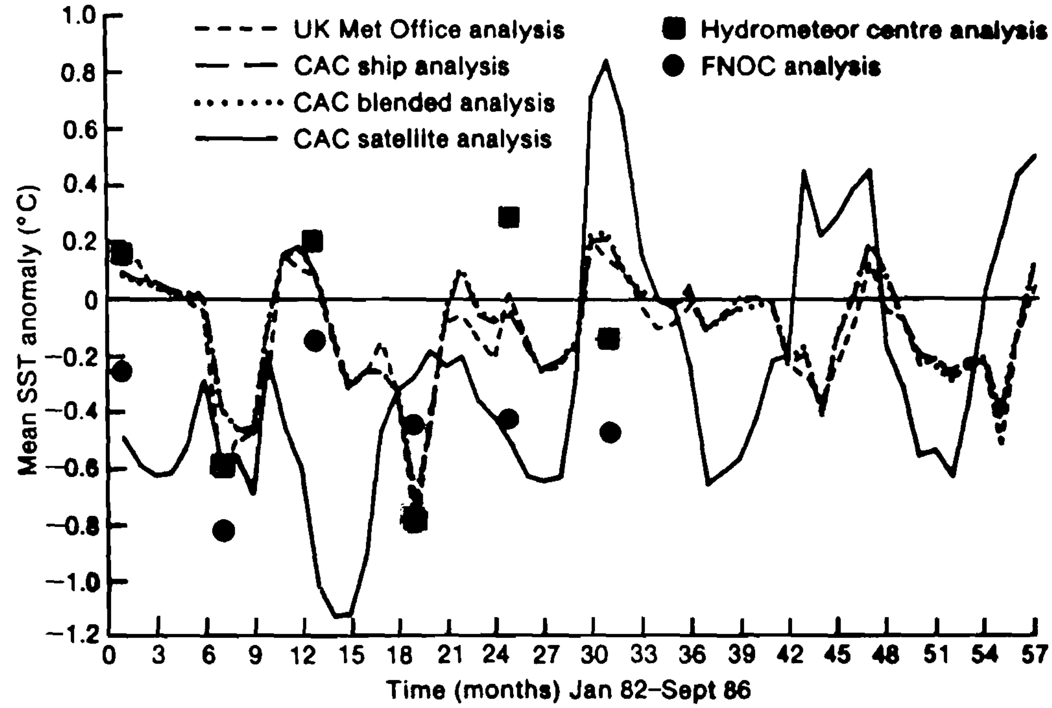


Figure 14a. Mean monthly SST anomaly for all six analyses for the extratropical North Pacific region.

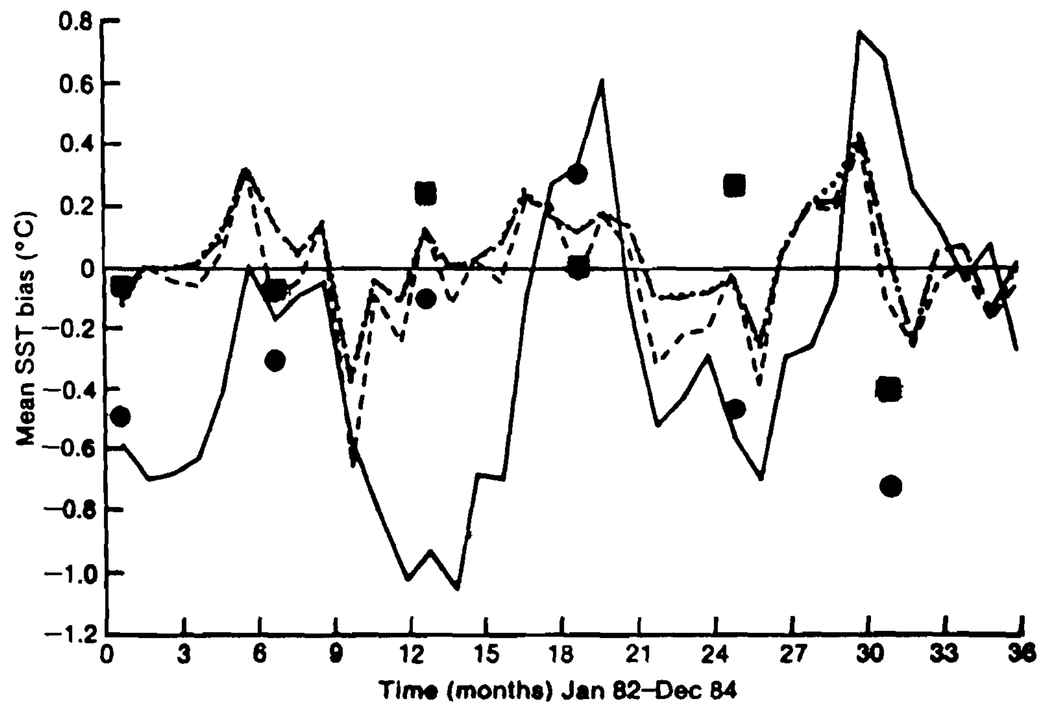


Figure 14b. Mean Monthly SST bias relative to the XBT SSTs (analysis-XBT) for all six analyses for the extratropical North Pacific region.

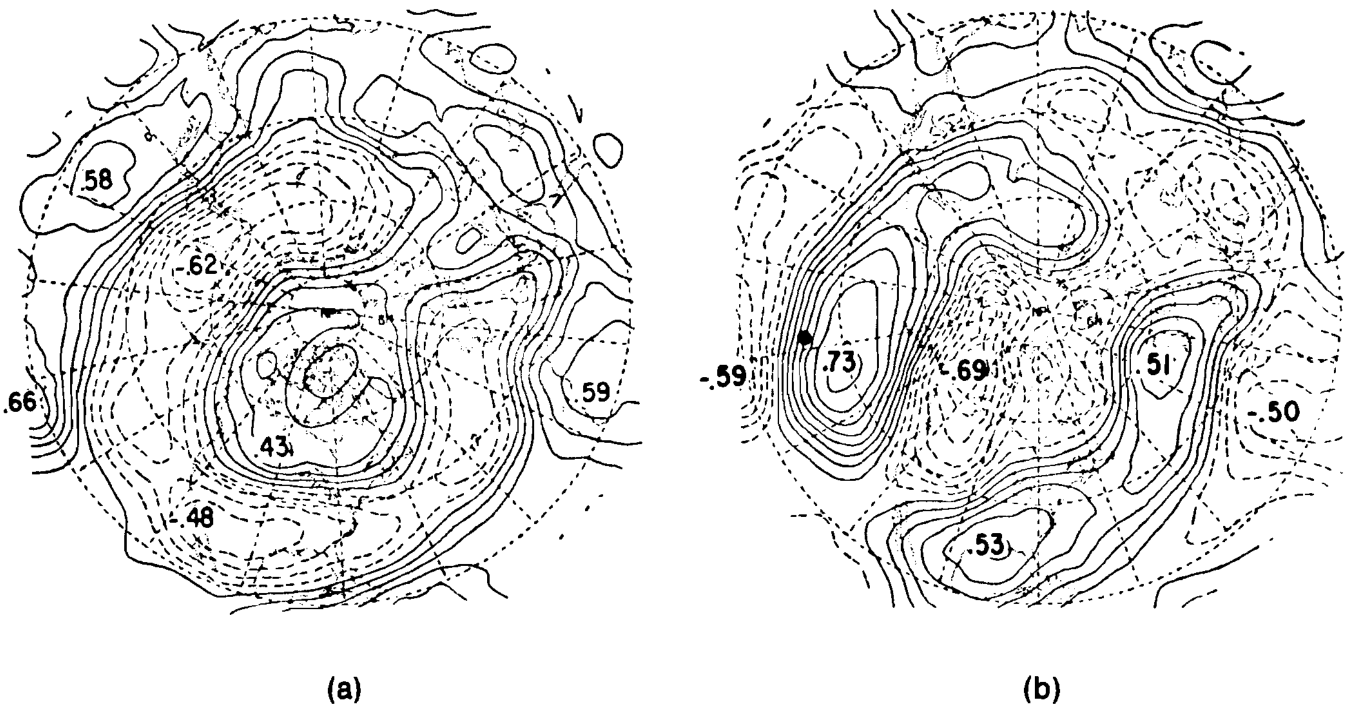


Figure 15. Contrasting wintertime hemisphere 500 mb height correlation patterns for (Panel a) equatorial Pacific sea surface temperature averaged over the region from 6°N-6°S and from the dateline eastward to South America, and (panel b) for sea surface temperature in the extratropical North Pacific averaged over a region 32°N, 165°W. (Provided by M. Wallace, University of Washington.)

support the contention that extratropical sea surface temperature has a significant influence on wintertime weather patterns over North America. Work is continuing on documenting and understanding these relationships.

11 Year Solar Cycle and Its Relationship with the Atmosphere

The search for links between solar variability and atmospheric changes continues. New and significant atmospheric observations correlated with solar variations have been confirmed. Researchers at NCAR and the Free University of Berlin have demonstrated that when atmospheric data were arranged according to one phase—the westerly phase in this instance—of the quasibiannual oscillation (QBO), temperatures and geopotential heights in the troposphere and stratosphere were clearly affected in winter by the 11-year solar cycle.

Stratospheric temperatures and geopotential heights in the northern hemisphere were positively correlated with the solar cycle at higher latitudes; they were negatively correlated at middle and low latitudes. During the minima, or when the sunspot number was low, in the western phase of the QBO the stratospheric temperature was lower. The opposite was observed in the easterly phase of the QBO.

The significance of these recent correlations lies in a new point of meteorological climate reference: the phase of the QBO. Scientists have shown that in the troposphere, relationships are especially clear in the west phase over North America and adjacent ocean areas. In the stratosphere, there is strong evidence that the solar maximum influence serves to depress the extratropical signals of the QBO.

Improvements in Seasonal Analog Prediction

NOAA's CAC is refining the analog prediction method, one tool used in forecasting U.S. seasonal temperatures. The method, first developed at the National Climate Program Experimental Forecast Center at Scripps Institution of Oceanography, was transferred to the National Weather Service for evaluation. Modifications of the system by CAC researchers have improved its overall usefulness. Mapped values of forecast skill are being generated to enable forecasters to weight the analog prediction in making a seasonal forecast. The addition of U.S. surface temperatures to the set of analog predictors also results in higher skill levels. The analog method, combined with persistence and other information, gives the best overall forecast result (Barneston and Livezey, 1987).

The CAC continues to improve its capability to provide useful seasonal forecasting for the United States. In cooperation with the experimental forecast centers and other university scientists, a collaborative program of applied and basic research is under way.

40-50 Day Atmospheric Oscillation

Recent studies at the NASA Experimental Forecast Center and by other researchers have generated great interest in understanding the causes of the observed 40-50 day oscillation in the atmosphere and its impact on long-range weather forecasting. Studies of outgoing longwave radiation over the Pacific suggest that the 30-60 day oscillation and the onset of the ENSO may be closely related (Lau and Chan, 1986, 1988.)

An important component of extratropical long-range prediction is the possible influence of the tropics on the circulation of the extratropics via atmospheric teleconnections. Lau and Philips (1986) show some evidence that the 30-60 day oscillation in the tropics may have an influence on extratropical geopotential height fluctuations.

On the monthly to seasonal time scale, specific teleconnections patterns that are related to tropical variability have been identified (Livezey and Mo, 1986). They found that most of the significant teleconnections appear during ENSO years.

A theory of the origin of the 30-60 day oscillations in the tropics has been advanced by Lau and Peng (1987). They suggest that the observed structure and propagation of the 30-60 day oscillation can be explained in terms of a positive feedback between convection and low level moisture convergence. The time scale of the oscillation is determined by the time it takes for a tropical "super-cluster" to travel completely around the globe along the equator.

Because of the influence of varying boundary conditions and large-scale mean circulation, the propagation speed of the wave disturbance is variable and may be the reason for the observed large variability in oscillation periods.

At present, this basic theory is being tested in GCM experiments performed by many research groups around the world.

World Ocean Circulation Experiment (WOCE)

The U.S. WOCE Science Steering Committee (SSC) was formed in 1984 to plan and implement the U.S. component of WOCE. Day-to-day coordination, management, and support are provided by the U.S. planning office located at Texas A&M University. Since 1984, the United States has completed an expanded outline of the U.S. WOCE implementation plan.

In January 1987, the U.S. WOCE began detailed planning for the WOCE Hydrographic Program (WHP). NSF organized a discussion of WHP at a meeting of the Ocean Drilling Program Council in April to discuss U.S. resource contributions to WHP. A small steering group for planning of global observations met at NCAR in April where it was decided to proceed with a Global Surface-Layer Program, which has three projects: surface-layer velocity measurements, surface-layer transport measurements, and surface-layer heat flux measurements.

The first of a series of regional WOCE meetings was held in July to disseminate WOCE plans to scientists and managers in countries not actively participating in the planning. A community modeling effort (CME) has been initiated to obtain benchmark calculations using eddy-resolving, multilayer, thermodynamic models. The first phase begins at NCAR. The University of Delaware has put into operation a pilot WOCE/TOGA data management program. The Scripps Institution of Oceanography has established an oceanic thermal-data center for TOGA in cooperation with the National Oceanographic Data Center (NODC).

Model Simulations of Climate Change

Global climate models are a basic tool for simulating future climates caused by changes in atmospheric composition. Although a great deal of emphasis is placed on model results, the physics of the models are limited by a lack of understanding of basic atmospheric processes, such as the effects of the ocean and feedbacks due to clouds

A number of general circulation models are in use at several laboratories in the United States and Europe. A comparison of future climate simulations of these models shows significant differences at global and regional levels.

Largely through the efforts of the DOE CO_2 program, an international project has begun to compare climate models and better understand their potential for regional climate predictions.

Principal general circulation modelers from the United States, Canada, United Kingdom, and the PRC met in Stony Brook, New York in June 1987 to develop the first experimental design for comparing climate models used to estimate possible CO_2-induced climate change.

The study is investigating how different representations of clouds in the models may contribute to differences in model results. Previous studies show that different clouds and representations of clouds in the model can cause differences in the representation of radiative energy balance and hence the resulting climate projections (Cess and Potter, 1986, 1987).

In addition, several models do not include a diurnal cycle; instead they present solar energy in terms of a daily average radiation. This approximation may affect cloud formation (e.g., thunderstorms) and the role of such clouds in the radiative balance. Results of these important comparisons will be available in 1988.

CO_2 in Surface Water of the Western Equatorial Pacific Ocean

The second joint PRC-U.S. TOGA expedition was conducted in the western Pacific Ocean from November 1986-March 1987. The ocean is an important active reservoir in the global carbon cycle. Previous research has demonstrated links between equatorial oceanographic conditions, carbon dioxide chemistry of the surface waters, and atmospheric CO_2 concentrations.

Scientists from the U.S. and the PRC aboard the PRC research ship "Xiang Yang Hong #5" collected samples from the upper 5 meters of water in an area bounded by 130°E to 165°E and from 5°N to 5°S. Measurements included temperature, salinity, pCO_2, total CO_2, oxygen, nitrate, phosphate, and silica. Air samples were also obtained at fifty-four locations for the determination of pCO_2 of the marine air in the study area.

The timing of the cruise provided an opportunity to measure CO_2 uptake and release in the ocean during an ENSO event. Results indicate that during an ENSO event, the pCO_2 of the surface waters of the western equatorial Pacific increases above non-ENSO levels, confirming previous but less extensive measurements. It was also apparent that for this region of low primary productivity, the total CO_2 concentration in water varied in direct proportion to salinity. This is in contrast to middle-and high latitude oceanic areas where CO_2 chemistry is controlled by biological activity.

This work contributes to the DOE effort to understand the carbon dioxide chemistry at the air-sea interface and the rate at which the ocean currently takes up CO_2 from fossil fuel combustion.

US-USSR Cruise in Pacific Measures CO_2 and CFCs in Surface Waters

Scientists from Working Group VIII of the U.S.-U SSR Bilateral Agreement on Protection of the Environment conducted a joint cruise aboard the research ship "Akademik Korolev" to sample and analyze a variety of climate-related trace gases and aerosols from a wide range of marine environments.

During the first leg of the cruise, which began May 1 from Hilo, Hawaii, atmospheric and oceanographic measurements were taken in Soviet territorial waters off the Kamchatka peninsula, a region critical for understanding water mass formation in the North Pacific and its relationship to climate variation, but off limits to non-Soviet vessels.

The Korolev then headed south to Wellington, New Zealand, measuring the levels of greenhouse gases in the atmosphere and in the ocean and their variation with latitude. From New Zealand, the ship sailed into the Indian Ocean for Singapore, making similar observations, and then returned to Hilo to drop off the U.S. scientists, before continuing to its home port of Vladivostok (figure 16).

The U.S. scientific party was headed by Dr. Richard Gammon of NOAA's Pacific Marine Environmental Laboratory (PMEL) and included researchers from the Scripps Institution of Oceanography, Washington State University, the University of Hawaii, the University of Washington, the Oregon Graduate Center, and the Air Resources Laboratory (ARL) of NOAA.

Climate Research

Paleoclimate

Paleoclimate Record from Dunde Ice Cap

Three complete ice cores from a subtropical region, the Dunde ice cap in the northeastern section of the Quinghai-Tibetan Plateau, were retrieved by a joint U.S.-PRC research expedition during summer 1987. A total of 6,500 water samples and 83 meters of frozen ice cores in pristine conditions were returned to the Byrd Polar Research Center at the Ohio State University and one 136-meter ice core and 3,600 water samples were returned to the Lanzhou Institute of Glaciology and Geocryology. Initial evidence suggests that these cores represent glacial stage ice, the first samples to be recovered from a nonpolar location.

Analysis of these cores will be completed in 1988. Quantitative climate reconstruction deduced from these cores will help calibrate the rich and diverse written historic records of China.

Chronology and Paleoclimatoloty of Loess Deposits in Central China

The loess deposits of central China are probably the most complete terrestrial record of Plio-Pleistocene climatic change. A detailed interpretation of the China loess sequence is among the most important land-based paleoclimatology problems today. During 1987, a Sino-American team of researchers conducted field studies in China. The critical problem addressed was to test methods of dating and qualitatively reconstructing climate conditions from the loess sediments. Measurements included geochemical and magnetic analyses of the sediments.

Results show a close correlation between the amplitude of the magnetic susceptibility of the sediments in China and the amplitude of oxygen isotopic ratios in deep sea cores. This correlation will allow the loess sediments to be more accurately dated and interpreted relative to the established chronology for deep sea sediments.

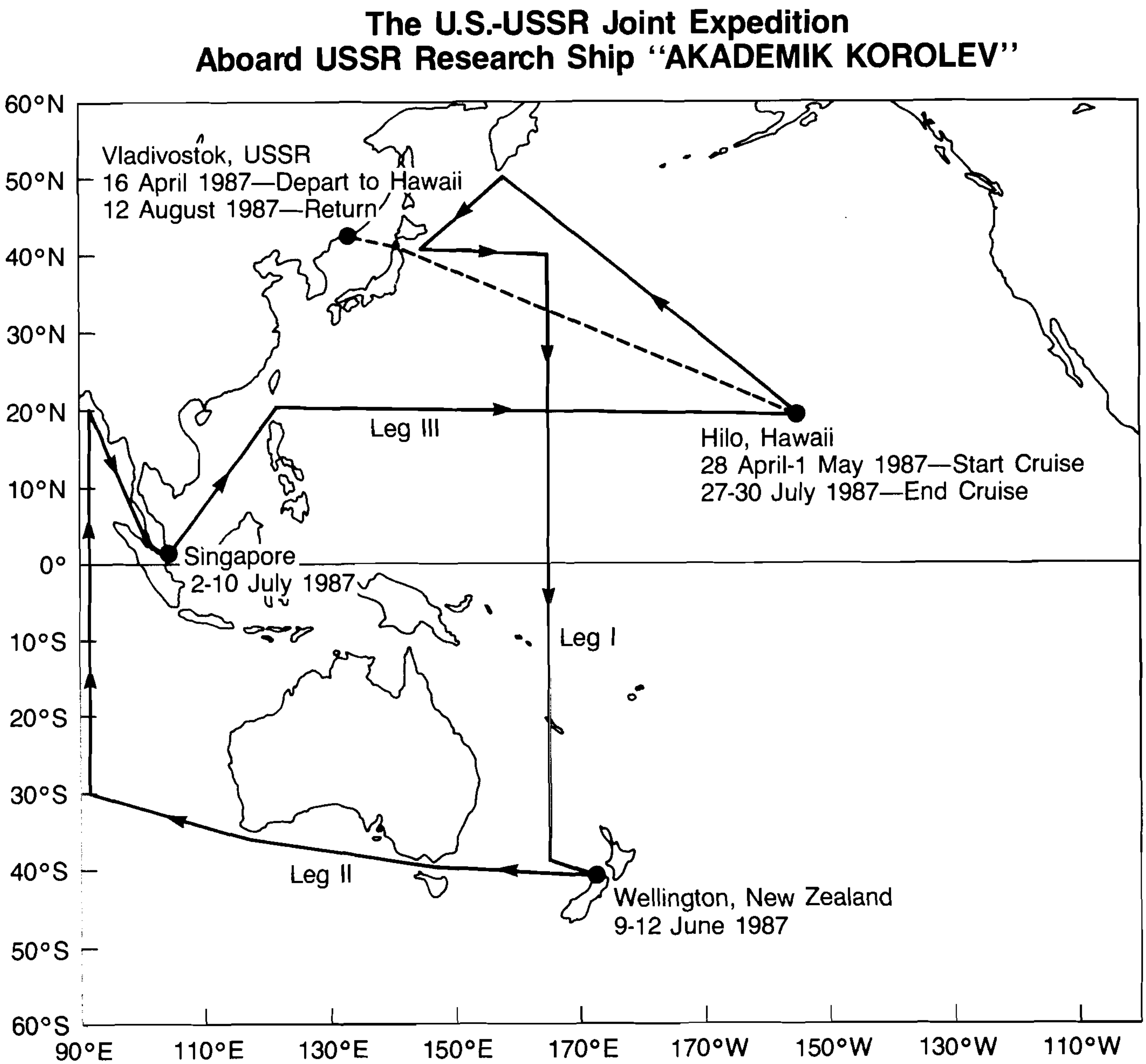


Figure 16. The U.S.-USSR Joint Expedition aboard USSR Research Ship "AKADEMIK KOROLEV."

Crary Ice Rise Project

Two core holes of 370 and 480 meters were successfully drilled to the subglacial bed underlying the Crary Ice Rise in Antarctica. The ice rise is located on the Ross Ice Shelf, where it is grounded on a submarine mountain peak 260 meters below sea level.

Thermistor cables have been installed in each hole for the long-term monitoring of temperature gradients within the ice shelf. Although the mean annual surface temperature at the ice rise is $-27^\circ C$, first measurements indicate that the temperature at the bottom of the ice shelf is only $-2^\circ C$, close to the freezing point of sea water. These data suggest that the ice rise is a relatively young feature, probably formed by thickening of the ice shelf only during the last few hundred years.

Fossil evidence from the cores suggests that open marine conditions existed in the interior basins of the West Antarctic during a portion of the Pliocene epoch some 3-6 million years ago.

The Pliocene epoch was a relatively warm period for the earth and one that may be an analog of future climates. The USGS is planning a major research effort and conference in 1988 to better understand this time period.

Tulelake, California: A 3-Million-Year Climate Record

A nearly continuous record of climate change for the past 3 million years has been reconstructed from a

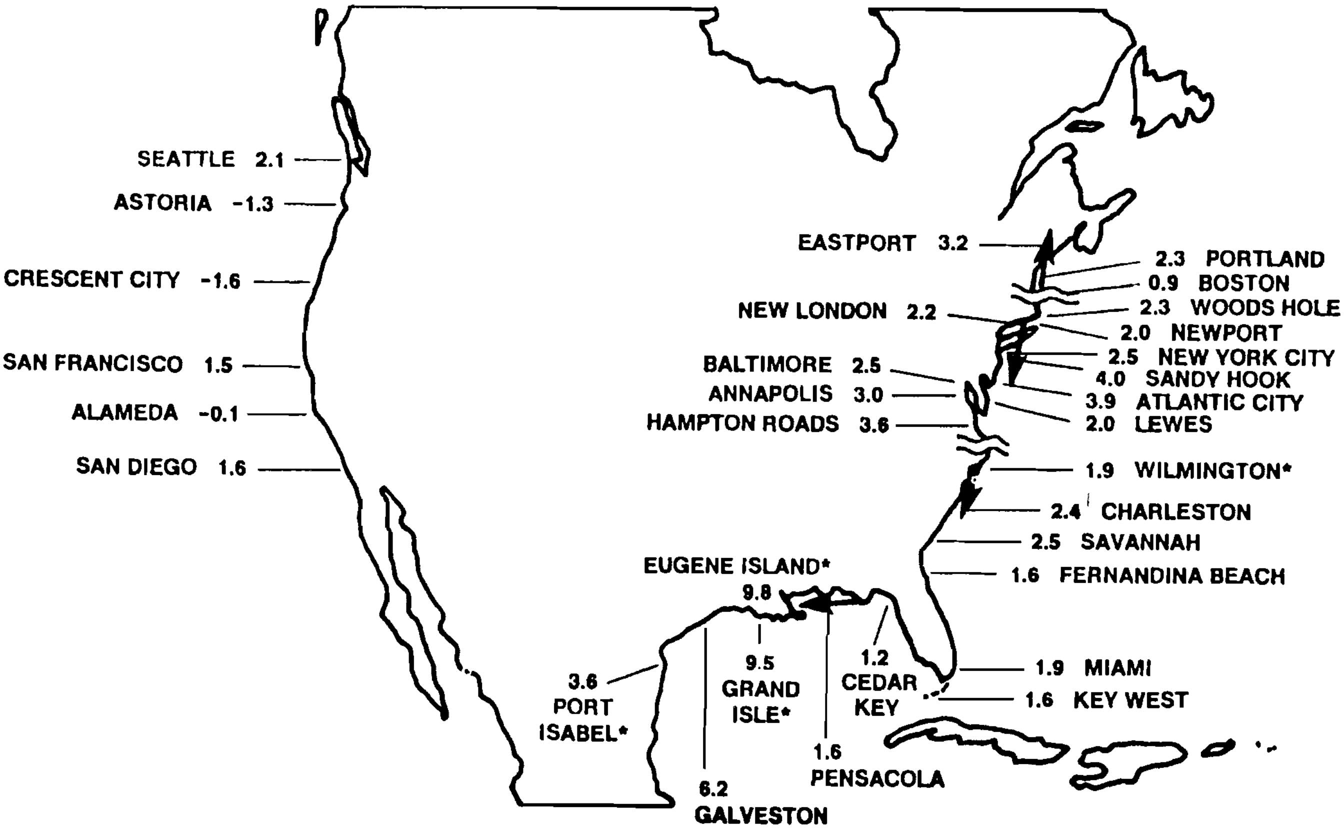


Figure 17. A summary of the present best estimates of local relative sea level changes along the U.S. continental coastline in mm/yr. The figures are based on the tide gauge records over different intervals of time during the period 1940-1980. Much regional variability is evident. Reprinted from "Responding to Changes in Sea Level, Engineering Implications," 1987, with permission form the National Academy Press. (NAE, 1987.)

334-meter sediment core from Tulelake in northern California. Radiometric dating of the core shows that sedimentation at this site has been nearly continuous during the past 3 million years except for an interval of about 400 and 600 thousand years ago.

Changes in the types of pollen preserved in the core show marked variations in wetness in this region. These variations in basin wetness are probably related to both changes in climate and local tectonics and geomorphology.

The most significant pollen changes occurred about 1.6 million years ago at the start of the Pleistocene. These changes reflected both global cooling and increasing rain shadow effect of the Cascades to the west. More detailed analysis and interpretation are in progress.

Climatic Change and Environmental Impacts

Greenhouse Climate Change

Continued worldwide attention has been focused on climate change induced by the greenhouse effect. A steady stream of congressional hearings and national and international meetings (see Program Administration) has raised the awareness of the international community to this important problem. Major national activities in 1987 include the following:

- Hearing of Senate Committee on Environmental and Public Works on implications of the finding of the expedition to investigate the ozone hole over the Antarctic (October 27, 1987).[4]
- NAS publication, *Current Issues in Atmospheric Sciences*, prepared in response to congressional request.
- Hearings of the Senate Committee on Commerce, Science and Transportation, on global climate change due to man-made changes in the atmosphere (July 16, 1987).

NAE Report on Sea Level Rise

"Relative mean sea level, on statistical average, is rising at the majority of tide gauge stations situated on continental coasts around the world." This was the major conclusion of a National Academy of Engineering (NAE) report, "Responding to Changes in Sea Level

[4] Observers to the hearing included six visiting Soviet scientists in the United States for activities of Working Group VIII of the U.S.-USSR Bilateral on Environmental Protection.

(NRC, 1987)". At all but a few stations along the Pacific coast, tide gauge records for the coterminious United States show rising sea level for the period 1940-1980 (figure 18).

Estimates of future mean sea level for the year 2010 from several reports are summarized below:

Table 1. Contributions to Future Sea Level Rise in the Year 2100 (centimeters)

Study	Thermal Expansion	Alpine Glaciers	Greenland	Antarctic	Total
Hoffman, et al., 1986	28-83	2-37	6-27	12-220	57-368
Thomas 1985	--	--	--	0-220	--
Hoffman 1983	29-115	[2]	[2]	[2]	56-345
NRC 1983	--	10-30	10-30	−10 to +100	--
Revelle [1] 1983	30	12	12	[3]	70

[1] Contributions in the year 2085.

[2] Assumes that the glacial contribution would be one to two times the contribution of thermal expansion.

[3] Revelle attributes 16 cm to other factors.

Source: National Resource Council, National Academy of Engineering, 1987. *Responding to Changes in Sea level.* Table 2-1, p.26.

Forest Service to Study Effect of Climate Change on Forests

The U.S. Forest Service has initiated a program to assess the impact of future climate change on forests. The program will address four main problems:

- What processes are involved with atmospheric effects on forests?
- How do atmospheric changes influence forest health and productivity?
- How do forest managements practices affect the atmosphere?

Recognizing the importance of climate change, the Forest Service is considering management options, through improvement of models, to predict growth and yield of forests and to understand climate impacts on forest ecosystems.

EPA Prepares Reports to Congress

Congress has asked EPA to assess the environmental implications of increasing atmospheric concentrations of CO_2, N_20, CH_4, CHC, and other greenhouse trace gases released by human activity. The reports are due to Congress in March 1988.

The reports will examine likely changes in hydrology, agriculture, and forestry in four regions of the United States. The areas include the Southeast, the Great Lakes, California, and the Great Plains. The Southeast has unique ecosystems and much coastal activity, forestry and agriculture; the Great Lakes are the largest source of fresh water in the world; California is an example of a highly populated area with high demand for and limited supply of water; and the Great Plains is among the most productive agricultural regions of the world.

Workshops and special studies were organized in 1987 to prepare these reports.

NATIONAL CLIMATE PROGRAM BUDGET, 1987-1989

The National Climate Program Act requires that the Office of Management and Budget (OMB) review all federal agencies' climate budget requests as an integrated, coherent, multiagency budget. The National Climate Program Office compiles this data from agency climate budget requests and analyzes the overall climate budget.

Total funding for the climate program, by agency, in FY 1987, and estimated for FY 1988 and FY 1989, is shown in Table 2.

Table 2. National Climate Program Budget, FY 1987 to 1989, by agency (million$)

Agency	FY 1987	FY 1988 (est.)	FY 1989 (proj.)
Agriculture	28.3	28.9	31.9
Commerce	56.1	53.1	66.7
Defense	13.0	14.3	11.2
Energy	13.9	14.7	18.5
EPA	9.0	9.8	17.7
Interior	1.0	1.0	1.0
NASA	17.4	16.3	18.9
NSF	55.4	56.5	66.1
TOTAL	194.1	194.6	232.0

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