nvironmental Research Laboratories
rograms and Plans

FY 1989 Programs and FY 1990 Plans

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

Environmental Research Laboratories Programs and Plans

FY 1989 Programs and FY 1990 Plans

December 1989

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Boulder, Colorado
Joseph O. Fletcher, Director

NOTICE

Mention of a commercial company or product does not constitute an endorsement by NOAA Environmental Research Laboratories. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

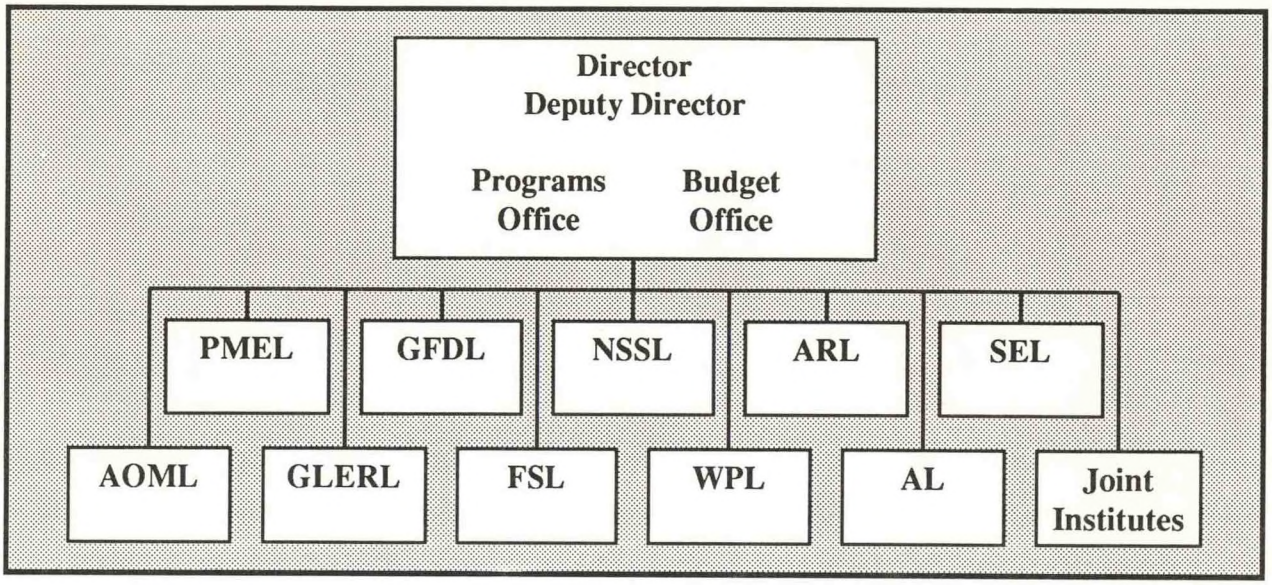
Document available in Programs Office, Environmental Research Laboratories, Boulder, Colorado

Environmental Research Laboratories

The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, the space environment, and the Earth.

CONTENTS

These are highlights of Laboratory accomplishments and abbreviated summaries of immediate objectives. More comprehensive and detailed descriptions of activities, results, and plans may be found in the Laboratories' annual reports (which may be obtained directly from the Laboratories) and in the open literature. Interested readers are referred to the annual *Environmental Research Laboratories Publication Abstracts*.



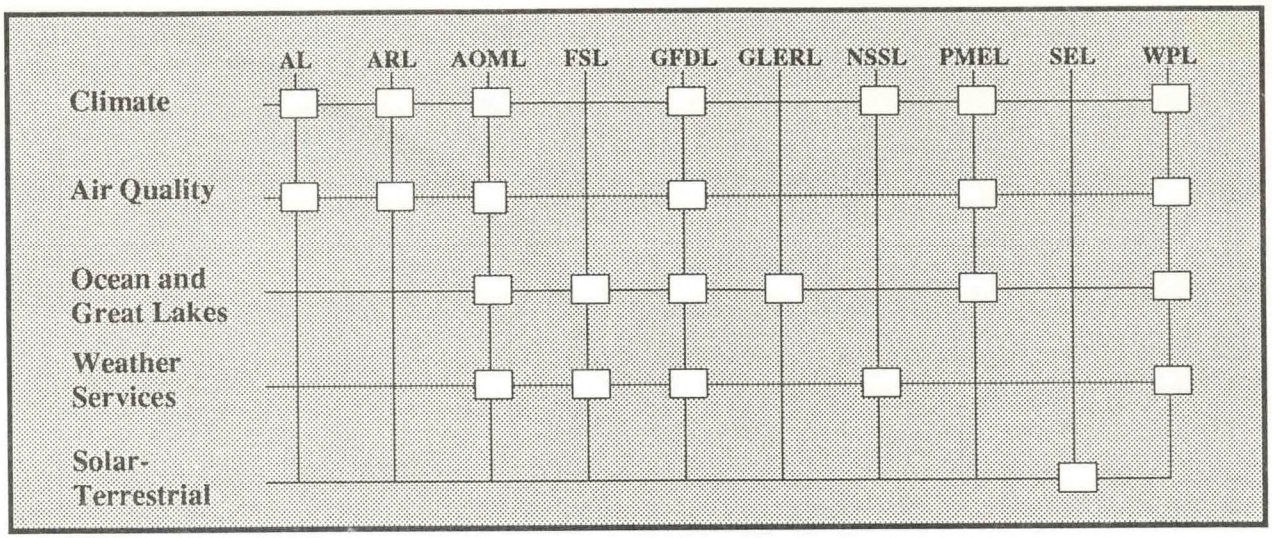
ENVIRONMENTAL RESEARCH LABORATORIES

The Environmental Research Laboratories (ERL) are organized within NOAA's Office of Oceanic and Atmospheric Research and have their headquarters in Boulder, Colorado. They include major units throughout the United States:

Aeronomy Laboratory (AL)	Boulder, Colorado
Atlantic Oceanographic and Meteorological Laboratory (AOML)	Miami, Florida
Air Resources Laboratory (ARL)	Silver Spring, Maryland
Forecast Systems Laboratory (FSL)	Boulder, Colorado
Geophysical Fluid Dynamics Laboratory (GFDL)	Princeton, New Jersey
Great Lakes Environmental Research Laboratory (GLERL)	Ann Arbor, Michigan
National Severe Storms Laboratory (NSSL)	Norman, Oklahoma
Pacific Marine Environmental Laboratory (PMEL)	Seattle, Washington
Space Environment Laboratory (SEL)	Boulder, Colorado
Wave Propagation Laboratory (WPL)	Boulder, Colorado

In addition, institutes administered jointly by ERL and universities undertake research for ERL. ERL also sponsors research through contracts and grants to universities, State and Federal agencies, and private enterprise. Many ERL research efforts rely on the cooperation of other NOAA elements, including the National Weather Service (NWS), National Environmental Satellite, Data, and Information Service (NESDIS), National Ocean Service (NOS), National Marine Fisheries Service (NMFS), and the Aircraft Operations Center.

ERL's program includes fundamental research to develop technology and improve NOAA services to the public. Samples of research results and applications are Doppler radar technology (to improve tornado detection and warnings), mathematical models (to predict climate and ocean variations and to improve hurricane forecasting), ocean current forecasts (to minimize ship operation costs), observations of ocean upwelling (to maximize fish catches), and solar activity forecasts (to protect astronauts and preserve



communications efficiency). Users of ERL research results include the atmospheric, marine, and space research communities, NOAA service components (NWS, NOS, NESDIS), other Federal agencies, State, and local governments, and the private sector.

The ERL program is broad, embracing studies relating to the oceans and Great Lakes, the lower and upper atmosphere, and the solar-terrestrial environment. Studies and services focus in five subject areas: Weather, Climate, Air Quality, Ocean and Great Lakes, and Solar-Terrestrial Environment.

The following summary of ERL research is organized in terms of these subject areas. Succeeding sections discuss the accomplishments and plans of the individual Laboratories and their units. The Appendix lists acronyms and initialisms used in all sections.

WEATHER OBSERVATION AND PREDICTION RESEARCH

Weather programs include research on observational systems; data acquisition, management, analysis, and display systems; severe storm prediction, including flash floods, hail, tornadoes, and wind storms; and hurricane prediction. The focus of ERL weather research is to provide the theoretical framework, scientific understanding, and technology to assure success of NOAA's program to modernize the Nation's weather services of the 1990s.

Major elements of ERL's weather research are conducted by NSSL, FSL, WPL, AOML, and GFDL. GLERL and PMEL conduct research specific to NOAA's ice, wind, and wave prediction mission.

During 1989, ERL weather research achieved some notable successes:

- The preproduction prototype for the Wind Profiler Demonstration Network was installed and passed the required tests. The FSL Profiler Program Office accepted the instrument and gave approval for the production of thirty more units to be installed in sixteen midwestern states. The Wind Profilers will be joined by Next-Generation Weather Radar (NEXRAD) Doppler radars and Automated Surface Observing Systems as part of the NWS Modernization and Restructuring Demonstration in the early 1990s. In the meantime, Wind Profiler data will be collected and distributed to operational NWS forecasters. Weather researchers in several agencies will begin using the Wind Profiler Demonstration Network data to improve understanding of atmospheric processes and to develop advanced prediction techniques.

- WPL has obtained high-quality soundings for the vertical temperature structure of the atmosphere by combining data from the Radio Acoustic Sounding System (RASS) with data from the TIROS–N Operational Vertical Sounder. A comparison of RASS temperature measurements with radiosondes, without correcting the RASS measurements for vertical wind, showed an rms difference of only 1°C. These are significant steps toward an integrated automatic atmospheric sounding system.

- A highly advanced interactive forecaster workstation was completed and installed at the NWS Forecast Office, Denver, CO. The Denver AWIPS Risk Reduction and Requirements Evaluation system is a functional prototype for the NWS advanced workstation of the 1990s, AWIPS. It is the culmination of several years development and evaluation by the FSL Program for Regional Observing and Forecasting Services. The system will allow the NWS to demonstrate many of the AWIPS functional requirements before finalizing procurement specifications and awarding a multimillion-dollar development contract to industry. It will also allow validation of concepts in planning for and transitioning to a restructured and modernized NWS field organization.

- The FSL Analysis and Prediction Program completed a study to apply Wind Profiler and NEXRAD Doppler radar data to severe winter weather predictions. The study compared conventional data with conventional plus Wind Profiler and Doppler data in a very intense snow storm. The addition of Wind Profiler data allowed calculation of wind flow that indicated impending heavy snowfall. Doppler radar measurements indicated the transformation of steady snowfall to intense rates. The identification of important time and space scales of heavy snowfall will allow ERL scientists to develop conceptual models for NWS forecasters in time for Wind Profiler Demonstration Network and NEXRAD network implementation.

- Several noteworthy hurricane research accomplishments occurred in 1989. GFDL studied a wave disturbance which later developed into Hurricane David, 1979, and contrasted that with analyses of a nondeveloped wave observed over the Atlantic a week earlier. Analyses of vorticity and heat budgets revealed that the sum of the effects due to vertical motion and latent heat release caused warm core formation only in the one case.

A Multilply-Nested Movable Mesh (MMM) model was used to produce experimental predictions of Hurricane Gloria, 1985. The model produced a track with accelerated movement after 48 hours, in good agreement with observation. The forecast error at 72 hours was 156 km in the MMM model, as compared with 480 km for the real-time forecast.

- A much improved nested hurricane track prediction model was developed and tested by the Hurricane Research Division of AOML. The model focuses maximum resolution on the hurricane core so that the most dense data, which are usually available from NOAA research aircraft in and near the core, may be accurately analyzed and included in model calculations. Comparisons of predicted hurricane tracks with those produced by a simple persistence-climatology model indicate track error reductions in the range of 23% to 31%. These error reductions indicate that the new nested model yields considerable improvement in the 12-to-36 h forecast.

- NSSL completed a valuable ten-year climatology of advective flow from the north over the Gulf of Mexico, and the return flow over the United States. The return flow is frequently the source of energy for violent weather outbreaks from the southern United States to the High Plains. The climatology is already being used in several NWS Southern Region Forecast Offices.

- A comprehensive study of computer-model long-range, one-month predictions was conducted by GFDL. Four packages of physics formulations were compared to evaluate prediction bias and the model's ability to simulate patterns of high pressure blocking, a phenomenon that may persist for several days but which has never been modeled in a consistent manner. Reliable simulation of blocking is very important to successful long-range forecasting. The model that used the most sophisticated physics produced the least bias and most accurate simulation of high pressure patterns.

CLIMATE RESEARCH

Climate research is performed by nearly all ERL Laboratories. The goal of ERL climate research is to recognize, diagnose, analyze, understand, and predict large-scale and regional causes and changes in the oceans and atmosphere.

In 1989, major climate research accomplishments included the following:

- Long-term satellite-observed ozone measurements were investigated and corrected by scientists from the Geophysical Monitoring for Climatic Change (GMCC) Division of ARL. The satellite measurements provide global coverage of upper atmospheric ozone, an important chemical constituent that helps regulate cancer-causing ultraviolet (UV) radiation. A drift in the 1979–1987 satellite measurements had long been suspected. GMCC scientists developed a correction technique using ground-based Dobson spectrophotometer measurements. However, the 1982 eruption of the El Chichón volcano in Mexico released great quantities of particles into the atmosphere, making the Dobson measurements less accurate. GMCC scientists then organized a worldwide network of lidar aerosol measurements to help correct the Dobson data. Analyses and corrections were completed and compared with theory with the assistance of NASA investigators. The corrected ozone data show a larger reduction in Northern Hemisphere upper-atmospheric ozone during 1979–1987 than had been suspected.

- AL scientists continued to lead stratospheric ozone research. AL scientists were research leaders on all fifteen flights by the DC–8, and contributed significantly to all fourteen flights by the ER–2, from Stavager, Norway, into the Arctic polar vortex during January and February 1989. The results clearly indicated that denitrifications and high levels of reactive chlorine, arising from the presence of polar stratospheric clouds, were present. The potential for ozone loss by the same mechanisms causing the Antarctic ozone hole is, thus, clearly there in any Arctic winter during which the vortex maintains cold temperatures into March, an infrequent but recorded occurrence. Interannual variations in the abundance and persistence of polar stratospheric clouds obtained from satellite observations were shown by AL to agree well with

the observed changes in ozone. These in turn were found to be in good agreement with seasonal and interannual changes in the abundances of OClO obtained from measurements at McMurdo Station, Antarctica.

AL also developed a new system for measuring stratospheric trace gases by using spectroscopic absorption of light in the UV and visible portions of the spectrum. The instruments will be installed at several global locations as part of a joint NOAA-NASA program for early detection of stratospheric change.

- Theoretically precise "line-by-line" benchmark solutions of shortwave radiative computations for a range of clear and cloudy atmospheres have been prepared at GFDL. These are solutions for the interaction of solar radiation with water vapor and water drops in the atmosphere. The need to develop this benchmarking capability was recognized by the World Meteorological Organization (WMO) and was the primary objective of the Intercomparison of Radiation Codes in Climate Models project. The solutions will enable the world modeling community to evaluate and enhance the simpler shortwave radiative transfer algorithms currently used in general circulation models.

- AOML made the first open-ocean measurements of dimethylsulfoxide and dimethylsulfone in surface air and precipitation. They also made the first simultaneous marine boundary layer measurements of all five known atmospheric oxidation products of dimethylsulfide. This is a significant step toward determining the role of phytoplankton-produced dimethylsulfide in the possible formation of cloud condensation nuclei, which are theorized to increase cloud-radiative and global temperature feedbacks.

- A new compilation by PMEL of historical bathythermograph (BT) data in the tropical Pacific allowed the discovery of westward-propagating long Rossby waves in the northern tropical Pacific. The new BT data show that although the Rossby waves can be very important in determining pycnocline anomalies to the west of regions of strong wind-stress-curl forcing (both on annual and interannual periods), there is little evidence that the waves reflect off the western boundary to affect subsequent evolution of a warm event on the equator, such as during an El Niño-Southern Oscillation (ENSO) occurrence.

- PMEL applied the GFDL ocean general circulation model to explore response of the central and eastern equatorial Pacific to multiday-duration episodes of surface westerly winds in the equatorial western Pacific. The model shows that forcing from a ten-day wind event can lead to SST warming for as long as several months later in the Far East and along the Central American coast. These results are an important step toward understanding and predicting ENSO phenomena.

- In model experiments without orography, the relative wetness of mid-latitude Northern Hemisphere regions agrees with paleoclimatic evidence in the late Tertiary before the substantial uplift of the Rocky Mountains and Tibetan Plateau occurred. In simulating these dry regions with good agreement to paleoclimatic evidence, GFDL has added significant capability to realistically simulate past climate change, a necessary precursor to accurately predicting future change.

- The response of a fully coupled ocean-atmosphere general circulation model to a gradual increase in CO_2 was studied at GFDL. It was found that the model response exhibits a marked interhemispheric asymmetry. Over the Circumpolar Ocean of the Southern Hemisphere, the increase in surface air temperature is very slow. The rise of surface air temperature is generally faster in the Northern Hemisphere of the model and increases with latitude. In addition, the model hydrological cycle changes. The snowmelt season ends earlier, and the middle latitude rainbelt of the Northern Hemisphere shifts poleward due to penetration of warm, moisture-rich air into higher latitudes. These results confirm an earlier study on the equilibrium response of an atmosphere mixed-layer ocean model to a doubling of atmospheric CO_2.

AIR QUALITY RESEARCH

ERL air quality research is led by ARL, AL, WPL, and GFDL. The goal of this research is to understand and predict the health of the atmosphere, thus providing policy makers the scientific information needed to reduce harmful effects. Efforts are focused on tropospheric ozone and acid rain.

During 1989, particular success was achieved in the following:

- ARL completed a series of tests to determine ground-level destruction rates of ozone. Specific conclusions were: (1) the destruction rate of surface ozone is strongly influenced by the type of surface and is frequently controlled by biological activity, and (2) ozone plumes may persist tens to hundreds of kilometers downwind from the source. Quantifying these findings is the first step in explaining and predicting high ozone episodes in rural areas by demonstrating the importance of mechanisms not well handled by existing models and by providing improved measures of air-surface exchange rates.

- AL completed a three-dimensional model study of the buildup of ozone pollution over the eastern United States. Results from the model agree well with the observed values of ozone, ozone precursors, and other photochemically important key species. The model was used to test the effectiveness of various control strategies for rural ozone. The results show that control of NO_x emission is about three times more effective than control of non-methane hydrocarbons in lowering the ozone level over rural areas.

- The oxides of nitrogen, NO_x, play a key role in the formation of ozone and other oxidants. During the summer and fall of 1988, natural emissions of NO_x from soils were measured by AL at sites representative of large land areas in the continental United States. NO_x emission rates were greatest at the northern Colorado prairie site. The NO_x emission was much lower at the Tennessee forest site and negligibly small at the South Carolina coastal site. These results identify regions where natural emission from soils may be a significant source of NO_x.

- Three-dimensional calculations for a boundary layer source of an insoluble tracer, a fully soluble tracer, and a partially soluble tracer (SO_2 gas) have been carried out at GFDL using the continental and tropical maritime squall line models. The only tracer to reach the upper atmosphere in significant amounts is the insoluble tracer. In contrast, virtually none of the fully soluble tracer was calculated to be at 10 km or above. These calculations indicate that rainout

is a very efficient mechanism for preventing a boundary layer tracer from reaching the upper troposphere.

OCEAN AND GREAT LAKES RESEARCH

ERL studies of the oceans and Great Lakes are focused in three principal areas: prediction, ecosystem assessment, and resource assessment. Principal research is conducted by AOML, PMEL, GLERL, and GFDL. Significant accomplishments in 1989 included the following:

- Analysis of a 140-year integration of a low-resolution ocean-atmosphere coupled GCM at GFDL reveals the existence of regular oscillations with 36–40 month time scales. This oscillatory mode is associated with well-organized changes in sea surface temperature, sea level pressure, and surface wind stress, as well as in the flow field and heat content of the upper ocean. The meteorological and oceanographic phenomena associated with these events bear a considerable resemblance to those observed during ENSO episodes.

- To understand climate change, it is important that ocean models have realistic vertical pathways of CO_2. Transient tracers present the most realistic check on this property of the models. At GFDL, the World Ocean Circulation model, a 44-level model including seasonal variations and isopycnal mixing that was designed for climate studies, has been used to predict the invasion of chlorofluorocarbons (CFCs) to the ocean. A comparison with data by GFDL in cooperation with PMEL shows that the model provides a good quantitative simulation of the downward pathways in the world ocean.

- An important step in understanding greenhouse forcing is to quantify the ocean's capacity to absorb anthropogenically produced CO_2. A 3-dimensional simulation of ocean uptake of anthropogenic CO_2 has been carried out at GFDL. Model results indicate that gas exchange has a minimal impact. An increase of 20% in gas exchange rate gives only a 2.5% increase in CO_2 uptake, while doubling the gas exchange rate gives only a 9.2% increase in CO_2 uptake.

- AOML led a team of government and university scientists in the discovery of the first hydrothermal field on the northern Gorda Ridge. The Sea Cliff Hydrothermal Field is a major source of heat and chemicals to the northeast Pacific and lies within the U.S. Exclusive Economic Zone, only 100 miles off the coast of Oregon.

- Using estuarine theory based on constituent-salinity correlations, a method to estimate non-point (i.e., diffuse) industrial inputs added to estuaries was developed by PMEL. The method is widely applicable in determining regional waste contamination management strategies.

- GLERL developed a phase-specific response model for the scavenging of Chernobyl radionuclides from Lake Constance, West Germany, in collaboration with scientists at the University of Constance and the West German Government. The response model will be applied to predict the fate of radionuclides released accidently, such as at Chernobyl.

- WPL has correlated backscatter power from a 13.5 GHz Airborne Radar Altimeter with ice type over the Beaufort Sea. The correlation will enable the albedo of the ice to be determined for global radiation balance studies as well as assist in the identification and tracking of ice islands.

SOLAR-TERRESTRIAL RESEARCH AND SERVICES

The ERL solar-terrestrial program is unique because it contains both research and service components and because the major user of the research component is the internal service component.

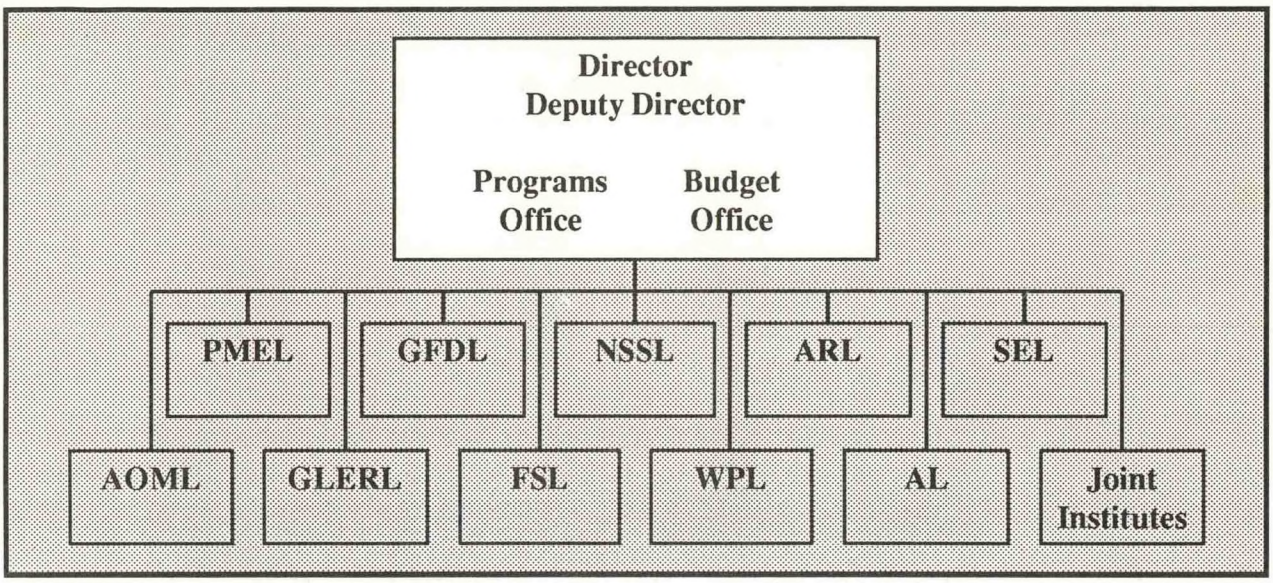
The program maintains continuous operation of the Space Environment Services Center (SESC) at Boulder, CO, for monitoring and predicting solar activity and events in the upper atmosphere, and for acquiring and processing data from space environment monitors on GOES satellites and the polar-orbiting TIROS-N and NOAA satellites. SESC, operated jointly with the U.S. Air Force Air Weather Service, is the national, regional, and international center for operational space and upper-atmosphere information.

The goal of solar-terrestrial research is to understand and model the physical processes responsible for observed energy release, in the form of electromagnetic radiation and charged particles from the solar surface during solar disturbances; the propagation and modification of this energy through interplanetary space to the near-Earth environment; the transfer of this energy into the Earth's magnetic field; and the behavior and subsequent effects of this energy within the magnetosphere, the ionosphere, and the upper atmosphere. The following were major accomplishments in 1989:

- Upgraded data acquisition. A new GOES satellite ground station at the Boulder, CO, site was installed. Requirements for the next-generation SEL Data Acquisition and Display System (SELDADS II) were written, and replacement of existing aging subsystems was begun.

- Improved forecaster tools. An operational verification data base with an on-line forecast evaluation scheme was implemented. Each forecaster can now assess the accuracy of his forecasts relative to all SEL forecasters. Feedback will encourage better analysis of physical factors leading to successful forecasts.

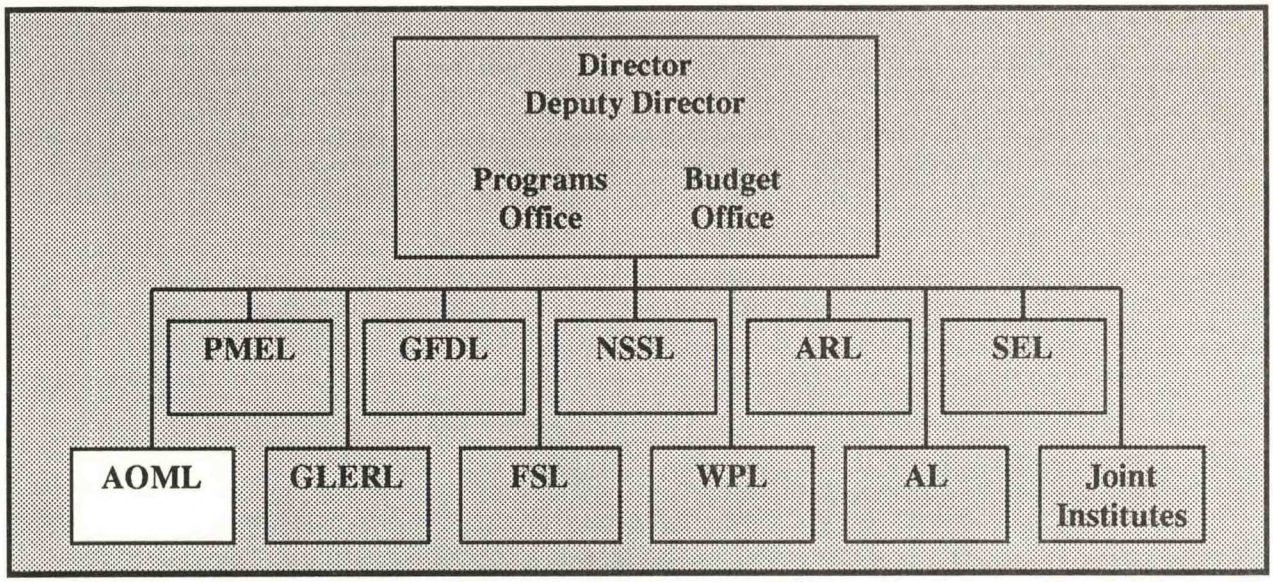
- Research to improve solar event forecasts and to understand the relationships between solar events and climate and global change. Topside ionospheric electron density data were used to improve an existing ionospheric conductivity and electron density model. Comparison has shown that the role of hydrogen ions above 600 km has not been properly assessed. Studies to develop forecast applications of Interplanetary Scintillation Observations were begun with the development of computer mapping of solar wind disturbance fronts propagating outward from the sun. Studies of these maps have disclosed the first insights into utilizing interplanetary scintillations as a forecast tool.



OFFICE OF THE DIRECTOR

Boulder, Colorado
(303) 497-6000
Joseph O. Fletcher, Director
Robert J. Mahler, Deputy Director

The Director, assisted by the Deputy Director, establishes policy and manages the overall activities of the Environmental Research Laboratories, including the NOAA-university cooperative research programs and the NOAA-National Research Council Resident Research Associateship Program. The Programs Office provides advice and support in areas of policy; program planning, coordination, and review; budget formulation and analysis; implementation of management decisions; and editing services. The Budget Office provides budget analysis and execution, and financial and management information in support of the Laboratories.



ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY

Miami, Florida
(305) 361–4300
Hugo F. Bezdek, Director

The Atlantic Oceanographic and Meteorological Laboratory (AOML) is organized to pursue basic and applied research programs in oceanography and tropical meteorology. Oceanographic investigations center on fluxes of energy, momentum, and materials through the air-sea interface; the transport and composition (thermal and chemical) of water in the ocean; and hydrothermal processes of mineralization at seafloor-spreading centers. Meteorological research is carried out to improve the description, understanding, and prediction of hurricanes. The research program is enlarged by the Cooperative Institute for Marine and Atmospheric Studies (CIMAS), a joint enterprise with the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. CIMAS enables National Oceanic and Atmospheric Administration (NOAA) and university scientists to collaborate on problems of mutual interest and facilitates the participation of visiting scientists. AOML's current research program concerns processes relating to global climate and air quality, weather observation and prediction, marine observation and prediction, and marine resources.

CLIMATE AND AIR QUALITY

Climate research at AOML focuses on aspects of ocean heat transport and storage in relation to interannual and longer term variations of weather and climate with an emphasis on collection and analysis of oceanographic data, the ultimate goal being to improve forecasting. Improvement of skill in the use of coupled ocean-atmosphere models is essential to achieving this goal.

Activities are currently concentrated on problems associated with two different time scales of climate variations. The shorter of these is the interannual time scale; the El Niño-Southern Oscillation phenomenon which is most clearly manifested in the tropical Pacific Ocean, but has global implication, is the best recognized example. Accordingly, AOML is a major participant in the Equatorial Pacific Ocean Climate

Studies (EPOCS) and Tropical Ocean and Global Atmosphere (TOGA) programs in the tropical Pacific. AOML activities in these programs are closely integrated with those of the Pacific Marine Environmental Laboratory (PMEL) and the Geophysical Fluid Dynamic Laboratory (GFDL) within the Environmental Research Laboratories, and extensive cooperation exists with the National Weather Service, National Marine Fisheries Service (NMFS), National Ocean Service (NOS), and scientists in universities and in several foreign countries.

On longer time scales, the ocean circulation of heat from low latitudes to high latitudes is believed to be one of the critical processes governing the climate of the Earth and its variations. Most evidence indicates that the Atlantic Ocean is particularly important in this process. Therefore, AOML is leading a program named Subtropical Atlantic Climate Studies (STACS) to learn more about the process. Although STACS is a much smaller program than TOGA, or even EPOCS, it too involves close interaction with other organizations, notably PMEL, NOS, and the University of Miami through CIMAS.

The Global Climate Change/Radiatively Important Trace Species (RITS) program at AOML concerns sources, transport and distribution, transformation, and removal of radiatively important atmospheric trace species in oceanic areas. The primary species being studied are ozone (O_3) and aerosols; among the related substances being studied are methane (CH_4), carbon monoxide (CO), low-molecular-weight non-methane hydrocarbons (NMHCs), odd nitrogen species, iodine species and sulfur. The program involves inorganic and organic chemistry, low-trophic-level (primarily marine) biology, meteorology, and physical oceanography, and has as its goals the generation of descriptive data on the distribution of important atmospheric trace species and quantitative understanding of geosphere-biosphere interactions.

There is a need for the provision of independent rainfall rate data for use in verifying open-ocean, satellite-derived rainfall rates. One promising method of obtaining this independent data is to measure the ocean acoustic noise generated by the falling rain and interpret the noise so produced in terms of rainfall rates. This is a joint program between AOML and the National Environmental Satellite, Data, and Information Service called Weather Observations Through Ambient Noise (WOTAN).

Accomplishments FY 89

TOGA/EPOCS

AOML was a principal participant in the TOGA Pan-Pacific Surface Current Study, a major element of the international TOGA Program. Other United States participation is from the Scripps Institution of Oceanography (SIO) and Woods Hole Oceanographic Institution (WHOI), supported by the National Science Foundation (NSF). Smaller participation from oceanographers in Australia was also begun. One hundred fifty satellite-tracked drifting buoys were released to measure sea-surface temperature and currents across the entire tropical band of the Pacific Ocean. A data center was established at AOML to provide a common base of uniformly processed data for all participants.

This data set offers many possibilities for evaluation of ocean processes and modeling skill in regard to tropical air-sea interaction. A new study was begun using drifting buoy data together with satellite altimeter data to investigate the structure and dynamics of warm-core rings or vortices recently discovered in the eastern tropical Pacific Ocean. Modest total energy requirements apparently make possible generation of eddies with very large kinetic energy in the eastern Pacific, but their oceanographic importance is not yet clear.

AOML staff were major participants in EPOCS research cruises in the tropical Pacific, where an equatorial conductivity, temperature, depth section was completed in cooperation with scientists and research vessels from PMEL, Ecuador, and Japan. Research vessel observations were made also in support of the EPOCS

investigation of the North Equatorial Countercurrent. AOML staff had a major responsibility for making ancillary

oceanographic measurements from the two NOAA ships engaged in the annual marine mammal observing cruises in the eastern tropical Pacific.

Close interaction was continued with scientists in several oceanographic research institutions in Latin America. In cooperation with these agencies, AOML is able to maintain an array of sea-level and surface meteorological observing stations along the Pacific coast of Latin America from Quepos, Costa Rica to Valparaiso, Chile. During the year, three scientists, two from Ecuador and one from Peru, spent several weeks as visiting scientists at AOML.

Work was also begun on implementing a conjugate gradient strategy for four-dimensional (4–D) data assimilation into the GFDL ocean general circulation model. This approach has great promise as the most effective way of using oceanographic measurements for both operational and diagnostic purposes, but it is a large undertaking, and its practical usefulness in terms of computer resources required cannot be predicted.

As part of the Acoustical Dynamic Height Measurements Experiment, data from a series of inverted echo sounder deployments east of Abaco Island in the Bahamas will continue to be analyzed.

STACS

Work continued on several aspects of the role of the North Atlantic Ocean in regulating global climate. Monitoring the Florida Current transport by means of sea-level and electrical potential measurements was maintained. Research cruises and moored instruments were used to investigate the extent and variations of the Western Boundary Undercurrent, an index to the vigor of convective overturning in the North Atlantic, a major process for both northward heat transport in the Atlantic Ocean, and for sequestration of anomalous atmospheric constituents; i.e., greenhouse gases, in the ocean. These investigations of climate-related processes in the Atlantic have been in close cooperation with scientists from PMEL, University of Miami, France, and Germany.

An international workshop was convened to develop consensus on objectives and strategy for implementation of a Volunteer Observing Ship (VOS) Program for the routine collection of oceanographic measurements in the Atlantic Ocean in the context of the developing NOAA program in Climate and Global Change. A comparable VOS program was begun in the North Pacific Ocean more than a decade ago, but the scientific objectives and the international context in the Atlantic are different.

RITS

AOML's Climate and Air Quality research efforts were focused on understanding factors controlling ozone distributions in the marine atmosphere. We conducted process-oriented field experiments using NOAA ships and aircraft, both in remote areas; namely, the equatorial Pacific and areas clearly impacted by continental inputs, such as the north Atlantic and the eastern tropical south Atlantic. The majority of our Climate and Air Quality resources were devoted to development and intercalibration of the techniques necessary to study the interactive system of ozone, odd-nitrogen, non-methane hydrocarbons, carbon monoxide, iodine species, and most recently, the sulfur system. We have undertaken a parallel development effort under Climate and Air Quality of a state-of-the-art capability for "clean" shipboard atmospheric sampling centered around a 30-foot, walkup-type bow tower, an automatic sampling control system, and special-purpose laboratory vans. We hope to have this aspect of development work completed by 1991.

Early models of the tropospheric ozone cycle suggested a stratospheric source and surface deposition sink. It is now clear, however, that ozone can be produced and destroyed photochemically within the troposphere. To unravel ozone control mechanisms in the marine atmosphere requires simultaneous measurements of a wide variety of chemical species in gas, aerosol, and precipitation phases. AOML's primary effort in Climate and Air Quality over the last several years has been toward developing in-house capabilities to measure the key species in the very challenging shipboard environment. Substantial progress was made during FY 89. Specific accomplishments include:

- Identified an artifact in ultraviolet absorption measurements of ozone concentrations in marine boundary layer air.

- Completed and field tested shipboard systems for measuring nitrogen oxides (NO_x = NO + NO_2) and peroxyacetyl nitrate (PAN) in remote marine boundary layer air.

- Made the first open ocean measurements of dimethylsulfoxide (DMSO) and dimethylsulfone ($DMSO_2$) in surface air and precipitation.

- Made the first simultaneous marine boundary layer measurements of all five known atmospheric oxidation products of dimethylsulfide (DMS), namely: DMSO, $DMSO_2$, sulfur dioxide (SO_2), methanesulfonate (MSA^-), and non-seasalt sulfate (nss-$SO_4^=$).

- Developed a method for measuring methyl iodide (MeI) in marine boundary layer air.

- Obtained Administrator's discretionary funds for purchase of a 30-foot, walkup-type bow tower and data acquisition system components, and initiated construction of the tower for the FY 90 field season.

WOTAN

A substantial portion of the data gathered in a FY 88–89 engineering deployment test of an advanced design WOTAN system was analyzed. The data from this test was very encouraging; correlations between radar, optical rain gauge, anemometer, and acoustical data were obtained. A second deployment at about 20 miles east of Cape Canaveral has been underway for approximately 60 days.

Plans FY 90

TOGA/EPOCS

AOML activities for the TOGA and EPOCS Programs are expected to continue pretty much along the same lines as in recent years. The Pan Pacific Surface Current Study is planned to continue with a stable level of participation from AOML, SIO, and WHOI. Australian scientists are expected to continue at a modest level, and oceanographers from France and Japan will begin releasing substantial numbers of buoys for the

study. Interest of oceanographers at the University of Miami as well as AOML in analysis and interpretation of drifting buoy data offers the prospect of creating a strong community of scientists in the area working with Lagrangian analyses. Use of these data in evaluation and improvement of ocean circulation models will receive new emphasis at AOML.

Enough unclassified altimeter data from the Geodetic Satellite (GEOSAT) have now become available to make possible evaluations of ocean current variability. These data will be used to investigate the frequency, origin, and fate of warm-core rings in the eastern tropical Pacific, as well as the annual cycle and other low-frequency variations of the North Equatorial Countercurrent and other regional features.

Close interaction with Latin American agencies will continue. Some upgrades of equipment are required to improve reliability and quality of data acquisition, and a new station will be installed on Malpelo Island, Colombia.

Work will continue on development of the 4–D data assimilation methodology. Verification runs will be made to learn the practical feasibility of the conjugate gradient method. The first such runs likely will be done with data for the Mediterranean Sea rather than the tropical Pacific, because collaborators from the Massachusetts Institute of Technology (MIT), with access to computer resources at the National Center for Atmospheric Research (NCAR), are available. Presently available NOAA computer resources are not conducive to rapid progress on this problem.

A new thrust in ocean circulation modeling for EPOCS will be initiated. Through collaboration with scientists at the National Aeronautics and Space Administration (NASA) and the Goddard Space Foundation, an alternative modeling strategy will be tested for its long-term stability characteristics relative to the GFDL ocean general circulation model as the oceanographic part of a future coupled model for El Niño prediction.

Continued processing of the inverted echo sounder deployments near Abaco Island is planned.

STACS

1990 is expected to be a year of transition for AOML research on circulation in the Atlantic Ocean. Some of the activities begun under the STACS program will become quasi-operational, and some of the investigations opened for the STACS Program will be continued or expanded under an Atlantic variability theme of the NOAA program for Climate and Global Change. Initially there will be little perceptible change in activities. Sea-level and electrical potential studies on the Florida Current, as well as research cruises for investigations of the boundary currents, will continue, but more and more AOML activities will be integrated with national and international programs, such as Climate and Global Change and the World Ocean Circulation Experiment, that have both a broad base of support and a need for broad community participation.

Interaction with scientists in many countries of the Caribbean Basin will continue through the International Oceanographic Commission to encourage and assist them to participate in the Global Sea Level Observing System (GLOSS) Sea Level Program. The specter of rising sea level is one of the greater regional effects of potential greenhouse warming. Acquisition and availability of data on sea level at an adequate number of locations is essential to appraising this threat.

Finally, a data center will be established at AOML to receive and process volunteer observing ship expendable bathythermograph (XBT) data and to produce and disseminate ocean climate diagnostic products as well as produce a unified ocean temperature data base for use in research into climate variations and processes.

RITS

The following items are planned for FY 90:

- Search for evidence of photochemical destruction of ozone within the deep ozone minimum of the equatorial Pacific.
- Field test a new capability for determination of methyl iodide in the marine atmosphere.
- Test a hypothesis that iodine species emanating from the sea surface are controlling, in part, ozone destruction and sulfur gas oxidation.
- Determine the extent of natural chemical interferences in the measurement of ozone over sea water.
- Develop and field test a new capability for measurement of total reactive nitrogen (NO_y) in the marine atmosphere.
- Test a hypothesis that processes other than acid-base displacement reactions are responsible for loss of chloride from seasalt aerosols.
- Test a hypothesis that enhanced levels of atmospheric nitrate in the vicinity of the Samoa island group in austral summer are due to cross-equatorial transport of northern hemisphere air.
- Prepare for participation in an NSF-sponsored sulfur gas measurement intercomparison experiment expected to begin in early FY 91 (contingent upon funding of the NSF program).
- Determine the existence and magnitude of the diel variation in carbon monoxide concentrations in the equatorial Pacific region.

WOTAN

The WOTAN device deployed off Cape Canaveral will be recovered in October 1989. The data gathered in this deployment will be processed utilizing the results of a calibration performed by the Naval Research Laboratory in Orlando, Florida in FY 89. Additional WOTAN deployments in the Gulf of Mexico and off the island of Barbados are planned.

WEATHER OBSERVATION AND PREDICTION

AOML's Hurricane Research Division (HRD) is NOAA's primary focus for research on hurricanes. Research teams concentrate on field programs, numerical hurricane modeling, and theoretical studies of

hurricanes. The Laboratory's hurricane field program makes use of NOAA research aircraft to acquire unique data sets.

Accomplishments FY 89

Synoptic-Scale Aspects of Hurricanes

This work is designed to investigate the synoptic-scale flow on the periphery of mature hurricanes and its impact on hurricane tracks. Omega dropwindsondes (ODWs) released from the NOAA WP–3D research aircraft are used on an experimental basis to obtain information over the data-sparse oceanic regions. The ODWs measure temperature, relative humidity, pressure, and horizontal wind from flight level to the sea surface. During these experiments, ODW and flight-level data are transmitted from the aircraft to the National Hurricane Center (NHC) and to the National Meteorological Center (NMC) in real time. The observations are used at the NHC in preparation of the official forecasts and at NMC in the initialization of dynamical hurricane track prediction models.

In its program of experimental hurricane track forecasting, HRD employs a numerical model that utilizes an accurate and flexible spectral method, called SAFER [Spectral Application of Finite Element Representation]. SAFER provides very high quality grid nesting and minimal truncation errors. Studies to test SAFER in the context of a barotropic hurricane track prediction model (code name VICBAR) are under way. VICBAR has been initialized with vertically averaged real horizontal winds and geopotential heights. These input data are processed and analyzed using a nested spline analysis code developed at HRD. The latter assimilates data from a wide variety of platforms, including airborne Doppler radar, ODWs, NOAA P–3 aircraft, other reconnaissance aircraft, rawinsondes, and satellites.

VICBAR has been tested in a research mode for the cases in which ODW data are available. These include hurricanes Debby (1982), Josephine (1984), Gloria (1985), Emily (1987), Floyd (1987) and Florence (1988). Forecasts were made with and without initial data that included the ODWs. Results showed that the ODW data reduced the track forecast errors by 21%, 13%, and 12% at 12, 24 and 36 hours, respectively, and that the VICBAR model has considerable forecast skill relative to climatology and persistence for these forecast cases.

A version of VICBAR was developed that runs in real time. The initial data include a background field from the NMC analysis, rawinsondes, satellite winds, Television and Infrared Observation Satellite (TIROS) heights, and aircraft observations (NOAA and/or Air Force). Winds and heights are analyzed at four levels (850, 700, 500 and 200 mb) and are vertically averaged from 850 to a top pressure that is chosen so that the average environmental wind surrounding the storm is as close as possible to the current storm motion.

A special scan-type analysis was formulated in storm relative cylindrical coordinates and is used to analyze aircraft and other observations within about 400 km of the storm center. The scan analysis eliminates the need for an initial "bogus" vortex provided that aircraft observations are available.

The real-time system has been run for tropical storms and hurricanes that occurred in 1989 and results have been made available to NHC forecasters before forecast deadlines. The official NWS guidance package for one of the hurricane Gabrielle forecasts specifically mentions NHC's use of the VICBAR forecast.

Hurricane Air-Sea Interaction Studies

A joint NOAA-Navy air-sea interaction experiment was conducted in the Gulf of Mexico using NOAA research aircraft to study Hurricane Gilbert's impact on the Gulf. The objective of the experiment was to

assess the role of turbulent mixing and horizontal advection processes on near-inertial time scales in the Gulf's response to hurricanes. The experiment involved five P-3 flights: one prior to the storm, two within the storm, and two after the storm made landfall. Measurements of ocean currents and temperature profiles from the surface to 1500 m were made with Airborne Expendable Current Profilers (AXCPs) and, elsewhere, the temperature profiles to 300 m were measured with airborne expendable bathythermographs (AXBTs). A total of 92 AXCPs and 60 AXBTs were deployed between 14 September and 19 September 1988. More than 25 NOAA–10 high-resolution infrared satellite images over the Gulf of Mexico were acquired for the experimental period.

Little change in sea-surface temperature (SST) was observed over the western Caribbean during Gilbert's explosive deepening to a record 885 mb on 13–14 September. However, a dramatic decrease in SST accompanied the storm's traverse of the Gulf of Mexico on 15–16 September. A gradual basin-wide decrease in SST from 30°C to 28°C preceded the arrival of the storm. A further SST decrease to 25°C abruptly followed in the storm's wake over a 100–200 km wide area to the right of the storm, except for an area in the central Gulf that was dominated by a warm anticyclonic eddy. The small SST decreases in the Caribbean Sea and Gulf are attributed to initial mixed layer depths (MLDs) in excess of 70 m. The large SST decreases across the undisturbed Gulf are attributed to initial MLDs of less than 30 m.

Strong mixed layer currents, associated with gravity-inertia waves generated by the storm, were measured to the right of the storm track 1.5 and 3 days after storm passage. Magnitudes of the currents were on the order of 1.5 m s^{-1}. A reversal in current directions occurred immediately below the mixed layer with very strong vertical shears in the upper thermocline. Thus, a large area of the Gulf was set in motion by Gilbert and this motion persisted for 7–10 days after storm passage.

Studies of Hurricane Climatic Variations

The relationship of long-term variability of winds over the tropical Atlantic to hurricane cycles are under investigation. As part of this work, the relationship of the quasi-biennial oscillation (QBO) to Atlantic tropical storm activity was examined. Monthly averaged 30 and 50 mb zonal winds at Balboa were used to determine the relationship of the QBO to Atlantic tropical storm activity during the years 1952–1986. The largest correlations between storm activity and the 30 mb wind were found in June, which is three months before the peak of the hurricane season. A near in-phase relationship between tropical storm activity and the zonal wind at about 50 mb was found.

Zonal winds, filtered to remove periods less than about a year, were used to establish correlations between the QBO and tropical storm activity for 1955–83. These correlations are essentially independent of the month considered. A correlation at 30 mb was found with a conservative estimate of true skill, from both in-phase and out-of-phase information, that explains 30% of the variance in storm activity. This skill is much greater than that estimated from seasonal classifications of the QBO. The statistics are insensitive to removal of the effects of the El Niño cycle. When El Niño years are explicitly excluded, the true skill explains an estimated 32% of the variance.

Research was started to describe the Atlantic hurricane cycles and tropical wind variability associated with the 30–60 day oscillation, and the predictability of these cycles. Preliminary results indicate that hurricane cycles are related to an objective index of the global oscillation, as well as to Atlantic tropical wind variability. This work used wind observations from the years 1977–84 based on NHC's tropical analysis with periods less than about 15 days filtered out.

Plans FY 90

Synoptic-Scale Aspects of Hurricanes

Plans to conduct several synoptic-flow experiments during the 1990 hurricane field program are being developed. Cooperative studies with NHC and NMC to examine the impact of the ODW data on the NMC operational analyses and the NMC hurricane track models will continue.

The real-time utilization of VICBAR will continue. The timeliness of the forecasts will be improved. The skill of the VICBAR forecasts will continue to be evaluated through further comparison with operational track prediction models. Methods for computing the deep-layer mean winds used as input to VICBAR will be improved.

Hurricane Air-Sea Interaction Studies

An improved version of the stepped frequency microwave radiometer (an instrument used to remotely sense surface wind speed from aircraft) algorithm will be installed on the P–3 research aircraft and real-time transmission of surface winds to NHC will be started.

An in-depth analysis of the Hurricane Gilbert ocean response experiment will continue. This work will concentrate on measuring the details of the storm-induced internal wave response.

Studies of Hurricane Climatic Variations

The study of the 30–60 day period variability of Atlantic tropical winds and hurricane cycles will be continued. Spectra will be made of the Atlantic tropical winds for selected regions, and maps of energy in the 30–60 day band will be made at both lower (near-surface) and upper (near 200 mb) levels. Winds for the years 1980–89, filtered to isolate the 30–60 day band, will be used to perform a regional empirical orthogonal function (EOF) analysis over the Atlantic area. A Hilbert transform will be used to study the amplitude and phase behavior of the dominant EOF modes. The dominant modes will be related to an objective index of the global oscillation.

MARINE RESEARCH

AOML studies in Marine Research concern processes occurring in seafloor ridges, the dispersion of wastewater in the ocean environment, and the effects of the environment on fishery populations.

AOML studies are directed at determining the chemical and thermal effects on the ocean of seafloor hydrothermal venting from representative segments of the Gorda-Juan de Fuca Ridge system and the Mid-Atlantic Ridge in support of NOAA's global ocean environmental mission. The studies are collaborative with NOAA/PMEL, NOAA's Undersea Research Program (NURP), and with a network of leading scientists from other U.S. and foreign government agencies and universities which multiplies NOAA funding five to ten times and augments scientific productivity. These efforts are contributing to the NOAA VENTS Program, to the development of NOAA initiatives, and to NOAA's role as the lead U.S. agency with IFREMER (Institut Français de Recherche pour l' Exploitation de la Mer) in the U.S.-France Bilateral Agreement.

The Fisheries Oceanography Coordinated Investigations (FOCI) involves NOAA scientists at PMEL, AOML, and the National Marine Fisheries Service Northwest Center as well as academic contractors. The program seeks to gain understanding of the controls upon recruitment variability of walleye pollock in the Shelikof Straits of the western Gulf of Alaska. The major emphasis over FY 86–89 was field studies of the spawning event and its physical-biological context. The system was selected because of the importance of the resource, the physically restricted study area, previously documented variability in recruitment, and the existence of ongoing NMFS fisheries catch and hydroacoustic monitoring programs. The specific goal of the AOML component was to document the temporal change in the spatial distribution of both eggs and larvae in relation to physical processes (e.g., advection and dispersion). Field studies conducted during cruises in FY 86–88 enabled us to examine the fine-scale (meters to tens of meters) distribution of pollock eggs, pollock larvae, and zooplankton prey using a towed submersible camera system, specialized net sampling systems, and most recently, high-frequency acoustics.

The FOCI project represents an important scientific and technical contribution toward NOAA's increasing focus upon the theme of Fisheries Oceanography. The results obtained to date by this successful pilot program lead towards prediction of the variability of populations of commercially harvested marine species. This ability is essential both for managing our natural resources efficiently and for distinguishing natural variability from anthropogenic effects.

The Oceanic Plume Studies program seeks to study the interaction of water mass types and the processes which occur at their boundaries. Wastewater plumes comprise one category of water mass type which is released in turbulent flow into the receiving oceanic waters. Understanding the dilution which such plumes undergo is an extremely important environmental concern and is a process for which very limited data are available.

Understanding the effects of human-originated discharges in the coastal ocean is key to competent resource management. In this program, advanced technology, unique to NOAA, is being utilized to obtain information on anthropogenic discharges of different types and is a component of NOAA's environmental studies mission area.

Accomplishments FY 89

VENTS

Gorda-Juan de Fuca Ridge

An AOML Chief Scientist led a team of government and university scientists in the discovery of the first hydrothermal field on the northern Gorda Ridge. The Sea Cliff Hydrothermal Field is a major source of heat and chemicals to the northeast Pacific and lies within the U.S. Exclusive Economic Zone only 100 miles off the coast of Oregon. It is readily accessible as a natural laboratory for the study of hydrothermal processes.

A comparative study of hydrothermal plumes at the Juan de Fuca Ridge and the Mid-Atlantic Ridge revealed basic differences in physical dynamics which cause plumes from equivalent hydrothermal sources to rise higher and spread wider in the Atlantic Ocean than in the Pacific Ocean. The differences, in turn, influence the chemical and thermal effects of the plumes on the surrounding ocean.

A study of the magnetic and related mineralogic properties of rocks from hydrothermal study sites on the Gorda Ridge and Mid-Atlantic Ridge was prepared for publication. It provided new insights into the chemical interactions involved in subseafloor hydrothermal circulation.

Western Pacific

AOML participation in a cooperative NOAA–JAMSTEC [Japan Marine Science and Technology Center] dive series at a hydrothermal site in the Izu-Bonin back-arc basin sponsored by NOAA/NURP provided a basis for future development of joint programs to determine global effects of seafloor hydrothermal venting.

Mid-Atlantic Ridge

A new hydrothermal plume was delineated and reported at the TransAtlantic Geotraverse site on the Mid-Atlantic Ridge. It was of sufficient size to impact the chemical budget of vanadium in the global ocean. The NOAA and IFREMER groups analyzed and reported their discovery of a previously unknown type of hydrothermal system that produces solutions with different chemical and thermal properties evolved from deep interaction between circulating sea water and sub-crustal rocks.

AOML played a central role on the U.S. Task Group in the preparation of a Science Plan for the U.S.-France Bilateral Agreement that will maintain NOAA leadership in cooperative research at the Mid-Atlantic Ridge.

FOCI

The following items were accomplished in FY 89:

- Demonstration of the utility of in-situ photographic determination of teleost egg distributions and publication of results.
- Delineation of the fine-scale distribution of pollock eggs using in-situ photographic data.
- Confirmation of the closely coupled relationship between coastal eddy formation and structure and critical plankton processes such as grazing and primary production.

Oceanic Plume Studies

Data gathered in a series of FY 88 wastewater plume cruises have been partially analyzed. Acoustical systems were shown to be capable of providing good quality data on plume dispersion features and dilution rates. Detection of previously unmeasured oceanic subsurface plumes was achieved.

Coastal Zone Oceanography/Ocean Dumping

A cooperative coastal oceanography program with the Institute of Marine Environmental Program in Dalian, China was begun in FY 89. A senior Chinese scientist and an engineer came to AOML to learn about the AOML acoustical systems methodology. Two AOML scientists went to Dalian in June 1989 to participate in the first field experiment of the program. Due to the events which occurred in China in June, the AOML scientists were forced to return and the program postponed.

A coastal ocean field study of a series of dredge material discharges off Mobile, AL, was undertaken in August 1989. The data gathered will be analyzed with objectives of studying discharge dispersion in relation to water column structures.

Plans FY 90

VENTS

Conduct work in collaboration with NOAA/PMEL to advance understanding of the chemical and thermal effects of venting from the Gorda-Juan de Fuca Ridge system on the northeastern Pacific.

Prepare a comparison of the tectonic and volcanic controls of hydrothermal venting on the southern Juan de Fuca Ridge and the northern Gorda Ridge.

Organize and conduct an *Alvin* dive series in collaboration with scientists from IFREMER, WHOI, MIT and Cambridge University (England) to continue characterization of venting from the Mid-Atlantic Ridge on the world ocean as a component of chemical and thermal effects on the world ocean.

Plan, organize, and conduct a joint scientific program with scientists from IFREMER on the Mid-Atlantic Ridge including a joint cruise, contingent on funding and ship scheduling, in support of NOAA's role as the lead U.S. agency in the U.S.-France Bilateral Agreement.

FOCI

The following items are planned for FY 90:

- Complete analysis of data on biological/relationships within a weak coastal eddy.
- Describe the relationship between vertical distributions of larval pollock, their prey, and predators.
- Complete development of integrated optical/acoustic sampling system and test in local sea trials and mesocosm simulations.
- Develop requisite software permitting real-time generation of size frequency histograms from acoustic data.

Ocean Plume Studies

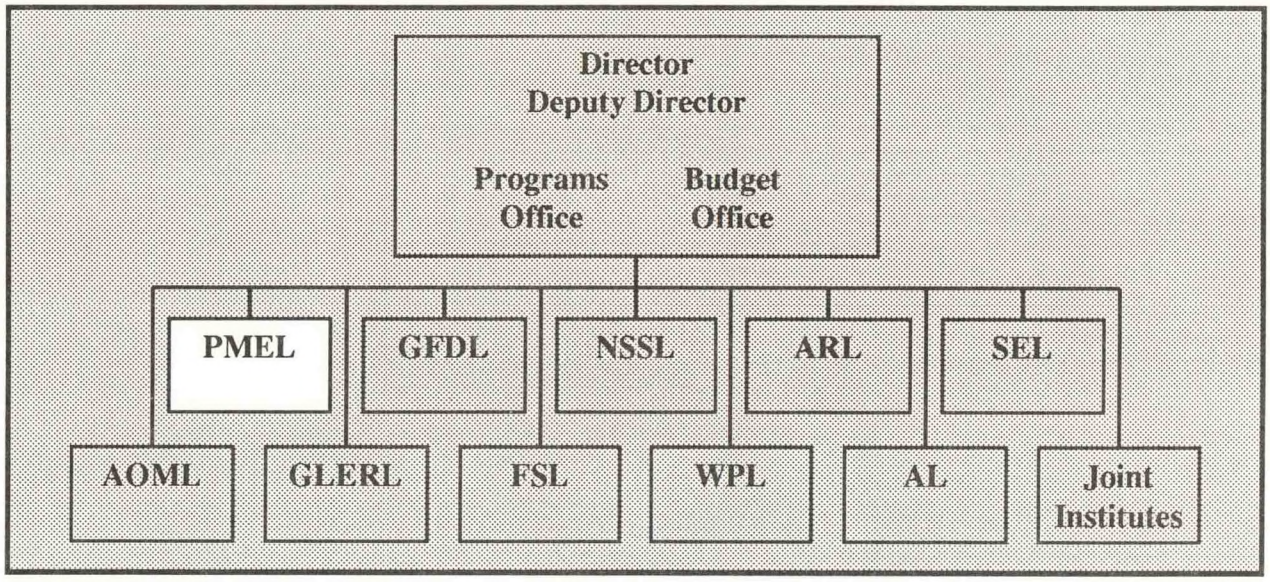
Processing and analysis of wastewater plume data gathered in FY 88 will continue. A new, more extensive, set of plume dispersion measurements is planned for FY 90; acoustical, chemical, biological and physical oceanographic measurements are planned.

Coastal Zone Oceanography/Ocean Dumping

The following items are planned for FY 90:

- Plans for the joint U.S.-China project are indefinite pending receipt of further directions from NOAA offices.

- Processing and analysis of discharged dredge material plume data gathered in FY 89 will continue. Potential additional field experiments will be reviewed.



PACIFIC MARINE ENVIRONMENTAL LABORATORY
Seattle, Washington
(206) 526–6810
Eddie N. Bernard, Director

The Pacific Marine Environmental Laboratory (PMEL) conducts interdisciplinary scientific investigations in oceanography, marine meteorology, and related subjects. Current PMEL programs focus on climate, marine observation and prediction, marine resources, and marine environmental assessment. Studies are conducted to improve our understanding of the complex physical and geochemical processes that determine the extent of human effect on the marine environment; to define the forcing functions and the processes driving ocean circulation and the global climate system; and to improve environmental forecasting capabilities and other supporting services for marine commerce and fisheries.

PMEL complements its research efforts through two ERL cooperative institutes: the Joint Institute for Study of the Atmosphere and Ocean, with the University of Washington; and the Joint Institute for Marine and Atmospheric Research, with the University of Hawaii. PMEL also complements its research through the National Marine Fisheries Service.

CLIMATE RESEARCH

The National Oceanic and Atmospheric Administration (NOAA) Ocean Climate Program was developed following the passage of the National Climate Program Act in 1978 in response to increased public awareness of the effects of short and long-term climatic changes and a concern about the potential impact of technology and population growth on world climate.

Understanding and forecasting climatic change requires an understanding of the processes of heat, moisture, and momentum exchange between the ocean and atmosphere as well as the large-scale transports of heat within the atmosphere and ocean. PMEL's ocean climate research program conducts studies of both local and basin-wide ocean dynamics and the coupled ocean-atmosphere circulation, with the goal of determining the physical mechanisms that generate anomalies in sea-surface temperature (SST) distributions

in the tropical ocean. A crucial step is to develop and validate ocean circulation models that are capable of simulating the evolution of globally important events such as El Niño.

Heat transport by major western boundary currents (the Gulf Stream and the Kuroshio in the Northern Hemisphere) is also postulated to have an important effect on world climate. Western boundary current studies at PMEL continue to focus on the Florida Current as part of the Subtropical Atlantic Climate Studies (STACS).

Accomplishments FY 89

Equatorial Dynamics

In support of the Tropical Ocean and Global Atmosphere (TOGA) program, PMEL maintains an array of moored and island stations in the tropical Pacific. A total of 21 moored stations measure the vertical distribution of the current velocity, temperature, and salinity between the surface and 500 m on the equator and the temperature profile down to 500 m off the equator. Both types of moorings transmit wind velocity, air temperature, and SST in real time; in addition, the currents at 10 m and the off-equatorial temperature profiles are also reported in real time.

Automated wind stations are also maintained on islands in the western and central Pacific (Kapingamarangi, Nauru, Baker, and Christmas Island). The data from these stations are used collectively, along with other data sets, to diagnose the current state of the tropical Pacific, to validate the operational ocean general circulation model at the National Meteorological Center (NMC), and to study air-sea interaction processes responsible for annual and interannual variability of the tropical Pacific.

Influence of SST on surface winds

The influence of SST on surface winds is at the heart of understanding the coupled ocean-atmosphere system. A recently completed study used the moored wind and SST measurements in the eastern tropical Pacific, where SST gradients are large and variable, to examine this problem.

The Equatorial Front is advected by the monthly surface current variability associated with the tropical instability waves. This signal, which is not directly forced by the local winds, provides an interesting probe for investigating the effects of SST changes on surface winds. Correlations of SST and surface-wind changes showed that the southeast tradewinds were enhanced when they crossed from the equatorial cold tongue to the warmer water north of the front. This effect suggests that boundary layer stratification is an important component of the surface-wind dynamics and needs to be incorporated into the operational atmospheric models and the simple coupled El Niño-Southern Oscillation (ENSO) models if more realistic ocean-atmosphere feedbacks are to be obtained.

Role of extra-equatorial Rossby waves in El Niño events

A new compilation of historical bathythermograph (BT) data in the tropical Pacific allowed the observation of westward-propagating long Rossby waves in the northern tropical Pacific. The new BT data show that although the Rossby waves can be very important in determining pycnocline anomalies to the west of regions of strong wind-stress-curl forcing (both on annual and interannual periods), there is little evidence that the waves reflect off the western boundary to affect subsequent evolution of a warm event on the equator; e.g.,

a trigger for the onset of El Niño. Modeling studies which show that ENSO-like behavior can be generated with no involvement of extra-equatorial waves support the BT data.

Ocean modeling

Considerable progress was made this year using the Geophysical Fluid Dynamics Lab (GFDL) ocean circulation model to explore possible types of response in the central and eastern equatorial Pacific to multiday-duration episodes of surface westerly winds in the equatorial western Pacific. The model shows that forcing from a ten-day wind event can lead to SST warming for as long as several months later in the far east and along the central American coast. Further observational and modeling work is needed to examine the importance of such forcing in real ENSO events.

Western Boundary Currents

The Florida Current transport is continuing to be derived from observations of the cross-stream cable voltages between Jupiter, FL, and Settlement Point, Grand Bahama Island. The seven years of data have been carefully scrutinized for errors, edited using improved estimates of the geomagnetic and tidal variations, and adjusted for the long-term decrease in the calibration factor caused by the secular change in the earth's magnetic field. The new magnetic station at Settlement Point now permits the removal of the geomagnetic variations on a daily to weekly basis. The voltage stability of the cable-seawater contact at West Palm Beach is also under study using an Ag-AgCl electrode installed in the ocean near the power station.

Marine and Atmospheric Chemistry for Climate Change

PMEL conducts two important marine chemistry programs for NOAA under the National Climate Program. One program studies how the ocean affects the atmospheric concentration of several climatically important trace species. This study focuses on the biogeochemical cycles of carbon, sulfur, nitrogen and oxygen. The other program measures the changing concentration of anthropogenic fluorocarbons in the ocean to elucidate pathways and rates of thermocline ventilation and circulation.

Biogeochemical cycles

PMEL conducted two field programs in 1989 to study the climate forcing trace gases and aerosols that affect climate. The first, a cruise aboard the NOAA ship *Discoverer*, carried 25 scientists from 11 institutions from Seattle, south along 105°W to 61°S and then back. PMEL measured the carbon cycle trace gases (CO_2, CO, and CH_4) in surface waters by continuous, automated gas chromatography. Carbon dioxide and alkalinity concentrations were also measured at various depths in the water column. The major sulfur species in seawater and the atmosphere were also measured to assess the ocean's role in the formation of sulfate aerosol particles.

The second major field project, Pacific Stratus Investigation, was a multiagency (NOAA, National Aeronautics and Space Administration, National Science Foundation (NSF), Department of Energy, and Department of Defense) interdisciplinary study of the effect of the sulfur cycle on marine stratus clouds and climate. The study, conducted off the Washington coast, included measurements from the NOAA ship

McArthur, a coastal research station at Cheeka Peak, three research aircraft, and the Advanced Very-High-Resolution Radiometer (AVHRR) satellites.

PMEL also participated in NASA Chemical Instrumentation and Test Evaluation-3 (CITE–3) sulfur intercomparison studies designed to intercalibrate the various research groups around the world making sulfur measurements and to compare various measurement techniques.

Tracer program

As part of the *Discoverer* cruise, a freon tracer survey collected more than 1700 samples to produce a unique image of the ventilation of the southeast Pacific thermocline, a region where no measurements of freon or any other transient tracers had ever been made. In addition to documenting the freon transient invasion into the Antarctic Intermediate Waters, PMEL scientists were able to detect a freon signal in the recently ventilated Antarctic Bottom Waters. These data, and similar measurements along 150°W–170°W in 1984, are the only existing freon values in the high southern latitudes of the Pacific. They are being used by the World Ocean Circulation Experiments (WOCE) tracer community to guide their ship-track and sampling plans for the pan-Pacific survey scheduled for 1990–93. The data are also being used in collaborative work with GFDL to validate global ocean circulation models.

Plans FY 90

Equatorial Dynamics

- Complete data collection and begin analysis of moored measurements in the Pacific North Equatorial Countercurrent.
- Begin the diagnosis of SST and upper ocean heat content variability in the western equatorial Pacific warm pool.
- Begin the analysis of equatorial current variations on a basin scale from moorings spanning 110°W–147°E.
- Develop a real-time capability for current profiles along the equator.
- Cooperate with Japan to expand the TOGA Thermal Arrays for the Ocean (TAO) in the western Pacific.
- Complete studies of the mechanisms of seasonal warming and cooling in the equatorial waveguide, using model and observational studies.

Western Boundary Currents

- Install a voltage-recording system for the Key West-Havana cable.
- Continue to improve the cross-stream measurements of Florida Current.
- Study suitability of other telephone cables for monitoring ocean transport.

Marine and Atmospheric Chemistry for Climate Change

- Conduct a major international oceanographic-atmospheric expedition in the Pacific Ocean aboard the U.S.S.R. research vessel *Academic Korolev* to study the photochemistry and ocean-atmosphere exchange of the equatorial marine boundary layer and the freon distributions in the source waters of the North Pacific Intermediate Water near Kamchatka and into the Sea of Okhotsk.
- Conduct a second multiagency study off the Washington Coast to study the effect of the marine sulfur cycle on stratus clouds and climate.
- Complete a study of the Deep Western Boundary Current in the southwest Pacific Ocean to improve our understanding of the invasion of freon tracers into the abyssal waters of the Pacific Ocean.
- Participate in both a freon intercalibration with WOCE and a sulfur intercalibration with NSF.

MARINE RESOURCES

Accomplishments FY 89

VENTS Program

Hydrothermal venting, now known to occur along the entire global seafloor spreading-center system, is a significant contributor to the heat and mass budgets of the ocean. In order to quantify, and eventually predict, the thermal and chemical oceanographic consequences of venting, the VENTS Program is engaged in a multidisciplinary effort to (1) determine the effects and fate of hydrothermal mass and heat on seawater through chemical and geochemical studies, (2) determine the physical oceanographic processes whereby hydrothermal heat, chemicals, and gases are distributed throughout the ocean, and (3) determine conditions that control the location, style, and duration of active venting through geological and geophysical studies.

The FY 89 VENTS Program continued its efforts to identify all major venting sites on the Juan de Fuca Ridge and to assess the effects of the emissions from those sites on the regional hydrography and chemistry of the northeast Pacific Ocean. In FY 89 a continuous conductivity, temperature, depth (CTD)-transmis-

someter tow-yo was made of the Endeavour Ridge and the Cobb Segment of the Juan de Fuca Ridge. The only major venting source encountered was the known field at 48°N on the Endeavour Ridge. Minor plumes were encountered over the topographic high of the Cobb Segment around 47°43'N.

Physical oceanography studies have continued to focus on determining flow characteristics which transport hydrothermal plumes away from the Juan de Fuca Ridge. Data from year-long current-meter mooring deployments during 1987–88, on the saddle between Axial and Brown Bear Seamounts, revealed an oscillating flow with a frequency of about four days together with a long-term average flow of 4 cm s^{-1} to the south. These measurements suggest a possible alternating exchange of water north and south of the Cobb-Eickelberg seamount chain throughout the year.

During FY89, a PMEL-designed bottom pressure recorder (BPR) was deployed within the caldera of Axial Volcano. Analysis of the initial BPR data indicates that the summit area of the volcano is currently in a dynamic phase, evidenced by ground deformation caused by magma deflation, possible eruptions, or shallow magma intrusions on the southeast flank. Sea-surface gravity over Axial indicates the presence of a significant anomaly which appears to be the hotspot which created Axial Volcano and the rest of the Cobb-Eickelberg Seamount Chain. The gravity anomaly is located beneath the volcano's southern rift zone.

In FY 89, a special issue of a geophysical research journal was dedicated to a series of papers focused on the last few years of interdisciplinary research at Axial Volcano. NOAA VENTS Program investigators and their collaborators contributed a large number of manuscripts dealing with research topics including: (1) high-resolution bathymetry and geological mapping of the caldera and the vent site, (2) evidence of ground deformation and its possible relationship to active venting, (3) hydrography of the non-buoyant hydrothermal plume, (4) regional oceanographic circulation around Axial Volcano, (5) gravity surveys of Axial Volcano, (6) distribution and composition of particulates carried in the non-buoyant hydrothermal plume, (7) relationships between the distribution of hydrothermal fluids in the vent field and boiling hydrothermal fluids, and (8) the chemistry of phase-separated hydrothermal fluids.

A major objective during FY 89 was to determine the geological setting of the Megaplume Site in order to (1) test hypotheses for the formation of the megaplume and (2) investigate the nature of the hydrothermal venting giving rise to the megaplume. The continuing presence of a vigorous "normal" hydrothermal plume (100–200 m above the seafloor) mapped near the ridge crest between 44°53'N and 45°00'N suggests that the megaplume was generated along this portion of the ridgecrest. Initial mapping from the *Discoverer* using a deep-towed camera system revealed an extensive zone of semi-continuous venting over a distance of about 12 km. In the southern portion of the area, the venting is associated with fissuring of older volcanic terrain. In the northern part of the area, a very young lava flow was discovered. These preliminary observations suggest that this portion of the rift valley is undergoing tectonic extension accompanied by extrusive volcanism.

The processing of all northeast Pacific spreading-center Sea Beam data collected during the period from 1980 to 1988 was completed in FY 89 and the results assembled in a digital data base. Detailed bathymetric maps of any area of the northeast Pacific spreading-center plate boundary now can be produced at any scale. Advanced image-processing and digital signal-processing techniques have been developed for use with sidescan sonar data, resulting in greatly improved imagery of detailed seafloor morphology.

During FY 89, a pilot study was initiated to detect episodic seafloor events along the northeast Pacific spreading-center system by means of T-phases received on Pacific Missile Range/Missile Impact Location System hydrophone arrays. Other studies have demonstrated that acoustic energy from such events can be utilized to provide a much more sensitive threshold of detection than is feasible by means of conventional P and S phases sensed by land-based seismic arrays. Moreover, T-phases are also capable of providing information about the nature of an event's source. T-phases have been used to discriminate between submarine volcanic eruptions, shallow and deep earthquakes, and manmade explosions. Objectives of the study include (1) monitoring of earthquakes and/or volcanic activity along the northeast Pacific spreading-center system,

(2) establishing relationships between ridgecrest earthquakes, volcanic activity, and hydrothermal venting, and (3) detecting active submarine eruptions.

FOCI

Each year there are fluctuations in the quantity of commercially valuable fish and shellfish in the Gulf of Alaska and Bering Sea. To understand the causes of variability in recruitment to these stocks, scientists from PMEL and the Alaska Fisheries Science Center have been conducting Fisheries Oceanography Coordinated Investigations (FOCI). The present focus of the program is on walleye pollock *(Theragra Chalcogramma)* in the western Gulf of Alaska. Research has been directed at determining (1) what meteorological, oceanographic and biological conditions are correlated with historical year-class success, (2) whether interannual variations in transport affect larval concentrations, and (3) how mortality is affected by small-scale physics, food availability, and predation.

A vital step toward understanding the relation of pollock to the environment was undertaken this year. A numerical model was developed to examine the time-dependent dispersion of larvae. The model produces contours of larval concentrations on a 1-by-1-km grid which spans the entire study area. This approach allows a natural integration of biotic and abiotic data. Observations of the velocity field from satellite and in-situ platforms provide estimates of advection and diffusion. Estimates of hatching and mortality rates from sequential cruises provide source and sink terms. As development of the basic model continues, tests of soundness of the necessary approximations will be examined by simulating historical distribution patterns of larvae. In addition to intrinsic value, the model will be a useful tool in determining the direction of the field program.

During the 1989 field season, an experiment was conducted to examine the impact of over-water winds on vertical structure of the horizontal current field. Measurements were successfully made from an Atlas-type surface buoy using System ARGOS data transmission. Current measurements were collected using an acoustic Doppler current profiling instrument moored 65 m below the surface.

Observations from previous years suggests biotic and abiotic differences in environmental conditions between Alaska Coastal Current (ACC) and nearshore waters. These differences may have significant impact on survival of pollock larvae. For 1989, an experiment was designed to provide a description of transport and biological conditions in the two regions. Observations were collected from moored instruments, aboard ship and from satellite images (AVHRR). Measurements included acoustic Doppler current profiles, fluorescence, microzooplankton, towed net camera and conductivity and temperature versus depth. Preliminary analyses show strong differences in zooplankton concentrations across the Shelikof sea valley. When all data sets are processed, the analysis of these data will answer the question of different survival rates and provide valuable input to the model.

Plans FY 90

VENTS Program

- Plan and implement an interdisciplinary hydrothermal flux experiment on the southern Juan de Fuca Ridge.

- Continue monitoring plume intensity and distribution along the Juan de Fuca Ridge.

- Conduct an *Alvin* submersible program at the northern end of the Cleft Segment; i.e., the Megaplume Site.

- Model the relationship between the heat, major element, and seawater content of the hydrothermal fluids within the buoyant plume regime located at the southern end of the Cleft Segment.

- Continue development of the VENTS Submersible-coupled in-situ Sensing and Sampling System by enhancing capabilities of in-submersible control/data logging modules.

- Continue the analysis of the heat-^{3}He-Si relationships in off-axis regions.

- Analyze sediment-trap materials for major and trace elements and determine chemical fluxes to the sediments in on- and off-axis regions west of the Juan de Fuca Ridge.

- Synthesize all current-meter measurements.

- Develop and deploy two improved BPR instruments.

- Monitor tectonic/volcanic processes in the megaplume area by, (1) deploying a short-term, ocean-bottom seismometer array, (2) making seafloor gravity measurements, and (3) conducting an active seismic-refraction survey.

- Analyze existing T-phase data along the Gorda Ridge for evidence of tectonic and volcanic activity.

- Initiate efforts to reactivate the Midway Pacific Missile Range/Missile Impact Location System hydrophone array as well as other arrays in the Aleutian Islands and off California with the overall objective of establishing tectonic/volcanic/hydrothermal event detection along Pacific spreading centers.

FOCI

- Obtain estimates of divergence of velocity which affects patches of pollock larvae using Long-Range Aid to Navigation-C (LORAN–C) tracked buoys.

- Continue long-term monitoring of water properties, pollock egg and larval distributions; continue satellite image analysis to define the mean current on all spatial scales.

- Continue model development and use the model as a tool to help establish priorities of field and laboratory studies.

- Conduct preliminary analysis of physical data collected to examine difference between ACC and nearshore waters.

- Use long-term current, water property, and climatological data to establish a monthly mean description of the physical environment.

- Conduct an experiment to observe concurrent over-water and island winds together with horizontal current profiles.

- Examine integration FOCI data sets with larger data bases to investigate relationships on basin wide and climate scales.

MARINE OBSERVATION AND PREDICTION

Accomplishments FY 1989

Arctic Research

The Beaufort Sea mesoscale circulation study

The Outer Continental Shelf (OCS) Beaufort Sea study was completed. The principal conclusions of the study are:

- Below the upper 40–50 m, the major circulation feature of the outer shelf and slope is the Beaufort Undercurrent, a strong flow which in the mean is directed eastward but which is subject to frequent reversals toward the west. These reversals are normally accompanied by upwelling onto the outer shelf. The undercurrent is very likely part of a basin-scale circulation within the Arctic Ocean.

- While the influence of the wind on the subsurface flow in the southern Beaufort Sea is statistically significant, it is generally of secondary importance and accounts for less than 25% of the flow variance below 60 m.

- There are large changes in wind variance with season, with the largest variance occurring in late summer-early autumn and again in January.

- Despite the seasonally varying wind field and the large seasonal differences in the upper-ocean temperature and salinity fields, there is no evidence for a seasonal variability in the subsurface circulation. This situation contrasts with that in Bering Strait, and probably also in much of the Chukchi Sea, where a seasonal wind-driven cycle in the transport is readily apparent.

- The atmospheric sea-level pressure field was well represented by the Fleet Numerical Oceanography Center (FNOC) surface analysis if the 12-hour lag of the FNOC pressures is taken into

account. However, the FNOC surface air temperature field shows a systematic over-prediction during winter and spring of 10–20°C, leading to an annual over-prediction of air temperature by 3–13°C.

The FREEZE experiment

The FREEZE experiment, begun in 1987, continued the study of finescale and mesoscale processes related to ice formation over the western arctic shelves. A combination of current meter and pressure gauge moorings were used to estimate dynamical effects, drifting ice buoys to trace ice motion and ice edge advance, and CTD surveys to map heat and salt budgets prior to and during initial fall freezeup.

Investigations in the Greenland Sea

Convection and water-mass transformation in the Greenland Sea, which is being studied under the International Greenland Sea Project (IGSP), is of major consequence to the ventilation of the deep ocean. During FY 89 PMEL was involved in five of the IGSP cruises and an instrument deployment to monitor the Denmark Strait overflow. The work employs long-term moored instrument arrays and seasonally repeated hydrographic censuses of very high accuracy. Preliminary examination of the hydrographic data suggests that during 1988–89 the upper two kilometers of the ocean were successfully ventilated following several years of little, if any, deep convection.

Two new instrumented arrays were deployed in 1989 to monitor the southwestern part of the Greenland Sea, where recirculation from the East Greenland Current may provide fresh water to the convective gyre. The gyre appears to be rather delicately poised with respect to its ability to sustain convection so that small variations in the fresh water supply can alter or stop the convection.

Sea ice processes and modeling

As a major step in improving forecasts of coastal sea ice motion around Alaska, the existing one-dimensional (1–D) coastal sea ice-barotropic ocean model is being expanded to two dimensions conforming to the topography of the western arctic shelves. The new model has nominal 18-km grid spacing, employs the ice thickness-strength relation developed for the 1–D model, and retains both the barotropic and wind-driven forcing critical to ice motion on these shelves. The effects of different lateral boundary conditions are being examined together with a sensitivity study of the various model parameters. The model is expected to lead to a full forecasting capability for the Navy-NOAA Joint Ice Center in two to three years.

Coordinated Eastern Arctic Experiment (CEAREX)

The objective of the PMEL CEAREX effort is to collect a comprehensive high-Arctic meteorological data set covering fall through spring. The regional pressure gradient was determined from drifting buoys, while radiation, atmospheric soundings, and near-surface wind and temperature profiles were measured from a drifting ship and ice camp. During spring, two flights were made over the ice camp with the NOAA P–3 research aircraft, providing detailed observations of the vertical variation of turbulence, wind, and tempera-

ture. A regional atmospheric model will be developed capable of improving ice forecasting and climate models by including the low level temperature inversion structure found in the Arctic in winter.

Vessel icing

At high latitudes, spray generated by ships in heavy seas can freeze to vessel structures, producing an extreme hazard. The operational NOAA vessel icing forecast algorithm was evaluated against advances in understanding the icing process and against recent operational experience. The NOAA algorithm shows excellent results when compared with a new cold-water data set from the Labrador Sea, as well as having provided excellent forecasts to over 140 fishing vessels in Alaskan waters during late January 1989, the worst icing episode of the decade.

Tsunamis

The long-term goal of the Tsunami Project is to improve our understanding of the dynamics of tsunami generation, propagation, and shoreline inundation. To this end, the Pacific Tsunami Observation Program (PACTOP) was developed to acquire high-quality tsunami measurements in the deep ocean and coastal environment. Continuous maintenance of the PACTOP deep ocean network required three cruises in 1989 to recover and redeploy bottom pressure recorders (BPRs) and collect CTD data.

Data reduction, analysis, and numerical modeling efforts continued to focus on three small tsunamis generated in the Gulf of Alaska on 17 and 30 November 1987 and 6 March 1988. These events were recorded by PACTOP BPRs and by coastal tide gauges. These data were used to test a surface deformation model to compute estimates of the vertical seafloor displacement. Several tsunami simulations were performed, and a preliminary comparison with the BPR observations indicates good agreement in the case of the 6 March tsunami, but poor agreement for that of 30 November. These preliminary results demonstrate the critical nature of accurate tsunami source specification. The results also suggest that the simple earthquake fault plane model for the 6 March event is perhaps more realistic than that for 30 November, possibly due to inaccuracies in the seismologically derived fault plane parameters for 30 November, or to a fundamental inadequacy of the rectangular fault plane idealization to deal with more complex earthquake mechanisms.

Plans FY 90

Arctic Research

- Continue analysis of the circulation on the Alaskan shelves, including effects of upwelling and Pacific inflow.

- Develop a cooperative shelf circulation research program with the U.S.S.R., focusing on the Chukchi Sea.

- Recover the FREEZE moorings from the northern Bering and Chukchi seas, and complete a third survey of the western arctic shelves during autumn 1989.

- Calibrate and process the 1988–89 IGSP data set, and analyze earlier moored measurements in the southern Greenland Sea.

- Recover moored arrays in the Greenland Sea during June–July 1990.

- Apply the 2–D sea ice-barotropic model to the Bering and Chukchi seas, and perform a sensitivity study with historical climate data.

- Compare CEAREX ice-atmosphere data with an Arctic atmospheric model.

Tsunamis

- Complete comparison of numerical tsunami simulations and deep-ocean measurements.

- Maintain the PACTOP network by the recovery and redeployment of all deep-ocean BPRs.

MARINE ENVIRONMENTAL ASSESSMENT

Accomplishments FY 89

Long-Range-Effects Research

Marine environmental assessment at PMEL emphasizes understanding of the complex physical and geochemical processes that ultimately determine the health of marine systems and their ability to assimilate contaminants. Included are studies of the geochemistry of trace metals and organic compounds, distributions of hydrocarbons and synthetic organics, coastal and estuarine circulation, and transport processes. Although the geographic focus of these studies has been Pacific Northwest and Alaskan coastal and estuarine waters, the scientific knowledge acquired and methodologies developed are applicable to other marine systems.

Estuarine Circulation

During 1989, the study of bottom-water intrusions focused on temporal variations in the onset of intrusions as a result of fluctuations in the horizontal density gradient caused by salinity variations across the sill in the Strait of Juan de Fuca. Salinity changes outside the sill in the Strait of Juan de Fuca estuary appear to be the result of autumn and winter storms on the Pacific coast causing reversals of surface flow and variations in deep flow more than 135 km from the coast. These observations are the first to show that this effect can penetrate the full length of the Strait causing near-bottom salinity variations of sufficient magnitude to influence flow into Puget Sound.

Contaminant Transport

The quantification of point and non-point inputs and an understanding of the physical and geochemical processes acting on contaminants are needed to understand the impact that humans are having on our nation's coastal regions. Using estuarine theory based on constituent-salinity correlations, a method to estimate non-point industrial inputs added to estuaries was developed. During wet weather, 60% of the dissolved Cu and Zn transported out of Elliott Bay, Washington, was found to have originated from non-point sources associated with shipyard activities. Wet-weather periods also produce high river flow which causes the formation of a thin surface layer of freshwater (<2 m) in Elliott Bay. Because of the short residence time of freshwater in the Bay (<1 day), dissolved metal contaminants added to the surface water are not adsorbed onto particles and few particles settle out of the freshwater surface lens. Since most of the transport of dissolved and particulate trace metals occurs during the wet season, little of the annual load of these trace metals are lost to the sediments of Elliott Bay.

Transport Modeling

A hydrodynamical model of Admiralty Inlet and the main basin of Puget Sound was completed and simulations of circulation and salinity are being compared with field measurements. The long, deep, and narrow character of Puget Sound allows for a laterally averaged, 2–D formulation. The reduced dimensionality permits simulations resolving tidal flows over time intervals of several months. The model differs from previous estuarine models in that it combines three elements essential to flow in Puget Sound: branched channel hydrodynamics, time-varying turbulence closure, and numerical techniques that prevent the artificial (numerical) diffusion of density fronts as they propagate into the estuary.

Some important results of the work are: (1) fortnightly variations of salinity in the Strait of Juan de Fuca dominate the control of quasi-fortnightly intrusions of dense water into the main basin of Puget Sound; (2) fresh water discharge from riverine sources is effectively trapped in the main basin by the vigorous vertical mixing in Admiralty Inlet; (3) vertical advection speeds approaching 1 cm s^{-1} are possible at some locations in the Sound; (4) evanescent internal tides appear in the main basin after periods of sufficient fresh water discharge; and (5) downward mixing of fresher Whidbey basin discharge occurs during southerly winds and at time of intrusions. This circulation model permits the creation of a time series of advection and mixing fields requisite for subsequent models of particulate and chemical tracer transport.

The vertical transport of a chemical tracer in Puget Sound has been explored with a two-stage scavenging model. In the first stage, a dissolved tracer is scavenged by and desorbed from fine particulates while at the same time the fine particulates are scavenged and settled by macroaggregates. Application of the model to ^{234}Th data from Puget Sound sets the time scale for fine particle scavenging near 6 days, while disaggregation of the macroaggregates occur at time scales of only a few days. These processes control the speed at which contaminants are removed from the water column to the bottom sediments.

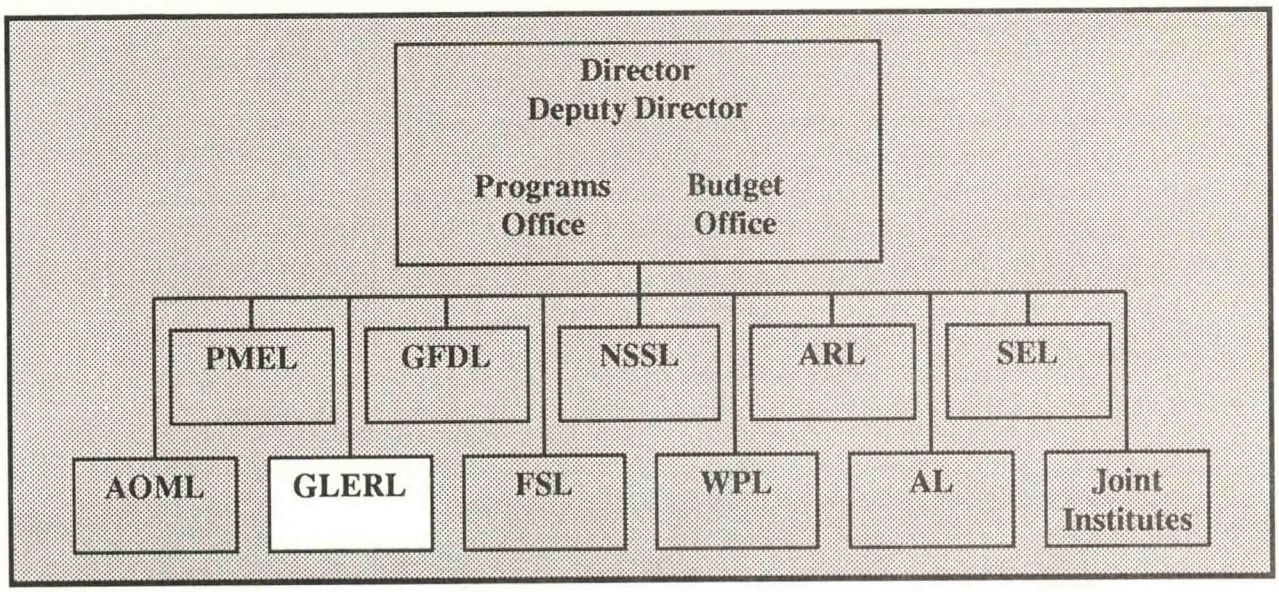
Work on the Puget Sound Reflux Model was completed. Results indicate that for the main basin only about one-third of the upper layer's seaward flow refluxes landward within Admiralty Inlet. This is one-half of previous estimates which were incomplete due to the neglect of side channels and the lack of adequate salinity and current data.

Sea Level in Puget Sound

A study of sea level in the Puget Sound region shows that most of the sea level fluctuations observed at Seattle propagate from the coastal region. For periods longer than 10 days, the amplitudes at Seattle are about 80% of those observed at Neah Bay, located 220 km away at the entrance to the Strait of Juan de Fuca. The winter fluctuations at Seattle lag those at Neah Bay with a time delay consistent with the propagation of barotropic waves. Highly variable from year to year, they are strongest during winter when storms impinge on the Washington and Oregon coasts. Groups of storms with low atmospheric pressure and southerly winds and separated by periods of high pressure and northerly winds produce a broad sea-level spectrum. Summer sea level is dominated by fortnightly fluctuations which vary greatly from year to year, unlike pure gravitational tides.

Plans FY 90

- Characterize the nature of Cu-organic interactions in Puget Sound during the FY 90 field season.
- Continue the study of sea-level processes in the Pacific Northwest.
- Continue the development of chemical dynamics models for estuaries.
- Understand and predict the mean seaward flow in Colvos Passage and the resulting recirculation around Vashon Island.
- Explore time-dependent scavenging models of tracer transport to evaluate water column residence times of chemical species.
- Examine the effects of wind on the circulation of Puget Sound using the laterally averaged model and a 1–D time-dependent model.



GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Ann Arbor, Michigan
(313) 668–2235
Alfred M. Beeton, Director

The Great Lakes Environmental Research Laboratory (GLERL) conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters, with special emphasis on the Great Lakes. GLERL's scientific programs support two major elements of the National Oceanic and Atmospheric Administration's Marine Prediction Research Program: (1) Coastal, Estuarine, and Great Lakes Environmental Processes and Assessments and (2) Marine Hazards and Lake Hydrology.

COASTAL, ESTUARINE, AND GREAT LAKES ENVIRONMENTAL PROCESSES AND ASSESSMENTS

Accomplishments FY 89

Toxic Organics and Environmental Contamination

GLERL has a continuing program in collaboration with the Evironmental Protection Agency (EPA), the U.S. Fish and Wildlife Service, and various Canadian agencies to develop and improve our understanding of the processes that control the distribution, cycling and fate of organic contaminants, their toxicology, and their biotransfer. A major focus of this research is the association of toxic organics with suspended and deposited sediments.

Sediment and resuspension processes

Sediments play a major role in the regulation of aquatic systems and serve as a natural repository of indicators of present and historical changes in ecosystem status and chemical loadings. GLERL's research in this area has application to diverse aquatic systems. It emphasizes the use of radiotracers to identify and model fundamental lake/watershed sediment transport processes. During FY 89, GLERL:

- Completed measurements and theoretical treatment of radionuclide profiles in sediments from the Oahe Reservoir system (South Dakota), in collaboration with the U.S. Geological Survey.

- Developed a multicomponent model for the response of water, sediments, and fish in Lake Sniardwy (Poland) to contaminants from the Chernobyl reactor accident, in collaboration with Polish scientists through support from the Marie S. Curie Fund administered by the U.S. Department of State.

- Developed a phase-specific response model for the scavenging of Chernobyl radionuclides from Lake Constance, West Germany, in collaboration with scientists at the University of Constance and the West German Government.

- Completed measurements and theoretical treatment of radionuclide profiles in sediments from Lake Ontario as part of an EPA-sponsored study of dioxin contamination.

- Developed a long-term fate model for contaminants in Lake St. Clair sediments in collaboration with EPA and the Canada Centre for Inland Waters (CCIW).

- Completed theoretical and experimental studies of epilimnetic cycling of natural and fallout radionuclides in Lake Michigan.

- Demonstrated that sediment-trap data from GLERL can be combined with similar data from CCIW without bias. This will allow a synthesis of sediment-flux information covering all five lakes.

Sediment-associated toxic organics: fate and effects

Contaminated sediments represent a large potential source, and in some cases the only apparent source, of contaminants to the food chain. In the Great Lakes, sediment-associated pollutants are implicated as either the major source or one of the major sources of environmental problems in 41 of the 42 Areas of Concern listed by the International Joint Commission (IJC) for the Great Lakes. A major part of GLERL's research on toxics is focused on the toxicology and bioavailability of contaminants from sediments in the Great Lakes. In FY 89:

- A 28-day mortality bioassay protocol using the benthic invertebrate *Pontoporeia hoyi (P. hoyi)* was developed and is expected to provide better sensitivity than the 10-day solid phase bioassay developed last year.

- The Gamma Scan System was modified to allow us to use a ^{109}Cd x-ray source to measure the porosity of sediments in a non-destructive manner.

- Oligochaete worms (*Stylodrilus heringianus*) collected from off-shore sites in Lake Michigan near Benton Harbor and Grand Haven were exposed to sediments also collected from these two sites, showing that the organisms collected from offshore Benton Harbor have developed some contaminant tolerance.

- A group of *P. hoyi* was exposed to four dose levels of a mix of polycyclic aromatic hydrocarbons (PAH). The dose-response characteristics suggested that narcosis is the probable mechanism of toxicity, and we observed that the rate of accumulation of the contaminants in the organisms increased as the concentration increased in the sediment, until an apparent plateau was reached.

- The effects of organic carbon on the bioavailability of sediment-associated contaminants to *P. hoyi* was studied. Organisms exposed to highest concentrations of organic carbon accumulated the lowest concentrations of contaminants, confirming that organic carbon plays a significant role in bioaccumulation.

Lake Michigan circulation and dynamics of the bottom boundary layer

We are studying the physics of the benthic boundary layer with focus on bottom currents and resuspension. An experiment was conducted near Grand Haven, MI, in April 1989, during which acoustic Doppler profilers were deployed alongside the Benthic Layer Interactive Profiling System (BLIPS) developed at Louisiana State University. The BLIPS provided measurements of sediment concentrations and fine-scale current structure within the lower 1.5 m of the water column, and our Doppler profilers measured and recorded Ekman layer currents.

Isotope biogeochemistry in limnology

GLERL's stable isotope research focuses on the processes that regulate the major biogeochemical cycles, using analyses and modeling of the fractionation of natural stable isotopes. During FY 89, sample preparation and cleanup systems for the stable isotope mass spectrometer were completed, making the isotope facility fully functional. A sediment core from the Mississippi delta was analyzed for stable isotopes to test a hypothesis that nutrient-enhanced productivity causes increased transport of carbon to the sediments.

Long-term distributed costs of environmental contamination

GLERL is engaged in a study of the long-term costs of pollution that are borne by the public and paid out of public funds. This year the total costs of well-documented environmental pollution episodes (James River—kepone; Hudson River—PCB; New Bedford Harbor—PCB) were estimated and found to be much greater than the cleanup costs alone. Cleanup costs are often used as a measure of pollution damage, and do

not account for factors such as damage to fisheries. In the three cases examined, past and future damage to fisheries resources were major contributors to the estimated total costs.

Ecological Processes and Mechanisms

Food web processes have a dominant influence on the transfer of energy and contaminants throughout the ecosystem. GLERL conducts research on both pelagic and benthic ecosystem and food web dynamics to advance our knowledge of, and ability to more accurately model, the flow of materials and energy within the food web.

Contaminant fate models for Lake St. Clair

Lake St. Clair supports a diverse, productive and economically important fishery and provides habitats for large numbers of migrating and breeding waterfowl. GLERL previously developed a series of ecological and contaminant fate models for Lake St. Clair. This year we used these models to perform a calibrated simulation of carbon and nutrient dynamics in the Lake St. Clair ecosystem. The simulation revealed that the detrital food chain could be twice as important to fish productivity as the pelagic-based grazing food chain. Inputs of external particulate carbon, available for incorporation by food chains, were nearly four times that of carbon fixed by algae and submersed aquatic plants within the lake.

Phytoplankton in the Upper Great Lakes

GLERL continues to conduct research to clarify the role of nanoplankton and picoplankton in the Great Lakes ecosystem, and to examine the methods and technology for determining primary production. The research showed:

- Photosynthetic picoplankton are about thirty times more abundant than "traditional" phytoplankton and constitute approximately 17% of total photosynthetic biomass. On an annual basis, photosynthetic picoplankton contribute about 35% of total Upper Great Lakes primary production, with a peak contribution of nearly 75% during the late summer and early fall. These results will change existing ideas about Great Lakes plankton dynamics.

- Protozoan abundances and biomass in Lakes Huron and Michigan and were found to be similar to those reported for other oligotrophic environments. Because the biomass of microzooplankton rivals crustacean zooplankton biomass, microzooplankton may be more important grazers than once thought. Because of high turnover rates of ciliates relative to macrozooplankton, ciliates may be far more important in carbon and nutrient cycling than macrozooplankton.

Bacteria in Great Lakes food webs

GLERL studied the pathways of organic carbon and nutrient recycling mechanisms at the bacterial level, as well as the fate of bacterial carbon. This year we completed comparative bacterial uptake experiments

using thymidine, amino acids, and glucose as organic substrates. These experiments revealed that thymidine is not readily available as a carbon source to Lake Michigan bacteria during short-term bacterial growth-rate experiments. This is consistent with the assumption that thymidine uptake can be used as a measure of DNA synthesis.

Phosphorus dynamics and microplankton growth in Lake Michigan

To understand phytoplankton-bacterial interactions and the seasonal succession of phytoplankton in the Great Lakes, it is necessary to understand the dynamics of phosphorus (P), the limiting nutrient in the Great Lakes. GLERL continues to study the dynamics of and mechanisms behind seasonal succession of algae in Lake Michigan. During FY89:

- A new approach to estimate an upper bound on ambient phosphate concentration was developed and applied to Lake Michigan. This approach allows reliable estimates of ambient phosphate concentration required for testing mathematical models of phosphate cycling in the lower food web.

- Bacteria in Lake Michigan were shown to rely on organic phosphorus as a principal source of P and apparently takeup P by a transport system similar to that in non-aquatic bacteria.

Feeding dynamics and life-cycle strategies of zooplankton

Models of phytoplankton and zooplankton succession usually distinguish between two groups of herbivorous zooplankton, copepods of the genus *Diaptomus* spp. and cladocerans. The biology of *Diaptomus* species is less well understood, and these highly selective omnivores have been the recent focus of intense study to develop a behavior-based model of food selection and feeding rate, which is necessary to understand seasonal succession of plankton.

The cladoceran *Bythotrephes*, a northern European invader which was first found in the Great Lakes in the mid-1980s, has undergone a population explosion. We performed experiments to determine their feeding habits and found that their natural prey are the indigenous species of cladocerans, as well as copepod nauplii. There is the potential for severe disruption of the existing food web by *Bythotrephes*.

Benthic ecology and sediment nutrient/energy transformations

Benthic invertebrates have several important roles in the Great Lakes ecosystem. These organisms form a vital link between primary production and fish production; they feed on material settled from the water column and are, in turn, fed upon by most species of Great Lakes fish. We examine benthic processes related to both organisms and sediments to improve our understanding of how these two benthic components affect, and are affected by, the rest of the system. In FY 89 we completed a study of phosphorus cycling by mussels in Lake St. Clair. Mussel biodeposition may be an important source of nutrients to other biotic components in the lake, such as macrophytes and invertebrate deposit-feeders.

Long-term trends in the benthic fauna of the Great Lakes

Because of their limited mobility and relatively long life cycles (when compared to plankton), benthic fauna form stable communities that integrate and reflect environmental conditions over long periods of time. GLERL has an established research program to examine trends in benthic populations and to relate these observations to environmental conditions and control measures implemented to improve water quality. During FY 89 benthic organisms in sediments collected from Saginaw Bay, Lake Huron, were sorted and counted to assess long-term trends as a biomonitor of changes in water quality. The data show a two-fold increase in the abundance of pollution-tolerant oligochaete worms since the early 1970s. *Hexagenia* species, the pollution-sensitive Mayfly larvae, was completely absent. Thus, it appears that the benthic community in Saginaw Bay does not yet reflect recent efforts to improve water quality in Saginaw Bay.

Green Bay Mass Balance Program

Green Bay, a large embayment on the west side of Lake Michigan, is plagued with toxic organics, especially polychlorinated biphenyls (PCBs), in the water, sediment, and biota. The EPA initiated a major interagency study of Green Bay in FY 88 to develop a mass balance for PCBs. During FY 89 GLERL conducted three mass-balance projects which receive partial funding from EPA and the balance from GLERL's base under the Marine Ecosystems Assessment Program. The results are still being analyzed.

Water volume transport measurements in Green Bay

The models necessary to develop a comprehensive Green Bay contaminant mass balance require a knowledge of water volume fluxes throughout the Bay, its tributaries, and to and from Lake Michigan. GLERL is responsible for measuring water volume exchanges between the upper and lower parts of Green Bay and between the Bay and Lake Michigan. Winter current meter moorings established in Green Bay in late FY 88 were recovered in May 1989 and an array of 18 current meter moorings and four thermistor chains were deployed in May 1989 to determine the circulation in Green Bay during the summer and fall seasons.

Understanding fish food web, nutrient, and contaminant dynamics in Green Bay: an integrated modeling approach

To understand the relative importance of the various food and water pathways of PCB accumulation by fish, it is necessary to understand food web relationships, population structure and the bioenergetics of the fish in Green Bay. GLERL is developing a predictive model of fish population dynamics and variability in Green Bay, and during FY 89 bioenergetics models of alewife, perch, and walleye populations were developed and calibration of these models was started.

Sediment resuspension in Green Bay

In Green Bay, most of the PCB reservoir is found in sediments, and information about resuspension of these sediments is needed for the development of the Green Bay mass balance. GLERL is using both

instrumented tripods and a bottom-resting flume in which the flow can be controlled to develop an empirical relationship between bottom resuspension and current velocity in Green Bay. During FY89, four instrumented tripods were deployed in Green Bay near the sites of seasonal current meter moorings, and a meteorological station was established to measure overlake winds and air and water temperatures.

Plans FY 90

Toxic Organics and Environmental Contamination

- Complete a study and model of epilimnetic cycling of radionuclides in Lake Michigan.
- Apply the phase-specific scavenging model to Chernobyl fallout radionuclides in Lake Constance.
- Complete a study on the history and theoretical treatment of silicon accumulation in the lake sediments in Lake Erie.
- Apply the automated Gamma Scan System to a study of time-dependent diffusion coefficients in the transport of sedimentary tracers.
- Complete the calibration of GLERL's new high-resolution extended range gamma detection system.
- The 28-day mortality bioassay and the sediment-avoidance bioassay will be calibrated using additional materials, including standard toxicants with known mechanisms of action and contaminated sediments provided by EPA.
- The sensitivity of oligochaetes to endrin, as determined with the Gamma Scan system, will be used to evaluate the value of bioturbation as a chronic end-point.
- Experiments to refine methods to determine the assimilation efficiency of *P. hoyi* for sediment-associated contaminants will continue, using benzo(a)pyrene and hexachlorobiphenyl as the initial contaminants.
- Initial studies of the effects of aging and the duration of contact between sediment and contaminant on the bioavailability of organic contaminants will be completed.
- BLIPS and current meter data collected during an April 1989 field experiment conducted off Grand Haven, Michigan will be analyzed.
- Complete carbon and stable isotope analyses of two Lake Erie cores.

- Design, construct, and calibrate automated sequencing sediment traps to be deployed in Green Bay.

- Complete collection and analyses of sediment trap samples from Green Bay to determine mass flux, carbon flux, and particle-settling velocities.

Ecological Processes and Mechanism

- Model the effects of zebra clams, a recent exotic specie invader from Europe, on primary and secondary productivity of Lake St. Clair.

- Determine the effects of salt on nitrogen transformations in estuaries.

- Compare lipids in *P. hoyi* from Lake Michigan to *P. hoyi* from the Baltic Sea.

- Estimate the net release rates of amino acids and glucose by Lake Michigan phytoplankton to examine the dynamics of these organic-rich substrates in the microbial food web.

- Investigate the association of organic contaminants with different lipid classes in two species of Great Lakes macroinvertebrates, *P. hoyi* and *Mysis relicta.*

- Determine the diel cycle and division rate of major components of the microbial food web, flagellates, and picoplankton, and examine the utilization of picoplankton as prey.

- Study the abundance, composition, and contribution to total primary production of bacteria-sized photosynthetic eukaryotes.

- Identify the mechanism(s) that *Diaptomus* species and other Great Lakes copepods use to remotely detect potential food particles.

- Study and describe the mechanism used by larval *Anopholes*, the malaria mosquito, to capture particles on the surface film of water.

- Test whether specific Great Lakes forage fish can be kept in captivity and used in experiments to study the food web and predator-prey relationship with *Bythotrephes*.

- Evaluate the latest video technology for observing the feeding mechanisms of *Bythotrephes*.

- The seasonal lipid concentration in *Limnocalanus* will be determined and related to its reproductive and life-cycle strategies.

- Identify organisms collected from Saginaw Bay, Michigan during FY 89 to the species level for entry into the long-term trends data set.

- Use a manned submersible to collect additional samples inside and outside fish exclosures placed in Lake Superior during FY 86.

- Complete a study of long-term trends in mussel abundance over three decades in western Lake Erie.

Green Bay Mass Balance Program

- Retrieve instrumented current meter, thermistor chain, and meteorological moorings from Green Bay and begin processing and analyzing the data.

- Instrumented tripods in Green Bay will be recovered during the fall 1989, redeployed, and recovered again in spring 1990.

MARINE HAZARDS AND LAKE HYDROLOGY

Accomplishments FY 89

Surface Waves and Water-Level Fluctuations

GLERL research in these areas includes field and analytical investigations to develop simulation and prediction models of over-water wind and wind waves, water surface oscillations, storm surges, and flooding; and hydrologic lake levels.

We are assessing the importance of shallow water effects on wind waves in the Great Lakes by identifying the circumstances and locations in which shallow water effects have a significant impact on wave growth, propagation, or decay and quantifying the extent of that impact.

- A Wave Rider Information Processing System (WRIPS) buoy was deployed in Green Bay to obtain data on waves in this shallow embayment.

- An initial study was conducted to compare the most advanced third-generation Wave Modeling (WAM) model and the GLERL/Donelan model for prediction of surface waves on Lake Michigan. Results of both models were closely similar for the 10-day test covering October 1988.

Lake Hydrology: Hydrologic Properties

Major changes in water quantity in the Great Lakes are caused by annual and seasonal variations in the water supply, consumptive use, and interbasin diversions. Superimposed upon the natural fluctuations are a number of anthropogenic changes which have or could have major effects on Great Lakes water quantity. GLERL's hydrologic research program is directed toward improving our knowledge of the hydrologic and hydraulic processes, improving methods of forecasting and simulating water supplies and lake levels.

Lake evaporation forecasting and simulation

Evaporation from the Great Lakes is on the same order of magnitude as precipitation and runoff to the lakes. It therefore represents a significant component of the lakes net supply and its determination is crucial in estimating lake levels. Existing evaporation estimation techniques result in the major portion of forecast errors. This research will lead to working models of lake evaporation that can be used effectively on daily, weekly and monthly time intervals for each of the Great Lakes. These models will be incorporated into the GLERL water supply and lake level simulation and forecasting procedures. During FY 89:

- A water surface temperature data base was constructed for Lake Michigan and used to calibrate the existing model.

- The evaporation model was reviewed by outside reviewers and relevant strengths and weaknesses were analyzed. This formed the basis for several of our current plans.

- Work was begun on heat storage concepts and heat storage superposition; wind-mixed aging and mixing of aged heat additions was implemented in the superposition.

- Bowen's ratio was removed as a means of computing sensible heat transfers and replaced with direct calculation of sensible heat from the computed transfer coefficient and other terms; this improved both the sensible and long-wave flux estimations as compared to other investigators' experiences.

- Intermediate recalibration and reapplication of the evaporation and heat storage model was made to each of the Great Lakes, representing an available intermediate application for outside agency interests.

Lake level management

On 1 August 1986 the Governments of the United States and Canada, pursuant to Article IX of the Boundary Waters Treaty of 1909, forwarded a Water Levels Reference to the IJC. The Reference requested that the Commission examine and report upon methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin. GLERL scientists provide hydrological and climatological analyses, simulation and forecasting techniques, and technical expertise to the functional groups of the IJC, in support of the Reference. In FY 89, GLERL:

- Supported a hydroclimatic study to assess the impacts of doubled atmospheric carbon dioxide (CO_2) on Great Lakes water supplies and lake levels. We transferred net basin supply scenarios previously developed for the EPA, provided ongoing technical support and advice on the use of the supplies to determine lake level impacts, wrote and reviewed reports describing methodologies and results.

- Supported a Great Lakes hydroclimatic study to assess the effects of natural climatic variability not represented in instrumental records. We developed two historical scenarios representing the most extreme 12-year conditions in the past 134 years, transposed to present hydrologic conditions. We also transferred resulting net basin supply scenarios to other agencies, provided ongoing technical support on their use to determine lake level impacts, and contributed to reports describing methodologies and results.

- Conducted a Great Lakes hydroclimatic study to assess the impacts of a recurrence of the extreme wet climate regime of 1870–1885. We developed a data base of monthly temperatures and precipitation for 1870–1885, used the data with conceptual models for each component of net basin supply, and examined impacts on lake levels using existing regulation rules and connecting channel conditions.

- Provided support for reviews of United States and Canadian policy and institutions affecting Great Lakes levels management.

Great Lakes snow cover

Snow cover represents a vast reservoir of freshwater that, during the spring, contributes to the water supply of the Lakes and to the groundwater of the basin. The climatology of the Great Lakes snow cover is largely unknown. Under this project we are developing an atlas of monthly, yearly, and period of record snow cover maps for the Great Lakes basin, and developing improvements to the methods available to map the Great Lakes basin snow cover, focusing on applications of remote sensing technology. During FY 89 an extensive data base of snowfall and snow ground cover was acquired and forms the basis for future work.

Lake Hydrology: Regional Impact of Climate Change in the Great Lakes

Due to the large and slowly changing storages of water and heat in large lakes, large lakes buffer the effects of most short-term (interannual) meteorologic variability and react to, and record, the longer period fluctuations characteristic of global climate change. Thus, large lakes may be ideally suited for studying the regional effects of global climate change, and GLERL has established a core research program to examine and evaluate the potential effects of climate change on the Laurentian Great Lakes as a start.

Global warming or cooling could significantly change the water levels and ice covers on the large lakes of the world. GLERL's research is focused on assessments of (1) the effects of global warming (as represented by a doubling of atmospheric CO_2) on large lake water supplies, lake levels, and ice cover, starting with the Great Lakes, and (2) the potential effects of precipitation in the Great Lakes as great as that recorded for the period 1870–1885, under present basin characteristics, diversions, regulations, and connecting channel regimes. During FY 89 we:

- Combined, for integrated modeling of Great Lakes hydrology and water levels, GLERL's Large Basin Runoff Model, the early lake evaporation and heat storage model, overlake precipitation, Great Lakes levels regulations plans, connecting channel flow routing models, and lake water balances.

- Applied data adjustments for an atmosphere with double CO_2 content to our historical data sets to construct climate change scenarios.

- Performed simulations with the integrated hydrology models and both historical time series and the $2xCO_2$ time series.

Plans FY 90

Surface Waves and Water-Level Fluctuations

- Continue evaluations and comparisons of the third-generation WAM model and the GLERL/Donelan model.

Lake Hydrology: Hydrologic Properties

- Continue to refine evaporation and heat storage models.

- Improve ice cover functions for the evaporation procedures using Lakes Erie and Superior as test cases.

- Recalibrate evaporation model for all lakes and lake segments.

- Incorporate boundary conditions on water surface temperature into lake evaporation calculations for both simulations and forecasts.

- Develop software for use of improved models in water supply outlooks.

- Update all water balance computations through 1987.

- Continue support of the Water Levels Reference through Phase II, via hydrological and climatological analyses, simulation and forecasting techniques, and technical expertise.

- Support the Drought Management and Great Lakes Water Levels Task Force to develop a guidebook on drought impact management, conduct a symposium on lake levels forecasting, and develop a policy framework for coordinated basin-wide drought response.

- Organize and conduct a symposium on Great Lakes Levels Statistics for Decision Making, to focus on (1) the state-of-the-art in lake level statistics, promising approaches for improving statistics, and future research needs, (2) incorporating lake levels statistics into effective information dissemination and education efforts, and (3) integrating the efforts of agencies and jurisdictions to enhance appropriate application of lake-level statistics.

- Initiate a new project to develop approaches that foster long-term contingency planning and increasing the resiliency of Great Lakes management to climatic uncertainty. Issues to be explored include, among others, the prospects and implications of moving to allocated or freemarket water rights systems.

- The snow data base will be completed and analyses of snow as a natural hazard and as a contribution to runoff within the basin, will begin.

Lake Hydrology: Regional Impact of Climate Change in the Great Lakes

- Begin integration of system process models with developing atmospheric mesoscale models.

- Study effects of general circulation model (GCM)–GLERL model linkages; extend the simulation study to assess changes in variability of the hydrologic variables.

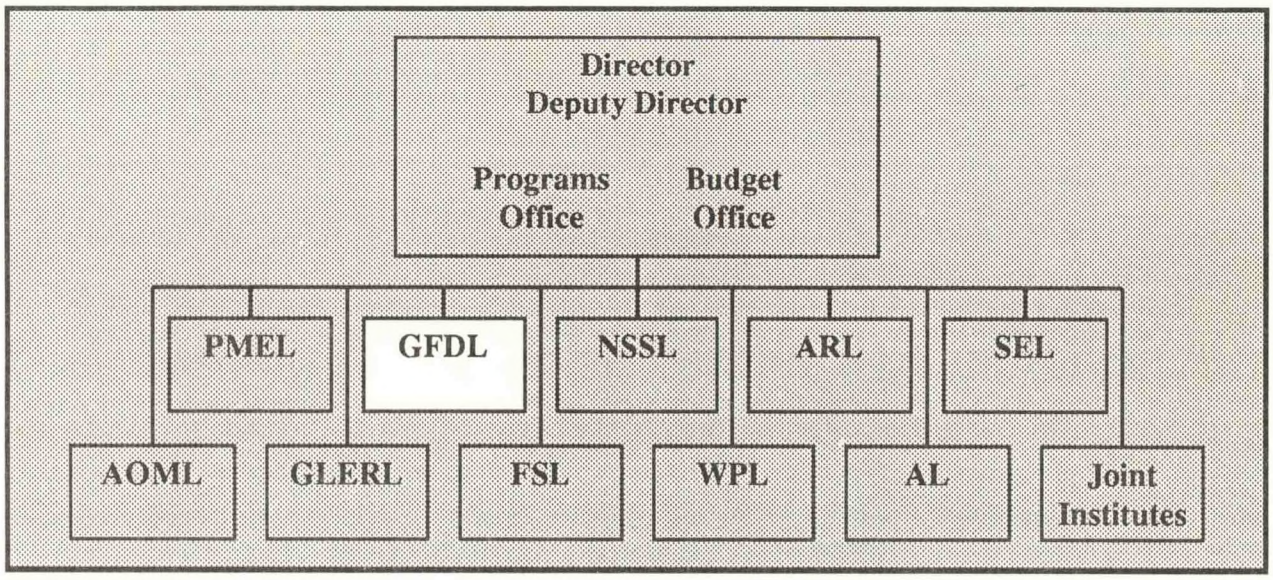
- Compare GCM results with historical data and compare hydrological and GCM outputs.

- Plan joint climate impact research with the Soviets and exchange climatic data bases for the U.S. Great Lakes and Soviet Caspian Sea basin.

- Begin to develop 1951–1980 base case for a selected U.S.S.R. site.

- Begin to adapt GLERL large basin runoff and lake evaporation models for application in the U.S.S.R.

- Begin to jointly assess GCM simulations over the Great Lakes and the Soviet Union with the Soviets.



GEOPHYSICAL FLUID DYNAMICS LABORATORY

Princeton, New Jersey
(609)452–6502
J. D. Mahlman, Director

The Geophysical Fluid Dynamics Laboratory (GFDL) is engaged in comprehensive long-lead-time research fundamental to NOAA's mission. The goal of this research is to expand the scientific understanding of the physical processes that govern the behavior of the atmosphere and the oceans as complex fluid systems. These fluids can then be modeled mathematically and their phenomenology studied by computer simulation methods. In particular, GFDL research concerns the following:

- The predictability of weather on large and small scales.
- The structure, variability, predictability, stability, and sensitivity of global and regional climate.
- The structure, variability, and dynamics of the ocean over its many space and time scales.
- The interaction of the atmosphere and oceans and how the atmosphere and oceans influence and are influenced by various trace constituents.
- The Earth's atmospheric general circulation within the context of the family of planetary atmospheric types.

The scientific work of the Laboratory encompasses a variety of disciplines including meteorology, oceanography, hydrology, classical physics, fluid dynamics, chemistry, applied mathematics, and numerical analysis.

Research is also facilitated by the Atmospheric and Ocean Sciences program, which is a collaborative program at GFDL with Princeton University. Under this program, regular Princeton faculty, research

scientists, and graduate students participate in theoretical studies, both analytical and numerical, and in observational experiments in the laboratory and in the field. The program is supported in part by NOAA funds. AOS program scientists may also be involved in GFDL research through institutional or international agreements, or through temporary Civil Service appointments.

WEATHER SERVICE

During the past two decades synoptic-scale weather forecasts have improved considerably because of the development of numerical models that include more of the physical processes of the atmosphere, have high spatial resolution, and parameterize turbulent processes more accurately. Successful forecasts for periods up to 5 days are now routine, and the limits of atmospheric predictability have been extended to several weeks. However, quantitative forecasts of precipitation remain elusive. For smaller spatial scales, there has been considerable progress in determining the mechanisms that generate severe storms, in explaining how mesoscale phenomena interact with the large-scale flow, and in simulating the genesis, growth, and decay of hurricanes.

These successes in the extension of atmospheric predictability have encouraged GFDL to ask more challenging questions. For example, can the weather be predicted on time scales of months? Are mesoscale weather systems and regional-scale precipitation patterns predictable, and if so, to what extent is the accuracy dependent on the prediction of the ambient synoptic flow? Research to develop mathematical models for improved weather prediction will also contribute to the understanding of such fundamental meteorological phenomena as fronts, hurricanes, severe storms, and tropospheric blocking.

Accomplishments FY 89

A seasonal forecast experiment using an air-sea coupled model was attempted for a second case, following the first successful case reported in FY 89. The forecasts were started from January 1982, 9 months before the observed El Niño emerged in September. A straightforward method and a method of systematic error correction were applied to the initial condition of the model-assimilated data set for the ocean and the National Meteorological Center (NMC) analysis for the atmosphere. The forecast based on the former method showed only a slight tendency for sea temperature warming at the eastern Equatorial Pacific, while the forecast based on the latter method was somewhat more successful.

It was found that tropospheric blocking activity is manifested by a distinct subpolar peak in the meridional distribution of low-frequency eddy kinetic energy. The models, which include the Mellor-Yamada turbulence parameterization, tend to have a well-defined peak of this energy distribution. Based on the numerical experiment and other studies, a hypothesis was postulated on a requirement for blocking: the westerly jet prior to the onset of blocking has to be displaced to a relatively lower latitude.

The GFDL reanalysis of First GARP [Global Atmospheric Research Program] Global Experiment (FGGE) data from the Global Weather Experiment is finally near completion. The new analyses are quite good compared with the original GFDL analyses or with the FGGE data reanalyses of the European Centre for Medium-Range Weather Forecasting. This implies, contrary to conventional notions, that continuous data assimilation works satisfactorily compared with intermittent methods.

An experimental three-dimensional (3–D) prediction of Hurricane Gloria, 1985, was successfully performed in cooperation with NMC. The 72-h time integration of the model after 0000 UTC 25 September produced track prediction with significantly accelerated movement after 48 h, in good agreement with

observation. The position error at 72 h was 156 km, compared with 480 km for the official forecast based on operational models. Also, the predicted distributions of the maximum surface wind and total precipitation during the passage of Gloria compared favorably with observations.

Budget analyses of the vorticity and heat for two disturbances, one that developed into Hurricane David, 1979, and another that did not develop, revealed sharp contrasts in the storm development above the surface depression between the two systems. Specifically, the sum of the effects due to vertical motion and latent heat release caused warm-core formation only in the case of the developed system. Also, the nondeveloping system became detached from the easterly wave trough.

Successful Limited Area HIBU [Hydrological Institute and Belgrade University] Model (LAHM) cyclone development simulations were completed for the period 25–28 January 1986. During this time period, three cases occurred along the eastern coast of the United States that illustrate the different processes by which cyclones are generated. The results indicate that low-level baroclinic development without upper-level development is not conducive to explosive cyclogenesis. In the two explosive cases, an upper-level trough and low-level baroclinicity occurred, although the conditions by which the surface baroclinicity was established were different.

A case of strong cyclonic development in the South Pacific was successfully simulated. During the period of 4–6 September 1987, cyclogenesis developed as the subtropical branch of the jet stream near 40°S moved poleward and merged with the polar branch of the jet stream. Preliminary results using innovative diagnostics show that cyclone development occurred through a combination of barotropic and baroclinic processes.

Two-dimensional African squall line simulations with and without the inclusion of a simplified ice bulk cloud phase were extended to three dimensions. Both 3–D simulations show a typical squall line structure with 2–D features at low levels and increasing three-dimensionality with height. The inclusion of the ice phase gave stronger vertical velocities in the anvil and a larger area with anvil rain than present in the model atmosphere without the ice phase.

Plans FY 90

- Numerical models for all scales of weather prediction will be improved with new physical packages such as the simple biosphere and a new vertical differencing scheme introduced for the HIBU model.

- Seasonal, mesoscale, and tropical cyclone forecasts will be extended to additional cases and integrated with improved initial conditions.

- Diagnostic and theoretical studies involving atmospheric and oceanic phenomena, such as blocking, baroclinic waves, tropical storms, and squall lines, will be continued. The analysis of FGGE data will continue as well as development of data assimilation techniques appropriate for the mesoscale.

- Cooperation with NMC involving exchange of physics packages, data bases, and new model development will continue.

CLIMATE

The purpose of climate-related research at GFDL is twofold: to describe, explain, and simulate mean climate and climate variability on time scales from seasons to millenia; and to evaluate the effect on climate of human activities such as the release of carbon dioxide (CO_2) and other gases in the atmosphere. The phenomena that are studied include large-scale wave disturbances and their role in the general circulation of the atmosphere; the seasonal cycle, which must be defined before departures from the seasonal cycle (interannual variability) can be understood; interannual variability associated with phenomena such as the El Niño Southern Oscillation (ENSO); very-long-term variability associated with the ice ages; and the meteorologies of various planets, the study of which enhances our perspective on terrestrial meteorology and climate. To achieve these goals, both observational and theoretical studies are necessary. Available observations are analyzed to determine the physical processes by which the circulations of the oceans and atmospheres are maintained. Mathematical general circulation models (GCMs) are constructed to study and simulate the ocean, the atmosphere, the coupled ocean-atmosphere-cryosphere system, and various planetary atmospheres.

Accomplishments FY 89

The response of a realistic-geography fully coupled ocean-atmosphere model to a gradual increase of atmospheric CO_2 exhibits a marked interhemispheric asymmetry. In the circumpolar ocean of the Southern Hemisphere of the model, the increase of surface air temperature is very slow due to the upwelling of deep water and efficient convection mixing. In the Northern Hemisphere of the model, the increase of surface air temperature is faster and increases with latitude. An exception is the North Atlantic region where the warming is relatively slow due to a weakening of the thermohaline circulation.

A 100-year integration of a new version of a coupled atmosphere-ocean model with a global computational domain, realistic geography, seasonally varying insolation, and predicted cloudiness has been completed. Preliminary analysis shows that the temporal variability of annual-mean sea-surface temperature (SST) resembles observed variability.

Climate simulations with and without orography indicate that mountains play an important role in maintaining arid climates in the midlatitude Northern Hemisphere. General subsidence and relatively infrequent storm development upstream of orographically induced stationary wave troughs contribute to the dryness of continental interiors. The relative wetness of these regions in the model experiment without orography agrees with paleoclimatic evidence of less aridity in the late Tertiary before the substantial uplift of the Rocky Mountains and Tibetan Plateau occurred.

Results from an atmospheric GCM experiment incorporating near-global SST variations indicate the important role of oceanic changes in the extratropical North Pacific and North Atlantic on the overlying atmospheric flow pattern. The midlatitude storm tracks are seen to serve as an intermediary between the imposed SST forcing and the quasi-stationary response.

Diagnosis of an 140-year integration of a low-resolution ocean-atmosphere coupled GCM reveals the existence of regular oscillations with 36–40 month time scales. The meteorological and oceanographic phenomena associated with these cyclical events bear a considerable resemblance to those observed during ENSO episodes.

A multiyear project to prepare global upper-air weather analyses for the period May 1958–April 1988 was completed. This provides a unique opportunity to study global climate changes based on a 30-year, nearly homogeneous record. This data set indicates that, over the 1964–1985 period, there was a general warming

of the troposphere and cooling of the lower stratosphere, in general agreement with model projections of the effects of greenhouse gases.

A study was made of recent claims that the Northern Hemisphere winter weather is significantly affected by a subtle combination of solar activity and the tropical stratospheric quasi-biennial oscillation (QBO). Analysis of historical meteorological and solar data for 1875–1936 was conducted using seven million different scenarios for the evolution of the QBO during this period. The results indicate that the claimed solar-QBO-weather relationship cannot be reproduced in historical data and thus probably is not a real effect.

Wavelike synoptic-scale disturbances with well-defined structural and propagation characteristics were identified in specific sectors of the tropical zone, using observational data. The occurrence of such features is associated with prominent changes in the quasi-stationary, large-scale circulation.

Midlatitude and tropical SST anomaly experiments were conducted with an idealized GCM in which the unperturbed climate is zonally symmetric. The significance of changes in the midlatitude storm tracks for the climatic response was analyzed using a linear stationary wave model. In neither case is there strong positive feedback from the storm track eddies.

An atmospheric GCM coupled to a mixed-layer ocean model was used to study the climatic change due to variation in the obliquity of the Earth's orbit and the longitude of the perihelion with respect to the equinoxes. For variations typical of those that have occurred in the past 200,000 years, temperature changes as large as 15 K are found over North America in summer.

Line-by-line techniques were used to obtain benchmark solutions for the interaction of solar radiation with water vapor and water drops for the first time. Alternative techniques, which are computationally more efficient and whose accuracies range from good to excellent, also were investigated; these provided reference solutions to carry out several sensitivity tests related to cloud radiative properties. The calculations are already being used as a benchmark standard for solar radiation under cloudy conditions.

Plans FY 90

- Analysis and study of the transient response of climate to a gradual increase of atmospheric CO_2 will be continued. Other scenarios for gradual changes of the CO_2 amount in the atmosphere, using the seasonal coupled ocean-atmosphere GCM, will be evaluated.

- To investigate the role of oceans in climate variability, a detailed analysis will be conducted of the 100-year integration of a coupled ocean-atmosphere GCM with seasonal variation.

- Results from a new set of experiments will be analyzed to clarify the role of cloud feedback in CO_2-induced changes of tropical disturbances.

- The SKYHI GCM will be under development to enhance the simulation of a number of physical processes. Intensive diagnosis of the model will continue.

- Research to understand the role of aerosols in the climate of the stratosphere and upper troposphere will be intensified.

- Climatological analyses of the present observational 30-year data set will be actively pursued. Trend analyses and comparisons with other data sets will be done in joint projects with other institutions. The present 30-year data set will be extended.

- Further diagnoses of the North Pacific and Atlantic SST anomaly experiments will be made. These will be conducted to understand the dynamical reasons for the different responses discovered in the perpetual and switch-on forcing experiments. The impact of SST anomalies located in regions other than the central North Pacific and Newfoundland sites will be examined.

- The series of SST anomaly experiments with an idealized GCM will be continued. Experiments in which the unperturbed climate is zonally asymmetric will be compared against experiments with zonally symmetric control climates.

- Quasi-geostrophic turbulence integrations will be performed using a multilevel model with realistic atmospheric vertical structure. The model will be used to determine if eddy heat fluxes are more sensitive to low-level or to mean tropospheric temperature gradients.

- The solar radiative transfer techniques investigated during FY 89 will be used to develop cloud radiative parameterizations that account for both water vapor absorption and water cloud extinction in overcast atmospheres.

ATMOSPHERIC QUALITY

The main goal of atmospheric quality research at GFDL is to understand the formation, transport, and chemistry of atmospheric trace constituents on regional and global scales. Such understanding requires judicious combinations of theoretical models and specialized observations. The understanding gained will be applied toward evaluating the sensitivity of the atmospheric chemical system to human activities.

Accomplishments FY 89

The GFDL Global Chemical Transport Model (GCTM) was used to investigate the behavior of reactive nitrogen (NO_y) emitted by combustion processes. NO_y controls the chemical production of ozone (O_3) in the troposphere, indirectly controls the chemical reactivity of the troposphere, and is an important nutrient source for the oceans. No more than 1.4 teragrams (Tg) of the 21.3 Tg (nitrogen only) of NO_y is deposited in the Southern Hemisphere, less than 10% of background. The 4 Tg exported from continents accounts for most of the Northern Hemisphere oceanic deposition. Local basin depositions are dominated by the upwind continental source regions.

A new GFDL SKYHI model (the GFDL stratosphere GCM) experiment has been started to investigate the chemical-transport radiative dynamical response of the stratosphere to the Antarctic ozone-hole. The model shows substantial mixing of the ozone-depleted air into midlatitudes during austral spring, but with relatively little memory of the low Antarctic values by the following winter. The ozone hole region produces spring polar vortex cooling of up to 10°C and zonal wind increases of up to 15 m s^{-1}.

Three-dimensional calculations for a boundary layer source of an insoluble tracer, a fully soluble tracer, and a partially soluble tracer (SO_2 gas) have been carried out using the continental and tropical maritime squall line models. The only tracer to reach the upper atmosphere in significant amounts is the insoluble tracer. In contrast, virtually none of the fully soluble tracer is found at 10 km or above. Rainout is thus a very efficient mechanism for preventing boundary layer tracers from reaching the upper levels.

Plans FY 90

- Detailed analysis will continue on mechanisms governing regional chemical transport, including both stratospheric and surface sources.
- A new series of model experiments will be under way to examine the various aspects of the tropospheric nitrogen budget. Emphasis will be placed upon differentiating natural and anthropogenic sources as well as the chemical behavior of the reactive nitrogen species.
- The long-term effort to develop a fully consistent ozone chemistry for the SKYHI model will be accelerated.
- The SKYHI simulations of the doubled CO_2 and Antarctic ozone hole effects will be run to completion and analyzed.
- Using a 3–D convective model, studies will continue for both stratospheric and tropospheric tracers under various atmospheric conditions and for different chemical constituents.

MARINE QUALITY

Research at GFDL related to the quality of the marine environment has as its objectives the simulation of oceanic conditions in coastal zones and estuaries, the modeling of the dispersion of geochemical tracers such as tritium and chlorofluorocarbons (CFCs) in the world oceans, and the modeling of the oceanic carbon cycle and trace metal geochemistry. For regional coastal studies 2–D and 3–D models of estuaries, basins, and western boundary regimes are being developed. The response of coastal zones to transient atmospheric storms, and the nature of upwelling processes (which are of great importance to fisheries), are being studied by means of a variety of models. Basin and global ocean circulation models are being developed for the study of the carbon cycle and trace metal cycling.

Accomplishments FY 89

A first 3–D simulation of the uptake anthropogenic CO_2 by the oceans was carried out.

Ocean biological processes are important to the ocean's carbon cycling. A simple ecosystem model of the euphotic zone of the upper ocean was incorporated into a 3–D North Atlantic circulation model.

An annual-mean model of the global ocean general circulation was used to study the effect of organic matter remineralization below the euphotic zone on the distribution of nutrients. An important role for dissolved organic matter in the carbon cycle is suggested by this work.

The South Atlantic Ventilation Experiment (SAVE) was completed in which measurements of radium-228 were collected. Laboratory measurements of a similar suite of ocean tracers in the North Atlantic are almost completed.

Plans FY 90

- The fossil CO_2 experiments and related carbon cycle development studies will continue to be highest priority.

- The analysis of SAVE nutrient observations will begin. Oceanic tracers will be studied by both measurement analysis and modeling studies.

OCEAN SERVICE

A variety of models that can be used for the prediction of oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, 1–D models of the turbulent surface layer of the ocean predict the SST and heat content of the upper ocean. More complex 3–D models are being developed to study many phenomena: the time-dependent development of Gulf Stream meanders and rings; generation of the Somali Current after onset of the southwest monsoons; response of coastal zones to atmospheric storms; and development of SST anomalies such as those observed in the tropical Pacific Ocean during ENSO phenomena.

Accomplishments FY 89

To understand climate change, it is critically important that ocean models have realistic pathways of CO_2. Transient tracers present the most realistic check of this property of models. The World Ocean Circulation model designed for climate studies was used to predict the invasion of the ocean by CFCs. A comparison with data shows that the model provides a good quantitative simulation of the downward pathways in the world oceans.

A hierarchy of coupled ocean models have been analyzed to provide an understanding of the El Niño phenomenon. Several types of equatorially trapped air-sea interactions take place, providing a partial explanation of the very large differences in individual El Niño events observed.

A series of experiments in a model with simplified geometry provided a systematic exploration of the physical factors in the global distribution of heat and salinity of the world oceans. The analysis allows a quantitative assessment of the relative source strength of deep and intermediate waters, unobtainable using conventional water mass analysis. The experiments demonstrate the dominant role of the North Atlantic thermohaline circulation in the World Ocean circulation.

A 3–D coupled ice-ocean model was developed and applied to simulate deep convective regions near the ice edge including intense small-scale (5–20 km) features called chimneys that ventilate the deep ocean.

Using a regional orthogonal curvilinear model of the Gulf Stream, studies indicate that Gulf Stream separation is sensitive to the southeastward-slope current and small changes in the inflow salinity. As part of an international program, a similar model is being created for the Mediterranean Sea, and verification data are being collected.

A series of four studies describing the temporal variability of the thermohaline structure of the North Atlantic Ocean has been completed. Statistically significant changes on gyre and basin scales have been found which indicate that substantial redistribution of heat and salt took place between the 1955–59 and 1970–74 pentads.

Plans FY 90

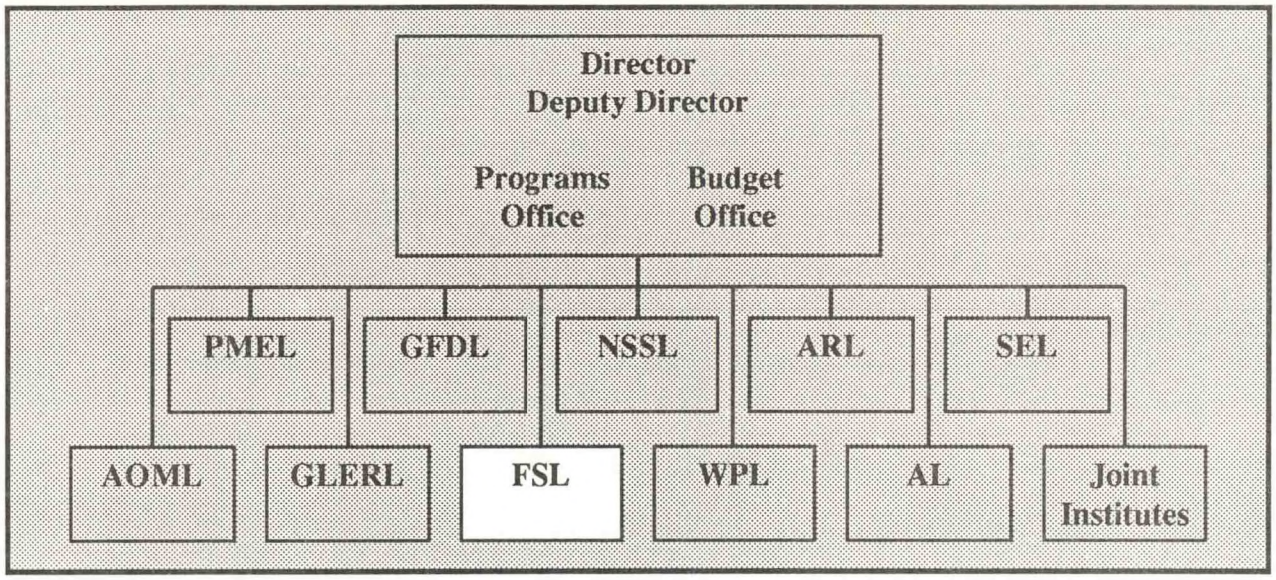
- The invasion of CFCs will be studied through a coupled ocean-atmosphere model as a test of the model's ability to simulate downward pathways in the ocean important for the greenhouse gas climate problem.

- Analyses of the various simulations of the El Niño will continue. Studies of the impact of the seasonal cycle on the Southern Oscillation will be initiated.

- The understanding of Gulf Stream dynamics and the enclosed basin of the Mediterranean will continue to be studied using the curvilinear model.

- The 3–D coupled ice-ocean model will be extended to the main Arctic basin and other seas to study basin circulations and water mass modifications.

- All available data sets will be used in the study of temporal variability of the thermohaline structure of the world oceans and to describe the climatological annual cycle.



FORECAST SYSTEMS LABORATORY

Boulder, Colorado
(303) 497–6818
Alexander E. MacDonald, Acting Director

The Forecast Systems Laboratory (FSL) is organized to transfer technological developments in atmospheric and oceanic research to the Nation's operational services. It conducts programs to integrate, evaluate, and apply developments to information and forecast systems. Its essential functions include the following:

- Exploratory System Development: Starting with requirements for the National Oceanic and Atmospheric Administration's (NOAA's) operational services, FSL develops and validates information systems which satisfy their needs.

- Research Applications: FSL utilizes research advances in understanding atmospheric and oceanic processes to develop improved data management systems, forecasting systems, and analysis systems for geophysical data.

- System Validation: FSL tests systems in realistic environments to assess their usefulness in improvement of NOAA's services.

- Technology Transfer: FSL facilitates the transfer of new techniques and systems to operational use, working directly with the users.

The FSL was created from the Environmental Sciences Group on 23 October 1988. It consists of three main programs: the Analysis and Prediction (A&P) Program (formerly the Weather Research Program), the Program for Regional Observing and Forecasting Services (PROFS), and the Profiler Program. The activities of the FSL programs are described below in terms of its major projects.

ARTIFICIAL INTELLIGENCE (AI)

The AI project seeks to inform the broader environmental science community about potential applications of this new technology in areas of interest to NOAA, and to apply that technology in selected areas.

Accomplishments FY 89

- An FSL scientist chaired the Third Workshop on Artificial Intelligence in the Environmental Sciences. The workshop provided a forum where AI practitioners in all of the environmental sciences were able to exchange views. A report on the workshop was published in a natural resources management journal and has been submitted to a meteorological journal.

- Conducted Shootout-89, an evaluation of AI systems that forecast severe convective storms. Traditional expert systems, an analogy-based system, and a system developed using methods from the cognitive science/judgement analysis tradition were tested.

- The Metalog program, a system to maintain and manage scientists' comments about data, was converted to the C computer language, was upgraded, and was ported to a second operating system. Metalog has now been used by the Wave Propagation Laboratory in three field experiments. Feedback from users indicates that Metalog provides a more useful and efficient vehicle for recording relevant experimental information than traditional hand-written notebooks. Metalog is also being used by the Profiler Program in FSL to maintain contemporaneous records of the behavior of prototype profilers. It is also being used by other research managers, and has also been distributed, at their request, to the Navy at the Stennis Space Center, Mississippi.

- The Forecaster's Intelligent Discussion Expert System (FIDES) prototype expert system for weather forecasting was completed and demonstrated at the 5th Conference on Interactive Information Processing Systems for Meteorology, Oceanography and Hydrology. FIDES uses the expert knowledge of a PROFS summer convective storms forecaster to provide strategic guidance and to train graduate students and novice weather forecasters.

Plans FY 90

- Complete analysis of data from Shootout-89, and submit an article on the results.

- Conduct Shootout-90 and prepare for Shootout-91.

- Complete the Metalog program and encourage its use by a wide variety of environmental scientists.

A&P

The A&P program conducts applied research to understand the genesis, structure, evolution, motion, dissipation, and predictability of synoptic-scale, mesoscale, and local-scale weather systems, and to improve forecasts of their attendant weather phenomena such as high winds, excessive rains or snowfalls, and flash floods. A&P places great emphasis on transferring research results and new knowledge to the National Weather Service (NWS) and the national user community.

Accomplishments FY 89

- A combination of conventional NWS data and soon-to-be operational data was used to investigate the mesoscale details of the precipitation-producing region of a winter-season cyclone. The identification of these and other relationships allows for the development of conceptual models that will be useful to the operational community as the Weather Service modernization proceeds into the 1990s.

- Performance of the Nested Grid Model (NGM), the NWS's operational forecast model since 1985, was investigated for two events characteristic of cold-season forecasting problems in the western United States. The systematic tendency for the NGM to overforecast cyclogenesis in the western United States, has resulted in NWS overpredictions of snowfall along the eastern slopes of the Rocky Mountains. The hypothesis that the tendency for overdeepening is related to the terrain and surface-roughness representations of the model was not confirmed in the 16 March 1987 case. Rather, the excessive deepening and anomalous motion of the forecast cyclone was a consequence of latent heating in the model.

- Rapid intensification of Pacific cyclones presents a problem for west coast forecasts, particularly when these systems are small scale. Aircraft observation of an explosively deepening cyclone on 29 November 1987 showed surface winds of 35 m s^{-1} and a central pressure near 960 mb. For successive runs, the NGM produced significant surface development, while the other National Meteorological Center (NMC) models consistently left the upper-level short wave open and nondevelopmental. Observations indicated that the greatest latent heat release occurred ahead and northeast of the low, not into the center of the low as was indicated in the NGM. Thus, the deepening obtained in the operational run, although resulting in a correct forecast, may not be based on physically correct mechanisms.

- The national-scale Mesoscale Analysis and Prediction System (MAPS) upper-air and surface systems were installed on the latest version of the PROFS meteorological workstation (DARE–II) in Boulder and at the NWS Forecast Office in Denver.

- The national-scale MAPS surface analysis system was implemented on a test basis at the NMC. This system includes data ingest and quality control, and produces analyses of nine variables every hour.

- Quality control techniques were developed to detect consistent biases in the wind reports from individual aircraft. Aircraft reports are the main asynoptic data source for the MAPS upper-air system. Feedback to aircarriers will allow for more rapid maintenance and more precise data from the systems.

- The Local Analysis and Prediction System (LAPS) ingests data from remote sensors, along with conventional and aircraft data, and generates operational products in real time, making LAPS the first real-time, quasi-operational meso-beta assimilation system in the United States. The predictive component of LAPS saw the establishment of a real-time two-dimensional capability to forecast downslope winds.

Plans FY 90

The role of mesoscale processes in precipitation events and the capability of new sensing systems to observe these processes will be studied.

- The utility of the frontogenetic/frontolytic formulation of quasi-geostrophic diagnostics will be investigated.

- The potential of a PC realization of the PROFS real-time workstation for research applications will be explored.

- Stable precipitation physics and a moist convective parameterization will be added to the MAPS isentropic model.

- A transition from isentropic to hybrid isentropic-sigma coordinates will be completed for the MAPS upper-air assimilation system. This will allow better resolution of the lower troposphere during conditions of weak static stability.

- The code for the MAPS upper-air assimilation cycle will be transferred to the NMC.

- With implementation of the DARE–II workstation, LAPS products will make their first appearance in workstation format.

- The Winter Icing and Storms Project, to be conducted during the cold season, will allow the testing and evaluation of LAPS products and analyses and numerical forecasts.

- LAPS products will be transmitted to the Department of Transportation's prototype traffic management system that will monitor air traffic and predict traffic flow problems.

PROFS

Accomplishments FY 89

DARE–II and Norman

- DARE–II supports NOAA–NWS modernization initiatives, including the Advanced Weather Interactive Processing System for the 1990s (AWIPS–90) and the Modernization and Restructuring Demonstration. The Denver AWIPS–90 Risk Reduction and Requirements Evaluation System II, an advanced hydrometeorological workstation, replaced DARE–I at the Weather Service Forecast Office (WSFO) in Denver. The DARE–II system provides enhanced functional capabilities for managing and displaying data as well as advanced scientific capabilities to support hydrologic and aviation forecast components.

- An advanced hydrometeorological workstation with supporting communications, local data ingest, and processing systems was developed for the NWS Forecast Office in Norman, OK. This workstation will interface with the first operational Next-Generation Weather Radar and with other systems as part of the NWS modernization effort.

Navy-NOAA Joint Ice Center

An ice forecasting and analysis workstation was developed for the Joint Ice Center (JIC) at Suitland, Maryland, in FY 88. In 1989, the capability for creating ice forecasts based on graphical information prepared on the display screens was completed.

PC Workstation Development

The goal of the PC workstation development is to provide a low-cost meteorological workstation for research meteorologists and forecasters to permit the study of significant weather events in both real-time and in retrospect. Many of the basic workstation functions have been implemented, including the user-interface, display manager, real-time data distribution and some of the data manager functions.

Plans FY 90

DARE–II and Norman

- The DARE–II System will fully replace DARE–I and Automation of Field Operations and Service as the operational system at WSFO Denver.

- Norman operational hardware will be delivered and system software integrated. The operational system will be tested.

- The capability to acquire meteorological products from the National Environmental Satellite, Data, and Information Service and NMC via the Information Stream Project for AWIPS and NOAAPORT communications link will be developed for both Denver and Norman.

Navy-NOAA Joint Ice Center

The JIC workstation will receive improved high-resolution map backgrounds, additional local data sets and new workstation applications.

PC Workstation Development

- A data review capability and the ability to execute on-demand meteorological applications will be developed on the PC workstation in response to the needs of the Center for Operational Meteorology, Education and Training.

- The possibility of making the PC workstation compatible with the National Center for Atmospheric Research Unidata system, specifically in the area of data management via the use of a common data format (NetCDF), will be investigated.

PROFILER PROGRAM

The Profiler Program Office was established to direct the procurement, installation, and assessment of a 30-site Central United States Wind Profiler Demonstration Network. The goal is to demonstrate that such a network can (1) support both routine operations of the NWS and major scientific and meteorological field experiments, and (2) foster advances in atmospheric research.

Accomplishments FY 89

- The Environmental Research Laboratories prototype profiler, with a supporting microhub and display equipment, was relocated to Vandenberg Air Force Base.

- The Profiler Program Office accepted both UNISYS prototypes and authorized UNISYS to begin producing the remaining 30 units, thus completing the contract option.

- Twenty sites were fully prepared for profiler installation; four more are being readied.

- Nine surface observing systems were procured and will be added as supporting meteorological equipment at selected profiler sites.

- The Profiler Program Office issued a request for proposals to industry for an integrated voice and data input communications system for communications between the Hub and each of the 30 profiler sites. Proposals were received, evaluated, and best offers furnished by proposers.

- The Profiler Hub became operational, with all hardware and software installed in a base operation configuration. Two independent communications links were established to allow data distribution from the Hub to the NWS Gateway. These links were tested and validated, thus allowing redundant data transfers.

- Four training sessions were conducted for WSFO "focal point" forecasters who will take the lead in teaching others in the WSFOs how to use profiler data in preparing forecasts.

- An in-plant training session was conducted by UNISYS at their Bloomfield, CT, facility for NWS and ERL supervisory personnel, who were taught the theory and procedures to be used in maintaining the network profilers.

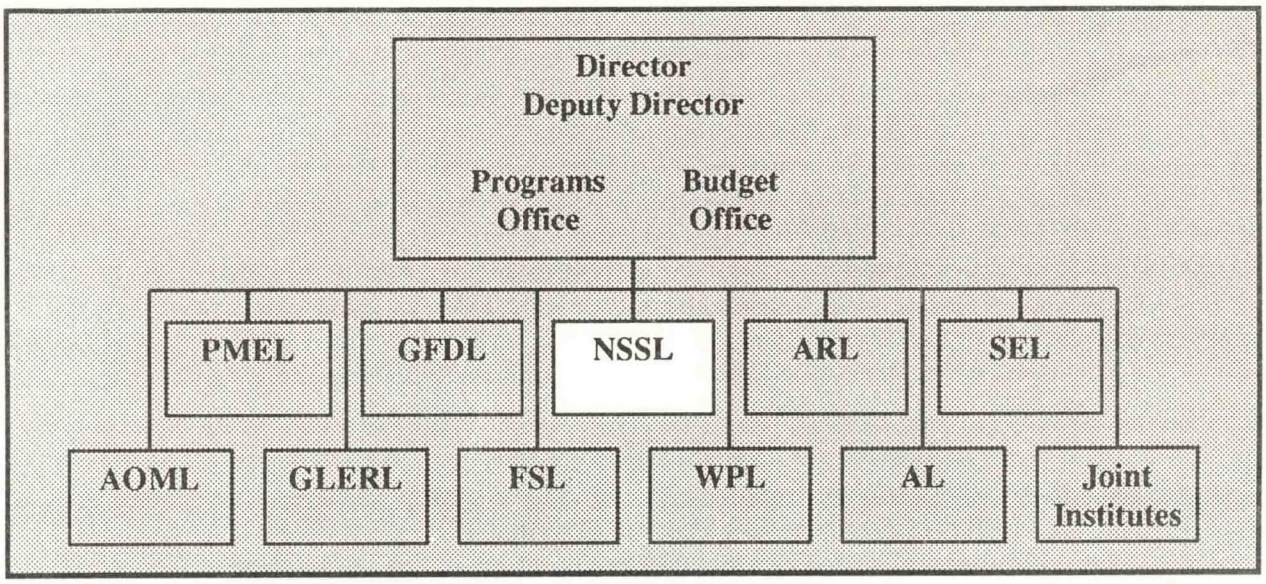
Plans FY 90

- Install the first production profiler at McCook, NE, in early 1990, with subsequent installations at the rate of two or three per month.

- Award input communications system contract and install system.

- Add enhanced monitoring and assessment reporting capabilities to the Hub.

- Implement a data archive for retrospective access to profiler data.



NATIONAL SEVERE STORMS LABORATORY

Norman, Oklahoma
(405) 366–0427
Robert Maddox, Director

The National Severe Storms Laboratory (NSSL) develops improved means for weather forecasting through studies of large and mesoscale weather processes, numerical and conceptual modeling of storm phenomena, and applications of new technologies in remote sensing. Technological developments, scientific discoveries, and new requirements are reflected in changing approaches to achieving the goals of accurate, timely forecasts and warnings. Recent studies have drawn heavily on observations from both airborne and ground-based Doppler radar, field observations gathered with an instrumented mobile laboratory, and lightning-mapping systems.

During the past two decades NSSL has examined individual storm cases to garner knowledge of physical processes in convective storms. Our research efforts are now beginning to address the important problem of improving forecasts of mesoscale weather phenomena and precipitation in a time frame of 3–36 h. In coming years, increasing emphasis will be given to expanding research to include larger scales of meteorological phenomena, to use modern research workstations, to incorporate wind profiler and digital satellite data into case study analyses, and to blend and use data from diverse observing systems in mesoscale numerical prediction models.

Through numerous relationships with other government agencies and universities, NSSL participates directly in many field research projects; for example, during FY 89 NSSL staff, in collaboration with the Federal Aviation Administration (FAA) and the National Center for Atmospheric Research (NCAR) participated in terminal radar development activities at Kansas City, MO. Laboratory staff were also involved in hailstorm studies in North Dakota and extensive evaluations of both the first Next-Generation Weather Radar (NEXRAD) and ways to utilize NEXRAD data in conjunction with ground-based and airborne research Doppler radar. Special upper-air soundings were gathered, in coordination with the Wave Propagation Laboratory (WPL) and the Forecast Systems Laboratory, at Craig, CO, during January 1989 to study Boulder windstorms and in Arizona during September to prepare for studies of the role of organized convective storms within the southwestern United States monsoon flow. The laboratory intends to maintain a high level of involvement in field observing efforts during the next several years.

MESOSCALE RESEARCH DIVISION

Accomplishments FY 89

Mesoscale Convective Systems Research

Research projects within the NSSL Mesoscale Research Division (MRD) continued to focus primarily on the analysis and interpretation of observational data of mesoscale convective systems (MCSs), thunderstorms, and related phenomena. Principal accomplishments in FY 89 were the following:

- Completed the documentation of the precipitation and kinematic structure of a non-squall line MCS. The MCS occurred on 4 June 1985 near the Preliminary Regional Experiment for STORM [Stormscale Operational and Research Meteorology] (PRE–STORM) Kansas dual-Doppler radars. Air-motion analyses reveal different vertical motion profiles in the convective bands of the MCS, and retrieved patterns of perturbation pressure, and buoyancy from the Doppler wind fields reveal that the momentum flux by the convection was much more three-dimensional (3–D), and down-gradient, than for squall lines.

- Completed study focusing on the environment associated with cyclonic vortices that resulted from MCSs. The locations and tracks of 24 mesoscale convectively-generated vortices (MCVs) over the central United States from 1981 to 1988 was determined from satellite imagery, and environmental data were composited relative to the center of each vortex. Results of the composite analyses indicate that the typical MCV synoptic setting is very weak flow—the predominant feature at 500 mb was a longwave ridge with weak winds and wind shear, with both the winds and shear decreasing with time as the MCV develops. These results suggest that both the scale and duration of latent heating and the character of the background synoptic setting are critical factors controlling the development of MCVs.

- Completed momentum flux study using data collected during the Cooperative Convective Precipitation Experiment (CCOPE) squall line of 17 July 1981. The study examined how horizontal momentum was transported in the convective region, how the momentum is generated by the pressure forces, and how the environment of the squall line is affected by the generation and redistribution of momentum.

- Completed a study of convective vertical motions obtained by direct penetration of convective cells by the P–3 aircraft during the 1988 Taiwan Area Mesoscale Experiment project. Vertical motions were weak compared to mid-latitude convective storms. Water loading of the updraft played a substantial role in reducing buoyancy.

Climatology of Southwest Monsoon Mesoscale Convective Systems

A preliminary study of the characteristics of Mexican MCSs has been completed. Examination of Geostationary Operational Environmental Satellite imagery during the warm season revealed several MCSs similar in satellite characteristics to central United States MCSs. Documentation over northern Mexico

suggests a strong role of orographic circulation upon the initial development of thunderstorms. A shift in the thunderstorm activity and MCSs from the eastern states during the spring months to the western states during mid-to-late summer coincides with the mid-tropospheric subtropical ridge intensifying northward and westward across the Gulf of Mexico. Comparisons with classical climatological depictions of thunderstorm frequency in Mexico indicate that past studies substantially underestimate (by as much as 500%) the actual frequency and distribution of convective activity over Mexico.

Cooperative Oklahoma P–3 Studies (COPS–89)

NSSL successfully conducted the COPS–89 field project during May–June 1989. A total of 18 flight hours were used in obtaining data on 5 days. Data were also obtained by the Cimarron Doppler radar, the Mobile Cross-chain LORAN [Long-Range Aid to Navigation] Atmospheric Sounding System (MCLASS) radiosondes launched by NSSL1 mobile lab, and NSSL's lightning ground-strike-detection system. Project goals are:

- Test and evaluate new equipment and techniques for studying MCSs.
- Gather coordinated data sets between the P–3, Cimarron Doppler radar, and electric-field meters to study MCS electrification mechanisms.
- Gather coordinated data to study dryline structure.

Thunderstorm Studies at the Kennedy Space Center

Several studies were completed to understand the relationships between radar echoes, surface convergence, and lightning, using data collected at the Kennedy Space Center. A compositing technique was developed to depict the relationship between the location of cloud-to-ground (CG) lightning flashes, surface winds, and radar echo relative to the location of maximum radar reflectivity. Results show that the zone of largest CG activity is on the upshear side of the storm in the highest reflectivity gradient.

Microburst Handbook

A full-color publication on the visual identification of microbursts was published. Photos and accompanying text describe the theoretical and observational evidence for a thunderstorm-induced vortex circulation that impinges on the ground. This Handbook has been selected by the United Nation's World Meteorological Organization for worldwide distribution in several languages.

Plans FY 90

MRD will continue to emphasize diagnostic studies of mesoscale convective weather systems during the coming year. Specific efforts include:

- Implement a site-error determination algorithm to extensive cloud-to-ground strike data collected in Colorado, Florida, and Oklahoma-Kansas during the past several years.

- Investigate the 3–4 June PRE–STORM MCS with emphasis on the dynamics of air motions and momentum flux profiles to squall lines.

- Complete the diagnostic study of the vortex circulation structure observed by the WPL Colorado Profilers on 9 June 1988.

- Analyze satellite imagery of MCSs over Mexico and convection in the southwest United States to begin to define the role that these systems play in the regional climate. A small, exploratory field program using the P–3 will investigate the kinematic and precipitation structure of Mexican MCSs and the monsoon circulation during 15 July to 15 August 1990 (Southwest Area Monsoon Project).

- Analyze the relationship between cloud-to-ground lightning, radar echoes, and surface convergence at the Kennedy Space Center. Focus will be on storm structure, as determined by volume scan information, surface convergence (updrafts), and lightning.

- Distribute the microburst handbook and develop a poster version.

- Analyze and document COPS-89, 3–4 and 7 June cases, to formulate hypotheses of the roles of mesoscale updraft/downdraft and wind shear in the separation of ambient electric charge.

- Analyze the kinematic structure and balance of forces for the COPS cases to investigate why the predominate vertical motion was organized on a large mesoscale area rather than on the convective scale. Microphysical and dynamical interactions will be examined to assess the role that melting/evaporation played in the evolution of the perturbation pressure fields.

METEOROLOGICAL RESEARCH GROUP

Accomplishments FY 89

During the past year, major efforts of the Meteorological Research Group have focussed upon follow-on data processing, archival, and dissemination of Gulf of Mexico data; and small mesoscale and non-hydrostatic scale 4–D data assimilation.

Mesoscale Convective System Studies

A 3–D, time-dependent mesoscale kinematic model, which accepts time-dependent input airflow analyses and lateral boundary conditions on heat and water substance, was developed to generate proxy data on the

mesoscale environment for input to a diagnostic dynamic model. A mesoscale objective analysis routine, which can accept both radiosonde and wind profiler data, was developed to provide input airflow analyses for the kinematic model as well as diagnoses of hydrostatic pressure, temperature, and water vapor contact.

Low-Level Jet Studies

A brief field project was conducted during July 1988 to assess the potential for the NEXRAD, 403 MHz radar wind profilers, and digital sounding systems to monitor the low-level wind, temperature, and humidity fields during clear-air conditions. The height of the maximum wind speed of the low-level jet on all days studied was below the lowest range gate of the National Oceanic and Atmospheric Administration (NOAA) 403 MHz radar wind profiler, indicating that a combination of NEXRAD and profiler data might be needed to sample the important wind field structure of the lower atmosphere.

Retrieval of Dynamic Variables in Thunderstorms From Radar Data

The dynamic retrieval method was applied to an isolated severe hailstorm that occurred in Montana during the CCOPE project. The relationship of the pressure decrease across the updraft to the environmental shear verified results of previous studies. This contrasted with the pressure field in a tornadic storm case where the shear vector rotated with height producing large vertical gradients and consequent effects on the production of new updrafts and storm motion.

Activities Related to the Center for Analysis and Prediction of Storms (CAPS)

In December 1988, it was announced that the Oklahoma Science and Technology Center was one of eleven of 325 proposals in the nation to be funded. The Center is initially funded for five years with an extension to a total of eleven years possible. Research will focus on (1) development of a state-of-the-art numerical prediction model capable of ingesting data from the new observing systems to be deployed in the central United States during the next decade, (2) evaluation of the accuracy and sensitivity of model predictions to the quality and quantity of initial and boundary conditions and to other factors, and (3) design of assimilation techniques to produce optimal initialization of numerical simulations. Several NSSL scientists are collaborating with CAPS investigators to plan research projects and contribute to formal proposals.

Storm Electrification Research

The formulation and testing of a 3–D, time-dependent kinematic storm electrification model to improve understanding of electrification processes in thunderstorms, was completed. The model assisted in identifying the non-inductive graupel-ice charging mechanism as primarily responsible for the initial electrification of a mountain thunderstorm.

Severe Storm Case Studies

Preliminary results of the 10 May 1985 tornado outbreak in northern Kansas rule out gravity waves and symmetric instability as possible causes of the observed 160-km length, 2 1/2-h period waves that occurred along the dryline during this PRE–STORM case. A study of splitting convective clouds during PRE–STORM on 28 May 1985 was completed. The observation of towers splitting rapidly even when there is little precipitation accumulation in their updrafts implies that the splitting was probably caused by dynamic forcing and not by effects of rainwater loading.

Effects of Landscape Variability on Convective Clouds

Visible and infrared satellite images and detailed landscape information were examined during periods of cloud formation over relatively flat terrain when forcing from the atmosphere was weak. A case was documented in which clouds were observed to form first over a mesoscale area (100x300 km) of harvested wheat in Oklahoma where the ground temperature was warmer than over adjoining areas dominated by growing vegetation. In addition, clouds were suppressed over relatively long bands downwind of small man-made lakes and areas characterized by heavy tree cover. The observed variability of cloud relative to landscape type was compared with that simulated with a 1–D boundary layer model (in collaboration with the National Aeronautics and Space Administration Goddard Space Flight Center. The model confirmed that clouds form earliest over regions characterized by high sensible heat flux, and are suppressed over regions characterized by high latent heat flux during relatively dry atmospheric conditions. This observation has significance to understanding the feedback mechanisms of land modification on climate, as well as to relatively short-range weather forecasting.

Plans FY 90

- Assessments of the quality and utility of satellite-derived moisture and winds will be conducted with the National Environmental Satellite, Data, and Information Service (NESDIS) branch in Madison, WI. This includes impact studies with numerical models and comparisons with other data sources.

- Numerical experiments will begin with CAPS to determine the quality and quantity of observed data needed to initiate a realistic thunderstorm simulation.

- The reliability and impact of several convective parameterization schemes will be evaluated on the 7 May 1985 PRE–STORM case by directly inserting output of a 1–D thunderstorm model into a kinematic mesoscale model at known deep convection locations, and verifying model predictions with supplemental radiosonde observations.

- Computing support from NCAR will be obtained to use the Colorado State University (CSU) Regional and Mesoscale Meteorology Branch mesoscale model to produce 2– and 3–D simulations of the COPS 24 May 1989 dryline.

- A statistical study of surface moisture return from the Gulf of Mexico will be completed.

- Upstream propagation of MCSs will be examined using observations and model simulations from the Penn State-NCAR mesoscale model with explicit microphysics.

- CAPS support will be obtained to adapt the Klemp-Wilhelmson dynamic model to perform data assimilation experiments on the University of Illinois CRAY–2.

- An NSSL warm cloud microphysics module will be inserted into a dynamic cloud model developed at Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), and comparative numerical experiments with an existing detailed microphysics module and identical cloud dynamics will be performed.

- Efforts will continue to retrieve dynamic variables and analyze the structure and evolution of the 3–4 June 1985 PRE–STORM MCS.

- The role of cloud cover on the earth-atmosphere radiation budget will be investigated jointly with CIMMS and NESDIS. Work is planned to determine the effect of cloud frequency, tropopause height, season, landscape, geographic location, and other related factors on the net radiation budget.

- The relation of observed lightning activity and electrification processes in the tornadic Binger, OK, storm will be studied.

- Research will begin to apply adjoint data assimilation techniques to numerical cloud-scale models.

- Theoretical work on the generalized Q vector will be completed.

STORM ELECTRICITY AND CLOUD PHYSICS GROUP

Accomplishments FY 89

Electrification of Mesoscale Convective Systems

We developed a new generation of balloon-borne electric field meter to accompany a LORAN sonde. Flights were made into MCSs as part of COPS–89. We found that in the transitions zone of an MCS the electric field was generally dominated by the vertical component, suggesting large horizontal stratification of charge. Fields were high, with a maximum of over 110 kV m^{-1}. Five different charge layers were found, and our measurements in one case support the CSU model of stratiform charging.

Use of Climatological Lightning Data in Forecasting

Results of collaborative research with the Technical Data Laboratory of the National Weather Service (NWS) provided a good correspondence between lightning frequency, radar echo intensity, low-level moisture flux, and circulation. Contrary to the literature, freezing-level height and wind shear were not as important as the boundary layer fields in determining thunderstorm formation and subsequent positive ground flash activity. A significant correlation was also found between the occurrence of severe local storms and elevated rates of 30 or more positive flashes to ground per hour.

Electric Field and Storm Structure of Great Plains Thunderstorms

Preliminary results from studies of vertical profiles of electric fields through several storms over the Great Plains show both polarities of electric field in excess of 100 kV m^{-1}. We compared our results with work done in the 1930's, which is still accepted as the "classical" picture. We found that contrary to the classical picture, some storms have more than three charge layers.

National Ground Strike Lightning Detection Network

We continued to be involved with the Office of Federal Coordinator for Meteorology on plans to provide data from CG lightning strike locating networks to operational components of NOAA. We also completed the evaluation of NSSL's network for detection of +CG strikes. A comparison of the results for positive flashes and negative flashes suggests (1) that false detection is negligible in our system for +CG flashes with range-normalized amplitudes of at least 50 Lightning Location and Protection units and (2) that no more than 15% of the +CG flashes with smaller amplitudes are false detections. This evaluation forms the basis for using the data in research and is incorporated into our recommendations for the National Plan for Use of Lightning Data.

Lightning Physics and Applications to Climate Studies

We used a physical model of lightning strikes to aircraft to interpret the initiation of intracloud flashes depicted with the French UHF–VHF interferometric system. We found intracloud discharges are initiated as a simultaneous bi-directional development of the negative stepped leader and the positive leader-continuous current process. The observations during the junction stage of intracloud flashes revealed continuous current flow and a "multistroke" feature typified by current pulses superimposed within periods of rising continuous current. These new findings are applicable to the analysis of the production of NO_x and other trace atmospheric chemicals and their role in the global climate.

Plans FY 90

- Investigate lightning generation mechanisms in MSCs using data from a NOAA P–3, instrumented balloons, ground-based radars, mobile laboratory, and NSSL's lightning-ground-strike

network. From analysis of COPS–89 data, we will formulate hypotheses to explain charge generation and separation in MCSs for testing with models and in future field programs.

- Analyze the lightning and satellite data of MCSs to determine the relationships between lightning and MCS evolution and precipitation.

- Develop a model to describe electrification of anvils to test conflicting hypotheses in the scientific literature.

- Collaborate with NCAR to continue improving LORAN sondes and MCLASS for making thermodynamic and wind measurements inside storms and stratiform precipitation.

- Continue instrument development and make preliminary measurements of the electric field and charge and size of precipitation particles in storms and stratiform rain to determine the electrical charge structure of convective storm regions and provide information for thunderstorm models.

- Work with OFCM to implement the National Plan for Use of Lightning Data and use of lightning data in operations.

DOPPLER RADAR AND REMOTE-SENSING RESEARCH GROUP

Accomplishments FY 89

Polarization Studies

We quantified power loss in the main channel of a circularly polarized radar (wavelength 10 cm) due to depolarization by rain along propagation paths. Heavy precipitation (>50 mm h^{-1}) causes loss of over 3 dB along a 30-km path length and increases to more than 10 dB if the path length is 50 km. These findings, backed by differential phase measurements with the NSSL radar, impact NEXRAD design.

Weather Hazards to Aviation

During 1989, the NSSL continued its long-term cooperation with the FAA in the development of computing techniques to detect wind shear phenomena using Doppler radar and continued studies on meteorological phenomena that are hazardous to aircraft. Specifically, NSSL personnel worked on the following projects:

- Enhanced gust front detection/wind shift prediction algorithm.

- Refined velocity dealiasing scheme. This algorithm was chosen for use with the Terminal Doppler Weather Radar (TDWR) and NEXRAD.

Initiation of Updraft Rotation

We developed an alternative conceptual model for the initiation of updraft rotation based on a study of a developing supercell thunderstorm that passed over Agawam, OK, on 6 June 1979.

Solitary Waves

We adapted the theory for weakly nonlinear waves in an incompressible static fluid to a compressible sheared atmospheric flow to understand the interrelationships between wind changes generated by solitary waves and its ambient environment.

Plans FY 90

- Collaborate with CAPS to incorporate single Doppler radar data into model assimilation techniques.
- Begin multiple Doppler radar (surface and P–3 aircraft) case study of a tornadic thunderstorm that occurred in central North Dakota on 28 June 1989 during the North Dakota Thunderstorm Project.
- Investigate convection initiation of two PRE–STORM severe hailstorms on 26 May 1985.
- The distribution of mesoscale low pressure, moist downdrafts, and environmental winds will be examined to determine their roles in driving thunderstorm rear inflow.
- Add thin-line and azimuthal shear detection to the NEXRAD gust front algorithm.
- Add time continuity to the NEXRAD tornado vortex signature (TVS) algorithm and test with TVSs in the NSSL data base.
- Analyze data collected in the stratiform region of mesoscale convective complexes (MCCs). Compare polarimetric measurements with two dimensional particle probes. Other in-situ measurements and rawinsonde data will be used to help relate polarimetric observations to the microphysical evolution of aggregates.

SCIENTIFIC SUPPORT DIVISION (SSD)

The SSD continued to upgrade facilities to support NSSL Scientific goals. Three major areas were upgraded: The computer facility, the Cimarron Doppler radar, and a new Mobile Laboratory (NSSL2). Specific accomplishments are as follows:

Accomplishments FY 89

Facilities

Computing

A VAX 6310, MicroVAX III with a 4660 Ramtek display, and a Concurrent 3280 replaced the PE–3242 at Norman. Many PCs were added at both the Norman and Boulder facilities, plus a Ramtek 4660 at the Boulder facility. A SUN workstation was added to the FAA program. A 9600 baud link was installed between the Norman and Boulder Facilities to allow the Boulder group to use the Norman computing facilities and vice versa. A T1 link was installed between the University of Oklahoma and Norman Facility allowing NSSL to tie into the University Network. Most PCs are now networked along with several laser printers and with the addition of a terminal server to the network, modems and the MICOM switch can now be accessed from the network.

Cimarron radar

New programmable signal processors and host computer systems were obtained to support the Cimarron radar. A microwave link between Cimarron and Norman and a backup power generator for Cimarron are being installed.

Mobile laboratories

In January, NSSL1 traveled to Craig, CO, to participate in Downslope wind studies in Colorado, then traveled to Kansas to launch CLASS soundings to support a Winter storm study. NSSL1, NSSL2, and NSSL3 supported spring and summer NEXRAD Initial Operational Test and Evaluation - Part II, and NSSL1 worked in COPS–89. In July and August, NSSL1 traveled to Kansas City to participate in FAA TDWR testing. September found NSSL1 in Arizona for a feasibility study of using MCLASS to support proposed programs in Arizona.

A new on-board computer (COMPAQ–386) was installed on NSSL1 and a UNIX operating system is used to support the Electric Field Meter, Optical and Charge device, Packet radio, and meteorological surface measurements. All the surface measurement instrumentation were evaluated, and the wind speed and direction sensor was replaced with an RM Young instrument, and the Humidity sensor was changed to a Rotronic.

Plans FY 90

- NSSL plans to add a third mobile laboratory. A distrometer will be added to NSSL2.

- Boulder computing facilities will be expanded with an additional VAX computer and a 6250 Tape drive and disk subsystem. The PC network will be expanded and a new high-resolution color camera will be added to the graphics computer. An uninterruptible power supply will be added to the Norman computer facility.

- The Cimarron radar will be upgraded with full remote operation capabilities. The Norman processor will be interfaced for algorithm processing and real-time evaluations.

FORECAST APPLICATIONS RESEARCH GROUP

Accomplishments FY 89

NEXRAD

NEXRAD operational testing and evaluation, March–September 1989, was supported by forecasting data collection periods, conducting storm intercept and damage surveys on 43 days, algorithm evaluation, and operation of a system loader. Input was provided to the final report on the NEXRAD test, prepared by the Air Force Operational Test and Evaluation Center.

An improved form of vertical reflectivity integration and radial divergence of single-Doppler velocities was developed to identify hail. It appears that not only can hail be identified, but also hail size can be estimated. Mesocyclone detection and input to warning forecasters has been improved by construction of a similarity index which compares radar velocities to a theoretical mesocyclone model. Tropical cyclone structure was studied and, with the Atlantic Oceanographic and Meteorological Laboratory, a 3–D simulation was developed. NEXRAD-like radar data were derived from the simulation to interpret land-based Doppler measurements of wind fields.

Training

Three remote training modules on thunderstorm characteristics and severe storm structure were prepared for NWS Headquarters. Preparation of text and case examples for two additional modules on Doppler radar principles and characteristics was begun.

An NWS NEXRAD Training Unit was established in Norman (in a building adjacent to NSSL). The Laboratory is the scientific advisor to the Training Unit.

Seminars and workshops on mesoscale and radar meteorology were presented at several NWS Offices and at other locations. A chapter on radar detection of severe thunderstorms was prepared for a book on the use of radar in meteorology.

A color guide was printed and distributed by the NEXRAD Joint Systems Program Office. It provides the only training material currently available for teaching NEXRAD users how to interpret the patterns, or signatures, on a Doppler velocity display.

Experimental Forecasting

In cooperation with the Norman NWS Forecast Office, forecasts of mesocyclone and tornado formation and MCS development were made. Some of this information was released to the public daily during the spring months. Skill scores for 1989 and two previous years indicated that the forecasts were completely successful

about half of the time. Improved mesoscale sensors (NEXRAD network, wind profilers, etc.) will be necessary for substantial forecast improvement.

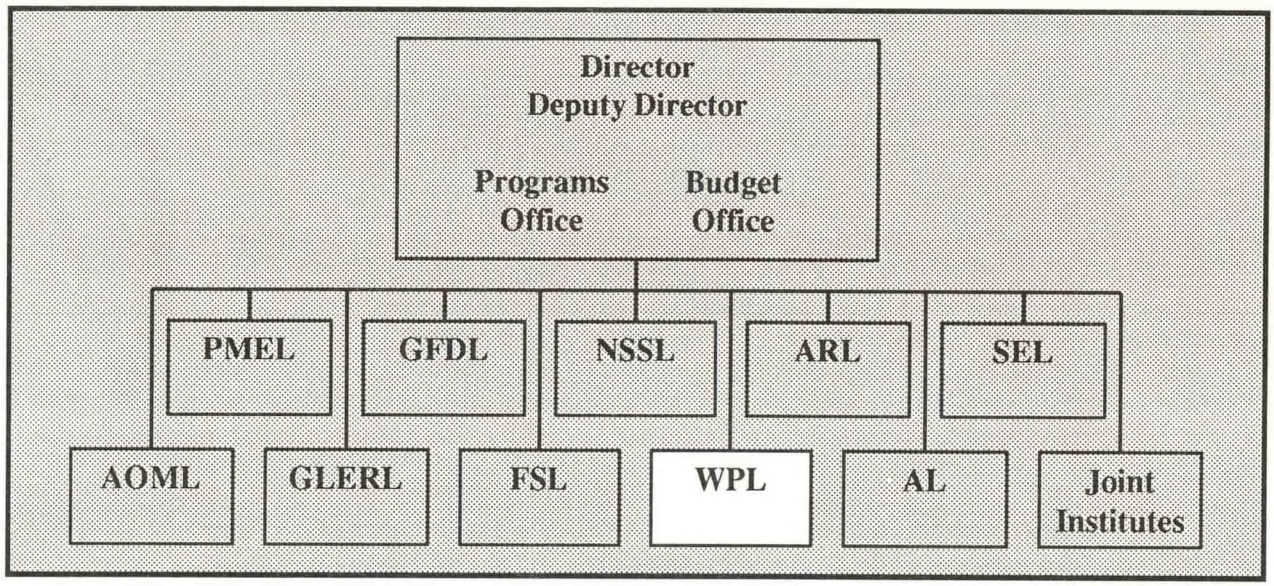
Plans FY 90

- Under the direction of the Norman-based Operational Support Facility, there will be participation in follow-on testing of NEXRAD. Improved algorithms for mesocyclone and hail detection will be tested. Airborne dual Doppler observations of recent hurricanes and simulations will be used to begin development of a tropical cyclone detection and tracking algorithm. Improvements in locating individual tornadoes and better tracking of storms in squall lines will be explored.

- Remote training modules on Doppler radar will be prepared. Support to the NWS Training Unit and UNISYS will continue, including lectures to training classes.

- Cooperation in mesoscale forecast exercises with the Norman NWS Forecast Office will continue as deployment of new mesoscale sensors begins in Oklahoma. Forecasts of mesocyclones, tornadoes, and MCSs will be studied to help improve techniques.

- A tornado proximity sounding set from NSSL archives will be established so that the relationship between storm-relative helicity and tornado intensity can be tested statistically. The tornado forecast method, if proved useful, will be implemented at the NWS office.



WAVE PROPAGATION LABORATORY
Boulder, Colorado
(303) 497–6291
Steven F. Clifford, Director

The Wave Propagation Laboratory's (WPL's) mission is to improve the Nation's geophysical research and services through the development, demonstration, and transfer of cost-effective remote measurement systems. To achieve this goal, WPL successfully performs the following functions:

- Conducts detailed theoretical and experimental studies of the interactions of acoustic and electromagnetic waves with the atmosphere or ocean with particular reference to the use of such interactions for remote-sensing purposes.

- Develops and experimentally evaluates new geophysical remote-sensing concepts and systems.

- Applies the unique advantages of newly developed remote-sensing techniques to atmospheric and oceanic research.

- Improves the Nation's atmospheric and oceanic research, and forecasting and warning services, through transfer of remote-sensing technology.

WEATHER RESEARCH

WPL's contributions to weather research support the National Oceanic and Atmospheric Administration's (NOAA's) largest and most important single service; namely, weather forecasts and warnings. This service

is required on many space and time scales. WPL's remote-sensing program includes contributions on all scales from the micrometeorological to the global.

MICROMETEOROLOGY

Research on micrometeorological processes in the atmospheric boundary layer is important because these processes, which include the turbulent fluxes of heat, moisture, and momentum, change the dynamic and thermodynamic properties of air masses. Remote sensors contribute uniquely to the research by providing the temporal and spatial resolution and continuity that are required to observe, monitor, understand, and predict these important boundary layer processes.

Accomplishments FY 89

Sensor Development

- Developed a theory of dual-spatial-filter measurement techniques which should allow optical measurements of wind velocity as a function of height.

- Determined the flow distortion characteristics of the new Wave Propagation Laboratory-Atmospheric Technology Inc. sonic anemometer.

- Applied the adaptive Kalman filter technique to the problem of optimal control of operating wavelength for differential absorption lidar using only a single laser.

- Evaluated several lidar methods for profiling humidity. Progress in coherent lidar technology with carbon dioxide (CO_2) and Ho:YAG lasers make these newer possibilities attractive for further research into micrometeorological processes.

Research

- Determined the dropsize distribution that provides the best correlation between rain rate and attenuation at millimeter wavelengths. This is an important step toward remote sensing of rain rate over an area larger than would be feasible for direct measurement.

- Successfully used circular depolarization ratio techniques in the North Dakota Thunderstorm Project to track parcels of air "tagged" with chaff. The project showed the technique can be employed to study transport and diffusion of natural and manmade pollutants and particulate matter.

- Completed a study of long-term radar-measured structure constant for refractive index (C_n^2) from data obtained by the Colorado Wind Profiler Network from 1984–1988. Annual variations were observed, and a long-term trend (increase) in C_n^2 was found that is presently unexplained.

Plans FY 90

- Apply three-channel microwave radiometer measurements of cloud liquid to the sensitivity of cloud radiative properties and cloud spatial structure.

- Identify mechanism(s) for integrating retrieved temperature, moisture, and wind information into numerical weather prediction models.

- Document the design changes needed for the current 3.2 cm wavelength Doppler radar to allow it to be used to implement the Combined Oceanic and Atmospheric Sensing Technique for measuring marine boundary layer winds and ocean surface currents.

- Using the data from the Santa Barbara Eddy Investigation, document the three-dimensional (3–D) structure of the eddy and its evolution through the diurnal cycle. Compare structure determined from empirical data with mixed layer model simulations of the eddy.

- Demonstrate Radio Acoustic Sounding System (RASS) temperature measurements with corrections for vertical wind.

MESO-BETA AND -GAMMA SCALES

A single ground-based scanning radar or lidar system can remotely monitor atmospheric processes on the meso-gamma (2–20 km) and perhaps the meso-beta (20–200 km) scales. Such measurements are required for an extraordinarily wide range of atmospheric research problems, as well as for short-term local weather nowcasts and forecasts.

Accomplishments FY 89

Sensor Development

- Performed a systematic comparison of RASS temperature measurements with radiosondes. Even without correction of the RASS measurements for vertical wind, an rms difference of only about 1°C existed.

- Improved radar (X-band and K-band) RF signal processing of the small backscatter signals from cirrus clouds.

- Developed a model and performed simulations to explain the RASS technique when applied to wind profiler radars.

Research

- RASS data were obtained in rain, frontal passages, icing conditions, and pollution events. Results to date indicate that RASS will become an important addition to the UHF NOAA Wind Profiler Network.

- Obtained high-quality temperature soundings by combining data from the RASS with data from TIROS–N Operational Vertical Sounder soundings from NOAA polar orbiting satellites. This is a significant step toward an integrated automatic atmospheric sounding system.

- Improved understanding of tornadogenesis through the analysis of the 2 July 1987 tornado near Denver, Colorado. The analysis indicated strong vortex formation near the surface (ground) which rapidly grew to more than 4 km above cloud base.

Plans FY 90

- Demonstrate RASS with a NOAA Network Wind Profiler.

- Determine an acoustic source that will minimize the environmental hazard and noise pollution of the RASS profiler.

- Complete the definition of the relationships between cloud liquid content and cloud reflectivity observed by satellites and the resultant effect upon parameterizations used in general circulation climate models.

- Assess by simulation and experiment the impact of combined ground- and satellite-based remote-sensor information on the quality of retrieved upper-air temperature and moisture profiles. Incorporate the results into design of multiple remote sensors for Telesonde system.

- Begin development, if funding is available, of High-Resolution Interferometer Spectrometer (HIS) for remote ground-based measurement of atmospheric temperature and humidity profiles and trace constituents.

- Perform radiative transfer calculations to determine optimum spectral coverage and resolution and to improve retrieval techniques for HIS.

- Determine impact of HIS information on combined data from other sensors used by Telesonde.

- Plan for and initiate, if funded, the design of a ground-based HIS and begin to specify the hardware.

SYNOPTIC AND MESO-ALPHA SCALES

Arrays of individual ground-based remote sensors can be used to study atmospheric processes up to continental scale. A suitable array of WPL-developed profilers could continuously provide 3–D fields of wind, temperature, and humidity on the meso-alpha (200–2,000 km) and synoptic (2,000–10,000 km) scales. Such data would have major value for numerical weather prediction (NWP) since they could be (1) time-averaged to remove aliasing of high-frequency components, (2) entered more frequently into the NWP algorithms, and (3) inserted in the form of time derivatives as well as time averages. In addition, the wind field data (which are critical to mesoscale NWP) should be considerably more accurate and representative than those from radiosondes.

Accomplishments FY 89

Sensor Development

- Constructed and tested microwave radiometers at 23.87, 31.65, 53.85 and 56.02 GHz as a part of a transportable sounding system.

- Demonstrated that a newly designed K-band offset Cassegrain antenna will function under high power electric fields.

Research

- Verified interactions between baroclinic and diabatic processes during storm intensification from analysis and numerical simulation of the *Queen Elizabeth II* Atlantic Ocean storm development. These processes will aid in differentiating between "normal" ocean storms and explosive ones.

- Analyzed an eastern Pacific cold front and its associated stratospheric-to-tropospheric ozone injection. It showed a horizontal-scale collapse of the front to less than 2 km with a greater than 5 m s^{-1} ascending plume at the leading edge of the front. The ozone transport was an unexpected finding with implications to stratospheric ozone depletion. The narrow ascending plume helps explain the forces which contribute to the development of explosive ocean storms.

- Used a Newtonian nudging technique for vertical wind profiler data assimilation, including both simulated data and special rawinsonde observations from the Genesis of Atlantic Lows Experiment. The improved initial state provided by using the Newtonian nudging technique provided further improvement in the subsequent forecast. Short-range numerical weather prediction will benefit from this technique.

- Vertical profiles of aerosol backscatter were taken under a wide variety of synoptic weather conditions at the Mauna Loa observatory. The profiles will be used to characterize the backscattering properties of the clean Pacific airmass and will have a strong impact on the planning of the National Aeronautics and Space Administration's (NASA's) Laser Atmospheric Wind Sounder instrument and the planning of the Global Backscatter Experiment (GLOBE).

Plans FY 90

- Complete analysis of the data from 1988–1989 Experiment on Rapidly Intensifying Cyclones over the Atlantic. Analysis will include airborne radar observations, satellite imagery, 22-km horizontal grid-resolution simulation of the storm, and a comparison between the model-simulated structures and physical processes with those analyzed and diagnosed from the field program data sets.

- Complete the mesoscale analyses that will describe the 3–D structure of the two polar lows detected during the 1989 Coordinated Eastern Arctic Research Experiment.

AIR QUALITY

NOAA's weather service mission includes research to understand meteorological processes relevant to air quality. WPL contributes to this program by using its remote sensors to measure 3–D fields of wind, turbulence, and aerosols.

Accomplishments FY 89

Sensor Development

- Modified the Doppler lidar system design to improve pollution and cloud-monitoring capability of the system.

Research

- Produced a model which integrates air chemistry and visibility measurements with local meteorology. The model is being used by the Department of Energy for the design of a study of air pollution in Mexico City. It is also providing guidance for state-of-the-art remote-sensing contributions to the California Air Resources Board study of ozone formation.

- A research effort investigating the meteorological factors that contribute to air pollution along the Front Range of Colorado showed that:

  (1) The evaluation of emission control strategy cannot be divorced from meteorological considerations.

  (2) Observations of air pollution meteorology in complex terrain reveals dynamical processes similar to those governing mountain lee cyclogenesis and downslope wind storms.

  (3) The interchange, mixing, and aging of the secondary particle precursors (NO_x, SO_2, and biogenic sources of ammonia) depend strongly on mountain-valley circulations.

Plans FY 90

- Participate in the San Joaquin Valley Ozone Study to determine the relationships between the thermally driven slope flows, the along-valley nocturnal jet, and the residence times for ozone and its precursors.

- Analyze Doppler lidar observations of smoke-plume structure and kinematics of forest fire in Battersby, Ontario, Canada. Relate the analysis to both climate effects and air quality.

- Evaluate a waveguide CO_2 laser as a stand-alone sensor for measurement of atmospheric winds and species concentrations.

CLIMATE

Accomplishments FY 89

- Numerical simulations showed that a technique for retrieving El Niño's oceanic temperature profile is very promising.

- Generated and documented the first observation-based, long-term, global record of ocean-surface solar irradiance. This new data set was incorporated into climate variability studies.

- Used optical scintillation method to measure stability and atmospheric surface layer fluxes of heat and momentum. An improvement in the measurements and reliability was maintained over irregular terrain and varying meteorological conditions.

- Identified three new non-linear radiation scattering methods for measuring the size and shape of cirrus particles for use in climate change studies of the Earth's radiation budget.

- Applied the normal-mode extension of tomography inversion to the study of subsurface ocean structure and dynamics that accompany interannual climate change.

- Showed that a compact, high-resolution ultraviolet differential absorption lidar system, measuring planetary boundary layer ozone fluxes, can be developed.

- Investigated cirrus cloud radiative and microphysical properties through radar and lidar observations of backscattered signal strength and depolarization ratio. Long-term changes in cirrus clouds could prove to be important indicators of climate change.

Plans FY 90

- Compare model simulations of ocean surface solar irradiance fields with the temporal and spatial variability of satellite-based records.

- Evaluate the climate-important information content of multiple-wavelength (i.e., lidar and radar) measurements of cirrus clouds.

- Evaluate the applicability of using an Nd:YAG lidar to profile tropospheric ozone flux.

- Use the NOAA coherent-pulsed lidar to calibrate the similar NASA instrument and assess the absolute atmospheric backscatter coefficients around the Pacific basin during the DC–8 GLOBE missions.

OCEANS AND GREAT LAKES

Accomplishments FY 89

Sensor Development

- Developed a theoretical model for analyzing underwater sound propagation to great distances, using adiabatic mode theory. The model would be used for interpreting basin-scale ocean acoustic tomography measurements of ocean temperature changes.

- Demonstrated that ocean surface monitoring capabilities can be added to over-the-horizon defense system radars at modest cost. The demonstration used a Navy radar and the wind directions over the Caribbean were mapped.

- Completed a study of the RF signals obtained by the use of spaced antennas observing scattering from the ocean surface. The concept may lead to ocean current mapping by a single Doppler radar.

Research

- Discovered situations where random outputs occurred while modeling underwater sound propagation in an ocean with specified horizontal structure. It was found that the model's sensitivity to operating parameters establishes limits to how much ocean structure can be inferred from acoustic measurements.

- Extended the Abel inversion of ocean acoustic tomography to include the case where source and receiver are off the sound-channel axis. The data showed which parameters of the horizontal structure can be extracted from tomography measurements. This information will enable a more accurate interpretation to be made of global ocean acoustic transmissions in terms of ocean-climate variability.

- Correlated the backscatter power from a 13.5 GHz Airborne Radar Altimeter with ice type over the Beaufort Sea. The correlation will enable the albedo of the ice to be determined as well as assist in the identification and tracking of ice islands.

Plans FY 90

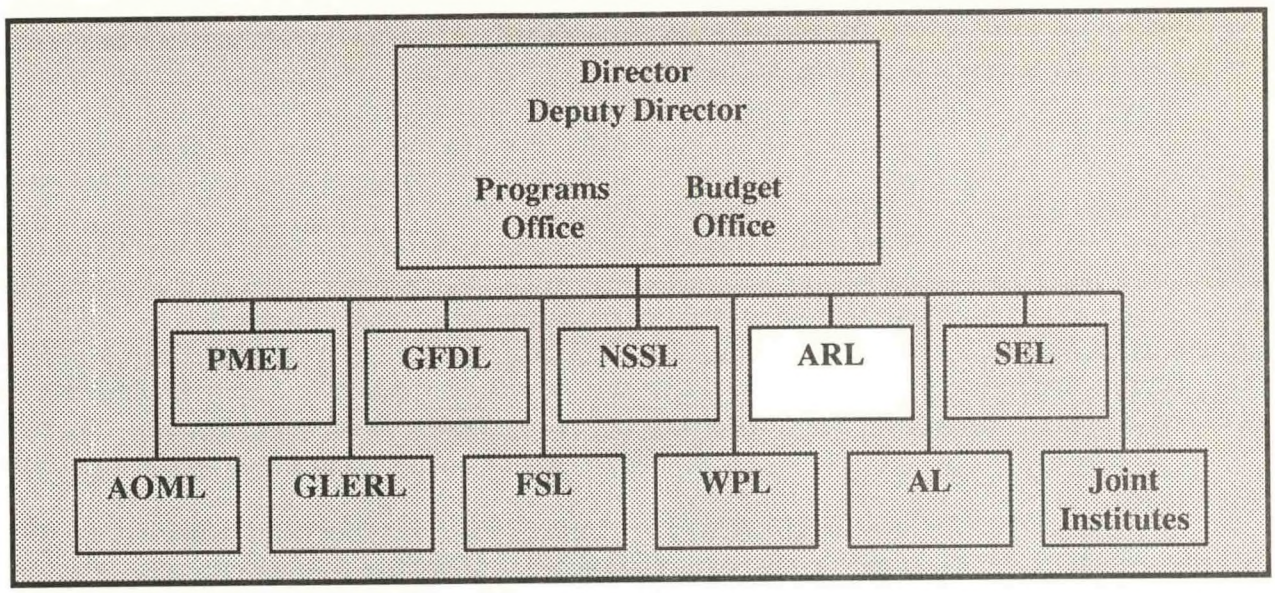
- Demonstrate the use of military over-the-horizon radar for mapping ocean surface wind directions.

- Measure the optical properties, from airborne lidar observations, of several commercially important fish species.

- Using the concept of the spaced antenna (SA) technique, determine if the 2–D sea-surface current measurements from a single VHF radar are comparable with dual Doppler measurements and determine the conditions that limit the use of the SA technique.

- After the completion of the Lake Ontario Winter Storms program, summarize the meteorological causes and effects of lake-effects snowstorms.

- After the equatorial Pacific Tropical Ocean and Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment pilot cruise, document the use of the eddy-correlation and inertial dissipation air-sea flux estimates along with radiative fluxes and bulk meteorological variables.



AIR RESOURCES LABORATORY
Silver Spring, Maryland
(301) 427–7684
Lester Machta, Director

Air Resources Laboratory (ARL) research is geared to needs of users, frequently other Federal agencies, with related missions. These include the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), and the Environmental Protection Agency (EPA). ARL is the official Government source for information on atmospheric transport and diffusion to guide emergency responses. The general areas of study are Air Quality and Climate, which include turbulence and diffusion in the atmosphere, global transport of pollutants, meteorology of air pollution, acid rain, global climate change, and monitoring of atmospheric constituents that can produce climatic change. The work includes observational and theoretical studies as well as instrument development.

ARL consists of the Headquarters Group located in Silver Spring, MD; the Field Research Division in Idaho Falls, ID; the Atmospheric Turbulence and Diffusion Division in Oak Ridge, TN; the Atmospheric Sciences Modeling Division in Research Triangle Park, NC; the Sun-Climate Staff, the Geophysical Monitoring for Climatic Change (GMCC) Division, and the Climate Research Division, all located in Boulder, CO.

AIR QUALITY

MODEL DEVELOPMENT AND VERIFICATION

Accomplishments FY 89

Atmospheric dispersion can be predicted best for idealized cases not often encountered in practical problems. Recent work is directed toward extending dispersion-prediction capability into more complex and

realistic situations. ARL and Wave Propagation Laboratory (WPL) staff conducted field studies in California and Colorado, within the Atmospheric Studies in Complex Terrain (ASCOT) program, and developed improved understanding and models for nocturnal flows and pollutant transport on slopes and in valleys. ASCOT is the only ongoing national program of diffusion studies in irregular terrain. The field program demonstrated the effectiveness of the new remote-sensing and tracer technologies developed by the Environmental Research Laboratories (ERL).

Developmental research focused on three different dispersion models: (1) A reactive gas puff dispersion model was developed and tested for the NRC and DOE. In its initial form, this model is tailored to releases of uranium hexafluoride. (2) A two-dimensional hydrodynamic model was extended to simulate diffusion in nighttime slope flows; tracer data obtained in ASCOT were used for evaluation. (3) An integrated puff model was modified for dispersion in a deep, narrow valley, and used to simulate ASCOT tracer data. During 1989, variations of turbulent dispersion parameters in a valley drainage flow were measured and data from two dual-tracer tests were analyzed to develop a time sequence of concentration contours along and across the valley.

An investigation of the theory of nocturnal flows over isolated ridges and the generation of gravity waves indicated that the generation of such waves constitutes a significant contribution to surface drag that is not accounted for in existing models. Also, these waves may break, producing intermittent episodes of nocturnal mixing that may be a principal mechanism for nighttime dispersion and coupling to flow aloft.

A sulfate tracking version of the EPA Regional Acid Deposition Model (RADM) was developed to determine the impact of non-linear aqueous phase reactions on wet-sulfate deposition.

The first of two field experiments to provide a data base for evaluating the RADM in a major acid deposition impact area was completed. In the polluted clouds, sulfuric acid was forming in the clouds and resulting in pH values as low as 2.3; trajectory analysis showed that the polluted air had lingered over the Ohio River basin and that unpolluted air was arriving from the western Atlantic Ocean.

A model for temperature and sunlight profiles through deciduous and coniferous forest canopies was developed because isoprene and terpene emissions are sensitive to these variables.

The Regional Oxidant Model (ROM2.0) was evaluated against field data. Model performance showed an overall 2% overprediction of daily maximum surface ozone concentration with a large range of variability. The spatial extent and concentrations of the plumes were generally well simulated but a bias in the calculated winds caused a more easterly transport than observed in plumes from the east coast. Significant changes were made to the chemical kinetics mechanism in the version used for regional ozone modelling. These included specification of a variable water vapor concentration and improved representation of oxy-radical chemistry.

Plans FY 90

- The reactive chemistry routines included in the reactive puff model will be generalized for application to other chemical species.
- The effect of ambient winds and stratification on flow structure and entrainment will be studied.
- A random walk dispersion model, using a Lagrangian particle approach, will be tested for complex terrain by adapting it to simulate ASCOT tracer data.

- A major field study will be conducted in the area around Oak Ridge, TN, during 1990. In particular, an ASCOT field experiment will be conducted for a 1-month period during the Oak Ridge study.

- ARL staff will coordinate and collaborate in a multilaboratory study of flow channeling, eddy correlation measurements of local energy budgets, and gravity wave genesis and production of nocturnal mixing.

- Direct meteorological research support to EPA will include development and evaluation of air quality dispersion models for inert and reactive pollutants and the associated meteorological models on all temporal and spatial scales. Emphasis will be on (1) application and improvement of regional oxidant models; (2) continued work on the new Regional Acid Deposition Model (RADM–2) in preparation for its application to acid precipitation problems; (3) conduct of a large field study program to evaluate regional models; and (4) continued efforts to improve the analyses of sources unique to toxic gases such as heavier-than-air gas releases.

- The second experiment for evaluating RADM will be carried out in April–May 1990.

- An observational data base for evaluating acid deposition models will be developed. A field study will use a surface sampling network of about 60 sites in the northeastern United States and will provide several intensive wet deposition and air concentration sampling periods.

FLUID MODELING

Accomplishments FY 89

Wind-tunnel measurements were made to determine the conditions under which a dense gas would be trapped in a topographic depression (valley), and under trapping conditions, how rapidly it would be removed by an entraining crosswind. In accordance with theoretical expectations, it was found that the removal rate increased with the cube of wind speed just above the surface of the dense gas, except at very low speeds, where molecular viscosity and diffusion become important. The latter were explored thoroughly, and it was concluded that molecular effects are dominant even at large scales when the wind speed is as low as 1 ms^{-1}. In another dense-gas flushing study, the density (or release rates) of the gases was not large enough to result in trapping or decoupling from the air above the valley, but nevertheless possessed sufficient negative buoyancy to reduce flushing times markedly.

The Boston Wastewater Outfall was modeled in the stratified towing tank to aid in its engineering design. The recommendations from this study will result in very significant cost savings (about $25 million) and improved performance over the preliminary engineering design. Simulations of building wakes were conducted in the wind tunnel. The cross-stream distributions were compared with dispersion model calculations for distances less than 20 building heights downwind. These comparisons indicate that a Gaussian puff model can be used to simulate the overall characteristics of building-wake dispersion.

Plans FY 90

The Fluid Modeling Facility wind tunnels and water channel/towing tank will be used to study flow in complex terrain, flow around buildings and other obstacles, basic characteristics of boundary layer flow, and dispersion of dense gas plumes in air and water.

TRACER STUDIES

Accomplishments FY 89

Data from the Across North America Tracer Experiment were put into final form, with quality assurance completed. The data were distributed to users to validate models for long-range transport and dispersion.

The Third Cooperative Institute for Research in Environmental Sciences/National Oceanic and Atmospheric Administration (CIRES/NOAA) Arctic Gas and Aerosol Sampling Program (AGASP–III) intensive airborne research program was conducted in the Norwegian Arctic, March–April 1989. The data are being analyzed to characterize Arctic pollution and air-surface energy exchanges. The last of eight field research operations in the central United States characterized the seasonal trends and altitude dependance of carbon monoxide, methane, hydrocarbons, ozone, hydrogen peroxide, sulfur dioxide, and sulfate.

The Coordinated Air-Sea Experiment of the Western Atlantic Ocean Experiment (CASE/WATOX) was conducted 17–28 July 1988. Analyses show that the concentrations of hydrogen peroxide and ozone at low altitude over the Gulf Stream decreased from the continental-influenced values of about 1.2 and 50 ppbv to the maritime values of about 0.5 and 15 ppbv. Average boundary layer sulfur dioxide concentrations were almost tenfold greater near the east coast than near Bermuda (~0.5 vs. ~0.06 ppbv), and free troposphere sulfur dioxide concentrations near the east coast were greater than near Bermuda, but by a lesser factor (~0.11 vs. ~0.07 ppbv).

Plans FY 90

Along with scientists from NOAA's WPL and Pacific Marine Environmental Laboratory (PMEL), University of Washington, Naval Postgraduate School, and Office of Naval Research, AGASP scientists will plan for an Arctic research program in 1992. AGASP–III data will be analyzed and manuscripts prepared.

DEPOSITION (INCLUDING ACID RAIN)

Accomplishments FY 89

Wet Deposition

Analysis of initial data received from Lijiang, People's Republic of China, indicates that precipitation chemistry from the remote western mountainous section of western China has the same approximate

composition as precipitation in other pristine areas of the globe. Volume weighted pH is approximately 4.8 including partially-dissociated organic acids.

Global Trends Network (GTN) data were analyzed but show no clear trend in precipitation concentrations or depositions in remote areas. Concentrations of major ions, including nitrate and sulfate, are all very low relative to industrialized areas of the United States when adjusted for seasalt contributions. We believe that GTN data give a reasonable indication of pre-industrial levels of materials commonly found in precipitation for the northeastern United States and other industrialized areas of the world.

Dry Deposition

A technique was developed to study the effects of aerodynamics and configuration on dry deposition to building materials. Scale models of the testing surfaces were used to show that deposition is uniform over the central portion of the test surfaces, but is much more rapid and variable near the edges. These results must be considered when estimating dose-response functions from field tests. Preliminary tests were also conducted on complex objects such as model statues, to examine deposition rate relative to flat surfaces.

Plans FY 90

Wet Deposition

Recent GTN data will be interpreted. Air mass tracers measured during the WATOX 1988 field intensive will be analyzed and Atlantic nitrogen and sulfur budgets will be recalculated.

Dry Deposition

The nested network monitoring operation will be refocused to quantify the bi-directional exchange of many chemicals.

Reports for the State-of-Science series of documents of the National Acid Precipitation Assessment Program will be completed.

ATMOSPHERE-SURFACE EXCHANGE

Accomplishments FY 89

A collaborative field experiment by ERL scientists at ARL's forest research site addressed the exchange rates of sulfur dioxide (SO_2), ozone (O_3), nitrogen oxide (NO), and ammonia (NH_3). The forest floor was observed to act as a sink for both SO_2 and O_3 while simultaneously emitting NO and NH_3. The canopy was found to act nearly as a perfect sink for nitric acid (HNO_3) with little or no resistance to uptake by the canopy elements.

New fast response chemical sensors and analytical methods were developed to examine processes that control atmosphere/surface exchange rates. A prototype open path gas analyzer was fabricated and success-

fully tested. The sensor simultaneously measures the concentrations of carbon dioxide (CO_2) and water vapor (H_2O), and its resolution was determined to be adequate for measuring CO_2 fluxes over the ocean.

Plans FY 90

We will investigate the possibility of measuring methane (CH_4) with the prototype open path gas analyzer.

EMERGENCY OPERATIONS

Accomplishments FY 89

A memorandum of Understanding (MOU) among the U.S. Air Force, DOE, EPA, Federal Aviation Administration (FAA), Food and Drug Administration, NOAA, and NRC was completed. NOAA/ARL was assigned the responsibility to provide information to Government agencies, the press, and the general public on transport and dispersion forecasts of radiological or potentially harmful non-radiological pollutant releases into the atmosphere.

ARL completed major portions of an Analysis-Forecast Transport and Diffusion (AFTAD) Immediate Response Program. The program is composed of: (1) Program for Operational Trajectories (POT), which is now documented; (2) Program for Operational Transport and Dispersion (POTAD), which is based on NOAA/National Meteorological Center (NMC) model output; and (3) Program for Operational Meteorological Support.

Several tests were run throughout the year to exercise all parts of the Volcanic Hazards Alert program. As a result of these tests, an implementation plan was developed and will be included as part of an October 1989 MOU between NOAA and FAA on volcanic hazard alerts.

The Hazardous Atmospheric Release Model was enhanced to handle reactive chemical as well as radiological releases, real-time data assimilation, site-specific building-wake effects, and results of experimental investigations of local dispersion. A site survey was conducted at the Portsmouth, OH, uranium enrichment plant to determine the optimal amount of meteorological monitoring necessary to provide input to the model.

Plans FY 90

The AFTAD emergency response program will be updated by making POT more efficient and user-friendly and by transferring codes to personal computers. Development of POTAD will emphasize operational efficiency in the forecast mode. Some chemical species and oxidant-concentration calculations will be included on the regional scale.

OZONE

Accomplishments FY 89

Global total ozone and ozone profiles were updated through 1988. The global total ozone increased from about 3.0% below average in 1985 to about 1.5% below average in 1988, an increase anticipated due to the increase in sunspot number by about 80 during this interval. Between 1960 and 1988, there was correlation of 0.54 between seasonal values of sunspot number and global total ozone two seasons later, a correlation significant at the 1% level taking into account the serial correlation in the data. Based on linear regression during this interval, global total ozone increased by 1.5% for an increase in sunspot number of 100. North temperate Umkehr data suggest that the relation between ozone and sunspot number is better in the low stratosphere where transport processes dominate than in the high stratosphere where photochemical processes dominate, an unexpected finding worthy of further study.

A retrieval method was developed to estimate the solar backscatter ultraviolet (SBUV) satellite albedo using ground-based Umkehr measurements. Results of the investigation suggest that the method of estimation may be very useful for quantifying the drift rate of the SBUV calibration which has been a continuing serious problem with this instrument. Tests indicated that the retrieved SBUV albedos for the seven ozone profiler wavelengths should be estimable to a precision of 5% or better.

Total ozone and Umkehr data were collected at seven Dobson spectrophotometer stations, and total-ozone data only were collected at nine other stations. Ozone vertical profile measurements were made with balloon-borne electrochemical concentration cell ozonesondes at Boulder, Colorado; Hilo, Hawaii; and South Pole, Antarctica. All data were provided to the National Environmental Satellite, Data, and Information Service for validation of SBUV–2 ozone data obtained aboard the NOAA–F satellite. Ozonesonde observations were also made during 1988 at Mirny, Antarctica, in cooperation with U.S.S.R. scientists, to study ozone depletion in Antarctica; and during January through March 1988 at Point Barrow, Alaska, to study possible similar ozone depletion in the Arctic.

Photochemical ozone destruction over South Pole, Antarctica, in 1988, was relatively moderate. The 15–31 October total ozone mean at South Pole was 251 Dobson units (D.U.), compared to the 1987 value of 138 D.U. Above average ozone amounts were transported poleward in the Southern Hemisphere from the tropical stratosphere ozone source region, beginning in June 1988. At American Samoa, where ozone had been decreasing at a rate of 3%/decade since 1976, ozone values during the second half of 1988 reverted to values equivalent to 1976.

A calibration check was performed 24 June–17 August 1989 on World Standard Dobson spectrophotometer No. 83 at Mauna Loa Observatory. Results obtained will be used in a continuing assessment of calibration drifts of the Total Ozone Mapping Spectrophotometer and SBUV satellite ozone instruments. During the summer of 1989, Dobson spectrophotometer No. 65 was established at Mauna Loa Observatory as a secondary standard instrument for total ozone measurements.

Ozonesonde data from the NOAA observatories, two Canadian stations, and stations in Japan and New Zealand, for 1984–1987, were analyzed to provide information on the vertical distribution of ozone as a function of altitude (0–35 km) and latitude (pole-to-pole). The data are used to verify ozone distribution predictions of photochemical/dynamical computer models; as a priori data for processing satellite and Umkehr profile data; and to validate satellite ozone profiles. A surprising result of the analysis was that the Southern Hemisphere troposphere contains about one-half as much ozone as does the Northern Hemisphere troposphere.

Surface ozone measurements with an ultraviolet absorption ozone photometer were conducted at American Samoa, Mauna Loa Observatory, Point Barrow, and South Pole. At Point Barrow, summertime surface ozone

amounts are increasing at nearly 1% per year while at Samoa and South Pole, summer values have decreased. Surface ozone observations were begun at Bermuda, Barbados, and Mace Head, Ireland.

Plans FY 90

Surface, aircraft, and tethered-balloon ozone observations will be gathered as a part of the ASCOT field study to be conducted in Oak Ridge, TN, early in 1990. These observations will be coupled with eddy correlation measurements and a dense array of meteorological observations to improve our understanding of the interaction of chemistry and dynamics.

- A trace gas photochemical model will be constructed to explore the relative roles of dynamics and chemistry on air-surface exchange rates and concentration distributions. Regional scale oxidant and photochemical models will be examined to determine how near-surface observations and detailed descriptions of the boundary layer can be included in regional-scale models.

- We will further explore the use of Umkehr observations for tracking the calibration drift of SBUV satellite data.

- Pending the acceptance of new ozone absorption coefficients for the Dobson instrument, we will begin developing with Canada an updated version of the 1964 Umkehr ozone profile inversion algorithm used by the World Ozone Data Center at Canada.

Observations of total ozone and Umkehr vertical distributions will continue, as will reprocessing of total ozone data from the network stations to improve data quality.

- Calibration procedures will be automated.

- Special total ozone calibration observations will again be made with Dobson instrument No. 83 at Mauna Loa Observatory.

- An international comparison of Dobson instruments will be conducted at Arosa, Switzerland, in July 1990. A dozen countries are expected to participate. Calibrations will be made of other foreign as well as domestic instruments.

- Ozone vertical distribution measurements at South Pole will continue. The frequency of similar observations at Boulder and Hilo will, however, be reduced.

- The North Atlantic network of surface ozone monitoring sites will be completed with the installation at Tenerife, Canary Islands. This will form a network of four Atlantic sites plus the four GMCC sites.

CLIMATE

DATA SET DEVELOPMENT

Accomplishments FY 89

- Work toward release 2 of the Comprehensive Ocean Atmosphere Data Set (COADS) continued, in cooperation with the National Center for Atmospheric Research (NCAR) and NOAA's National Climatic Data Center. Differences between wind data from the U.S. Navy and from NCDC were found to be due to numerical procedures used in converting the data from one set of units to another. A uniform procedure was developed. Wind data from buoys and ships show substantial differences, partly due to different measurement heights. Corrections have been explored.

- The historical data archive was expanded to include daily climatic summaries from the United States for the period 1901–1986 for approximately 750 stations. We also acquired a set of high-quality surface-temperature data for Australia, consisting of approximately 50 stations with 60 or more years of record. These data will be added to our existing archives of global surface-temperature data which now number over 1200 stations for the Northern Hemisphere and over 600 stations for the Southern Hemisphere.

- The highly reflective cloud data set was completed with the addition of data through the end of 1988. This data set constitutes the longest continuous record of convective activity in the global tropics. Data for a full, continuous 18-year period are now available for use by interested scientists.

Plans FY 90

- The updated release 2 of COADS will be completed.

- Data will be examined for biases. Climatologies will be produced for daytime and nighttime data to remove other biases. Methods for combining wind data collected by different techniques will be investigated.

- We expect to obtain daily surface records for Canadian stations for a period of record similar to that of the United States. Special upper air data from long-term radiosonde stations will be added. A set of high quality, rural stations with long-term records from around the world will be compiled. A subset of this data will consist of high-altitude sites at special observatories, such as Niwot Ridge, CO, and Mt. Washington, NH.

CLIMATE DIAGNOSTIC STUDIES

Accomplishments FY 89

A technique was developed to improve the consistency of analyzed wind fields. These fields, produced by weather centers around the world, result in estimates of heating, especially in the tropics, that are too weak. This technique was extended through the entire troposphere, allowing for more realistic estimates of interannual variation in tropical heating.

A study of the global climate fluctuations associated with both extremes of El Niño-Southern Oscillation (ENSO) has been completed. Large regions of coherent, significant signals were shown to exist in both the cold and warm extremes of the Southern Oscillation, with warm event signals generally opposite to those during cold events. Also, during the years preceding the development of an extreme of the Southern Oscillation, climatic anomalies tended to be opposite to those during the following year. This confirms the existence of a biennial component in the Southern Oscillation in remote regions of the globe as well as in the tropical Pacific/Indian Ocean.

A nonrandom behavior was identified in the recurrence of strong El Niños between 1525 and 1988, a 464-year record. Analysis shows recurrence of these events at joint periods of 6.75 and 14.0 years. The results are statistically significant (0.1% level). The record shows approximate 95-year periods, alternating between recurrence of strong events at 6.75 and 14.0 years. At present we appear to be near the transition from the 14.0 to the 6.75-year mode of recurrence.

Analysis of seasonal precipitation in the United States (1895–1987) shows some association of precipitation with strong El Niños. During spring, precipitation in the southeastern United States was below normal the year prior to and the year of El Niño, but above normal the year following the event. During fall, somewhat similar results are observed for the central and southern plains and Mississippi Valley.

Plans FY 90

Studies of the interactions between interannual and intraseasonal fluctuations will continue. A detailed examination of the most recent two cycles of warm-cold episodes of the Southern Oscillation will be carried out to relate the location and intensity of the 30–60 day oscillation to the development and decay of the warm and cold phases. It is clear that the 30–60 day oscillation is modified by the Southern Oscillation. The question to be investigated is whether the reverse is true.

Simple numerical model experiments will be performed to examine the impact of tropical heating on the midlatitude circulation. The complicated nature of the midlatitude response implies that more than one forcing mechanism must be important, and these mechanisms must be working together to produce the observed effects. General circulation model experiments will be designed to complement the simpler model studies.

Comparisons of the characteristics of the analyses of the U.S. NMC and the European Centre for Medium-Range Weather Forecasts will continue. Adjustments to both sets of data will be made to compare heating rates. If stable estimates of tropical heating can be obtained, the interannual variability of the heating will be examined. Cluster analysis techniques will be used to examine the properties of ENSO events contained in COADS before 1940. Since warm episodes occur only every 4–5 years or so, it is important to increase the number of events studied. Questions to be addressed include how constant are the centers of action of the Southern Oscillation over the past century.

The chronology of strong El Niño events will be studied in an attempt to project both strong El Niño events and precipitation anomalies in the United States into the near future.

CLIMATE MONITORING

Accomplishments FY 89

The record of global tropospheric and low-stratospheric temperatures, beginning in 1958, was updated through the summer of 1989. The global tropospheric temperature in 1988 was the maximum observed since the beginning of the record in 1958, 0.53°C above the long-term average, and 0.02°C warmer than 1983, 0.06°C warmer than 1987, and about 0.16°C warmer than 1980 and 1981, where the 95% confidence limits for these global annual averages range from ±0.1 to ±0.2°C. Between 1958 and 1987, there was a correlation of 0.94 between these annual tropospheric temperature deviations and the global surface temperature deviations of the Goddard Institute for Space Studies (GISS). In accord with the record warmth of the troposphere in 1988, the 300 mb north circumpolar vortex was more contracted in 1988 (4.6% less than average size) than in any year since the beginning of the record in 1963.

Between 1958 and 1988, there has been a correlation of about 0.7 between the sea-surface temperature (SST) in eastern equatorial Pacific and global tropospheric temperature about two seasons later. The El Niño experience of 1987 indicates that caution is necessary in relating the record warmth of 1988 to the "greenhouse effect" (1983 was also an El Niño year). Owing to the anomalously cold SST in the eastern equatorial Pacific in late 1988, the global tropospheric temperature during the first 3 seasons of 1989 was only 0.20°C above average, a decrease of 0.32°C from the annual average for 1988.

Estimates of the water vapor content of the atmosphere between the surface and 500 mb were made for the period 1973–1988 using the same sampling network used for the temperature record. Preliminary analysis of these data suggest that there has been a small increase in the water vapor over this period in the tropics, particularly over the western Pacific. There is also the suggestion of a weak decrease in polar regions. The 9-year record of stratospheric water vapor measurements at Boulder suggests an increase of about 1% per year. This is nearly twice the amount expected from the increasing atmospheric burden of methane.

The records of United States sunshine duration and cloudiness data, beginning in 1950, was updated through the spring of 1989. In the spring of 1988, the cloudiness was a record 20% below average and the sunshine duration a record 20% above average in north central, south central and southeast regions of the United States, and in the summer of 1988, there were record values in north central and northwest regions. Nevertheless, United States cloudiness increased by 3.5% between the first half and last half of the 1950–1988 record. Between 1950 and 1988, there was a correlation of 0.79 (significant at the 1% level) between annual cloudiness and precipitation within the United States, and a correlation of -0.43 between annual cloudiness and temperature (above-average cloudiness associated with below-average temperature), the latter correlation not quite significant at the 5% level.

Plans FY 90

- The records of temperature, humidity, and cloudiness will be updated.
- A joint study with Scripps Institution of Oceanography on the time and spatial variations of tropospheric water vapor will be carried out.
- Algorithms used to process the humidity data will be revised to permit more flexible analyses.

- Rocketsonde temperature data of the upper atmosphere will be updated.

- Profiles will be made of water vapor at Boulder to detect long-term changes in the stratosphere. Water vapor in the stratosphere will be measured at Alert, Northwest Territories, and South Pole in a continuation of the study of polar stratospheric clouds and their role in ozone depletion.

TRACE GASES

Accomplishments FY 89

We completed a new flask design that gives better stability for both CO_2 and carbon monoxide (CO), while being fully satisfactory for CH_4. A primary gravimetric concentration scale for calibrating CO measurements was established and we began construction of a system for the calibration of CO_2 standards.

We found that the oceans play a smaller role in the current uptake of fossil fuel CO_2 than terrestrial ecosystems. This work was done in collaboration with the NASA/GISS and Lamont Doherty Geological Observatory.

The spatial gradients measured in the flask network were used, also in collaboration with NASA/GISS, to constrain the global budget estimates of atmospheric CH_4. Correlations between CH_4 and CO_2 concentrations in the atmosphere are not by themselves sufficient to determine the global emissions of CH_4 from urban and industrial sources.

ARL is monitoring and analyzing atmospheric concentrations of nitrous oxide (N_2O), CFC–12, CFC–11, methyl chloroform (CH_3CCl_3), and carbon tetrachloride (CCl_4). These gases, like CO_2 and CH_4, may affect the temperature of the earth's surface through the greenhouse effect. Increased levels of N_2O and the chlorofluorocarbons (CFCs) may also alter the equilibrium concentration of stratospheric ozone (O_3). Concentrations of these gases continued to increase in the atmosphere.

The Montreal Protocol has called for a large cutback in the production of CFCs. Some of the largest manufacturers are planning to switch to compounds that will cause less ozone depletion. These compounds have been referred to as the hydrochlorofluorocarbons (HCFCs). The gases include HCFC–22 ($CHClF_2$), CFC–113 ($CCl_2F–CClF_2$), and halons H–1211 (CF_2ClBr) and H–1301 (CF_3Br). ARL is monitoring these gases from flask samples once a month from most of the NOAA/GMCC baseline observatories and at Niwot Ridge, CO. First measurements of HCFC–22, CFC–113, and halons H–1211 and H–1301 were at the baseline stations, except South Pole. Because measurement of these trace gases requires standard gases of known concentrations, we are developing techniques and gas standards for N_2O, CFC–12, CFC–11, CFC–113, CH_3CCl_3, CCl_4, HCFC–22, HCFC–134a, HCFC–123, and halons H–1211 and H–1301.

Atmospheric and surface water N_2O, CFC–11, CFC–113, CH_3CCl_3, and CCl_4 were measured aboard the NOAA research ship *Discoverer* over a 50,000 km track in the eastern and central Pacific during February–May 1989. Biological experiments were conducted to estimate the source of oceanic N_2O into the atmosphere. Since the cruise took place during a non-ENSO event year, these data will be compared to the N_2O data of the Soviet-American Gas and Aerosol Experiment (SAGA II) from March to August of 1987, which showed low fluxes of oceanic N_2O into the air during the ENSO event of 1987.

The first NOAA/GMCC infrared spectral archive measurements were made at the Kitt Peak Observatory in January 1989. These data will permit the determination of the total column abundance of gases like CO_2, CH_4, and N_2O in the atmosphere. The spectra will be archived so concentrations of gases not currently measured can be estimated in the future.

Plans FY 90

- Monitoring of CO_2, CH_4 and CO will continue and a study will be made of changes in the global growth rate of methane.

- A system for the calibration of CO_2 standards will be built. Our concentration scale for CO will be compared to existing scales at the National Institute of Standards and Technology and the Oregon Graduate Center. A primary gravimetric concentration scale for CH_4 will be established.

- Stable isotope measurements of CO_2 in flask samples will be started, in collaboration with the University of Colorado for the better elucidation of the separate roles of the oceans and terrestrial plants in the carbon cycle.

- An automated gas chromatograph for the measurement of N_2O, CFC–12, CFC–11, CH_3CCl_3, and CCl_4 in flasks will be completed and new technologies to measure the HCFCs in the atmosphere developed.

- ARL will participate in the SAGA III cruise with the Soviets and PMEL to measure the interhemispheric gradient of N_2O and a number of halocarbons in the atmosphere during January–April 1990. Flux and combustion studies to determine the source of the N_2O increase in the atmosphere will be started.

AEROSOL AND RADIATION MONITORING

Accomplishments FY 89

Instruments (aethalometers) for the measurement of aerosol carbon were installed at Barrow, Mauna Loa, and South Pole. Aerosol carbon is climatically important because it is highly optically absorbing and is primarily anthropogenic.

We participated with the Soviet Union in the Desert Aerosol Lifting Experiment, located in the desert region south of Dushanbe, U.S.S.R. A single-wavelength nephelometer, condensation nucleus counter, and two multiwavelength sunphotometers were included in this experiment.

The net solar and infrared measurements made at South Pole Observatory were analyzed for variations caused by cloudiness. Clouds suppress the outgoing infrared, therefore retarding surface cooling. During summer, clouds increase the net downward total (infrared and visible) radiation thus increasing the flux of heat into the snow.

A ground truth solar and infrared surface radiation site was set up on Kwajalein and has been operating continuously since March. The measurements are being used by Government and university scientists to validate Earth Radiation Budget Satellite algorithms over ocean areas. Net solar radiation measurements made from the top of the Boulder Atmospheric Observatory have been used to validate Earth Radiation Budget Satellite algorithms for estimating the surface net radiation. The agreement between satellite and ground-based measurements was found to be excellent.

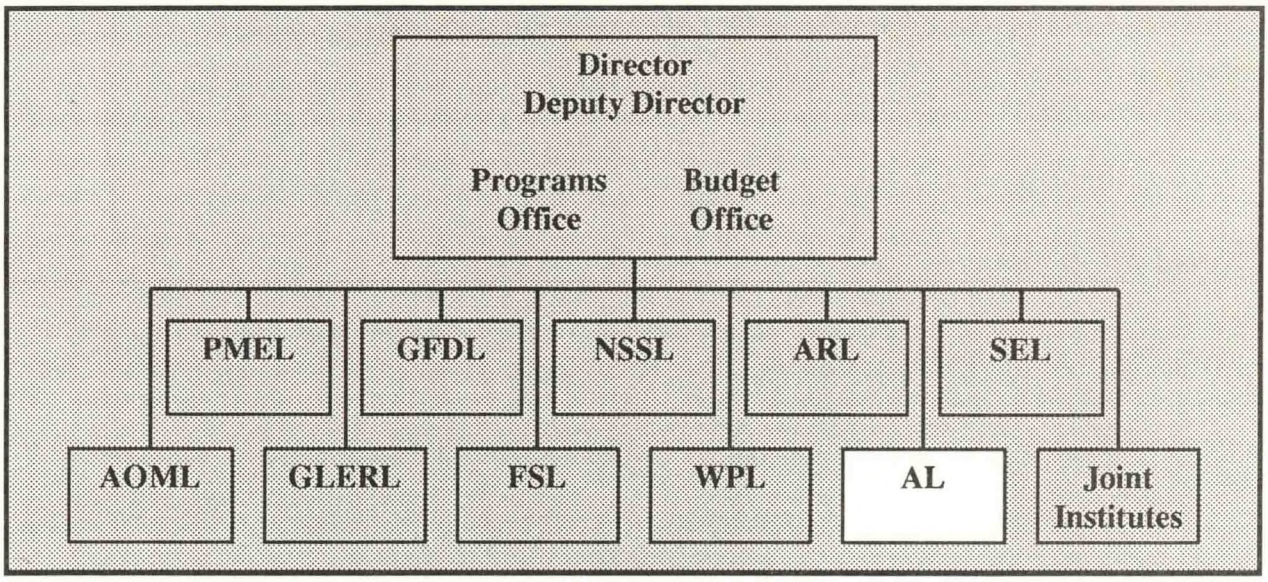
The U.S. NWS/ERL-operated solar radiation network of 31 stations was completed. All solar radiation sensors, pyranometers and pyrheliometers, have been recalibrated by the NOAA Solar Radiation Calibration Facility and will be cycled into the network. Procedures will insure a calibration of 1% (average) traceable to the World Radiation Reference with a verified precision of 0.3%.

Plans FY 90

- An analysis of the results of the South Pole aerosol physical and chemical properties experiment will begin. We will participate in a NASA circum-Pacific airborne aerosol experiment and in the Pacific Dust Experiment planned by NCAR.

- We will analyze solar and infrared measurements now being made at Kwajalein to develop an understanding of the effects of clouds on the radiation balance over this ocean location, and will investigate diurnal and seasonal radiative forcing by clouds at the Boulder Atmospheric Observatory.

- We will organize a Global Baseline Surface Radiation Network for the World Climate Research Program. This network will become an international effort to provide quality surface radiation data to validate earth radiation budget satellite results and to study effects of clouds on the radiation balance.



AERONOMY LABORATORY
Boulder, Colorado
(303) 497–5785
Daniel L. Albritton, Director

The Aeronomy Laboratory (AL) conducts research on chemical and physical processes of the Earth's atmosphere to advance the capability to monitor, predict, and control the quality of the atmosphere. The research concentrates on the stratosphere and troposphere, but also involves the mesosphere and thermosphere.

The research methods involve both in-situ and remote measurement of critical atmospheric parameters, including chemical composition and dynamic properties such as wind velocity, turbulence, and wave motion. Theoretical programs in atmospheric photochemical modeling and in atmospheric dynamics and transport support the observation programs. An experimental laboratory chemical kinetics program supports the theoretical photochemical modeling program and also supplies input for the development of new atmospheric monitoring and measurement technology.

The major focuses of research are Air Quality and Climate. Several environmental issues are currently addressed: stratospheric ozone depletion (global, Antarctic, and Arctic), tropospheric ozone production by pollutants (both in rural continental areas and globally), greenhouse effect, acid rain, El Niño-Southern Oscillation, and climate change.

ATMOSPHERIC WAVES AND TURBULENCE THEORY

This program is devoted to theoretical studies of turbulence, wave, and eddy transport of constituents, energy, and momentum in the atmosphere. These phenomena are basic to many areas of geophysics, including meteorology, climatology, pollution dispersal, oceanography, space physics, and aeronomy.

Wave and turbulence fluctuations have a striking effect on transport of pollutants and were intensively observed as long as three decades ago. However, because of mathematical and conceptual difficulties, no theories of turbulence and nonlinear wave interactions were available for determining the strength of the

fluctuations and how they influence pollution dispersal and meteorology. The development of such theories has become a principal concern of this program.

Accomplishments FY 89

Turbulence Modeling

The long-term goal is to develop a reliable turbulence model of the planetary boundary layer by using rigorous theory to replace failed empirical models. Accomplishments leading to our goal included the following:

- Developed a comprehensive, rigorous theory for predicting triple correlations such as energy flux.

- Our pressure-strain (correlation of pressure and velocity) theory was tested and confirmed by computer simulations at Stanford University.

- Simplified and extended recent, exciting advances in statistical turbulence theory. The simplification is much more versatile and less expensive.

- Showed theoretically that the dissipation rate (loss by molecular interactions) of energy flux is five times the previously accepted value. Knowledge of this rate is essential to predict energy fluxes.

- Extended contemporary turbulence theory (two-point theories) to spatially inhomogeneous turbulence—the case typical of the atmosphere.

Atmospheric Gravity Waves

- Resolved a serious uncertainty in gravity wave transport theory.

- Developed a theory to predict the superadiabatic excess, the key wave quantity for predicting transport in the middle atmosphere.

- Developed a theory to explain and predict the contribution of waves to the very intermittent bursts observed in atmosphere and oceans.

- Deduced theoretically the RMS source of gravity waves in the troposphere from radar measurements in the mesosphere. This source is needed for modeling but has defied measurements.

- Collaboration begun with Utah State University to study breaking waves in the atmosphere.

Plans FY 90

Turbulence Modeling

- Develop an analytic theory of sheared turbulence.
- Generalize pressure strain formula to include time-varying turbulence—variations found in the earth's boundary layer.
- Determine the diffusivity of stably stratified turbulence.
- Continue our major program to derive a reliable model of planetary boundary turbulence by applying contemporary theory. More than 60 terms need be derived.

Atmospheric Gravity Waves

- Develop a nonlinear theory for many interacting gravity waves.
- Predict the average total energy of gravity waves at each height.
- Explain the -3 power law of gravity wave spectra observed ubiquitously in atmosphere and oceans.
- Collaborate with Utah State University (radar experimenters) to find isolated specimens of breaking waves.
- Continue the major effort to determine the nonlinear properties of gravity waves from a rigorous, analytical approach. It is this nonlinearity that ultimately governs transport.

ATMOSPHERIC CHEMICAL KINETICS

This program investigates chemical reactions that are important to understand the natural, unperturbed atmosphere and to evaluate the effects of anthropogenic chemical species on the Earth's atmosphere. Human activities can deplete the ozone layer in the stratosphere inadvertently, but with disastrous consequences. The major environmental problems associated with the troposphere include air pollution, acid precipitation, and global warming. Most chemical reactions that take place in the atmosphere involve reactive free radicals. Their reactions define the formation and destruction of atmospheric ozone, the oxidation of natural and anthropogenic chemicals released into the atmosphere, and the formation of acid precipitation. This program emphasizes quantitative studies of the rates and mechanisms of the important gas phase reactions of radicals.

Accomplishments FY 89

The following studies were completed:

- Rate coefficients for the reaction of ClO with ClO were measured under stratospheric conditions. The product of this reaction was shown to be Cl_2O_2. The ultraviolet (UV) absorption cross section of Cl_2O_2 was measured. These data are required to make quantitative calculations of ozone loss in the polar regions.

- The kinetic and photochemical parameters that control the rate of degradation of the halons ($C_xF_yBr_z$) were determined. These results are essential to evaluate the ozone depletion potentials of these molecules which are regulated by the Montreal protocol.

- The UV absorption cross section of BrO was determined. These data are applicable to the detection of BrO in the atmosphere and laboratory.

- The photochemistry and kinetics of hydrogen peroxide and methylhydroperoxide were studied. These results apply to both the acid precipitation and clean-air chemistry.

- The mass accommodation coefficient of ozone on liquid water was measured using a wetted wall flow tube reactor. We conclude that the transport of ozone to the water drops is not a rate-limiting step in the sulfate production in water drops.

- Studies of the kinetics and mechanisms of CH_3S reactions with O_3, NO_2, and O_2 were carried out. This species is an intermediate in the oxidation of dimethyl sulfide which is believed to influence climate in the marine environment.

- The reactions involved in the oxidation of CS_2 in the atmosphere were studied. It was concluded that the oxidation of CS_2 is a source of tropospheric SO_2 and of COS which provides sulfur for the stratospheric sulfate layer.

The following projects are still in progress:

- The measurements of the rate coefficient for the reaction of BrO with BrO.

- Studies of the tropospheric and stratospheric degradation rates and mechanisms for the partially hydrogenated ethanes which will replace the currently used chlorofluorocarbons (CFCs).

- The measurements of mass accommodation coefficients of radicals on liquid surfaces.

Plans FY 90

- The photolysis pathways for Cl_2O_2 and reactions of ClO with species such as OClO.

- The vibrational line positions and intensities for OH.
- The products of the reaction of HO_2 with NO_2.
- Spectroscopic studies on HOCl and HOBr.
- Mechanisms of the oxidation of atmospheric hydrocarbons and sulfur compounds.

ATMOSPHERIC DYNAMICS

The Atmospheric Dynamics program combines observational and theoretical studies of atmospheric dynamical processes, focusing on internal gravity waves, vertical air motion, and turbulence. Our immediate objective is to improve understanding of these dynamical processes, but the results of our research also contribute to improvements in weather forecasting and the transfer of advanced meteorological measurement technology.

Much of our research is based on data obtained using wind-profiler [also called Mesosphere-Stratosphere-Troposphere (MST)] radars. Such radars can measure wind profiles about 1,000 times faster than routine balloon soundings and they can also directly measure the vertical wind velocity.

Accomplishments FY 89

We continued our systematic studies of the properties of the atmospheric gravity wave field. Using data from our Flatland radar near Champaign-Urbana, Illinois, we showed that over flat terrain the short-period fluctuations in the vertical air velocity are almost entirely due to gravity waves. We also showed that the gravity wave field at short vertical wavelengths is saturated and dissipating at all altitudes, consistent with our earlier model. The acceleration of the wind due to dissipating upward-propagating gravity waves was estimated using data from the Middle- and Upper-Atmosphere radar near Kyoto, Japan. Such accelerations modify the general circulation pattern of the atmosphere and thus modify the weather.

In view of the important effects of gravity waves, we are studying their generation by fronts and convection at the Flatland radar.

Plans FY 90

The second phase of the Flatland radar development will be completed by implementing four oblique beams, in addition to the present vertical beam, so that the horizontal wind as well as the vertical air motion can be measured. A network of sensitive-pressure sensors will be installed in the region around the Flatland radar. These new capabilities will permit a wide range of additional studies.

The most important study will be the first measurements of the vertical flux of horizontal momentum and wind acceleration over very flat terrain. This will permit assessment of the relative contributions to the wind acceleration of flat terrain (which, including the oceans, occupies at least 80% of the surface of the Earth) and mountainous terrain.

The vertical wind velocities measured by the Flatland radar will be compared with those calculated from synoptic-scale measurements. If these studies show that radar-measured vertical velocities are accurate, then many stations in the National Oceanic and Atmospheric Administration (NOAA) Profiler Network could be used to provide vertical velocity measurements to weather prediction models.

We will study the horizontal structure of waves and turbulence by making simultaneous observations with the Urbana MST radar, which is 25 km away from the Flatland radar, and by using the network of pressure sensors.

TROPICAL DYNAMICS AND CLIMATE

The research goals of Tropical Dynamics and Climate are an improved understanding of tropical circulation systems and their impact on global climate. The primary contribution of the Program Area's research lies in the use of remote sensing wind profilers, developed within the Aeronomy Laboratory, to provide continuous information on atmospheric winds in the tropical Pacific. A close link is maintained with programs such as Tropical Ocean and Global Atmosphere (TOGA) that share common objectives.

Accomplishments FY 89

Routine wind observations at Christmas Island were made for TOGA. These observations are used operationally by the world meteorological centers, and monthly summaries of the winds are published in two monthly climate bulletins.

We spectrally analyzed Christmas Island winds and found intra-seasonal oscillations with periods of 10–70 days. The strongest of these is a 60-day oscillation most pronounced during northern winter.

Substantial progress was made in the construction of a trans-Pacific network of wind-profiling Doppler radars. The first phase of a VHF wind-profiling Doppler radar was completed in Piura, Peru. The Pohnpei, Micronesia, wind profiler is being modified and upgraded. We negotiated a research agreement with the Indonesian National Institute of Aeronautics and Space agency that should lead to the construction of a new profiler at Biak, Indonesia.

We continued to develop and field test a highly-portable UHF lower tropospheric wind profiler to complement the VHF wind profilers used in the tropics.

Rawinsonde measurements of temperature in the tropical atmosphere were used to show that the warming associated with El Niño events is easily detected and can be used as a "marker" to trace the spread of the EL Niño influence through and beyond the tropics. An overall warming trend in the tropical atmosphere over the 1966–82 period was established.

Plans FY 90

Our operations at Christmas Island will continue with TOGA funding, six-hourly data will be transmitted via satellite to the scientific community, and the high-time-resolution tapes will be archived at the AL.

We plan to complete the modifications to the Pohnpei wind profiler and complete construction of the wind profiler at Piura, Peru. We expect to begin the installation of a new wind profiling Doppler radar at Biak, Indonesia.

Pending TOGA funding, the 915 MHz lower tropospheric wind profiler will be used as part of a pilot field study for the TOGA Coupled Ocean-Atmosphere Response Experiment. We plan to collaborate with colleagues from the National Center for Atmospheric Research's (NCAR's) Atmospheric Technology Division to operate the wind profiler with other instruments on Manus Island. Observations of lower tropospheric winds will be made for several months to study the phenomenon of westerly wind bursts near the equator. During this expedition we also plan to collect the first shipboard profiler data.

We plan to collaborate on tropical meteorology research with the Australian Bureau of Meteorology's Research Centre. As part of this program, we will install a 50 MHz wind profiler at Darwin, Australia. We also plan to collaborate with the Office of Naval Research and the Naval Postgraduate School in the Tropical Cyclone Motion Experiment. Our contribution will be to operate a wind profiler at Saipan during the intensive field campaign.

We will continue to use the available tropical Pacific rawinsonde data base in studies of coupling mechanisms between the ocean and atmosphere. The role of convection and radiation processes in the coupling will be explored, and the behavior and vertical structure of the El Niño warming at extra-tropical latitudes will be investigated.

THEORETICAL AERONOMY

The Theoretical Aeronomy Program undertakes theoretical studies of important atmospheric problems, constructs and uses computer models of the chemistry and dynamics of the troposphere, and analyzes data collected within the Laboratory or by collaborative experiments. In the past year the principle research activities were focused on problems of tropospheric oxidants and acid rain. The ultimate goal of the program is to attain an understanding of the composition and energy budgets of the atmosphere sufficiently that trends can be accurately predicted.

Accomplishments FY 89

In collaboration with the Tropospheric Chemistry program, we completed a three-dimensional model study of the buildup of ozone pollution over the eastern United States. Results from the model agree very well with the observed values of ozone, ozone precursors, and other key photochemically important species such as PAN, HNO_3, and total reactive nitrogen (NO_y). We used the model to test the effectiveness of various control strategies for rural ozone. Our results show that control of NO_x emission is about three times more effective than control of non-methane hydrocarbons (NMHCs) in lowering the ozone level over rural areas. It is shown that because of the presence of large amounts of natural NMHC, the ozone production is limited by the availability of NO_x.

We carried out a theoretical and modeling investigation of deriving the atmospheric concentration of the most reactive oxidant, the hydroxyl radical (OH), from measured distributions of NMHCs. The investigation resolved the long-standing mystery that the derived OH concentration decreases with the reactivity of an NMHC. Our analysis shows that the phenomenon is caused by the inseparable interaction between atmospheric mixing and photochemical loss in affecting the distribution of an NMHC. As a result, when NMHCs are sampled downwind, a more reactive NMHC will contain more molecules that have been emitted at a later time and/or by a closer source. This study suggests that a puff source release is the more accurate method to derive OH from the distributions of NMHCs.

In collaboration with the Tropospheric Chemistry Program, a study of the effect of biogenic NMHCs on ambient OH concentration was completed. It is shown that the effect is changed drastically by the presence of high levels of anthropogenic NO_x, When only natural NO_x emissions are present, the NO_x level is sufficiently low that biogenic NMHCs can suppress OH in the surface air by more than a factor of five. However, in rural areas of the industrialized countries, the decrease in OH is less than 50% because the photochemical sink of OH is changed drastically by anthropogenic NO_x emissions. Since OH is the most reactive atmospheric oxidant, this may be a potentially serious environmental problem.

Plans FY 90

The research will focus on two subjects: (1) a study of the ozone budget in the free troposphere, in collaboration with the Tropospheric Chemistry Program and (2) a study of the OH photochemistry and distribution, in colla-boration with the Optical Aeronomy and the Tropospheric Chemistry Programs.

OPTICAL AERONOMY

The Optical Aeronomy Program uses spectral measurements of the atmosphere as a tool for studying fundamental atmospheric processes. The center for the observational program is the Fritz Peak Observatory situated in the mountains west of Boulder, CO.

Accomplishments FY 89

Tropospheric OH Radical

Major progress was made in the development of the long path tropospheric OH experiment at Fritz Peak. Long path absorption of UV light is being used to measure spectroscopically the OH molecular absorption between Fritz Peak and Caribou Mine 11 km away. The new 2-m echelle spectrograph completed both laboratory and field tests and exhibits excellent scattered light rejection and spectral resolution greater than 500,000. A new double reticon array detector was developed and tested for use on the spectrograph. The entire detector system was home built and is now operational at the Peak. Preliminary OH abundance determinations were made in early fall 1989 and the system appears to be working well.

Tropospheric Long Path

Recognizing that the chemistry of OH cannot be understood from a single species measurement, we have completed construction of a new long path experiment to measure ozone, water vapor, nitrogen dioxide, formaldehyde, sulfur dioxide, and other molecules over the same long path in the troposphere at the same time OH is measured. A double spectrograph with reticon array detector is used. The system was first used in the AL Niwot Ridge field campaign (July–August 1989) and performed very successfully.

Stratospheric Trace Gases

A program was started to develop a new observing system for measurement of stratospheric trace gases by using spectroscopic absorption of light in the ultraviolet and visible portions of the spectrum. The instruments developed as part of this program will be installed at several global locations as part of a joint NOAA–NASA program for early detection of stratospheric change. The first spectrograph prototype has been constructed in the instrument shop and is now undergoing laboratory testing. A new telescope feeds system is nearing optical design completion.

Stratospheric OH Radical

The ground-based absorption measurements of stratospheric OH continued through FY 89 at Fritz Peak. Measurements were completed at Truk Island in the equatorial Pacific. The average level of OH increased significantly in FY 89 over previous years, and the seasonal behavior of OH was observed to covary with solar activity over the past 10 years.

Plans FY 90

Routine measurements of tropospheric OH are anticipated in FY 90. Full seasonal determinations of ozone, water vapor, nitrogen dioxide, and other molecules in support of the OH experiment are underway. An OH Pesios interferometer will be relocated in Lauder, New Zealand to obtain Southern Hemisphere data. Full-up prototype testing is expected to begin in FY 90 of the new trace gas measurement system.

METEOROLOGICAL CHEMISTRY

The focus of the work in this program is the interaction between meteorological and chemical processes. This interaction is crucial from the point of view of global changes in the chemical composition of the Earth's atmosphere, and is therefore germane to both scientific and policymaking points of view. The program's major foci have been and are (1) the chemical, meteorological and radiative state of the Arctic and Antarctic stratospheric vortices in winter and spring and their interactions with their mid-latitude environs, (2) the flux of air and trace chemicals between the upper troposphere and the lower stratosphere, and (3) the nitrogen oxide and ozone content of the clean Pacific troposphere.

Accomplishments FY 89

Airborne Arctic Stratospheric Experiment (AASE)

There were fourteen flights by the ER–2, and fifteen by the DC–8, into the Arctic polar vortex during January and February 1989 from Stavanger, Norway. The results clearly indicated that denitrification and high levels of reactive chlorine, arising from the presence of polar stratospheric clouds, were present. The potential for ozone loss by the same mechanisms causing the Antarctic ozone hole is thus clearly there, in

any Arctic winter during which the vortex maintains cold temperatures into March, an infrequent but recorded occurrence.

Airborne Antarctic Ozone Experiment (AAOE)

The production of papers from the Punta Arenas mission of August and September 1987 continued, and some were published in the first volume of a two-volume special journal issue in August. A total of sixty-two papers will be published, of which twenty-nine involve Meteorological Chemistry group members, in eleven cases as the first author. This mission, with its more recent Arctic companion, has had a major impact both scientifically and politically.

Mauna Loa Observatory Photochemical Experiment

The analysis of the data and production of papers from this multi-institution experiment, which took place in the summer of 1988, is underway. It will reinforce and modify our understanding of the ozone balance in the clean maritime boundary layer.

Tropospheric Ozone Lidar

The lidar produced its first ozone profiles in the troposphere above Fritz Peak Observatory, CO.

Plans FY 90

Data Analysis

Results from the AAOE, AASE and the Tropical Cloud Mission of the Stratosphere-Troposphere Exchange Project will continue to be analyzed. It is hoped to gain insight into the way the general circulation in the lower stratosphere transports the effects of polar ozone loss to mid-latitudes, and what the implications are of the low tracer mixing ratios in the vortex for CFC lifetimes. This information is important for both recovery times if CFC emissions are stopped, and for the ozone depletion potential of any replacements.

Instrument Development

Preliminary laboratory investigations are beginning into the feasibility of some new atmospheric instruments for measuring key trace species. These are (1) evolution of the NO or NO_y instrument so it is capable of simultaneous measurement of NO, HNO_3 and NO_y, (2) a far-infrared laser magnetic resonance technique for OH and HO_2, (3) a laser ionization aerosol mass spectrometer, which would provide information on chemical composition of particles as a function of size, and (4) a small time-of-flight mass spectrometer to measure molecular hydrogen.

TROPOSPHERIC CHEMISTRY

Accomplishments FY 89

Regional Ozone Production

Ozone is formed in the lower atmosphere by photochemical reactions involving the precursor volatile organic compounds (VOCs) and nitrogen oxides (NO_y compounds). Emissions of these compounds account for ozone abundances that are often higher (e.g., 75–150 ppb) than the natural background (approximately 10–30 ppb) in most populated regions of the Northern Hemisphere. Such high levels of ozone are detrimental to human health and cause crop and vegetation damage. Research has focused on determining (1) the source strength of the ozone precursors, (2) the chemical processes whereby the ozone is formed, and (3) the influence of small- and large-scale meteorological processes on the ozone distribution.

Since the potential role of natural VOCs was noted in experimental and theoretical ozone studies carried out in the AL in the mid-1980s, one of the major research emphases of the laboratory has been the understanding of the chemical and transport processes that influence rural ozone. This requires the integration of field and laboratory studies with theoretical modeling. The contribution of the Tropospheric Chemistry Group has been to develop techniques and instruments that can measure the ozone precursors and the other key photochemically active trace species that shape the chemistry in rural and remote environments, and to use these techniques to measure the species in the atmosphere in rural areas where the ozone levels are high.

During the summer of 1989, studies were carried out at the Niwot Ridge site located in the Colorado mountains. In this study, the emphasis was on the development of new detectors for important trace gases that are associated with the photochemical processing of ozone, since it is recognized that the techniques required to measure the concentration of many of these compounds with the required sensitivity and free of interference in the rural and remote troposphere do not exist. The most important elements of this study were intercomparisons between different techniques simultaneously measuring the same species: (1) hydrogen peroxide and organic peroxides using an enzymatic fluorometry technique being developed at the AL and a high performance liquid chromatographic technique being developed at NCAR; (2) gas chromatography of organic nitrates using direct injection being developed at the AL and a charcoal preconcentration method being developed at Texas A&M University; (3) aldehydes and ketones involving gas chromatography being developed by the AL and a derivatization technique being developed at Washington State University; (4) measurement of nitrate using the filter collection technique developed at the AL with an aqueous-stripping technique being developed at NCAR. In addition, a second field test of the direct injection, gas chromatographic measurement of non-methane hydrocarbons developed by the AL was completed.

Global Ozone Production

Ozone plays two very important roles in the troposphere: (1) ozone controls tropospheric photochemistry, and (2) ozone is an important greenhouse gas. For these reasons, it is important to understand the processes that shape ozone on a global as well as a regional level. An improved understanding of the processes requires a comprehensive set of measurements of ozone and its precursors in the remote free troposphere. Such a set of measurements were made at the Mauna Loa Observatory that is operated by the Air Resources Laboratory of NOAA. This site is located at an elevation of 11,000 ft on the island of Hawaii. Much of the time the air sampled at this site was characteristic of the remote free troposphere. These measurements were made in collaboration with the Atmospheric Chemistry Division of NCAR. The AL provided the key measurements

of NO, NO_2, NO_y, HNO_3, and nitrate particulates. From the standpoint of measurement capability, this study was notable for the very low levels of ozone precursors that were successfully measured.

Biosphere Atmosphere Exchange

As noted above, the oxides of nitrogen, NO_x, play a key role in the formation of ozone and other oxidants. One of the principal natural sources of these compounds is emissions of NO_x from solids as a byproduct of natural biogenic activity. Although this is an important natural source, at present it is poorly characterized. During the summer and fall of 1988, emissions of NO_x from soils were measured at sites representative of large land areas in the continental United States: (1) a short-grass prairie in northern Colorado which is typical of the Great Plains, (2) a coastal marine-estuarine site in South Carolina, and (3) an oak-hickory forest site in Tennessee typical of the eastern hardwood forests of the United States. NO_x emission rates were greatest at the prairie site. The NO_x emission was much lower at the forest site and negligibly small at the coastal site. These results indicate those regions where natural emission of NO_x from the soils may be a significant source of the NO_x that is entering the atmosphere.

Evaluation of Measurement Capability

A key element in the development of an understanding of atmospheric photochemistry is the ability to make unequivocal measurements of the photo-chemically active trace compounds. It is vital to have reliable estimates of the uncertainties in the measurements, since they are the touchstones against which theoretical understanding is tested. In recent years, the atmospheric chemistry community has devised a way to address measurement uncertainties in an arduous but effective way: formal, rigorous, and unbiased inter- and intra-method comparisons of the techniques and instruments. The AL has assumed a leadership role in the intercomparisons. During the past year, the AL hosted such an intercomparison aimed at evaluating the techniques currently used to measure ammonia.

Ammonia is thought to be emitted in copious quantities from natural biogenic sources. Presently it is thought that sufficient quantities of ammonia are introduced into the atmosphere from these sources to significantly influence both atmospheric chemistry and acid deposition, and that the amounts are increasing with time. However, the amount of ammonia emitted into the atmosphere on regional scales, and hence its role in atmospheric chemistry, is quite uncertain.

That ammonia remains one of the least well-characterized atmospheric species relevant to atmospheric chemistry is largely due to technical difficulties in measuring ammonia. However, new techniques are emerging that hold considerable promise for ammonia measurements. In order to establish the capability of these new techniques, a double-blind intercomparison of these instruments was held in Boulder. The intercomparison involved six techniques: two filter and one acid-coated denuder tube, all three with ion chromatograph analysis of the extract; a molybdenum oxide annular denuder tube and a tungsten oxide denuder tube, both with chemiluminescence detection of NO; and photofragment-two photon-laser induced florescence. The instruments were tested sampling synthetic air with spikes of NH_3 and suspected interferants, whole air from a common manifold, and ambient air through independent manifolds. The results of the intercomparison are currently being assessed by the intercomparison referee.

Plans FY 90

At present, there is still substantial debate concerning the relative importance of anthropogenic VOCs vis-a-vis natural VOCs in the production of rural ozone. Although the measurements made by the AL at Scotia, PA, represent the most comprehensive study to date of the photochemistry of the rural atmosphere, it must be remembered that this is a single location. Before the tentative conclusions drawn from that study can be generally accepted, more measurements in other regions of interest must be done. For this reason, the AL is proposing a comprehensive study of the photochemistry in the southeastern United States. This new program, Rural Oxidants in the Southern Environment, will involve the measurement of the photochemical trace compounds, determination of the rate of emission of the NMHC from the forests, and, using the capabilities of the Theoretical Aeronomy Group, model simulation of the concentration of ozone and its precursors.

MIDDLE ATMOSPHERE STUDIES

The objective of the Middle Atmosphere Studies Program is to undertake theoretical and field studies aimed at a fuller understanding of the chemistry and transport processes taking place in the Earth's middle atmosphere (approximately 10 to 100 km). The field program is based primarily on acquisition and interpretation of optical data at sites such as McMurdo Station, Antarctica, and Fritz Peak, CO. Particular emphasis is placed on further understanding the effects of chemistry and transport on the distributions and variability of trace species in the stratosphere and mesosphere. The special ozone chemistry of polar regions is a major research focus.

Accomplishments FY 89

Field Measurements

NO_3 plays an important role in the nitrogen chemistry of the stratosphere, which is in turn critical to the abundance and stability of the stratospheric ozone layer. Previous observational studies of stratospheric NO_3 suggested that an unidentified "scavenger" might selectively remove this species, casting doubt on the understanding of its sources and sinks. We have demonstrated that NO_3 is not scavenged in the Earth's stratosphere. Rather, attempts to observe this species using absorption of incoming lunar light must account carefully for a previously unrecognized overlap between the absorption of light due to water vapor and that due to NO_3. The elucidation of this observational problem resolves a long-standing and important issue in stratospheric research.

Observations of Antarctic ozone have revealed large fluctuations in the extent of ozone depletion from one year to another. For example, the Antarctic ozone depletion of 1987 was particularly severe while that of 1986 was much less pronounced. It is now well established that the bulk of the Antarctic ozone depletion is due to chlorine chemistry, which is particularly enhanced in Antarctica due to reactions on polar stratospheric cloud surfaces. We have participated in a joint study with scientists from the NASA Langley Research Center that examined some of the causes of variations in Antarctic ozone depletion in detail. Interannual variations in the abundance and persistence of polar stratospheric clouds obtained from satellite observations were shown to agree well with the observed changes in ozone. These in turn were found to be

in good agreement with seasonal and interannual changes in the abundances of OClO obtained from our own measurements at McMurdo Station, Antarctica.

Stratospheric and Mesospheric Modeling

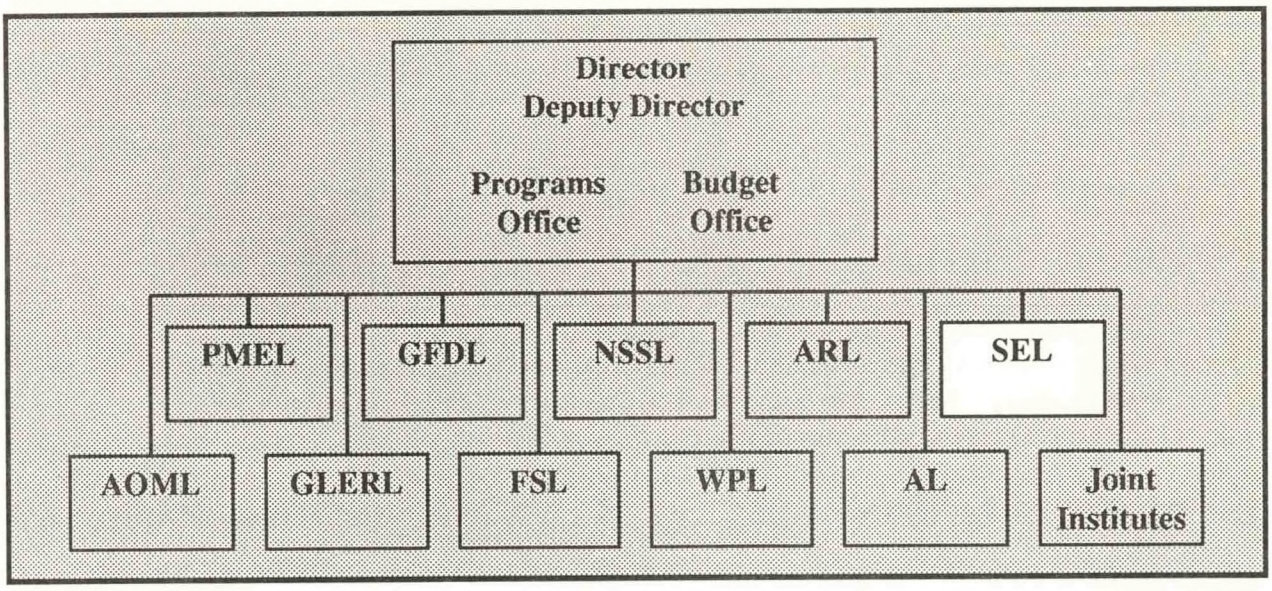
In recent years, increased emphasis has been placed on understanding the detailed seasonal and latitudinal variability of stratospheric ozone. One means of evaluating such variations is to consider the annual and semi-annual components of the ozone abundance. We evaluated these terms using our two-dimensional dynamical-chemical model of the middle atmosphere. These were shown to compare well with observations analyzed in a similar fashion. Further, use of the model allows for detailed interpretation of the origin of annual and semi-annual changes in ozone abundance.

In collaboration with scientists from the United Kingdom Meteorological Office and NASA's Langley Research Center, we participated in the theory team for the AASE during January and February 1989. A coupled cloud microphysics and photochemistry model was constructed for use along air parcel trajectories, allowing study of the chemical changes associated with exposure to stratospheric clouds and the subsequent ozone chemistry. This provided a major tool for understanding and interpreting AASE observations of ClO, NO, and other trace constituents, and evaluating their implications for ozone destruction in the Arctic.

Plans FY 90

Both observational and theoretical studies will continue. Near-term observational studies will focus on understanding the chemistry of stratospheric NO_3, making use of the Fritz Peak Observatory as the observing site. Preliminary measurements suggest that observations of NO_3 carried out during sunrise provide a unique means of determining not just the overhead column abundance of this species, but its detailed vertical profile. This study represents a new approach to ground-based observations of some stratospheric species. Another area of primary interest is the study of light scattering and its implications for our measurements.

Several theoretical projects are also in progress. A major focus is the further interpretation of coupled heterogeneous and homogeneous chemistry along air parcel trajectories. This modeling approach is of particular importance in considering the possible ozone loss in the Arctic stratosphere both in 1989 and in other years.



SPACE ENVIRONMENT LABORATORY
Boulder, Colorado
(303) 497–3311
Ernest Hildner, Director

Activities of the Space Environment Laboratory (SEL) are directed toward understanding, monitoring, and forecasting solar and geomagnetic events that have undesirable, harmful, and costly effects on activities on and near Earth, and that may even be health or life threatening. SEL activities encompass real-time collection of solar-terrestrial data; dissemination of indices and a portion of these data; issuance of forecasts, alerts, and warnings of adverse solar-terrestrial conditions; archiving and processing of global data from satellites and observatories; and development of a better understanding of the behavior of the solar-terrestrial environment to yield significant service improvements.

SEL is composed of three divisions: Space Environment Services, Research, and Systems Support. Space environment services are provided by the Space Environment Services Center (SESC), the center of the Nations solar-terrestrial services. Operated jointly by SEL and the U.S. Air Force Air Weather Service in Boulder, CO, SESC provides real-time monitoring and forecasting services to meet a wide variety of civilian, military, commercial, and Federal agency requirements. As solar activity rises toward the maximum of the next cycle, now expected to occur in the first half of FY 90, the demand for SEL's services is rising rapidly.

Research and development are carried out in all three divisions. The Research Division carries out research with the dual objectives of improving our understanding of the effects of solar and magnetospheric disturbances on human activities and improving our capabilities to forecast and analyze these events. Research Division staff also serve as the responsible scientists for the real-time detector systems that support the Laboratory's space environment services. The Systems Support Division plans, develops, and supports instrument and data systems. Research in the Services Division includes forecast verification and the development of forecasting algorithms.

SPACE ENVIRONMENT SERVICES

Accomplishments FY 89

SESC Operations

SESC, the national space weather service which is operated jointly by NOAA and U.S. Air Force personnel, maintains a continuous, up-to-the-minute watch on storms and disturbances in the solar-terrestrial environment. It receives observations from other Federal agencies as well as public and foreign institutes. The data are sent in real time to SESC, where they are used to monitor key variations in solar activity, solar radiation, and the effects on Earth's environment. Indices are compiled, activity is summarized, and forecasts are made. These products are issued to programs whose activities are affected by such variations in space weather. SESC functions as the World Warning Agency for the International URSI-gram and World Day Service, operated under the aegis of the International Council of Scientific Unions, to provide international exchange of space weather data and daily forecasts. The following sections describe highlights of space environment services provided in 1989 and plans for the coming year.

Some of the biggest and most severe solar-terrestrial events on record occurred in FY 89, including the third largest geomagnetic storm on record and the largest solar energetic particle event since 1972. The impact and extent of the disturbances were so severe that our response to inquiries from customers strained available resources. The March activity resulted in an electrical power outage in Canada, while the August activity produced an increased radiation dose to astronauts on Shuttle Mission STS–28. An extremely intense energetic particle event in late September produced increased radiation doses for passengers on board commercial SST flights at high latitudes.

Solar Cycle 22, which began in September 1986, continues to rise rapidly; it is currently projected to be one of the largest on record. To assist customers whose operations are affected by the extreme conditions in this large solar cycle, several new products and services were developed in FY 89.

A survey of SESC customers and their requirements resulted in streamlining of service and products, and termination of little-used products. New products and services available to users include a new daily report of the solar corona and solar cycle predictions. Among the special projects supported were rocket launches, the National Aeronautics and Space Administration (NASA) shuttle, the Solar Maximum Mission (SMM), and Max '91 (a program defined in the section on SEL research).

On-Line Services Group Operations

Requirements for an upgrade of the SEL Data Acquisition and Display System (SELDADS II) were written, and funds were received to start replacing two aging subsystems: the preprocessors, where raw data is ingested and processed, and the real-time monitors, where the data are displayed. There were 61 new application processes implemented in SELDADS during the year. Of these packages, 33 constitute the Air Force Global Weather Central backup package, which allows Air Force products to be issued from SELDADS.

A new Geostationary Operational Environmental Satellite (GOES) ground station was installed at the Broadway site in Boulder, CO, and it has become our primary receiver system.

The satellite broadcast system provides data and forecasts to customers in real time. A Request for Proposals for continuing this was issued, resulting in a 40% reduction in cost from the previous contract. The receivers, purchased by the customers of this service, have undergone a 20% reduction in cost.

Geomagnetic Services Development

Initiated in FY 89, the Solar Coronal Disturbance Report specifically addresses the problem of geomagnetic storm forecasts; it is issued daily at 0200 Universal Time. It reports those solar observations; it is particularly associated with interplanetary disturbances, including long-duration solar x-ray events, filament disappearances, and coronal holes. Actual satellite observations of coronal mass ejections (CMEs) are appended to the message.

An important improvement to Geomagnetic Services in FY 89 was the implementation of an operational verification data base with an on-line forecast evaluation scheme. Forecasters can now compare their individual performances with those obtained by climatology and persistence, and SESC as a whole. The physical factors (flares, coronal holes, etc.) leading to successful or unsuccessful forecasts can now be better analyzed.

Technique Development

The 10.7-cm solar flux parameter is of particular use in predicting satellite drag and, ultimately, mission lifetime of low-Earth-orbiting space craft. Techniques were developed in FY 89 that use exploratory data analysis to organize past data and project it into the near future. These techniques are used to monitor and predict the altitude of the Long-Duration Exposure Facility, a low-orbiting satellite scheduled for shuttle retrieval in mid-December 1989.

The U.S. Air Force is funding development of operational models that incorporate state-of-the-art understanding of the ionosphere, the magnetosphere, and the neutral atmosphere above 90 km. These models will be implemented at the Space Forecast Center in Colorado Springs, CO, and the results will be routinely available to SESC. SEL and SESC personnel have participated in the design review boards monitoring the progress of those models, which represent a major step forward in organizing geophysical observations and in quantifying our understanding of the solar-terrestrial environment.

Plans FY 90

SESC Operations

- Implement improved verification system. Through a contract with verification experts, make available space environment climatology and additional numerical guidance as well as the ability to monitor and interpret their verification scores on a near-real-time basis.

- Analyze the results of the recent customer survey, and take action as needed to improve products and service.

- Review and implement changes in delivery systems (teletype, telephone, facsimile, etc.).

On-Line Services Group Operations

- Upgrade SELDADS by purchasing and developing the new preprocessor and real-time monitor network.
- Automate control of the solar telescope in the Boulder Observatory.
- Assess the benefit of continuing the Satellite Broadcast Service.

Geomagnetic Services Development

- Begin receiving data via Internet from the new global geomagnetic data network run by U. S. Geological Survey. This service will expand our present capabilities for real-time data exchange with Europe, Asia, and Africa. Potentially up to 70 observatories could be connected, making accurate global geomagnetic indices an operational reality.

Technique Development

- Develop an improved algorithm and associated displays for GOES electron data.

RESEARCH

Accomplishments FY 1989

Ionospheric Studies

During FY 89, a book was completed that gives an up-to-date account of the effects of the ionosphere on radio waves, from extremely low to super-high frequencies, and the associated solar-terrestrial physics.

Topside ionospheric electron density data were used to improve the ionospheric conductivity and electron density model by comparing observations with calculations. Topside ion models of ionized atomic oxygen were found to be inconsistent with observations, and it appears that hydrogen ions are much more important above about 600 km than is usually assumed.

Atmospheric-Ionospheric-Magnetospheric Interactions

The objectives of research in the Atmospheric-Ionospheric-Magnetospheric Interactions are to understand the transfer of energy (in the form of both electrical and mechanical energy) from the magnetosphere into the upper atmosphere, and to understand and characterize the various possible consequences in the Earth's ionosphere and upper atmosphere.

A time-dependent calculation was performed to study dynamical and compositional responses of the thermosphere to auroral disturbances. The main result indicated that during auroral disturbances the radiative cooling by nitric oxide (NO) is greatly enhanced by the increase in NO number density as well as by the temperature increase.

Magnetospheric Physics

The objective of the Magnetospheric Physics Project is to improve our understanding of dynamical processes that influence the transfer of energy from the solar wind and interplanetary space into the magnetosphere, storage of energy within the magnetosphere, and dissipation of energy from the magnetosphere into the Earth's atmosphere or back into interplanetary space via the Earth's geomagnetic tail. Improved understanding of magnetospheric processes will lead to improved forecasts of geomagnetic activity and its consequences.

A cooperative study of strong compressions of the magnetosphere to within geostationary orbit (6.6 Earth radii) was initiated with scientists from the Los Alamos National Laboratory. This study will better define the response of the magnetosphere to solar wind conditions responsible for causing the compression.

In FY 89, we investigated the role of chaos (extreme sensitivity to initial conditions) in the structure and stability of the geomagnetic tail. Chaos probably plays an important role in the acceleration of particles as well as the substorm process. The near-term goal is to calculate ion diffusion, which could be compared with low-altitude proton precipitation observations.

A ridge structure, predicted from earlier theoretical work, was found in energetic ion data by instruments aboard the International Sun Earth Explorer-1 (ISEE–1). This result suggests that energetic ion observations can be used as remote probes of the geomagnetic tail structure.

Data obtained by the ISEE–3 spacecraft during its journey through Earth's distant geomagnetic tail in 1983 were studied under a wide range of geomagnetic conditions. Evidence was found for the persistence of reconnection of the magnetic field in Earth's distant geomagnetic tail (more than 1,000,000 km from Earth).

As a result of ISEE–3 observations, four types of magnetic phenomena were considered candidates for producing the north-then-south magnetic field perturbations characteristic of plasmoids observed in the distant magnetotail. A new plasmoid characteristic noted here is the presence of intense magnetic fields within the plasmoid that can exceed the magnitude of the surrounding lobe field.

NASA/Johnson Space Center (JSC) reiterated their need for close radiation support during the current space shuttle missions. An analysis of Television and Infrared Observation Satellite (TIROS)/NOAA data obtained during the high-inclination, August 1989, shuttle flight, STS–28, indicated that the shuttle would encounter considerably enhanced fluxes of energetic particles. Examination of the onboard dosimeters by NASA/JSC revealed that the radiation levels did, indeed, increase significantly during this flight. We have started to analyze the variable energetic particle cutoff latitudes and auroral oval positions for methods of improving our forecasts of radiation levels found at various geographic latitudes.

Interplanetary Physics

The objective of the Interplanetary Physics project is to improve forecasts of the occurrence, duration, and severity of geomagnetic storms. The strategy to accomplish this goal is (1) to develop methods of monitoring disturbances from their generation at the Sun through their travel toward Earth, and (2) to develop, test, and implement physically based, numerical, magnetohydrodynamic (MHD) models that would be driven by real-time solar observations and checked by monitoring interplanetary and near-Earth observations.

The major solar flares and major geomagnetic storms during solar minimum in early February 1986 presented an opportunity to conduct a number of tests of the 2 1/2-dimensional interplanetary global model (2 1/2–D IGM). Earlier comparisons of the model with solar wind data were extended in FY 89 through an extensive parametric study of forward and reverse MHD shocks, their signatures at 1 astronomical unit (AU), and their characteristics at and within 1 AU. These characteristics were also examined as a function of the solar flare energy input. By assuming that several solar flares had a substantially longer period of energy input to the solar wind than that assumed earlier, an improved match with actual and inferred solar observations was obtained.

We continued the study of our 3–D IGM by conducting three numerical experiments. The first experiment incorporated the injection of a simulated, solar-generated, spherical section of plasma into a unipolar, hemispheric solar wind flow. Shockwave formation and draping of the interplanetary magnetic field (IMF) was clearly demonstrated.

The second experiment incorporated a single, simulated, solar-flare-generated shockwave that propagates into a heliospheric solar wind containing a flat current sheet. We observed that a plasmoid was formed by the reconnection of opposite-directed interplanetary magnetic field lines. This is thought to be a result of numerical diffusion.

The third experiment closely associates the 3–D IGM with SEL's interplanetary scintillation (IPS) program. In this experiment, the solar wind density output from the the model was used to generate a simulated "all-sky" map similar to those developed by the IPS group in England.

Solar Physics

The Solar Physics project studies the nature of solar activity, its origins, and its evolution, to provide the new fundamental knowledge needed for improving predictions of solar-terrestrial disturbances. The structure and evolution of the solar corona is studied to help improve forecasts of medium- and long-term solar activity. Analysis of x-ray wavelengths is used to improve forecasts of solar disturbances that originate in the highest level of the solar atmosphere.

In collaboration with colleagues from Lewis & Clark College, Oregon, and the University of Sydney, Australia, a model of polarity reversal of the magnetic field at the Sun's north and south poles was developed in an effort to construct a new model of the solar cycle. A detailed record of the course of the current, rising Solar Cycle 22 was maintained.

During Solar Cycles 20 and 21, scientists noted a gradual migration of flares from northern to southern latitudes on the Sun. Our recent studies of solar cycle records revealed that the north-south evolution is dependent on flare intensity as well as solar cycle: the more intense the flare, the higher the initial latitude and the larger the rate of north-to-south drift. These studies confirm the hypothesis that a coherent global structure splits the spatial distribution of solar active regions into relatively quiet and "super-active" regions.

The strongest solar magnetic fields are found in the relatively dark, roughly circular umbra of a sunspot, which has a lighter surrounding region called the penumbra. In an FY 89 theoretical study of unipolar sunspots, it was shown that the amount of magnetic flux returning to the photosphere vs. the amount of umbral flux on open field lines is directly related to the relative sizes of the umbra and penumbra. A recent study using the Return-Flux theory demonstrates that the Wilson Depression (the deepening of the Suns surface at the center of a sunspot) can be estimated analytically from the measured radial magnetic profile near the photosphere. These estimates compare favorably with optical determinations of the Wilson Depression for the same sunspot.

A study was begun to analyze the evolution of solar active regions in an effort to improve 2–7 day flare forecasts. The software for this project, called TELSAR [Tracking and Evolution of Solar Active Regions],

was developed in cooperation with students from the University of Colorado. TELSAR analyzes archived solar active region classifications to determine whether or not a given active region is likely to produce flares.

Forecasters in SESC and elsewhere around the world have been classifying sunspots, seen near the Sun's surface, according to the McIntosh classification scheme. This year the authoritative manuscript on this system was published.

An FY 89 study of a solar eclipse observed by the x-ray sensors on GOES led to an improved method for deriving flare properties. We conclude that the two common assumptions, either including or subtracting the entire preflare flux of x-rays, do not always limit the flare properties and may give derived flare properties that evolve differently from those derived from spatially resolved instruments. This led to a new method that essentially inverts the problem and assumes that the spatially resolved behavior is correct.

We confirmed in FY 89 that very-high-temperature flares are associated with a very small number of active regions that tend to recur at similar heliospheric latitudes. This suggests the possibility of fixed "hot spots" on the Sun.

Improvements to forecast capability resulting from the proposed Solar X-ray Imager (SXI) were explained and advocated at various scientific and technical meetings during FY 89. Air Force funding for SXI is expected to become available in FY 90.

A Large-Angle Spectrometric Coronagraph (LASCO) was proposed by the Naval Research Laboratory, leading a consortium that included SEL, to NASA and European Space Agency for flight on the Solar and Heliospheric Observatory Mission. It has been accepted for flight, pending adjustments to payload weight constraints.

During FY 89, a peculiar distribution of flare maximum emission with respect to maximum flare x-ray flux was found to hold for flares observed in Cycle 22, as had been shown for Cycle 21.

Max '91 is a coordinated effort to study solar flares during the present solar maximum. The program is jointly funded by NASA and the National Science Foundation for the development of long-duration balloon payloads and new, ground-based instrumentation. SEL provides real-time solar data to enhance observational efforts, as well as computer services, communications, and a base for operations. The first Max '91 observing campaign was held from 16 June through 2 July 1989. Campaign observations were directed from SEL, and scores of observatories were notified daily of solar activity and target selections.

Plans FY 1989

Ionospheric Studies

- Complete a global survey of the thickness of the ionosphere; construct global maps of the ionospheric total electron content; complete the inclusion of hydrogen into the model.

Atmospheric-Ionospheric-Magnetospheric Interactions

- Expand the current work utilizing TIROS/NOAA estimates of the power deposited in the terrestrial atmosphere by precipitating particles. The derived estimates will be used as input to models capable of predicting the dynamical and compositional response of the thermosphere and ionosphere during perturbed conditions.

- Expand present TIROS/NOAA data base by creating a similar synoptic data base using >30 keV data.

Magnetospheric Physics

- Continue the scientific oversight of data from particle and magnetic field instruments on GOES and NOAA operational spacecraft; monitor progress on development of instruments for the next group of spacecraft.

- Investigate frequency spectra of geomagnetic field data measured by NOAA/GOES satellites at geosynchronous orbit.

- Study the feasibility of assessing geomagnetic cutoff energies for operational use in estimating radiation hazard in space and at aircraft altitudes.

- Continue chaos studies; develop a theoretical model of particle/chaos diffusion, and compare with numerical results and with observations.

- Develop a magnetotail model, and study the resulting particle distribution functions within the magnetotail current sheet. Compare with observations obtained from NASA's ISEE mission.

- Continue to seek solutions of radiation hazard to humans in space, using shuttle data and analyzing particle cutoff latitudes and auroral oval positions.

Interplanetary Physics

- Review and document the benefit to operations of having real-time solar wind monitor.

- Examine the characteristics of solar energetic particle events observed to date in Solar Cycle 22 in comparison to events observed in earlier cycles.

- Begin assessment of the 2 1/2–D IGM for use as an operational model. It would be used to predict the solar wind conditions expected at Earth. Extend the existing parametric study of shock characteristics to include the erupting and co-rotating phases of high-speed streams from coronal holes.

- Examine, in more detail, plasmoid formation and shock propagation at the heliospheric current sheet. Develop in-house capability to generate synthetic all-sky IPS maps.

Solar Physics

- Collaborate with IPS Radio and Space Services, Sydney, Australia, on methods for long-term prediction of solar flares through the study of large-scale patterns in active-region formation and evolution of coronal holes through a full 11-year solar cycle. Study the cause of the x-ray line shifts and line broadenings observed during the rise phase of solar flares.

- Study conditions within the Sun which manifest as a saw-toothed (two- to five-cycle) pattern of sunspot number maxima, with a view to improving long-term solar cycle predictions.

- Continue adding maps to the 25-year archive of H-alpha synoptic charts; revise maps made during sunspot minimum in 1976 to improve data quality. Rewrite existing computer codes to allow improved plotting, data array generation, and easy transport to other computer systems.

- Search for unique properties of active regions that produce the hottest solar flares. Participate in computer simulation study of active-region magnetic fields, introducing MHD effects to a kinematic model of magnetic-field dissipation. Continue testing the TELSAR software, and analyze a portion of archived active-region data. The results of this study will be used to investigate improvements in 2–7 day flare data provided by including evolutionary statistics rather than assuming regional persistence.

- Monitor high-temperature flares during the current cycle, to determine if a group of high-temperature events follows a pattern similar to that observed in the previous cycle. If this coherence appears to exist, seek corroboration of the "hot spot" hypothesis in other data types.

- Develop SXI intrument procurement plans in response to the GOES I–M program difficulties.

- Help establish instrument calibration and checkout procedures for the LASCO coronagraph. Develop science programs for this instrument, and pursue the possibility of obtaining real-time data from C3 (outer corona) instrument.

- Examine the maximum flare emission power law theoretically in an effort to determine (where field containment equals thermal energy density) the critical relationship between field strength and containment volume, and how this relationship bears on other quantities (e.g., plasma density) that may be verifiable through observations.

- Continue Max '91 campaign activity, and expand to approximately four campaigns per year by the end of 1991.

- Analyze daily background x-ray flux data for forecasts of the later secondary (coronal) flux maximum.

- Study the effects of CMEs on the structure of the solar corona.

SYSTEMS SUPPORT

Accomplishments FY 1989

Operational Satellite Instrumentation

SEL continued to supervise the contract for the Space Environment Monitor (SEM) systems for the TIROS/NOAA K–M spacecraft, which will fly in the early 1990s. The preliminary design review was held in March, and the initial design was judged to be satisfactory. The contractor is now well on the way toward completion of the design phase.

Work continued on the modification of the existing total energy detector instruments in an effort to avoid the spurious data problem encountered with that instrument on NOAA–10. Calibration of a modified instrument gave satisfactory results.

SEL supported the GOES I–M program by participating in management and technical reviews for the spacecraft system, as well as for the individual SEM instruments. Work continued in preparation for the start of instrument development for the SXI, which is expected to be funded by the Air Force in FY 90 for flight on later GOES satellites.

SEL Scientific Work Station System

The SEL system now contains a high proportion of older work stations. These units require high maintenance costs and can marginally accommodate growth in system software. A plan was developed in 1989 to replace some of these older units during FY 90 without increasing overall costs. The scientific work station system is a major resource for SEL staff for interactive scientific computing and desktop publishing.

During FY 89 a committee was charged with preparing a plan for the future of SEL's computing environment in the 1990s. It was deemed necessary to evaluate our needs within the evolution of the computer marketplace, where high-end personal computers are taking over some tasks previously requiring work stations, and high-end work stations are rivaling mainframe computers for some applications.

Artificial Intelligence Technique Development

Work on the Scientist's Workbench System, which runs on the scientific work stations, was completed. The Workbench is intended to provide a uniform environment for the analysis and correlation of scientific data from disparate data bases by using object-oriented programming techniques.

Work by SEL collaborators at the University of Colorado resulted in a very promising implementation of THEO using neural network technology. THEO is a system (named after Theophrastus, the first astronomer to identify a sun spot) using white-light sunspot data for predicting solar flare probabilities, which is currently implemented using a rule-based expert system.

Wide-Area Networking

Wide-area computer networking is now very important to SEL as a means of communicating between cooperating scientists and institutions, disseminating SEL data, and acquiring data from other institutions and data centers.

In January 1989, SEL installed a MicroVAX computer system, funded by the NASA SMM project to provide an SEL interface to the NASA Space Physics Analysis Network communication network.

SEL led a cooperative effort to interconnect the local networks of the three DOC agencies in Boulder, and, with assistance from NASA, implement a link to the NASA Internet gateway at the National Center for Atmospheric Research (NCAR) in Boulder.

Interplanetary Scintillation Observations

In collaboration with the Interplanetary Physics group, work continued to reactivate the 3.6-hectare array at the Mullard Radio Astronomy Observatory (MRAO) of Cambridge University, England. Data from this system show promise of significantly improving our ability to predict geomagnetic disturbances caused by the arrival of solar-wind density disturbances.

Collaboration also continues with the group constructing a similar observing system at the Physical Research Laboratory in Ahmedabad, India, with Indo-U.S. funding. Data communications with Ahmedabad are being tested.

A study was undertaken to understand how the 2–D, all-sky scintillation maps can be used to infer the most probable 3–D structures of solar wind disturbances, their velocities, and their arrival times at 1 AU. In the first phase of this study, a computer program was developed to map onto the celestial sphere the intersection of lines of sight from Earth, with solar wind disturbance fronts propagating outward from the Sun. This study has disclosed many of the complexities of interpreting the all-sky scintillation maps.

Plans FY 1989

Operational Satellite Instrumentation

- Continue contractor and subcontractor reviews of the GOES I–M and the NOAA K–M programs to develop and fly SEM systems. Support the specification and contractor selection for the GOES SXI when Air Force funding is received.

SEL Scientific Work Station System

- Complete the replacement of first-generation work stations and the conversion to full Unix compatibility.

- Start work on extending the present H-alpha solar image processing system to automate the analysis of images and the preparation of daily maps.

Artificial Intelligence Technique Development

- Complete the initial evaluation of neural net and other experience-based reasoning systems for solar-terrestrial prediction.

Wide-Area Networking

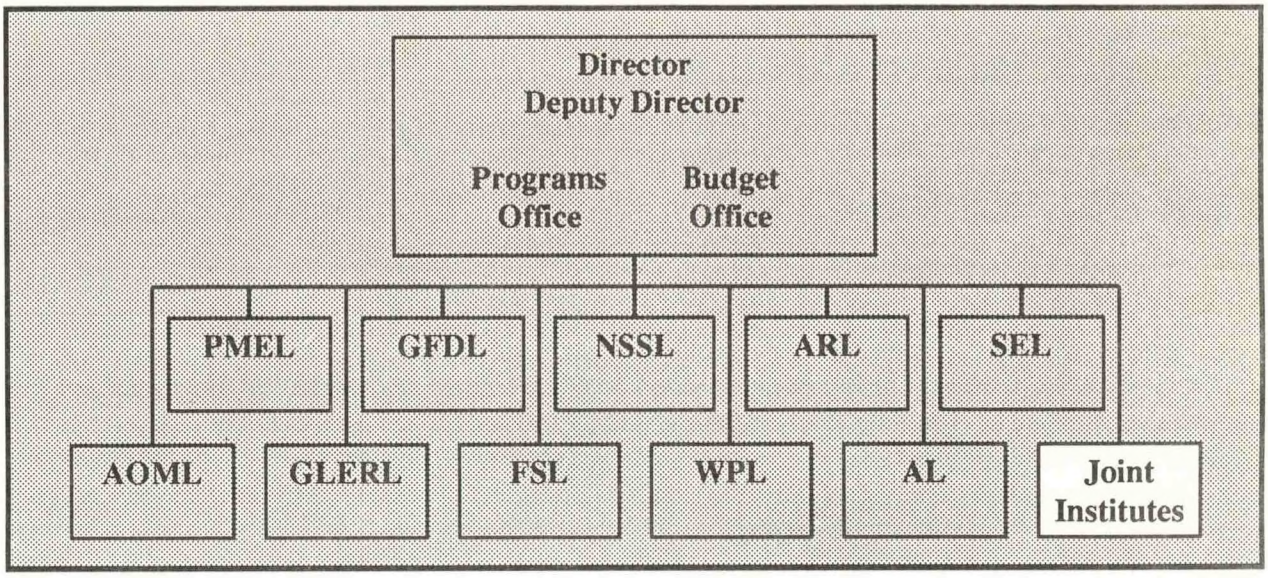
- Complete the integration of the SEL network into Internet through the NCAR network link. Unify the electronic mail systems from the various networks.

Interplanetary Scintillation Observations

- Completed the real-time software and work with MRAO to initiate the flow of data and develop interpretation techniques.

- Complete the Ahmedabad communication tests, and agree on the method to be used for data transmission to SESC.

- Begin near-real-time analysis of IPS all-sky maps for developing and testing geomagnetic forecasting techniques. Continue studies of scintillation caused by simulated solar wind disturbances.



JOINT INSTITUTES

The Joint Institutes Program (also referred to as the Cooperative Institutes) establishes formal, collaborative research agreements between the Environmental Research Laboratories (ERL), through the Office of the Director, and participating universities. The purpose is to increase the effectiveness of research and the quality of education in the environmental sciences by facilitating cooperation between government and university science. The Institutes have been a valuable vehicle for technology transfer in the many areas of atmospheric, oceanic, solar environment, and near-space research while also serving as a focal point for multidisciplinary collaboration of research works from local areas, the Nation, and the world. Collaborating agencies have included Department of Defense, Department of Energy, Department of the Interior, National Marine Fisheries Service, National Weather Service, National Aeronautics and Space Administration, National Center for Atmospheric Research, U.S. Geological Survey, National Geophysical Data Center, and National Environmental Satellite, Data, and Information Service. In August 1989, ERL established a new Joint Institute with the ERL Great Lakes Environmental Research Laboratory (GLERL) and the University of Michigan. The Cooperative Institute for Limnology and Ecosystems Research (CILER) at Ann Arbor, Michigan, was established with NOAA through a Memorandum of Agreement. Their proposed research will be incorporated into the NOAA system in FY 90. ERL has seven Joint Institutes at present:

- CIRES (University of Colorado)
- CIRA (Colorado State University)
- CIMMS (University of Oklahoma)
- CILER (University of Michigan)
- CIMAS (University of Miami)
- JISAO (University of Washington)
- JIMAR (University of Hawaii)

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

Boulder, Colorado
(303) 492–7943
Robert E. Sievers, Director

The University of Colorado and the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA) jointly sponsor the Cooperative Institute for Research in Environmental Sciences (CIRES) as a mechanism to foster collaborative research ventures between university and NOAA personnel and to train graduate students and young postdoctoral scientists in the sciences of the environment. Active collaborations during FY 89 at CIRES involved seven ERL Laboratories in the broad program areas of atmospheric and climate dynamics and environmental chemistry and biology. These laboratories were the Aeronomy Laboratory (AL), the Air Resources Laboratory (ARL), the Forecast Systems Laboratory (FSL), the National Severe Storms Laboratory (NSSL), the Pacific Marine Environmental Laboratory (PMEL), the Space Environment Laboratory (SEL), and the Wave Propagation Laboratory (WPL). Additional research at CIRES, not directly related to ERL missions, occurs in the program area of solid earth sciences. This report concerns CIRES activities in the first two of these program areas as well as in its centers of relevance to ERL, the Center for the Study of Earth from Space (CSES), the World Data Center-A for Glaciology [Snow and Ice] (WDC–A), and National Snow and Ice Data Center (NSIDC).

The Council of Fellows comprises the senior scientific staff at CIRES; its membership includes both NOAA and university personnel. University faculty on the Council represent eight academic deparments: aerospace engineering sciences; chemistry and biochemistry; environmental, population, and organismic biology; geography; geological sciences; electrical and computer engineering; mechanical engineering; and physics. In addition to a Fellow from the National Geophysical Data Center (NGDC) of NOAA National Environmental Satellite, Data, and Information Service (NESDIS), NOAA scientists on the Council are affiliated with AL, ARL, and WPL.

ERL support of CIRES research was supplemented by approximately equal funding from the university and outside sources during FY 89. CIRES research programs and plans associated with ERL-supported work are reported in this document in the individual laboratories' reports. This report concentrates on research of relevance to ERL missions that is supported by other sources.

ENVIRONMENTAL CHEMISTRY AND BIOLOGY

Environmental Chemistry and Biology research at CIRES occurs in collaboration with AL and ARL personnel, as well as within university laboratories. Accomplishments relating to the following topics are discussed in the laboratories' reports:

- Field measurement programs aimed at continuing the global data base of atmospheric carbon dioxide and methane measurements.

- Experiments to determine emission rates of oxides of nitrogen and ammonia from soils and hydrocarbons from vegetation.

- Investigations of the role of chemical reactions in the Antarctic "ozone hole" phenomenon.

- Studies aimed at understanding the formation of oxidants in rural areas.

Other CIRES research is summarized below.

Accomplishments FY 89

Climate and Global Change

Methane Flux Studies: Methane is one of the most important greenhouse gases. ERL and CIRES measurements in the Geophysical Monitoring for Climatic Change program have documented the rapid increase of methane in the atmosphere during the past decade. It is now very important to identify and quantify the sources of global methane. During 1989, the Limnology Center, with support from CIRES, initiated studies of methane flux from aquatic and wetland environments. The rationale for these measurements is twofold: (1) small water bodies to be studied typically contain large accumulations of organic matter and exhibit low redox potentials below the sediment surface and could be copious sources of methane, and (2) wetland habitat is extremely extensive and presents ideal conditions for formation of reduced species because of the saturation of soil with water. Preliminary results are establishing that very large methane fluxes originate from the wetland environments and the lakes studied.

Biogeochemical Cycling: The rates of elemental cycling are important parameters used to assess the potential influence of the major biomes on global climate. Measurements have been made of element fluxes in the Orinoco River mainstream and floodplain. Fluxes of carbon, nitrogen, phosphorus, and major elements have been documented by mass-balance methods. A central finding of the Orinoco studies is that the floodplain, contrary to initial expectation, is not a source for organic carbon, despite its high productivity. Organic carbon generated by the floodplain and transported to the floodplain by the river is efficiently processed by the floodplain, which implies virtually complete conversion of this organic carbon to carbon dioxide (CO_2) or methane.

Stratospheric Ozone Depletion

Gas phase kinetics work in CIRES focused on the reactions of bromine oxide with itself and with chlorine oxide. The bromine oxide reaction with chlorine oxide, which releases active bromine, has been identified as a potentially significant contributor to ozone depletion during the austral spring over Antarctica. Studies focused on the effect that trace gases such as ozone have on the rate of the reaction.

Regional Air Quality

Hydrocarbon Emission Studies: Ozone is a principal pollutant responsible for declining regional air quality. Non-methane hydrocarbons (NMHCs) and oxides of nitrogen are the precursors responsible for photochemical production of ozone. The NMHC emitted by forests are now recognized as a major NMHC source in the eastern United States.

Studies thus far have produced several important observations concerning the hydrocarbon emission process for some major forest species. First, the emission of isoprene has been linked to photosynthesis. For

aspen, the emission of isoprene can exceed 10% of the CO_2 fixed by photosynthesis. In the transition from light to dark, trees such as aspen and spruce are observed to emit large pulses of oxygenated hydrocarbons including acetaldehyde and ethanol. Spruce are found to emit acetone at levels comparable to their total monoterpene emissions. Finally, some varieties of spruce are found to be strong emitters of isoprene. Each observation has important implications for atmospheric photochemistry.

Field Measurements: In the troposphere, as in the stratosphere, aerosols play an important role in shaping chemical processing. However, little is known of the processes or the chemical composition of the aerosols that are responsible. Consequently, there is a pressing need for new methods to detect and analyze the chemical composition of these particulates. During this past summer, atmospheric particulates at Niwot Ridge were collected and analyzed for volatile organic constituents. Preliminary analysis of the data from these samples indicates the presence of many oxygenated compounds including alcohols, aldehydes, acids, and related species. A pilot system of chemiluminescence detectors as a selective means to determine nitrogen-containing compounds in atmospheric particulates demonstrated that primary amines and some other nitrogenous species can be easily detected by chemiluminescence. The extension of this chemistry to a working detector system for liquid chromatography is in progress and should eventually lead to a nitrogen-specific detector.

Plans FY 90

Methane Flux Studies: During FY 90, studies of methane flux from aquatic and semi-aquatic environments will focus on one of the world's great environmental systems, the Orinoco River floodplain.

Biogeochemical Cycling: Biogeochemical cycling research will involve high resolution spectrometry for determining constituents of vegetation canopies. This technique will be important to the remote sensing of processes such as photosynthesis, transpiration, and nutrient fluxes. Further research will concentrate on high spectral resolution data for determining leaf water content and structural components (e.g. cellulose) in conjunction with thermal measurements. This approach will permit estimation of water and carbon fluxes between vegetation canopies and the atmosphere.

Laboratory Kinetics: The kinetics program will initiate a new study designed to investigate the photochemistry of weakly bound cluster molecules. Of particular interest is the photolysis by visible light of clusters containing an ozone molecule associated with ozone, water, or nitrogen. If these clusters can be readily formed, this photolysis, providing the clustered ozone molecule is destroyed, could be important in the atmosphere as (1) a means of ozone destruction in the stratosphere, (2) a source of hydroxyl radicals in the troposphere, and (3) a global source of nitrous oxide.

Technique Development: A new effort in stratospheric ozone research will be undertaken in collaboration with the AL. To provide information concerning the composition of particulates, a new method, supersonic jet spectroscopy with post-source pulse focusing, is being developed. The aim is to build a laser mass spectrometer capable of directly desorbing and detecting the chemicals adsorbed on particulate matter.

Field Measurements: The Arctic Gas and Aerosol Sampling Program (AGASP) will continue its study of Arctic haze chemistry. Earlier measurements have revealed the photolytic destruction of tropospheric ozone in the Arctic spring boundary layer associated with bromine (Br) photochemistry. A source for the Br molecule involved in the ozone destruction reaction has been identified as being of under-ice biological origins released to the atmosphere as bromoform and bromodichloromethane. An intensive, multi-sensor bromine-ozone destruction experiment is being planned for the winter of 1990 at Barrow, Alaska. This study will include the measurement of nitrogen gas and aerosol species, in addition to expanded bromine chemistry measurements.

ATMOSPHERIC AND CLIMATE DYNAMICS

This research at CIRES involves the physical aspects of Earth's fluid environment, including the behavior of its energy source, the Sun. Many of the projects involve collaborations with other CIRES program areas; this underscores the multidisciplinary nature of environmental research. In addition to research accomplishments and plans of non-ERL funded projects discussed here, there is a wide variety of CIRES/ERL collaborations in Atmospheric and Climate Dynamics with the ERL Laboratories. Highlights include:

- Development of new methods of ocean acoustic tomography and ocean current remote sensing, improved data processing of lidar data and modeling of lidar systems, new applications of profiler data, and improvements in interpreting satellite data, with WPL scientists.

- Statistical studies of tropical-extratropical interactions and data quality of the Comprehensive Ocean-Atmosphere Data Set (COADS), climatological analyses of the propagation of disturbances in the tropics and the onset of the Australian monsoon, comparison of satellite-derived stability analyses with other data sets, development of new statistical forecasting techniques, and analyses and modeling of the behavior of solar disturbances in relation to the variability of irradience in the atmosphere, with ARL and SEL scientists.

- Use of Doppler radar data to analyze the behavior of squall lines and the life cycle of thunderstorms, development of improved data assimilation techniques for mesoscale modeling, design and implementation of a profiler data management system, and design and improvement of automated weather observing systems for use abroad, with FSL and NSSL scientists.

- Studies of atmospheric variability at the Shelikov Straight (Alaska) as a part of the Fisheries Oceanography Coordinated Investigation, with PMEL scientists.

In addition to these ERL collaborations, CIRES Atmospheric and Climate Dynamics research during FY 89 addressed problems of the interaction of Earth's surface and the atmosphere, atmospheric turbulence, the role of the polar regions in the global climate system, and climatological analyses relating to global change and interannual climatic variability.

Accomplishments FY 89

Surface-Atmosphere Interactions and Turbulence

For a number of years, CIRES scientists have been studying the interaction of ocean and atmosphere as a part of several inter-agency experimental programs: the Frontal Air-Sea Interaction Experiment (FASINEX); the Genesis of Atlantic Lows Experiment (GALE); the First International Satellite Cloud Climatology Project Regional Experiment (FIRE). In FY 89, this work was extended to continental areas with CIRES participation in the field observations of the First International Satellite Land Surface Climatology Project Field Experiment (FIFE). The aircraft measurements of turbulent fluxes obtained are being compared with other, ground-based observations. The goal is to relate these in situ observations to simultaneous satellite data sets.

FY 89 marked the completion of GALE, FASINEX and FIRE (Phase I) analyses. Findings included:

- The GALE cold-air outbreak of 28 February 1986 was associated with total surface heat fluxes (sensible plus latent) of over 1200 W m^{-2}. While large fluxes were anticipated, this value, thought to be the largest ever measured, was entirely unexpected. Also, a subcloud layer wind jet was observed in conjunction with the air mass modification. These processes are thought to be crucial in the development of the GALE-type east-coast storms.

- FASINEX analyses revealed that the coupled ocean-atmosphere system in the vicinity of strong ocean temperature gradients exhibits remarkably complex forcing. The oceanic response to varying wind fields is different on the two sides of the front; the varying sea-surface temperature affects the wind fields. While the time scales of response are different in the two media, it is clear that the coupling between ocean and atmosphere must be taken into account for a complete understanding of the behavior of either component. A monograph of FASINEX results is in preparation.

- The first phase of the FIRE project was concluded during FY 89; CIRES participation was oriented primarily toward the FIRE marine stratocumulus activities. Analysis of data obtained during the 1987 field program revealed a large sensitivity of these clouds' reflectivity to the conditions above the cloud layer and detailed the differences between the turbulent elements in the cloudy and clear areas. In particular, the differences in entrainment processes between the two areas was shown from the FIRE data to be consistent with turbulence energetics postulated in simple models. A numerical model of these convective elements—in which they are treated as plumes—suggests that diabatic processes (radiative transfer, condensation) have little direct effect on the individual drafts but that they indirectly affect the drafts by modifying their environment.

Atmospheric turbulence above the planetary boundary layer is also a topic of investigation at CIRES. The Stratosphere-Troposphere Exchange Project (STEP) is aimed at observing and understanding mixing processes across the tropopause. CIRES participation is oriented toward describing the small-scale turbulent structure associated with exchange events above thunderstorm anvils. The difficulties of obtaining turbulence measurements using a high-altitude National Aeronautics and Space Administration (NASA) ER–2 aircraft have presented unique experimental challenges compared to low-altitude turbulence work. One discovery of note is the possibility that electrical discharges in the altitude zone of interest in STEP produce an upper atmospheric source of NO_y compounds. This could have important implications for ozone chemistry in the lower stratosphere.

Atmospheric convection also initiates gravity waves, and this is also a topic of research at CIRES. Current work involves the construction of a global cloud-street climatology (with emphasis on cold air outbreaks off the east coasts of North America and Asia) to assess the feasibility of conducting aircraft observational efforts. While aircraft measurements of turbulence have provided useful data, they are very difficult and expensive to make, and the future of turbulence observations lies in remote sensing. Accordingly, the role of turbulence in scattering coherent light sources is being studied theoretically and experimentally at CIRES. Theoretical results quantified the centroid variance of stellar sources associated with atmospheric scattering. It was also demonstrated that the first-order effects of refractive turbulence can enhance the received power of lidar sources by as much as a factor of two.

Cryosphere-Climate Interaction

Because of their probable sensitivity to climate changes brought on by the accumulation of trace gases in the atmosphere, the Arctic and Antarctic are extremely important regions of Earth. Research into problems of the polar regions at CIRES became more focused in FY 89 by the creation of a Laboratory for the Analysis of Polar Processes to complement the data archival and distribution activities of the WDC–A (discussed below).

While most climate changes occur slowly, at least on the human time scale, the potential for catastrophic surges in ice sheets covering Antarctica presents a very different scenario. Meteorological conditions on the plateau determine snow accumulation rates, an important factor in the surge potential. A preliminary analysis of satellite-relayed data from a network of automatic weather stations on the East Antarctic Plateau was homogenized, setting the stage for a detailed examination of the 1987 observations.

Field work conducted during FY 89 included the third set of research aircraft missions into the Norwegian Arctic as a part of the AGASP. These flights were coordinated with surface measurements at the Ny Alesund baseline station on Spitzbergen.

Studies of Arctic Ocean ice-climate interactions continued. The late-summer reversal of ice drift in the Beaufort gyre, forced by synoptic cyclones, was found to occur in approximately two-thirds of the summers examined. These reversals favor ice divergence and therefore are associated with decreased ice concentrations. Related work used aircraft lidar data to analyze leads in the ice pack and the associated plumes of ice crystals in the lower atmosphere that indicate substantial ocean-atmosphere interaction is taking place. These plumes may persist for hundreds of kilometers downwind, and they also penetrate the Arctic inversion and were observed to heights of 2–4 km. Their presence is significant for studies of Arctic cloudiness and for polar energy budgets.

Climatological Analyses

One of the most valuable resources for climate work is COADS, a data base developed over the past several years by NOAA and CIRES researchers. In addition to studies discussed elsewhere in this report (particularly the ARL section), CIRES scientists were involved in several applications of COADS.

In conjunction with the FIRE-related work discussed above, a climatology of marine stratocumulus cloud regimes (generally, these occur on the eastern sides of the subtropical oceans) was extracted from COADS. One important result from this study is the recognition of a negative correlation between the COADS total cloud cover and the sea-surface temperature in these areas. This suggests that global warming, with increased sea-surface temperatures, may be accompanied by less cloudiness. This positive feedback was tentatively estimated to be of the same order as the water vapor feedback associated with the atmosphere's tendency to maintain an approximately constant distribution of relative humidity. While this result needs to be verified, it points out the importance of marine stratocumulus clouds in the climate system.

On global scales, the over-ocean climatology of clouds from surface-based observations—from COADS—was completed and will be distributed in the next few months. The comparison of these observations with cloud data from satellites is in progress.

Because COADS consists of surface marine observations from all sources, including merchant ships, there are a number of potential problems with data quality. Although the operational COADS product was culled for obviously bad observations, it is necessary to perform comparative analyses of COADS data with other, more standard, observations. One such study involved the use of weather ship data, and showed a bias of the COADS ship winds toward higher speeds, particularly for low wind conditions. Also, since the data density

of COADS observations is highly variable in space and time, the weather ship data sets are being used to estimate data density requirements for representative samples.

Dealing with large amounts of data, as are contained in the COADS, requires the use of statistical techniques that must be tailored to suit the particular data application. Because of the current interest in global climate change, one important aspect of long-term data set analysis is finding statistically significant trends—long-term, nearly continuous increases or decreases in a particular quantity. During FY 89, CIRES researchers developed a new method to detect changes in the autocorrelation over long time scales in time series. This will be particularly useful in detecting changes in the behavior of atmospheric wave activity and the strength and phase of annual and interannual variability.

Climate change on the scale of decades is only one aspect of CIRES climate research. In another study, relationships between atmospheric wave activity and the El Niño-Southern Oscillation phenomenon are being investigated. Factors controlling variability of atmospheric convection have been found to vary strongly with longitude. In the eastern Pacific, short-time-scale (less than about a month) variations of convection appear to be associated with tropical-extratropical interactions. In the western Pacific, variations faster than about 10 days are local in nature, and intra-seasonal variations are associated with variability of the Asian jet. On interannual time scales, most of the variability in both regions appears to be linked to the changes in the sea-surface temperature.

Plans FY 1990

- Analysis of FIFE data will commence, and heat and moisture budgets for the boundary layer will be constructed. Planning for the second experiment (tentatively titled the Boreal Forest Experiment) will continue.

- FIRE data will continue to be analyzed and the draft model extended to a field of convective elements that modify their environment. Stochastic simulations of the boundary layer will begin. Planning for the second phase of FIRE will continue. The Atlantic Stratocumulus Transition Experiment, with field work tentatively scheduled for mid-1992, will investigate the processes of stratocumulus breakup and trade cumulus formation.

- While GALE and FASINEX have concluded, theoretical work on the results continues. In particular, the differences between the weak surface forcing in FASINEX (with surface temperature changes of a few degrees Celsius) and the strong surface forcing in GALE (with temperature differences of 10s of degrees Celsius) will be investigated.

- STEP research will be subsumed into the Stormscale Operational and Research Meteorology program activities.

- Aircraft measurements off the U.S. east coast will attempt to quantify atmospheric gravity waves generated by convective activity.

- Higher-order characteristics of lidar performance in scattering media will be evaluated, and experimental results will be compared with first-order theory.

- Numerical sea-ice modeling experiments are planned to examine the effects of winds on ice motion and divergence, and a comparison with satellite-derived ice motions will begin.

- Snow cover products will be derived from the Special Sensor Microwave/Imager (SSM/I) passive microwave data; these will be compared with other, existing data sets.

- A new study of the use of artificial intelligence techniques applied to the discrimination of clouds and snow cover and to the classification of sea ice and detection of leads will begin.

- Temperature trends over the Arctic Basin, derived from radiosonde data, will be estimated, and their utility in evaluating the magnitude of the global trace-gas induced warming will be assessed.

NSIDC AND WDC–A

The NSIDC and the colocated WDC–A are operated, in part, under a contractual agreement between CIRES and NESDIS/NGDC. The role of NSIDC/WDC–A is to acquire, archive and disseminate data relating to all forms of snow and ice.

Accomplishments FY 89 and Plans FY 90

SMMR Tβ Grids for North Polar regions distributed on CD–ROM

The NSIDC is distributing the NIMBUS–7 Scanning Multichannel Microwave Radiometer (SMMR) brightness temperature grids for the North Polar region on computer-compatible compact disk-read-only memory (CD–ROM). The first CD–ROM in the series contains grids for the period 29 October 1978 through 31 January 1980. Approximately five subsequent CD–ROMs will contain the Northern Hemisphere grids for 1 February 1980 through mid-August 1987 when the SMMR became inoperative. Following completion of the North Polar region series, South Polar region grids will be mastered on CD–ROM as well.

Air Force Global Snow Analysis Model

NSIDC revised the Air Force Global Weather Central Snow Cover Model. The overall goal of this project is to analyze weaknesses in the current version of the model, identify enhancements, and design and demonstrate the improved software system. Current work focusses on three basic areas. First, NSIDC is developing an improved interpolation method for station reports based on a nearest-neighbor weighting scheme which considers both the distance of the measurement point from the grid point as well as their relative elevations. Precipitation/elevation gradients and digital topography will be used to extrapolate into mountain zones where no surface observations are available.

The second task is to incorporate the all-weather capability of passive microwave satellite remote sensing into the model. The specific sensor will be the SSM/I on the Defense Meteorological Satellite Program (DMSP) orbiter.

The third task is to optimize application of the global snow cover climatology compiled by the Air Force. The climatology will be stored as a cross-correlation matrix such that whenever a reporting station is missing, the model can search not only for its nearest spatial neighbor but also for its nearest climatological neighbor.

SSM/I Snow Cover Studies

NSIDC was awarded three years' funding for research on SSM/I snow cover-climate data products under the NASA Program for Interdisciplinary Research in the Earth Sciences. The study has two main objectives: the development of a data system for production, archiving and distribution of validated snow cover products from the DMSP–SSM/I for community use; the preparation of a prototype snow cover climatology from the first three years of SSM/I data; an assessment of its utility as a climate system index in a conjunction with SSM/I-derived sea-ice products.

Greenland Ice-Sheet Project 2 (GISP2)

NSIDC will provide data management services for GISP2, which represents the renewal of the seven-year GISP1 program that ended in 1983 and produced a 2037 m deep ice core (70,000-year record) in southeastern Greenland. The GISP2 drill site is located in central Greenland where the depth to bedrock is estimated to be 3100 m. This site could provide a stratigraphic record of 200,000 or more years. The first field season for GISP2 was successfully completed during the summer of 1989.

CSES

CSES research activities focus on the use of satellite remote sensing of the Earth, mainly its atmosphere and land with emphasis on spectral imaging techniques.

Accomplishments FY 89 and Plans FY 90

Sensor System Studies

A model was developed to quantify scientific requirements for the High-Resolution Imaging Spectrometer (HIRIS), a facility instrument for the NASA Earth Observing System. The polar orbiting platform is slated for launch in 1997. The model converts scientific requirements derived from surface composition mixing within a pixel to engineering requirements for spectral resolution and signal-to-noise ratio.

The Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) obtained data in the Dolly Varden mountains of Nevada that can be used to simulate HIRIS and apply the model.

Inversion of Imaging Spectrometry Data

An analysis and interpretation system for imaging spectrometry data based on spectral mixing models has been developed. The method is cast in terms of a geophysical inversion problem in which the observable parameters are the reflectance or radiance spectra for each picture element and the unknown parameters are the abundances of the spectrally unique and distinguishable components occurring at the surface. Singular value decomposition and Marquardt-Levenberg inversion techniques are employed for linear and nonlinear mixing models. These methods provide the maximum insight into the numerical stability and spectral degeneracy of the unmixing procedure. The ultimate goal of the research is to allow conversion of the many images of the reflectance data set into a smaller set of images, each quantitatively showing the spatial abundance patterns of various mixing components. Future work will include applying these data reduction techniques to AVIRIS imaging spectrometer data acquired in Wyoming in a region of sedimentary rocks containing mineral facies variations.

Remote Sensing of Leaf and Canopy Water Status

The goal of this research is to develop a method of remotely measuring leaf water status that will provide meaningful information pertaining to the physiological status of the plant canopy. Recent advances in identifying the equivalent leaf water content of vegetation from AVIRIS have been made at CSES. Using absorption features of liquid water that are offset from water vapor (0.94 and 1.14 mm), the liquid water content of these can be quantified. This is a new area of research in CSES and preliminary results using laboratory spectrometer data from leaves has been promising. Future work will make use of AVIRIS data over areas of known leaf water stress.

Extracting Column Atmospheric Water Vapor

Accurate measurements of the total amount of water vapor in a column extending from the surface to space is important in climatology, space geodesy, surface-atmosphere energy exchange, and self-calibration of imaging spectrometry radiance measurements. At present, satellite measurements of column water vapor over land areas have an accuracy of only ±25%. Imaging spectrometer data are being used to extract total column water vapor on a pixel-by-pixel basis. Nonlinear least-squares curve fitting of water vapor spectral models to measured spectra are used to derive the amount of water in the vertical column. Precisions of ±5% or better have been recorded in AVIRIS data, and based on one radiosonde measurement the accuracy is equivalent to the precision.

COOPERATIVE INSTITUTE FOR RESEARCH IN THE ATMOSPHERE
Fort Collins, Colorado
(303) 491–8448
Thomas H. Vonder Haar, Director

The Cooperative Institute for Research in the Atmosphere (CIRA) was formed in 1980 between Colorado State University (CSU) and the National Oceanic and Atmospheric Administration (NOAA) to increase the effectiveness of atmospheric research of mutual interest to NOAA, CSU, the State, and the Nation. CIRA

operates under the auspices of the CSU Graduate School and its Office of Vice President for Research. Additional objectives are to provide a center for cooperation in specified research programs by scientists from Colorado, the Nation, and other countries, and to enhance the training of atmospheric scientists. All CSU and NOAA organizational elements are invited to participate in CIRA's atmospheric research programs. Initial participation by NOAA has been primarily through the Environmental Research Laboratories (ERL) and the National Environmental Satellite, Data, and Information Service (NESDIS). At the University, the Departments of Atmospheric Science, Civil Engineering, Computer Science, Earth Resources, Economics, Electrical Engineering, Physics, Psychology, and Statistics are involved in CIRA activities. As its research themes, CIRA concentrates on air quality, cloud physics, mesoscale studies and forecasting, satellite applications, climate studies, agricultural meteorology, model evaluation, and economics and societal aspects of weather and climate.

Accomplishments FY 89

Each year CIRA sponsors at least two workshops at the CSU Pingree Park mountain campus, one of which is held for all CIRA research personnel. The workshop for research personnel was held 21–23 June 1989 and was attended by representatives of CIRA, CSU, the NOAA/NESDIS/RAMM [Regional and Mesoscale Meteorology] Branch, and students whose research is supported by CIRA. The purpose of the research workshop is to encourage new thought and explore new concepts of existing research.

In September 1988, NOAA provided a two-week training session on climate computing (CLICOM) at CIRA for the World Meteorological Organization (WMO) SHARE team members. CLICOM emphasizes a "package" concept which includes computer hardware specifications, user-friendly software, and training. The training was given by National Weather Service personnel and was the first time under this program that an international group had been trained in the United States.

As a cooperative function between the Center for Geosciences and CIRA, a summer workshop was held 23–25 August 1989. The workshop, the topic of which was precipitation measurement and modeling, was well attended by over 30 prominent scientists. Other workshops sponsored by the Center for geosciences focused on information extraction, hydrology, large eddy simulation, and the Regional Atmospheric Modeling System.

Plans FY 90

In addition to the regular research, CIRA will continue cooperating with the Army Research Office at the Center for Geosciences at CIRA. Plans include a major field program and several scientific workshops. CIRA will also hold a general research workshop and an invitational workshop.

SATELLITE CLOUD CLIMATOLOGY PROJECT

Accomplishments FY 89

CIRA participated in the International Satellite Cloud Climatology Project (ISCCP) (part of the World Climate Research Programme) as a Sector Processing Center. It collected Geostationary Operational Environmental Satellite-6 (GOES-6) data and contributed to the ISCCP validation program.

- CIRA obtained more than 90% of the data required by ISCCP.

- New sensor calibration information was included in the satellite transmission, and these new parameters were incorporated in the data sets.

Plans FY 90

The Sector Processing Center will continue to collect and process GOES-West raw data into B1 and B2 resolution data sets. Expanded research will examine the diurnal variation of clouds from newly available Indian Satellite (INSAT) data. After completing the analysis of INSAT data, CIRA will host a small scientific workshop on "Cloud Variation over the Indian Ocean and the Indian Subcontinent."

SEVERE WEATHER RESEARCH

Accomplishments FY 89

Studies supported NOAA's severe weather prediction mission in the areas of mesoscale analysis and forecast product development.

- Documentation of the very large and consistent diurnal variation of deep convection associated with tropical cyclones. Results have been presented in conference proceedings and a journal article is in the review process.

- A test expert system for thunderstorm forecasting was introduced into the Cheyenne Weather Service Forecast Office. Results were positive and the expert system is being modified for use during the summer of FY 90.

- Mesoscale models were used to explore the effect of early morning cloud cover on later thunderstorm development. Results show that along the cloudy versus clear boundary a circulation in strength comparable to that with the sea breeze could develop by early afternoon.

- Mesoscale models were used to explore the effect of irrigated versus non-irrigated terrain on the development of atmospheric circulations. Results show a shallow moist layer with a shallow circulation developing along the irrigated versus non-irrigated terrain. This was verified by aircraft flights.

- Investigations reveal that super cell storms are best observed from a western GOES satellite. This is because the favorable viewing perspective afforded by the western satellite allows for the side of the cumulonimbus towers as well as the anvil to be clearly observed; with GOES-East the towers are normally obscured from view due to anvil masking.

- Arc cloud line investigations reveal that new convective development is a function of the ambient environment cloud field as well as velocity and depth of outflow boundary. Results have been included in conference papers and a journal article is under review.

- Analysis of VISSR (Visible and Infrared Spin-Scan Radiometer) Atmospheric Sounder (VAS) sounding data reveal that optimum field of views for averaging for sounding derivation may be determined by structure function analyses. Results have been included in conference papers and a journal article is in preparation.

- Satellite, aircraft, and conventional data are being analyzed for individual tropical cyclone genesis cases in the Northwest Pacific. A distinct maximum of deep convection has been found to occur very early and coincides with the initial formation of the weak, low-level mesoscale vortex. Also, low-level wind speed maxima (called surges) have been identified as key features in tropical cyclone developments.

Plans FY 90

- Continue focus on the determination of the spatial and temporal variability in VAS radiance measurements so that this data might be applied to both mesoscale sounding derivation and mesoscale product development.

- Continue analysis of VAS sounding, rapid scan satellite, Doppler radar, mesonet and conventional data.

- Develop products for use in extending advance warnings of severe weather.

- Develop training aids and participate in field forecaster training.

- Develop method to deconvolve GOES–IR data to show true scene radiance observed by spacecraft.

- Improve satellite monitoring techniques and the acquisition of mesoscale data bases.

AIR QUALITY JOINT RESEARCH WITH THE NATIONAL PARK SERVICE

Accomplishments FY 89

A cooperative effort of the National Park Service, NOAA, and CIRA continued to determine, evaluate, and analyze the visual effects of pollutants on specific scenic vistas.

- Developed photographic imaging techniques to accurately depict slight changes in visibility due to layered and regional hazes.
- Developed video production capabilities to depict air quality scenarios.
- Developed capability to produce video productions to depict research results.

Plans FY 90

- Continue development of software to digitize color slides, real-world images, and projected images in laboratory situations.
- Continue development of photographic imaging techniques to more accurately depict slight changes in visibility due to layered and regional hazes.
- Continue validation of the accuracy and precision of electro-optical measuring devices under controlled conditions.
- Conclude analysis of conditions when the Atmospheric Transport and Diffusion model approach can be used to assess air pollution transport.

WMO SHARE PROGRAMME

CIRA has contracted with the WMO to participate in t he WMO SHARE Programme. The Programme is a 3-year international project to develop meteorological analysis and display software for developing countries and to train scientists of these developing countries in the use of SHARE products. As a result, scientists from Argentina, Brazil, Jamaica, Kenya, Niger, Peoples Republic of China, Trinidad, and Turkey have visited CIRA.

Accomplishments FY 89

- Produced a VAX VMS Version 1.0 of the SHARE Workstation software.
- Assisted participating countries in training and installation of SHARE software.
- Provided software routines to process and display forecast products.

Plans FY 90

- Train scientists of third world countries to install software and to train others when they return to their respective countries.
- Complete a set of software for an IBM PC/AT to provide the same data as the VAX VMS Version 1.0.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

Norman, Oklahoma
(405) 325–3041
Douglas K. Lilly, Director

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) was established in 1978 as a joint venture of the University of Oklahoma (OU) and the National Oceanic and Atmospheric Administration (NOAA) through the National Severe Storms Laboratory (NSSL). CIMMS is administered by the University. The Council of Fellows, consisting of university faculty and NSSL staff, helps formulate policy. The Advisory Board of CIMMS meets annually to evaluate achievements and goals, and to make recommendations. The Board includes representatives from OU, NOAA, and outside organizations.

Program objectives and activities of CIMMS are selected to complement the research activities of NSSL, other Environmental Research Laboratories (ERL) of NOAA, and OU. The establishment at the university, during FY 89, of The Center for Analysis and Prediction of Storms (CAPS), one of eleven Science and Technology Centers sponsored by the National Science Foundation, significantly increases the potential for collaboration among university, NSSL, and National Weather Service scientists on the most challenging problems in meteorology today.

Specific themes in CIMMS are mesoscale modeling, mesoscale dynamics, mesoscale observations, and variational optimization analysis and remote sensing.

Accomplishments FY 89

Mesoscale Modeling

Convective cloud model with detailed microphysics

Development of the three-dimensional (3–D), non-hydrostatic, anelastic convective cloud model continued with considerable success. The novelties of the model are its detailed description of the principal warm rain-cloud microphysical processes and its prediction of cloud condensation nuclei and cloud droplet spectra at each grid point. Because the model does not parameterize the nucleation process, it keeps a better account of the replenishment of cloud condensation nuclei by advection and turbulent mixing, and therefore determines supersaturation quite accurately. An important extension of the work now under way is a comparison of the detailed model results with those of models in which the microphysical processes have been parameterized. Results so far have been presented at the Symposium on the Role of Clouds in Atmospheric Chemistry, Anaheim, CA, 1989, and in a paper submitted to an atmospheric science journal.

Short-term forecast model

CIMMS investigators have been cooperating with CAPS in the development of a new short-term forecast model; for example, by helping to evaluate parameterizations as described above.

4–D data assimilation

Development of an adjoint code for a 3–D non-hydrostatic mesoscale model continued with a series of tests that used identical twin experiments. These tests showed that the adjoint model recovers the initial state quite satisfactorily even when the input data consist of just one horizontal wind component.

Mesoscale Dynamics

Atmospheric turbulence

A model for intermittent turbulence was used to provide a quantitative explanation of mixing processes and statistics of cumulus clouds as derived from radar and satellite data. Further, the same model framework was used to generalize the solutions of the von Karman-Howarth equation to cases with finite Reynolds number, relating the limits of the inertial subrange to Reynolds number. The results have been reported at several international workshops and conferences.

Theoretical studies of moist frontogenesis and cyclogenesis

A 3–D semi-geostrophic diagnostic model for moist frontal circulations was developed and used to study the vertical motion field associated with frontal rainbands. The model was also incorporated into the

previously developed semi-Lagrangian and semi-geostrophic finite-element (SSF) model, to study moist frontogenesis and cyclogenesis.

Non-linear dynamics of 2–D quasi-steady mesoscale density flows

Semi-analytical models are under development to study how mesoscale density fronts, such as thunderstorm outflow or gust fronts, propagate under various environmental conditions.

Mesoscale Observations

The Gulf of Mexico (GUFMEX) project

The field phase of the GUFMEX project took place in the late winter and spring of 1988. At CIMMS, the research effort has concentrated on the analysis and application of data from the air-mass modification flight, beginning with acquisition and installation of software necessary to reduce P–3 data. These data are being used to initialize and evaluate the results of mixed-layer models of the marine boundary layer.

Cooperative Oklahoma P–3 Studies (COPS–89)

Investigators and graduate students supported by CIMMS participated in the COPS–89 study of mesoscale convective systems (MCSs), dryline and cold-front structure, and charge generation and separation mechanisms, using data from the P–3 and Next-Generation Weather Radar (NEXRAD) Doppler radars and from special instrumented balloon flights to measure thermodynamic and electrical properties and winds.

Remote Sensing

Techniques

Investigations underway with CIMMS support include the determination of relationships between microphysical parameters and kinematic fields in hailstorms, use of single Doppler data to estimate kinematic parameters of winds, and effects of nonlinearities of third order on models.

Aviation weather hazards

Investigators supported by CIMMS have participated in tests of the Terminal Doppler Weather Radar in the Great Plains environment, with emphases on development of a gust-front algorithm and ground-clutter filtering.

Plans FY 90

Mesoscale Modeling

Short-term forecast model

In collaboration with investigators in CAPS, development of a 3–D non-hydrostatic numerical model for short-term prediction will continue. Tests of the model will use real-time as well as experimental data.

Convective cloud model

Development of the model will continue, with emphasis on comparison with models that use parameterizations to treat the microphysics. One principal objective is to derive improved parameterizations that may be incorporated in the new forecast model being developed in CAPS.

4–D data assimilation

The adjoint technique will be extended to include more physical processes; for example, condensation. A more systematic sensitivity study will be conducted.

Mesoscale Dynamics

Development of the SSF model will continue and will include further study of moist frontogenesis and cyclogenesis. Emphasis will be on comparison with observational data and other model results.

Mesoscale Observations

The GUFMEX project

Data analysis will continue, with a possible extension of the work to include development of parameterizations for the marine boundary layer.

COPS–89

Analysis of data and case studies focused on individual MCSs will continue. Case studies relating lightning ground-strike locations with satellite infrared imagery will continue. Under National Science Foundation sponsorship, a balloon-borne particle size and charge measurement instrument will be developed.

Remote Sensing

Development of microphysical retrieval techniques, single-Doppler techniques and algorithms for application to Doppler radar data will continue.

COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH

Ann Arbor, Michigan
(313) 763–1438
Russell A. Moll, Director

The Cooperative Institute for Limnology and Ecosystems Research (CILER) is jointly sponsored by the University of Michigan at Ann Arbor, MI, and the National Oceanic and Atmospheric Administration (NOAA). This new institute will conduct Great Lakes-related research involving both university researchers and NOAA scientists.

The Institute is the seventh established by NOAA with universities throughout the United States, the only one with a primary focus on the Great Lakes. Research activities will fall into six interdisciplinary areas: toxic contaminants and chemical processes, water quantity and lake levels, physical processes, ecosystem dynamics and habitat, and climate and global change.

The Institute is being established in close cooperation with Michigan State University and is unique in that it will provide an opportunity to participate in the research programs of researchers at any Great Lakes Basin institution.

COOPERATIVE INSTITUTE FOR MARINE AND ATMOSPHERIC STUDIES

Miami, Florida
(305) 361–4185
William W. Fox, Jr., Director

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is an association between the National Oceanic and Atmospheric Administration (NOAA) and the University of Miami's (UM's) Rosenstiel School of Marine and Atmospheric Sciences (RSMAS) to stimulate cooperative research between the institutions. The two research themes of CIMAS are Climate Variability and Ecosystem Dynamics. Research is conducted at the CIMAS building, other laboratories on the RSMAS campus, and NOAA laboratories. CIMAS also provides partial support for visiting collaborating scientists who augment the expertise at RSMAS and NOAA.

The Tropical Ocean-Atmosphere Newsletter (TO–AN), which includes news of the International Tropical Oceans and Global Atmosphere Programme, is published by CIMAS. TO–AN promotes rapid dissemination of information about contemporary activities and ideas on topics of importance to large-scale tropical air-sea interaction in relation to global climate.

CLIMATE VARIABILITY

Research on climate variability encompasses ocean processes in the Subtropical Atlantic Climate Studies (STACS), tropical ocean and atmospheric processes in the Equatorial Pacific Ocean Climate Studies (EPOCS), and tropical environmental chemistry in the Radiatively Important Trace Species (RITS) program.

Accomplishments FY 1989

STACS

Climate research in the subtropical Atlantic Ocean concentrates on observing, describing, and analyzing oceanic fluctuations in the western subtropical and tropical north Atlantic, which are considered significant for the understanding and prediction of oceanic effects in climate dynamics. The research is conducted using data from moored current meter arrays, conductivity-temperature-depth (CTD) recorders, Pegasus ocean profilers, satellite altimeters, and measurements of chlorofluoromethanes (CFMs).

Florida Current

Utilizing the extensive data set collected during 1982–1984 as part of the NOAA STACS program, the structure of velocity (transport), layer thickness and potential vorticity in the Florida Current at 27°N (from STACS) was compared with results of similar experiments (using virtually the same observational methods) on cross sections farther north in the Gulf Stream. It was found that the structure of transport and potential vorticity as a function of 2.5°C-thick layers is quite similar at each section (ranging from 27°N to 38°N latitude). Below about 11°C, potential vorticity is quite uniform across the Gulf Stream, suggesting (as have float data) that relatively free exchange of water parcels across the Gulf Stream can take place at deep levels.

Western subtropical Atlantic

Analysis of STACS data sets from east of Abaco Island in the Bahamas, has continued with the goals of (1) determining the structure and variability of surface (above 800 m) and deep currents in the area; (2) comparing observations and models of the north Atlantic; and (3) analyzing combined data from current meters and from Pegasus (an acoustic ocean current profiler) to find the most cost-effective means of monitoring long-term (climatic) fluctuations of, in particular, the Deep Western Boundary Current (DWBC).

Two years of moored velocity measurements from a cross-isobath array east of Abaco, Bahamas, have been analyzed together with a north Atlantic wind data set produced by the National Hurricane Center. The results to date are:

- Mean currents in the upper 800 m show a clockwise rotation that appears to be associated with a quasi-permanent, anticyclonic gyre centered just northeast of the Bahamas.

- Mean meridional volume transport in the upper 800 m of the array was toward the north at 3 Sverdrup (Sv) (1 Sv=10^6 m^3 s^{-1}) and suggests the existence of a mean Antilles Current that provides part of the warm water thermohaline return flow to the North Atlantic.

- Below 800 m the DWBC is observed as a well organized, intense flow to the south with mean speeds reaching 20 cm s^{-1} in a core centered near the 2,500 m depth, located 25 km seaward of the Bahama boundary.

- Mean transports in the DWBC were estimated to be 2 to 3 times greater than previous estimates of inter-basin exchange of North Atlantic Deep Water (NADW) suggesting the existence of a deep gyre that recirculates a portion of the NADW into the interior.

- Transport time series show large variations on several-month and inter-annual time scales, but in contrast to predictions by basin-scale wind-driven models, the annual cycle is weak.

Western tropical Atlantic

Results from the first year array of current meters deployed to investigate the dynamics of the North Brazil Current/North Equatorial Countercurrent retroflection zone, at 6–8°N off the coast of French Guiana, were analyzed and show that:

- Seasonal variations in upper level mean currents are large and generally consistent with model results indicating a seasonal offshore retroflection of the North Brazil Current during July-January.

- A strong, steady DWBC flows southeastward at the base of the continental rise with mean core speeds of 30 cm s^{-1} at 4,300 m depth.

- Flow at 900 m depth in the Antarctic Intermediate Water lens is steadily northwestward over the continental slope at 10–15 cm s^{-1} with little seasonal variation.

- Low-frequency current fluctuations in this region are dominated by a clearly periodic, 40–60 day, oscillation related to the shedding anticyclonic eddies from the retroflection zone. Subsequently, these eddies propagate northwestward into the Guyana basin, carrying water of boundary current characteristics into the interior of the basin.

Chlorofluorocarbons (CFCs) were measured at sea on the February to March 1989 STACS cruise to investigate the response times of the interior deep basins of the western tropical north Atlantic to the climatic forcing of water mass formation in the high northern latitudes. Supporting inferences from the boundary current mass balances, these data show that the DWBC in the north Atlantic Ocean is a continuous feature of the mean circulation between Abaco (26°N) and Brazil (8°N). A deep core of high F–11 concentrations, located between 3,200 to 4,600 m, transports NADW. Another one at 1,000 to 1,700 m , with a temperature near 4°C, transports recently formed Subpolar Mode Water. This water probably formed sometime during the 1960s and 1970s when there was reduced convection in the Labrador Sea.

Satellite altimeter studies

Research continued on the use of Geodetic Satellite (GEOSAT) data in STACS. While the results indicate surface current structures with amplitudes and spatial scales consistent with STACS hydrography, clearly identifiable events were found only in the Gulf Stream meander region to the north of the STACS Abaco target area.

Tropical Ocean and Atmosphere Studies

EPOCS-oriented work on developing techniques for data assimilation into a numerical equatorial model was continued to apply variational methods to data assimilation in the Geophysical Fluid Dynamics Laboratory (GFDL) general circulation model (GCM). Using adjoint model codes and the conjugate gradient procedure developed in the previous year, a debugging technique was developed and proved very useful in verifying the adjoint code. Further development of the adjoint code, including vertical mixing and surface heat flux, was also completed.

To demonstrate the ability of the assimilation procedure to recover the state of the ocean, so-called identical-twin data assimilation experiments were conducted using the GFDL GCM and its adjoint. These experiments provide a basis for estimating data requirements for the model-fitting scheme to provide an adequate description of the ocean state over the observation interval.

Tropical Environmental Chemistry

Environmental chemistry research encompassed biogenic production of atmospheric trace gases by marine microplankton, and observations of oxidation products of dimethyl sulfide (DMS).

Five volatile compounds were found to be produced by many of the phytoplankton species. Of the 36 species examined, 56% of the diatoms and 57% of the prymnesiophytes produced a C_4H_8 compound. Thirty-six of the species examined produced 1,4-pentadiene, with only a red alga and one dinoflagellate not producing the compound. Only five out of thirty-eight species produced a C_6H_{14} compound. 50% of the prymnesiophytes and only a few other species produced a C_4H_9N compound. In agreement with previous studies, 83% of the prymnesiophytes, 80% of the dinoflagellates and 44% of the diatoms produced dimethyl sulfide.

The discovery that most phytoplankton produce 1,4-pentadiene is of particular interest because of its structural similarity to certain algal pheromones and because of its high degree of reactivity with free radicals. The fact that virtually all algae produce the highly reactive compound indicates that it may play a very important role in their survival and the chemistry of their environment.

Plans FY 1990

STACS

The emphasis in the STACS-related field work, as well as in analysis, will be split between extension in time of the Antilles region data base and a geographic extension toward the domain of tropical water inflow

into the subtropics, including the North Brazil Current. Work will continue with CFMs, and satellite altimeter data analysis will be extended into the Caribbean region.

Florida Current

Analysis of Florida Current transport time series and meteorological forcing fields during the STACS observation period from 1982 to present will be continued to improve understanding of seasonal and interannual variability. A fundamental remaining question is how and to what extent the Florida Current is influenced by direct, local, as opposed to indirect, regional forcing.

Western boundary currents of the subtropical and tropical north Atlantic

Investigation of heat and volume transport variability on time scales of days to years in the western boundary currents of the Bahamas and French Guiana will continue with collection of data from moored arrays. These currents are major conduits for global transport of heat and trace substances that influence and characterize north Atlantic circulation and global climate. The Abaco and French Guiana mooring sections established in STACS have been designated by planners of the World Ocean Circulation Experiment as important transects for which first-order understanding of transport processes is needed. Complementary funding to ensure continuity of this work at a critical level of effort was acquired from the National Science Foundation (NSF) by the UM/CIMAS researchers involved.

Data obtained will be compared with numerical model results and will be analyzed with these objectives:

- Describe the spatial structure and temporal variability of the current and temperature fields.
- Construct time series of volume and heat transports of the important current systems.
- Investigate the daily-to-interannual variability of the estimated transport time series.
- Investigate kinematics and dynamics of the current systems.
- Investigate the influence of wind stress and thermohaline forcing on observed flows.

Field work with moored current meter arrays will continue through June 1990. A three-mooring array was deployed in the Abaco section in October 1988 and will be recovered in May 1990. NSF recently funded continuation of this array with four moorings to be deployed in May 1990 for 1.5 years. To resolve the recirculating part of the deep flow will require additional mooring resources in the interior, for which it is planned to seek support from NOAA's new Atlantic Climate Change Program. The recirculation characteristics will also be addressed by measuring CFCs on a STACS cruise in June 1990, as a means of detecting recent intrusions into the basin interior of deep waters carried by the western boundary currents.

Analysis of the STACS Abaco data set will continue, merging the long-term current meter data with detailed information on current profile structure from free fall devices; e.g., PEGASUS (an acoustic ocean current profiler). Additional PEGASUS observations on STACS cruises will extend these observations to assess interannual variability. Through separate NSF funding a program was initiated in support of the NOAA

STACS effort to seed the deep currents off Abaco with acoustically tracked, free-drifting mid-depth Rafos floats.

In the tropical Atlantic boundary region, a moored array was deployed south of the intense eddy region across the Amazon Cone off Brazil in September 1989. Three STACS moorings were augmented, in a cooperative effort with the Federal Republic of Germany's University of Kiel, by three moorings along 44°W on and north of the equator. Recovery is planned for January 1991. The six-mooring array is designed to observe (1) flow characteristics in the North Brazil Current and offshore flux from this boundary current into eastward zonal currents above, within, and below to thermocline, including the North Equatorial Counter-current and Equatorial Undercurrent and (2) deep circulation and transport of water in both the upper and lower branches of NADW carried southward by the DWBC. This effort will be augmented by a large array of PEGASUS current profiler stations (24 stations) to provide detailed information about the vertical structure of these currents. An understanding of the behavior of these components is essential to one of the STACS goals: observing long-term fluctuations of northward heat flux in the north Atlantic and relating these fluctuations to variations in the different responsible current components.

Analysis of these processes will encompass:

- Combination of the tracer field information with the direct velocity measurements to get a direct measure of water mass spreading rates.

- Consideration of the dynamics of the DWBC relative to the problem of recirculation mentioned above.

A historical data analysis of tracer and hydrographic data in the Atlantic will complement the new observations.

GEOSAT applications

Continued analysis of sea-surface elevation transients in the Antilles region, based on GEOSAT Exact Repeat Mission altimeter data, will focus on providing assurance that the intermittent observations on research cruises, and the regionally limited current meter arrays, do not miss major transient events in the region.

Tropical Ocean and Atmosphere Studies

Data assimilation research in support of EPOCS will continue with emphasis on a sequence of real data assimilations. The adequacy of available Pacific Ocean data sets for the model-fitting scheme will be studied as a followup on the identical twin experiments conducted in FY 89 based on GFDL model data. To increase the efficiency of the analysis process, a comparative study of conjugate gradient algorithms will be undertaken. This effort occurs with guidance and cooperation of researchers at Atlantic Oceanographic and Meteorological Laboratory (AOML).

A new effort will be initiated to analyze and model the dynamics of satellite tracked drifter trajectories. The objective is to develop their use in the NOAA real-time modelling effort for El Niño-Southern Oscillation events.

Tropical Environmental Chemistry

After the experimental confirmation that phytoplankton produce volatile organic compounds with reactive double bonds, this work will focus primarily on the algal production of 1,4-pentadiene to determine why algae produce it and how environmental factors influence the rate at which it is produced. With a specific compound to analyze, a gas chromatograph has been set up to examine its specific concentrations in cultures. Experiments will examine how various environmental factors affect the production of 1,4-pentadiene. The factors to be examined are light intensity, light quality (including ultraviolet), diel timing, temperature, salinity, nutrient limitation, trace metal limitation, trace metal toxicity, free radical promoters, and free radical scavengers. Eventually time-course experiments will also be conducted to further establish the causal relationship between environmental factors and the production of 1,4-pentadiene.

ECOSYSTEM DYNAMICS

Ecosystem dynamics research concerns the processes related to tropical and subtropical fish stock variability, especially recruitment mechanisms and fishery dynamics. A significant new element in this program is the South and East Florida and Caribbean Recruitment (SEFCAR) project.

Accomplishments FY 1989

Larval Ecology of Bluefin Tuna

The index of abundance of bluefin tuna based on abundance of larvae was extended to include 1987 data. The index of abundance of adult spawning bluefin tuna based on the abundance of larvae is presently the only index useful for calibrating virtual population analysis of stock size. This analysis is the basis for international management of this valuable resource. Studies of the ecology of the bluefin tuna larvae are relevant to the index of abundance because oceanographic features affect the distribution, abundance, and survival of the larvae. Sampling at closely spaced intervals across satellite-observed temperature fronts in the Loop Current in the eastern Gulf of Mexico was done in 1987 in addition to the standard sampling at 60 mi intervals. Bluefin tuna larvae were caught only at or near the fronts or within cold-core eddies. Loop Current fronts were sampled again in 1988 but have not been analyzed. In 1989 a Multiple Opening and Closing Net Environmental Sampling System (MOCNESS) sampler was used to investigate the vertical distribution of bluefin tuna larvae in the Gulf of Mexico during April and May. These samples have not yet been analyzed.

SEFCAR

The SEFCAR project investigates the effects of coastal oceanography on recruitment of reef species, especially snappers and groupers and lobsters, to the Florida Keys.

Initiated in FY 89, this research project is attempting to determine if larvae and post larvae of reef-related organisms (spiny lobster and snappers) are recruited primarily from adults that spawn locally, from adult populations spawning at more distant sites within the Caribbean, or from a combination of spatially-dis-

tributed spawning populations. Direct plankton sampling and physical circulation observations are complemented by a biochemical genetic approach employing the techniques of conventional protein starch gel electrophoresis and mitochondrial deoxyribonucleic acid (mtDNA) restriction endonuclease analysis. This information will be useful to fisheries managers who must choose between different management practices. Results to date include:

Physical surveys

Two interdisciplinary cruises to survey the distributions of water mass properties and larvae concentrations were conducted in May, June, and August 1989. A moored array of three current meter moorings with three current meters per mooring was initially deployed in April 1989, then recovered and redeployed in August 1989 together with spiny lobster settling trap stations. Also an Acoustic Doppler Current Profiler (ADCP) was deployed offshore of Looe Reef on the Pourtales Platform at a depth of 215 m during the August cruise. Preliminary results confirm the existence of a pronounced gyre structure within which upwelling in the center and along the continental slope lifts the thermocline into the euphotic zone where nutrients are available for planktonic uptake. Confirmation of this hypothesized structure in the experimental area supports a basic premise in the SEFCAR project, viz existence of important physical processes in a critical region of lobster larval settlement.

Biological sampling activities

This began in coordination with the physical observation program. The initial cruise in May and June 1989 collected larval fishes and lobsters and other zooplankton using a MOCNESS sampler. More larval lobsters and fishes were found in the inshore and downstream portion of an eddy centered off Looe Key. An eddy located here could potentially retain fish larvae to allow them to recruit to their natal reef. Lobster larvae were most abundant between 50 and 25 m. The spatial and vertical distribution of these larvae will affect their recruitment because of differential transport by currents. Newly recruited larval lobsters were collected from the Keys for mtDNA analysis.

Biochemical genetic studies

The development of biochemical genetic markers is an essential step in identifying connections between populations studied. Achievements to date include:

- Purification of mtDNA from local adult spiny lobster. All subsequent steps depended on our ability to purify mtDNA.

- "Cutting" of purified mtDNA into several size fragments with several restriction enzymes. This accomplishment is important in two regards: (1) Each cut in the mtDNA molecule generates a genetic characteristic than can be used to compare the relatedness of two individual lobsters. At present approximately 12 genetic characters are available for comparisons; (2) Cutting the mtDNA into smaller fragments makes it easier to manipulate in the cloning process. This step was necessary to proceed with generation of the probe by cloning.

- Successful cloning of approximately 2/3 of the mtDNA molecule. Cloning refers to the transfer of the mtDNA molecule to bacteria for manufacture of limitless numbers of copies of the molecule. This step produces a probe which hybridizes with mtDNA from samples of other adult and larval lobsters, and identifies these molecules with no further purification necessary for each individual.

- Optimization of the storage conditions for organisms used for mtDNA analysis. It appears that planktonic samples stored in 70% Ethanol (normal conditions used by plankton biologists) will be sufficient for mtDNA samples. This finding defines an important aspect of the sample-handling protocol in the project.

Age, feeding, growth and behavior of snapper and grouper larvae

This research element complements the spiny lobster work in SEFCAR and involves both studies of populations in the field and rearing under controlled conditions.

Larval food distributions were measured during cruises in June and August. Initial results from samples collected during the June cruise indicate that numbers of small zooplankton are highest in the near-front regions.

Larvae of yellowtail snapper, mangrove snapper, lane snapper and lane-yellowtail crosses were reared and their growth determined at a single temperature. Rearing of larvae will continue to determine the temperature effects on growth and settlement times. Rearing of other species will begin as spawning fish become available.

Larvae were reared in the laboratory on wild caught zooplankton as well as cultured foods. Food preferences are being assessed from preserved samples of these larvae reared on wild zooplankton and from samples of larvae collected in surface samples sorted and preserved at sea during the June 1989 cruise.

Growth rates of early larval mangrove snapper and yellowtail snapper fed on two different concentrations were determined. Growth rates were not significantly different; however, survival to day 30 was reduced in tanks with low concentrations of food.

All species reared in the laboratory were sampled from hatching to settlement to establish age determination techniques by otolith inspection. Initial observations indicate that the otoliths of yellowtail snapper contain easily identifiable daily rings with no sub-daily rings evident.

A video recording and image analysis system was created to study larval behavior differences between species. Initial observations of larval behavior in tanks indicate some intriguing differences in the behavior of larvae from more estuarine-based species (mangrove snapper) and the more reef-associated species (lane and yellowtail snapper).

Mangrove snapper, lane snapper, yellowtail snapper and a yellowtail-lane snapper cross were raised to aid in species identification of larval stages. Samples were preserved of all stages of larval development and these will be used to describe larvae. It is hoped that the description of yellowtail snapper, lane snapper and lane-yellowtail hybrids may provide the basis to consolidate the genus *Ocyurus* and genus *Lutjanus*.

Fisheries Dynamics

A time series was produced of satellite-derived sea-surface temperature (SST) maps off the United States east coast for the period 1985–1988. For the first time in this region, a large volume of satellite information was summarized into an easily manageable data set: 3,953 individual passes of NOAA satellites were composited into 288 5-day composites (72 composites per year). The SST fields produced will be used by

the National Marine Fisheries Service (NMFS) to formulate or test hypotheses concerning the distribution and/or relative abundance of commercially important fish species. Additionally, the easily available data set should be of interest to researchers throughout the NOAA system and the academic community. The SST time series can be stored and distributed in personal computer diskettes. Documentation is available that allows users to access and utilize the data without any special hardware or software. In cooperation with scientists at the Southeast Fisheries Center (SEFC) of the NMFS, this data base was used to begin a study of associations between oceanic conditions and the distribution and abundance of swordfish (Xiphias gladius) exploited by the U.S. longline fishery. The first study concerns the conventional belief among longline fishermen that swordfish catches are higher near surface thermal fronts (fronts are areas where SST changes rapidly in short distances). While it was found that a large proportion of the fishing effort was concentrated near thermal fronts, no apparent association appeared between distance to fronts (or the strength of fronts) and swordfish catch per unit effort (CPUE). That is, although effort is undoubtedly deployed near fronts, CPUEs near these features were not necessarily higher than elsewhere. Our results, then, failed to support the conventional expectation of higher swordfish yields in the vicinity of fronts.

Plans FY90

Larval Ecology of Bluefin Tuna

This is a continuing project in support of the management planning for tuna fisheries. FY 90 activities projected are:

- Edit and supplement data base of bluefin larvae at NOAA-SEFC-Miami Laboratory.
- Analyze larval distribution and abundance at Loop Current Fronts.
- Update index of adult spawners based on larvae.

SEFCAR

FY 90 will be a major year of SEFCAR field activity as well as laboratory-based and model studies.

Physical observations

A shelf break current meter array will be maintained, and include redeployment of the ADCP mooring for an 8-month period starting in February 1990. The interdisciplinary survey cruises will continue on a seasonal basis, with the addition of acoustic mapping of water mass fronts and biological scatterers.

The work will be coordinated with a planned Minerals Management Service (MMS) study in the Florida Straits region to make the most use of the available data from both studies. The MMS study will provide important larger scaler observations defining the environment of the SEFCAR project. Analysis of the observations will be geared toward development of a dynamic characterization of the spatial scales, temporal variability and velocity and water mass structure, which can be used as the physical system characterization in a development of an ecosystem model up to the macro-zooplankton level.

Biological observations

Biological sampling will continue to be coordinated with the physical cruises, involving plankton net sampling as well as settling targets for spiny lobster larvae.

- Analyze snapper, grouper, and lobster larvae data from cruises in May, August, November 1989, and in February 1990.

- Collect adult lobsters from potential source regions in the Caribbean.

- Monitor recruitment of juvenile snappers, groupers, and lobsters to the Florida Keys.

- The biochemical/genetic studies will continue in order to clone the entire mtDNA molecule from spiny lobster to generate a probe for hybridization with other individuals.

- Analysis of the mtDNA of 12 to 20 lobsters from several sites within the Caribbean will determine how closely related the populations are to each other and to Florida lobsters. This will indicate if the spiny lobster is one large panmictic population, or alternatively if there is genetic divergence between populations.

- Collection of samples of larvae and post-larvae that are recruited to South Florida will be continued for future analyses.

- Application of mtDNA methodology to species of snapper will be pursued with two goals in mind: (1) to develop biochemical methods to distinguish the larvae of different snapper species which are difficult, at best, to distinguish by traditional morphometric or morphological means; and (2) to begin a Caribbean basin study of snappers that is analogous to our approach with the spiny lobster.

Continuation of the larval development and habit studies

Chlorophyll determinations will be performed at all CTD stations at all bottle depths starting during the November 1989 cruise. These samples will be used to help understand the linkage between the physics and the production cycle. Bottle samples of microzooplankton will continue.

Age validation will continue and we will attempt to determine the age of any field-caught samples provided.

Mangrove snapper will be reared on four concentrations of wild and cultured foods and their growth and condition (indicated from spectrophotometric determination of total lipid content) will be assessed. As rearing and field determinations of food abundances proceed, more feeding experiments will be conducted which can then accurately reflect the variability in food concentrations in the field.

Descriptions of all larvae reared will continue.

Fisheries Dynamics

Collaboration with SEFC scientists to investigate environmental influences on the swordfish longline fishery. The objective is to investigate associations between swordfish CPUE and topographic and oceanographic features (e.g., the shelf break, submarine canyons, warm core eddies, etc.) believed to influence the relative abundance of this species. Another avenue of research follows up on the failure to discover an association between swordfish CPUE and ocean fronts. Based on the assumption that fronts may be attractive to swordfish due to increased abundance of prey, it may be necessary to allow for the rate of accumulation or production of forage near fronts. Accordingly, the frontal history will be investigated in areas where logline sets were located. Assuming success of these approaches, the analyses will be extended to the 1988 longline data, currently being compiled by SEFC. The outlined analyses can be expanded to include other species exploited by the U.S. longline fishery. Subject to funding, the satellite-derived SST time series off the U.S. east coast, initially supported by CIMAS, will be continued. The series would be extended to include 1989 as well as 1983 and 1984 (these years are required for analyses of bluefin tuna data).

JOINT INSTITUTE FOR STUDY OF THE ATMOSPHERE AND OCEAN
Seattle, Washington
(206) 545–2585
J. Michael Wallace, Director

The Joint Institute for Study of the Atmosphere and Ocean (JISAO) was established to foster collaboration between the National Oceanic and Atmospheric Administration (NOAA) and the University of Washington. JISAO serves as a vehicle for funding grants and postdoctoral Fellows, and supporting collaborative research between NOAA and university scientists. During the past few years, JISAO has emphasized three core research areas: climate, environmental chemistry, and estuaries.

JISAO's climate research has tended to focus on two main themes: large-scale atmosphere-ocean interaction in the tropics and planetary-scale wave and mean flow interaction. These efforts have served to promote collaboration between the Pacific Marine Environmental Laboratories and university scientists involved in the Equatorial Pacific Ocean Climate Studies (EPOCS) program. It has also been active in efforts to direct interdisciplinary research toward and understanding of the global climate system and its sensitivity to human activities. The new Environmental Climate Forecast Center within JISAO was established for this purpose.

The main research themes in environmental chemistry include marine aspects of the carbon dioxide problem, organic carbon dynamics, and chemical processes involving the deposition of heavy metals. Recently, JISAO's chemistry research has broadened in scope to include other biogeochemical cycles of interest for global climate. Of particular interest is the chemistry of sulfur and its influence on cloud condensation nuclei and the cycles that involve long-lived radiatively interactive trace species such as nitrous oxide and methane.

Accomplishments FY 89

JISAO scientists, in collaboration with NOAA scientists, were involved in a variety of climate research activities. In the field of modeling, scientists explored the sensitivity of interannual variability in a coupled ocean-atmosphere model to the physics parameterizations and climatological mean conditions, giving

particular attention to identifying the stability of the coupled tropical ocean-atmosphere system. They also worked on the potential effect of cloud radiation feedback on the El Niño-Southern Oscillation (ENSO) phenomenon and formulated a consistent yet simple model for the tropical atmosphere surface winds. Additionally, research was conducted in conjunction with the OCEAN STORMS field experiment, resulting in the analysis of a comma-cloud-type storm using Nested-Grid Model output and research aircraft observations.

Research concerning the propagation of equatorial waves also continued. In particular, researchers investigated the propagation of these waves in the presence of mean currents, studied the propagation of equatorial Kelvin waves on a sloping thermocline, investigated how a coastal Kelvin wave can propagate on a sphere, and completed a study on aspects of Kelvin wave response to episodic wind forcing. Analysis aimed at clarifying the various mechanisms of oscillation in coupled ocean-atmosphere models also continued along with experiments using simple delayed-oscillator models to clear up points relating to the impact of stochastic forcing on the periodicity of such systems. Work also continued in the area of environmental chemistry with the analysis of data collected on the RITS–88 [Radiatively Important Trace Species] cruise and a Pacific Stratus Experiment (PSI) cruise conducted in June off the Washington coast. Aerosol size distribution measurements, concentration, and chemical composition data from these cruises is under analysis.

Estuarine studies continue with research focusing on wind effects on non-tidal circulation in fjords. In addition to near-surface wind effects, mid-depth compensating flows have been documented in two separate experiments under different mean flow characteristics using both empirical orthogonal function and lagged linear correlation analysis.

JISAO is also involved in research conducted at the Experimental Climate Forecast Center which began operation in January 1989. A computer system was acquired and work began on two problems: (1) exploring the predictability of the ENSO phenomenon and (2) examining the factors that influence climate change on time scales of 100 years.

Plans FY 90

- Work with NOAA to develop an expanding program for dealing with scientific issues relating to global climate change.
- Continue research on the predictability of ENSO events.
- Continue research on climate, focusing on coupled atmosphere-ocean interaction and biogeochemical cycles.
- Continue participation in research efforts involving EPOCS, Climate and Global Change, and PSI.
- Continue a vigorous visitor and seminar program.

JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH

Honolulu, Hawaii
(808) 546–8914
Dennis W. Moore, Director

The Joint Institute for Marine and Atmospheric Research (JIMAR), located at the University of Hawaii, was formed in 1977, under a Memorandum of Understanding between the National Oceanic and Atmospheric Administration and the University of Hawaii. The principal research interests of JIMAR have been equatorial oceanography, climate, and tsunamis. A new interest in fisheries oceanography was added in FY 88.

Accomplishments FY 89

Climate Research

JIMAR continued to produce, and publish in the Climate Analysis Center Bulletin, monthly subjectively analyzed mean surface wind fields for the Pacific. Diagnostic case studies of westerly wind bursts and their relation to El Niño-Southern Oscillation were also carried out.

A simple atmospheric model on an equatorial beta plane was used to study the coupling of a moist Kelvin wave with a low mode Rossby wave. An unstable mode which depends on the moisture convergence in the boundary layer has been described. The characteristics of the unstable mode are quite sensitive to the underlying sea-surface temperature distribution which determines the background state in the model.

Observational studies of the structure and propagation of Tropical Intraseasonal Waves were conducted. The data included outgoing longwave radiation plus 200 mb and 850 mb winds. Three major paths of propagation and the geographic dependence of the development were documented.

Equatorial Oceanography

Analysis of the Pacific Equatorial Ocean Dynamics (PEQUOD) PEGASUS current profile data revealed the existence of three deep equatorial currents in the central Pacific below 1500 meters depth. Two of these have transports (7 Sverdrups; 1 Sverdrup = 10^6 m^3 s^{-1}) comparable to deep western boundary currents.

Analysis of the Western Equatorial Pacific Ocean Climate Studies (WEPOCS) data from the Celebes Sea revealed the structure of a number of currents, including the New Guinea Coastal undercurrent and the Mindanao current. Low-frequency variability in the area is a combination of local response to local winds and a large scale response to the monsoon.

The Hawaiian Ocean Time-series (HOT) project, a five year program of monthly biogeochemical and physical oceanographic observations at a station north of Oahu, conducted its first cruise in October 1988. Hydrographic observations and acoustic Doppler current profiles collected on the cruise are being analyzed.

A major workshop and planning meeting for the Coupled Ocean-Atmosphere Response Experiment (COARE) was held in Noumea in May 1989. Continued participation in this experiment is anticipated. The Indo-Pacific sea-level network for Tropical Ocean and Global Atmosphere (TOGA) continued with four new stations in the Indian Ocean and two more Pacific stations upgraded to satellite transmission.

The TOGA Sea Level Center archived data for 72 of the 81 existing TOGA Pacific stations. There are 23 TOGA stations in the Indian Ocean, but data return is spotty.

A proposal was submitted to establish a sea-level center for the World Ocean Circulation Experiment (WOCE). This center would produce satellite transmitted data sets for distribution within a few months of the original data acquisition.

JIMAR scientists are included in the National Aeronautics and Space Administration's (NASA's) Topographic Experiment (TOPEX) Science Working Team.

Fisheries Oceanography

The final two of five cruises to Southeast Hancock Seamount were completed in the fall of 1988. The biological and physical data are being analyzed. The description of the current patterns over the seamount is nearly complete. The acoustic Doppler current profiler data indicates that the flow at levels above the top of the seamount is nearly uniform in space over the seamount, but quite variable in time from one cruise to the next. The distribution of two micronekton species are being analyzed in relation to these current patterns.

A description of larval distribution relative to current patterns around Johnston Island was completed. The data indicate high abundances of island-related fish larvae downstream of the island. Analysis of larval distributions around Oahu continues. A field program to study the relationship of the distribution of larval lobster to oceanographic conditions in the Northwestern Hawaiian Islands is also underway.

Tsunami Research

Numerical studies to support the Pacific Tsunami Observational Program continued. A variety of different source distributions were used to generate tsunamis in two models with different depth and grid resolutions. The effects of varying the source parameters, as well as the effect of grid resolution, were investigated. Comparisons of numerical results with open ocean pressure observations made during November 1987 and March 1988 were made. The numerical results are very sensitive to the assumed source parameters and the grid resolution.

An analysis of the tsunami evacuation zones for the state of Hawaii was begun, resulting in the redrawing of evacuation maps due to changing population patterns and urban development. The volunteer tsunami observer program has also been maintained, as has the publication of the Tsunami Journal.

Plans FY 90

Climate Research

- Modeling studies of tropical low frequency motions including effects of non-linear heating and monsoonal basic flows.

- Tropical cyclone motion will be studied using a beta plane model with background mean flow.

- Comprehensive Ocean-Atmosphere Data Sets, outgoing longwave radiation, and sea level data will be used to study equatorial air-sea interaction on a variety of time scales, from several months to interannual.

- Continue to produce monthly surface wind maps for the Pacific.
- Develop calibration methods for satellite-based rainfall algorithms.
- Evaluate moored buoy wind data being taken for TOGA and Equatorial Pacific Ocean Climate Studies.
- Continue diagnostics studies of westerly wind events and low-frequency wind variability in the equatorial Pacific.

Equatorial Oceanography

- Analysis and modeling of equatorial deep jets and El Niño current variability.
- Acoustic Doppler current profiler measurements will continue in TOGA and be proposed for WOCE.
- Continue to operate the Indo-Pacific sea level network.
- Continue to operate the TOGA Sea Level Center.
- Continue TOPEX work and prepare for acquisition of an operational sea-level data set supporting the TOPEX/POSEIDON altimeter data set.
- Continue the HOT project.
- Continue analysis of Line Islands Array and WEPOCS data.
- Continue COARE preparations, including publication of proceedings from the Noumea meeting, and preparation of an implementation plan.

Fisheries Oceanography

- Analysis of the response of micronekton and other "oceanic" species to flow patterns around the summit of Southeast Hancock Seamount.
- Begin planning for a followup cruise to Johnston Island in FY 91.

- Physical and biological measurements will be made in the North Pacific Transition Zone to assess the impact of the large-mesh fishery on the pelagic fishes.

Tsunami Research

- Numerical studies of the sensitivity of tsunami models to the source parameters and grid resolution will continue to determine how model results can be sensibly compared with open ocean observations.

- Continue studying the problem of comparing near shore tide gauge records with open ocean pressure observations and numerical models.

- Complete the revised tsunami evacuation maps for the State of Hawaii.

APPENDIX: Acronyms and Initialisms

AASE	Airborne Arctic Stratospheric Experiment
AAOE	Airborne Antarctic Ozone Experiment
A&P	Analysis and Prediction [program] (FSL)
ACC	Alaska Coastal Current
ADCP	acoustic Doppler current profiler
AFTAD	Analysis-Forecast Transport and Diffusion
AGASP	Arctic Gas and Aerosol Sampling Program
AI	artificial intelligence
AL	Aeronomy Laboratory (ERL)
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
ARGOS	[French satellite; not an acronym]
ARL	Air Resources Laboratory (ERL)
ASCOT	Atmospheric Studies in Complex Terrain (DOE)
AU	astronomical unit
AVHRR	Advanced Very-High-Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AWIPS–90	Advanced Weather Interactive Processing System for the 1990s
AXCP	Airborne Expendable Current Profiler
AXBT	airborne XBT
BLIPS	Benthic Layer Interactive Profiling System
BPR	bottom pressure recorder
BT	bathythermograph
CAPS	Center for Analysis and Prediction of Storms
CASE	Coordinated Air-Sea Experiment
CCIW	Canada Centre for Inland Waters
CCOPE	Cooperative Convective Precipitation Experiment
CEAREX	Coordinated Eastern Arctic Research Experiment
CFC	chlorofluorocarbon
CFM	chlorofluoromethane
CG	cloud to ground
CILER	Cooperative Institute for Limnology and Ecosystems Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CITE	Chemical Instrumentation and Test Evaluation
CLASS	Cross-chain LORAN Atmospheric Sounding System
CLICOM	climate computing
CME	coronal mass ejection
COADS	Comprehensive Ocean-Atmosphere Data Set
COARE	Coupled Ocean-Atmosphere Response Experiment
COPS	Cooperative Oklahoma P–3 Studies
CPUE	catch per unit [fish] effort
CSES	Center for the Study of Earth from Space
CSU	Colorado State University

CTD	conductivity, temperature, depth
DARE–II	[PROFS meteorological workstation; not an acronym]
DMS	dimethylsulfide
DMSP	Defense Meteorological Satellite Program
DOE	Department of Energy
D.U.	Dobson unit
DWBC	Deep Western Boundary Current
ENSO	El Niño-Southern Oscillation
EOF	empirical orthogonal function
EPA	Environmental Protection Agency
EPOCS	Equatorial Pacific Ocean Climate Studies
ERL	Environmental Research Laboratories (NOAA)
FAA	Federal Aviation Administration
FASINEX	Frontal Air-Sea Interaction Experiment
FGGE	First GARP Global Experiment
FIDES	Forecaster's Intelligent Discussion Expert System
FIFE	First ISLSCP Field Experiment
FIRE	First ISCCP Regional Experiment
FNOC	Fleet Numerical Oceanographic Center
FOCI	Fisheries Oceanography Coordinated Investigations (NOAA)
FREEZE	[experiment to study processes related to ice formation; not an acronym]
FSL	Forecast Systems Laboratory (ERL)
GALE	Genesis of Atlantic Lows Experiment
GARP	Global Atmospheric Research Program
GCM	general circulation model
GEOSAT	Geodetic Satellite
GFDL	Geophysical Fluid Dynamics Laboratory (ERL)
GISP	Greenland Ice Sheet Project
GISS	Goddard Institute for Space Studies
GLERL	Great Lakes Environmental Research Laboratory (ERL)
GLOBE	Global Backscatter Experiment
GMCC	Geophysical Monitoring for Climatic Change (ARL)
GOES	Geostationary Operational Environmental Satellite
GTN	Global Trends Network
GUFMEX	Gulf of Mexico [project]
HCFC	hydrochlorofluorocarbon
HIBU	Hydrological Institute and Belgrade University
HIRIS	High-Resolution Imaging Spectrometer
HIS	High-Resolution Interferometer Spectrometer
HOT	Hawaii Ocean Time-series
HRD	Hurricane Research Division (AOML)
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IGM	interplanetary global model

IGSP	International Greenland Sea Project
INSAT	Indian Satellite
IPS	interplanetary scintillation
ISCCP	International Satellite Cloud Climatology Project
ISEE	International Sun-Earth Explorer
JAMSTEC	Japan Marine Science and Technology Center
JIC	Joint Ice Center
JIMAR	Joint Institute for Marine and Atmospheric Research
JISAO	Joint Institute for Study of the Atmosphere and Ocean
JSC	Johnson Space Center
LAHM	Limited Area HIBU Model
LAPS	Local Analysis and Prediction System
LASCO	Large-angle Spectrometric Coronagraph
LORAN	Long-Range Aid to Navigation
MAPS	Mesoscale Analysis and Prediction System
MCLASS	Mobile CLASS
MCS	mesoscale convective system
MCV	mesoscale convectively generated vortices
MHD	magnetohydrodynamic
MIT	Massachusetts Institute of Technology
MLD	mixed layer depth
MMS	Minerals Management Service
MOCNESS	Multiple Opening and Closing Net Environmental Sampling System
MOU	Memorandum of Understanding
MRAO	Mullard Radio Astronomy Observatory
MRD	Mesoscale Research Division (NSSL)
MST	Mesosphere-Stratosphere-Troposphere
mtDNA	metochondrial deoxyribonucleic acid
NADW	North Atlantic Deep Water
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NESDIS	National Environmental Satellite, Data, and Information Services (NOAA)
NEXRAD	Next-Generation Weather Radar
NGDC	National Geophysical Data Center (NOAA)
NGM	Nested Grid Model
NHC	National Hurricane Center (NWS)
NIMBUS–7	[NOAA satellite; not an acronym]
NMC	National Meteorological Center (NOAA)
NMFS	National Marine Fisheries Service (NOAA)
NMHC	non-methane hydrocarbon
NOAA	National Oceanic and Atmospheric Administration
NOAAPORT	[access to NOAA real-time data base system; not an acronym]
NOS	National Ocean Service (NOAA)
NRC	National Research Council
NRC	Nuclear Regulatory Commission

NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSL	National Severe Storms Laboratory (ERL)
NURP	NOAA Undersea Research Program
NWP	numerical weather prediction
NWS	National Weather Service (NOAA)
OCEAN STORMS	[JISAO field experiment; not an acronym]
ODW	Omega dropwindsonde
OU	University of Oklahoma
PACTOP	Pacific Tsunami Observation Program
PCB	polychlorinated biphenyl
PEGASUS	[velocity profiler; not an acronym]
PEQUOD	Pacific Equatorial Ocean Dynamics
PMEL	Pacific Marine Environmental Laboratory (ERL)
POSEIDON	[French satellite; not an acronym]
POT	Program for Operational Trajectories
POTAD	Program for Operational Transport and Dispersion
PRE-STORM	Preliminary Regional Experiment for STORM
PROFS	Program for Regional Observing and Forecasting Services (FSL)
PSI	Pacific Stratus Investigation
QBO	quasi-biennial oscillation
RADM	Regional Acid Deposition Model
RAMM	Regional and Mesoscale Meteorology
RASS	Radio Acoustic Sounding System
RITS	Radiatively Important Trace Species
RSMAS	Rosenstiel School of Marine and Atmospheric Sciences
SA	spaced antenna
SAFER	Spectral Application of Finite Element Representation
SAVE	South Atlantic Ventilation Experiment
SBUV	solar backscatter ultraviolet
SEFC	Southeast Fisheries Center
SEFCAR	South and East Florida and Caribbean Recruitment
SEL	Space Environment Laboratory (ERL)
SELDADS	SEL Data Acquisition and Display System
SEM	Space Environment Monitor
SESC	Space Environment Services Center (SEL)
SHARE	[international program to develop meteorological analysis and display software for developing countries; not an acronym]
SIO	Scripps Institution of Oceanography
SKYHI	[GFDL stratosphere GCM; not an acronym]
SMM	Solar Maximum Mission
SMMR	Scanning Multichannel Microwave Radiometer
SSD	Scientific Support Division (NSSL)
SSF	semi-Lagrangian and semi-geostrophic finite-element [model]

SSM/I	Special Sensor Microwave/Imager
SST	sea-surface temperature
STACS	Subtropical Atlantic Climate Studies
STEP	Stratosphere-Troposphere Exchange Project
STORM	Stormscale Operational and Research Meteorology
SXI	Solar X-ray Imager
TAO	Thermal Arrays for the Ocean
TDWR	Terminal Doppler Weather Radar
TELSAR	Tracking and Evolution of Solar Active Regions
THEO	[system for predicting solar flare probabilities; named for Theophrastus; not an acronym]
TIROS	Television and Infrared Observation Satellite
TO-AN	Tropical Ocean-Atmosphere Newsletter
TOGA	Tropical Ocean and Global Atmosphere
TOPEX	Topographic Experiment
TVS	tornado vortex signature
UHF	ultrahigh frequency
UM	University of Miami
UNISYS	United Information Systems
URSI	Union Radio Scientifique Internationale
UTC	Coordinated Universal Time
UV	ultraviolet
VAS	VISSR Atmospheric Sounder
VENTS	[hydrothermal venting program; not an acronym]
VHF	very high frequency
VICBAR	[code name for barotropic hurricane track prediction model; not an acronym]
VISSR	Visible and Infrared Spin-Scan Radiometer
VOC	volatile organic compound
VOS	Volunteer Observing Ship
WAM	Wave Modeling
WATOX	Western Atlantic Ocean Experiment
WDC	World Data Center
WEPOCS	Western Equatorial Pacific Ocean Circulation Study
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiments
WOTAN	Weather Observation Through Ambient Noise
WPL	Wave Propagation Laboratory (ERL)
WRIPS	Wave Rider Information Processing System
WSFO	Weather Service Forecast Office
XBT	expendable bathythermograph

☆U.S. GOVERNMENT PRINTING OFFICE:1990 -773 -002/ 11022