Environmental Research Laboratories Programs and Plans

FY 1990 Programs and FY 1991 Plans

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

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Environmental Research Laboratories
Boulder, Colorado
Joseph O. Fletcher, Director

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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.

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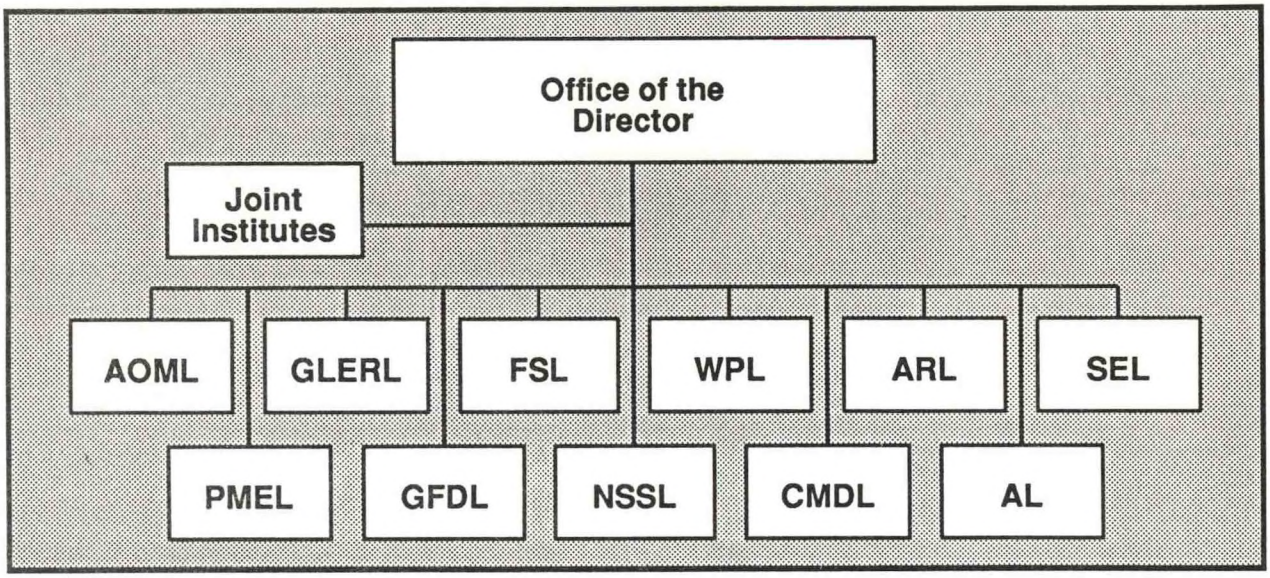
These are highlights of Laboratory accomplishments and abbreviated summaries of immediate objectives. More comprehensive and detailed descriptions of activities, results, and plans may be found in the Laboratories' annual reports (which may be obtained directly from the Laboratories) and in the open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



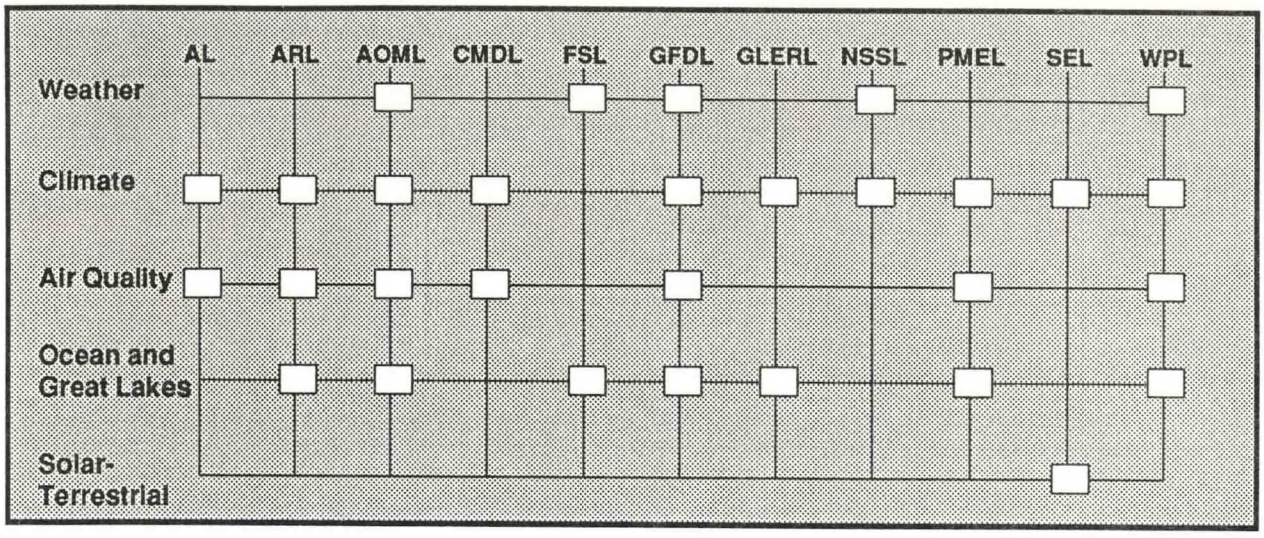
ENVIRONMENTAL RESEARCH LABORATORIES

The Environmental Research Laboratories (ERL) of NOAA's Office of Oceanic and Atmospheric Research are headquartered in Boulder, Colorado. ERL includes 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
Climate Monitoring and Diagnostics Laboratory (CMDL)	Boulder, Colorado
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, seven 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 Office of NOAA Corps Operations (ONCO).

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), cooperative fisheries and oceanography studies (to improve prediction and management of fisheries stocks), and solar activity forecasts (to protect astronauts and aircraft crews 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.

ERL is a key element in NOAA's response to major emerging National environmental programs including Climate and Global Change, Coastal Oceans, and the national STORM program. A broad spectrum of research responds to these programs as described in the programs of each Laboratory.

The ERL program embraces 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: Climate, Air Quality, Ocean and Great Lakes, Weather, and the 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.

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 1990, major climate research accomplishments included the following:

- Scientists from CMDL's Geophysical Monitoring for Climatic Change program analyzed global methane trends from 1983 to the present. Methane is an important trace gas in the Earth's atmosphere because it is active both radiatively and chemically and is particularly effective in depleting stratospheric ozone. Concentrations of this gas may have a large effect on the global climate. Results of the analysis showed that the average growth rate of methane in the Northern Hemisphere (12.9 parts per billion per year) exceeded that in the Southern Hemisphere (11.5 parts per billion per year). The growth rate of methane decelerated over this period, declining from an instantaneous growth of approximately 15 parts per billion per year in 1983 to approximately 11 parts per billion per year by 1990. GMCC scientists also found that the methane growth rate can change quite quickly, which gives hope that successful human intervention can severely limit the accumulation of this gas in the atmosphere.

- AL scientists continue to lead stratospheric ozone research and its integration into world policy-making processes. AL led the "Scientific Assessment of Stratospheric Ozone" called for by the Montreal Protocol of 1987, and signed by many members of the United Nations to begin to limit the production and use of chlorofluorocarbons (CFCs), which are predicted to deplete stratospheric ozone. A thinning of the ozone layer would allow an increase in the amount of ultraviolet radiation reaching the surface, harming humans and ecosystems. The Assessment focused on major advances in ozone research since the Montreal Protocol was crafted. Much of the research was conducted by AL scientists and has indeed been remarkable:

  The Antarctic ozone "hole" was shown to be due to CFCs, whose effect on ozone was enhanced by stratospheric ice clouds.

  The same ozone-destroying, ice-enhanced processes were found in the Arctic, where the degree of ozone loss will be less than that in the Antarctic, depending on the severity of Arctic winters.

  Southward trends in global ozone (i.e., extension beyond the polar regions) were discovered in the Northern Hemisphere and cannot be attributed to known natural causes.

- Researchers at AOML have developed a data-assimilating version of GFDL's general ocean circulation model. Extensive experiments with synthetic data sets demonstrated that the assimilation technique yields realistic results. The problem with using numerical models to predict states of the oceans and atmosphere is that available observations are sparse, asynoptic, noisy, erratically distributed in space and time, and generally inadequate to describe the initial state of the ocean or atmosphere completely. To deal with such data, AOML scientists developed a sophisticated method to combine the GFDL computer model with real observations. This data-assimilating version of the GFDL GCM will be used by the research community over the next decade in analyzing the large data sets to be collected in such programs as TOGA and WOCE.

- Recent research has made it evident that substantial chemical depletion of ozone is occurring inside the Antarctic spring polar vortex, but with significant modulation by seasonal and interannual dynamical processes. In response to this, GFDL used the 3°-latitude-resolution SKYHI model to explore the chemical–radiative-transport–dynamical response of the stratosphere to a parameterized polar vortex ozone destruction that approximately mimics the observed "ozone hole." GFDL has completed 4 1/2 years of SKYHI model integration. In addition to the substantial polar vortex cooling and concomitant polar jet strengthening previously reported, further analysis shows evidence of dynamically induced sinking motion over the entire polar region. In addition, a cooling of about 1°C in the 50–100 mb middle-latitude Southern Hemisphere summer appears to be due to meridional spreading of ozone-depleted air into these regions. The model predicts no effects in the Northern Hemisphere that are due to the Antarctic "ozone hole" phenomenon.

- PMEL scientists successfully documented and analyzed the 1986–88 ENSO event, and produced the best data set ever in terms of in-situ wind, ocean current, and temperature. Improved data describing initial ocean and atmosphere conditions have long been necessary input for advanced model predictions. Data from the equatorial Pacific were intensively collected and analyzed to describe variability on ENSO time scales and to test specific hypotheses of ocean dynamics and air-sea interaction. Results of analyses suggest that locally and remotely forced wind-driven zonal currents at the Equator are important in the evolution of mass and heat balance changes in the western Pacific. Year-to-year fluctuations in the eastern Pacific were found to be related primarily to zonal wind variations in the central and western Pacific. PMEL scientists also identified wind stress anomalies and energetic intraseasonal fluctuations of zonal current temperature. The descriptive analyses provide the necessary background for more detailed studies to test specific dynamic and thermodynamic hypotheses, and provide the observational framework needed to design and implement a basin-wide, tropical Pacific observing system, the TOGA Tropical Atmosphere-Ocean (TOGA-TAO) array, required for the second half of the TOGA decade.

- AOML led the TOGA Pan-Pacific Surface Current Study, a major element of the international TOGA program. Through cooperation with scientists from the Scripps Institution of Oceanography (SIO) and Woods Hole Oceanographic Institution (WHOI), and scientists from Japan and France, an array of 150 satellite-tracked drifting buoys was used to measure sea-surface temperatures 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.

- Scientists at AOML completed the first simultaneous inventory of all five recognized end products of dimethylsulfide (DMS) oxidation in the marine atmosphere. The full suite of data measured allowed AOML to assess the role of DMSO and $DMSO_2$ in the marine sulfur cycle, the data indicating that these compounds are minor players in the marine atmospheric sulfur cycle over the North Atlantic and that they probably have an insignificant effect on particle formation there. Attention can now be turned to other potential players.

AIR QUALITY RESEARCH

ERL air quality research is led by ARL, AL, and WPL. The goal of this research is to understand and predict the health of the atmosphere, thus providing policy makers with the scientific information needed to reduce harmful effects. The main focuses are tropospheric ozone and acid rain. During 1990, particular success was achieved in the following:

- ARL scientists completed one of the most scientifically successful projects in the National Acid Precipitation Assessment Program (NAPAP). The Western Atlantic Ocean Experiment (WATOX) is a NOAA contribution to the acid rain studies under NAPAP. Analyses of field data taken from ships and aircraft have determined the percentages of sulfur and nitrogen compounds that are transported off the coast of North America and have led to a much better understanding of the meteorological factors that influence transport of substances to the North Atlantic. The atmospheric chemistry field data are unique and will be used in global transport models and in studies to describe climate and global change over the western Atlantic Ocean.

- AL scientists have determined that ozone control strategies designed for urban areas will not be successful in rural environments. The researchers developed a three-dimensional mesoscale model and applied it to the eastern United States to study the formation of rural ozone and to evaluate ozone control strategies. Field programs, last year in Pennsylvania and this year in Alabama, provided input data for the model and also served as a critical test of model results. It is well known that ozone levels depend in a highly nonlinear fashion on ozone precursors — nonmethane hydrocarbons and oxides of nitrogen. Research results using the model and field data show that in the rural environment, reducing anthropogenic NO_x emission is, by a factor of 3, more effective than reducing NMHC in reducing ozone production. Because the roles of NO_x and NMHC in the formation of urban ozone are reversed from the roles in rural areas, the optimum rural ozone control strategy is probably to control the emission of both precursors.

- WPL and AL engineers and scientists designed and built seven 915-MHz experimental wind profilers, which WPL operated as part of the $14 million San Joaquin Valley pollution study. Supporting scientific data were also obtained by WPL from several sodars measuring mixing layer depth, from an array of highly sensitive microbarographs that measured surface pressure fields, and from a newly developed, portable, surface energy budget system that measured sensible and latent heat transfer as well as solar and long-wave radiation. This was the most complete array of such instruments ever deployed in a mesoscale study. This last set of data, when combined with profiler wind and reflectivity data, provides a critical test of boundary layer parameterizations used in conventional mesoscale air quality models. The outstanding success of 915-MHz profiler technology paves the way for widespread acceptance in air quality–air chemistry research.

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. These were significant accomplishments in 1990:

- AOML completed the first quantitative determination of the total heat flux from a seafloor hydrothermal field, comprising both the discrete component of heat flux from individual vents and the diffuse component from relatively large areas of the seafloor, based on measurements obtained at the ASHES vent field on the Juan de Fuca Ridge in the eastern Pacific. The study revealed that the diffuse component is one order of magnitude greater than the discrete component of the heat transfer from the hydrothermal field.

- AOML scientists organized and led a collaborative, international, multi-institutional diving cruise of the R/V *Atlantis II* and DSRV *Alvin* in January 1990 to characterize the contribution of hydrothermal venting from the Mid-Atlantic Ridge to the chemistry and thermal structure of the global ocean. This collaborative research collected the first comprehensive data to determine the chemical and thermal effects of hydrothermal venting in the central north Atlantic. The work was done by scientists from NOAA, the Woods Hole Oceanographic Institution, the Massachusetts Institute of Technology, the University of Cambridge (England) and the Geological Survey of Canada/University of Toronto. In addition, samples were taken for IFREMER (France) to support the FARA (French-American Ridge Atlantic) program.

- As part of the Fisheries Oceanography Coordinated Investigations (FOCI) program of NOAA, PMEL developed an advection-diffusion model to investigate the interactions of biological and physical mechanisms and to determine how these affect the survival of pollack larvae. The domain of the model extends from northern Shelikof Strait westward to the Shumagin Islands, an area far larger than that of observed larval patches. The model has many degrees of freedom, so that many variables can be accommodated, and changes can be easily made to keep pace with increased knowledge. The model represents the successful completion of the first step to aid the understanding of the causes of mortality and recruitment to the pollack fishery.

- GLERL organized a workshop and led the effort to develop a consensus strategy for applying a mass balance approach for examining contaminants in the Great Lakes. This was requested by the Water Quality Board of the International Joint Commission (IJC), an international coordinating mechanism between Canada and the United States. Mass balance modeling helps quantify emission sources. This approach makes it possible to determine the most effective method of load reduction for the Great Lakes ecosystem, and the most cost-effective source reduction strategy. Modeling helps provide estimates of the time required to achieve a particular load reduction, whereas monitoring only reveals the load reduction after the fact. Through the GLERL-organized workshop, strategies and numerical tools were identified to substantially improve the interpretation of contaminant monitoring data in the Great Lakes.

- The GFDL coupled ocean-atmosphere model used in greenhouse warming projections was evaluated by comparing simulations of chlorofluorocarbon (CFC) uptake by the oceans with measurements obtained by PMEL. This positive verification suggests that the deep ventilation produced by the model in the Southern Ocean is realistic. Such a validation is important, since the heat capacity associated with this deep, well-mixed water column effectively increases the climate system's thermal inertia. This simulation supports the conclusion drawn from coupled model experiments that a CO_2-induced climate change would be characterized by a slower increase in high-latitude Southern Hemisphere air temperatures.

WEATHER RESEARCH

Weather research concerns observational systems; data acquisition, management, analysis, and display systems; severe storm prediction, including flash floods, hail, tornadoes, and wind storms; and hurricane prediction. The aim 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 AOML, FSL, GFDL, NSSL, and WPL. During 1990, ERL weather research achieved notable successes:

- The Hurricane Research Division (HRD) of AOML implemented a real-time analysis model to improve hurricane intensity forecasts. The analysis uses NOAA WP-3D flight-level observations recorded every minute as the aircraft flies through the hurricane. Data are transmitted at half-hour intervals over the Aircraft-Satellite Data Link (ASDL) to the ground station at Wallops Island, then through National Weather Service (NWS) ground communications to the National Hurricane Center (NHC). At NHC, HRD constructs an objective hurricane track, interpolates the data into storm-centered coordinates, and generates graphical depictions of hurricane structure. This output allows forecasters to monitor changes in the vortex through immediate identification and tracking of convective rings, and provides an objective estimate of current hurricane motion — a major indicator of future motion.

- An engineering prototype of the Advanced Weather Interactive Processing System (AWIPS) for the 1990s was completed by FSL and is now the operation computer workstation system at the NWS forecast office in Denver. AWIPS will be procured and implemented nationally as a major element of NWS modernization.

- Experimental predictions for Hurricane Gloria were successfully performed with the GFDL Multiply-nested Movable Mesh (MMM) hurricane model. Results of the experiment indicated that high performance of the model could be extended to 132 hours, a significant improvement over operational models. The considerably accelerated movement of Gloria on the day of landfall was accurately represented, and the deep-layer mean wind was found to be a good indicator of the steering flow. The vortex spin-up in the Gloria simulation was quite slow, indicating a need to improve the initial vortex specification. The MMM model reproduced the marked asymmetry of Gloria in the wind and rainfall distributions. The high performance of the MMM model is an encouraging sign for future improvements in hurricane forecasting.

- Coupled atmospheric and oceanic GCMs, capable of sustained Southern Oscillations, have been developed at GFDL. The GFDL coupled atmosphere-ocean models have produced realistic El Niño and La Niña states with a rich spectrum of variability on time scales ranging from days to years. At present these are the only known models able to produce realistic El Niño and La Niña oscillatory events. Other successful models are idealized anomaly models with specified mean states. Researchers performed two sets of experiments in which the same atmospheric GCM is coupled to two oceanic GCMs with different spatial resolutions. The evolution of El Niño and of La Niña is different in the two sets of calculations. Detailed analysis of the subsurface thermal structure of the ocean in different stages of the Southern Oscillation revealed the dynamical processes responsible for this cyclic behavior of the ocean-atmosphere system. Analyses also suggest that a coupled model cannot be judged strictly on its ability to simulate realistic El Niño and La Niña states, but also must be judged on its ability to reproduce the dynamical processes responsible for the development of warm and cold states.

- NSSL successfully expanded weather research capabilities in several areas. First, the fore-aft airborne Doppler radar scanning technique was successfully demonstrated by NSSL scientists using NOAA's WP-3D aircraft. The new technique increases observational resolution and expands

potential applications of the aircraft. NSSL also demonstrated that routine, coupled operational NEXRAD scanning sequences are valuable for investigating flow fields within mesoscale convective weather systems. As NEXRADs are deployed, this capability will allow for enhanced mesoscale weather research in any region of the country. Other observational developments included the completion of two mobile laboratories capable of Mobile Cross-chain Loran Atmospheric Sounding System (MCLASS) operations. These mobile laboratories will obtain critical information on the vertical structure of the atmosphere.

- The compatibility of the Radio Acoustic Sounding System (RASS) temperature-profiling technique with the prototype NOAA wind profiler was demonstrated by WPL. This development opens the door for wind profilers, coupled with RASS, to provide unprecedented temporal and vertical temperature measurements in the lower troposphere. Several case studies demonstrated that wind profiler data can also be used to deduce raindrop size distributions.

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 following were major accomplishments in 1990.

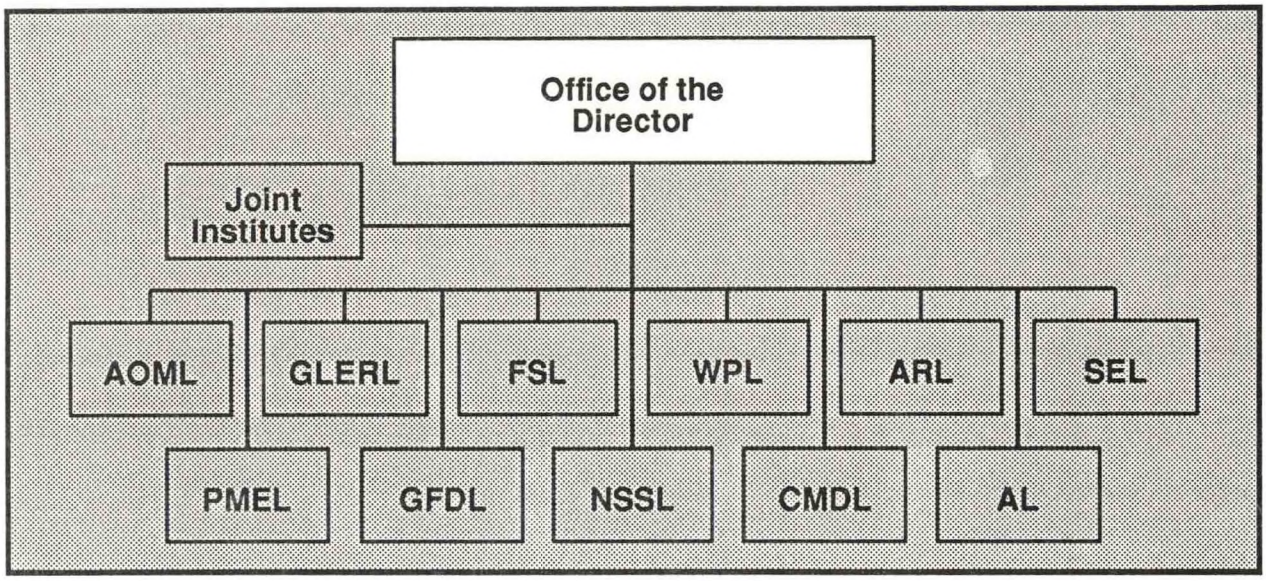
- A major review of product dissemination study was completed. Additional primary users were identified, and the cost effectiveness of the service was evaluated. The service was determined to be cost-effective at the current level of use, indicating that only minor service improvements need be planned. Cost-effectiveness was improved by replacing expensive customer notification telex messages with the full data stream through satellite broadcasts.

- An automated forecast verification system was developed and implemented. Verification results are on line and immediately displayable; this allows forecasters to modify their predictions on the basis of their past performance, and it allows managers to determine the forecast skill displayed by individuals or groups as they change year by year.

- An improved algorithm was developed and implemented to convert instrument measurements to actual fluxes of energetic particles at the NOAA GOES; the algorithm gives a more accurate representation of fluxes at low particle energies by removing the effects of high-energy particles on the low-energy measurements.

- *Ionospheric Radio* was published. This completely rewritten book replaces the earlier *Ionospheric Radio Propagation,* and, like its predecessor, will become a classic text and teaching tool around the world.

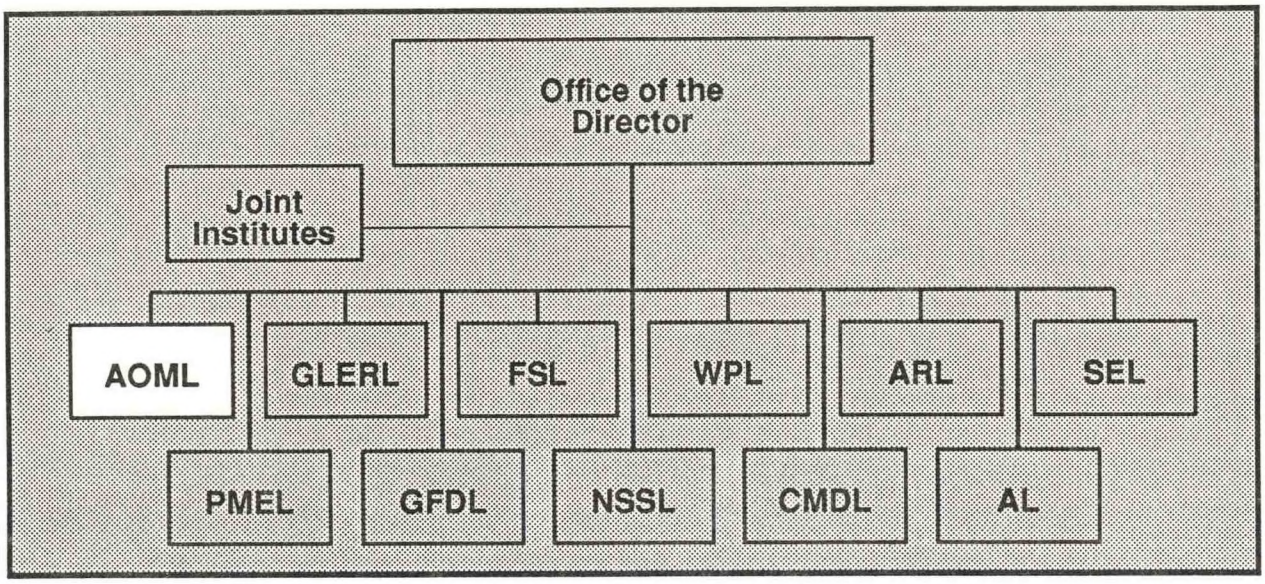
- A system to acquire and apply interplanetary scintillation data from the Mullard Radio Astronomy Observatory in Cambridge, England, was completed. Algorithms to map and display the data were developed and implemented. The data are critical to improving forecasts of geomagnetic disturbances caused by solar wind density disturbances.



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 (ERL), 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, budget formulation and analysis; program coordination and review; 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, atmospheric chemistry, 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. Atmospheric chemical research focuses on the biogeochemical cycles of trace species that may affect the radiative properties of the atmosphere. Meteorological research is carried out to improve the description, understanding, and prediction of hurricanes. The research program is enhanced 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 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. The emphasis is 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, and the best recognized example, is the El Niño–Southern Oscillation

(ENSO) phenomenon, which is manifested most clearly in the tropical Pacific Ocean but has global implications. 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.

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. The influence of Atlantic circulation on climate will be a major component of the NOAA program for Climate and Global Change. AOML scientists have had a leading role in developing plans for this research program, and will participate extensively in its implementation.

Air quality research at AOML is a multidisciplinary research program addressing four major process categories—sources, transport and distribution, transformation, and removal—which dominate biogeochemical cycles in the marine troposphere as well as in the global atmosphere. The program involves inorganic and organic chemistry, lower trophic level (primarily marine) biology, meteorology, and physical oceanography. The goals of the program include both the generation of descriptive data on the distribution of important atmospheric trace species and the evolution of a quantitative understanding of geosphere-biosphere interactions. The descriptive aspect of the program uses both ship and aircraft expeditions. These efforts are designed to (1) delineate the global distributions, temporal variability, and air-sea fluxes of Radiatively Important Trace Species (RITS) and substances that affect their cycles; (2) measure the extent to which marine physical, chemical, and biological processes can act as a permanent sink for atmospheric carbon dioxide; and (3) delineate the fate of reduced sulfur (S) species produced by marine biological processes in the atmosphere, and their effect on the atmospheric portion of the global S cycle.

The objective of the new MS&C initiative is to define the role of marine biogenic sulfur emissions in the formation of aerosol particles that may serve as cloud condensation nuclei, to quantify the effects of these species on cloud albedo and climate, and ultimately to provide the data needed to parameterize clouds and cloud processes in climate prediction models. Inadequate knowledge of the processes that determine how clouds affect the radiative properties of the atmosphere is by far the dominant source of uncertainties that prevent existing climate prediction models from providing useful guidance for policy decisions.

The Ocean-Atmosphere Carbon Dioxide Program is directed toward understanding the processes controlling the exchange of CO_2 across the air-sea interface and eventual storage of carbon in deep ocean waters. Specific components of the research include the following:

- Continued monitoring of tropospheric CO_2 with careful standardization of the observation networks.
- Research on the relative CO_2 uptake by the oceans and terrestrial biosphere.
- Research on the mechanisms of air-sea exchange of CO_2.
- Extension of the data base for the partial pressure difference of pCO_2 between the surface ocean and the troposphere on appropriate space and time scales.
- Development of a knowledge of secular trends in oceanic "storage" of carbon.
- Development of an understanding of how surface ocean productivity affects surface ocean pCO_2 and carbon vertical flux on seasonal time scales.

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

Accomplishments FY 90

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. Through cooperation with scientists from France and Japan it has been possible to maintain an array of 150 to 170 satellite-tracked drifting buoys for measurement of sea-surface temperatures 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 evaluating ocean processes and modeling skill in regard to tropical air-sea interaction. A study was completed 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 can apparently generate eddies with very large kinetic energy in the eastern Pacific, but their full oceanographic importance is not yet clear.

Research vessel observations were made by AOML personnel 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 continued with 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. This year a new and important observing station was established on San Felix Island in cooperation with Chilean authorities. Narco-terrorist threats in Colombia prevented installation of a station at Malpelo Island.

Work on implementing a conjugate gradient strategy for four-dimensional data assimilation into the GFDL ocean general circulation model advanced rapidly. This approach has great promise as an effective way of using oceanographic measurements for both operational and diagnostic purposes. It is a large undertaking and its practicality in terms of required computer resources cannot be predicted.

Atlantic Climate Change

Work continued on the role of the North Atlantic Ocean in regulating global climate. Monitoring of 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 which is an index of the vigor of convective overturning in the North Atlantic, a major process both for northward heat transport in the Atlantic Ocean and for sequestration of anomalous atmospheric constituents (e.g., greenhouse gases) in the ocean. These investigations of climate-related processes in the Atlantic have been done in close cooperation with scientists from PMEL, the University of Miami, France, and Germany.

An intensive study using the full National Ocean Data Center data files for the Atlantic Ocean was conducted to determine sampling and analysis strategies to be employed in the Voluntary Observing Ship XBT Program in the Atlantic basin. This element of the Climate and Global Change Program is a joint activity of AOML and NOS. NOS is responsible for operational management of the observation program, and AOML maintains a center for data processing and analysis.

RITS

A 45-day field program encompassing the equatorial Pacific from the west coast of the Americas to the date line was conducted in FY 90. The cruise took place in January and February in order to complete a picture of the annual cycle, complementing published data that cover the period from April through November. Atmospheric sampling was conducted from a 30-ft bow tower to minimize contamination by the ship. The investigations included measurements of the atmospheric chemistry of various sulfur, nitrogen, halogen, and carbon compounds and their biogeochemical cycles, including ozone measurements using three different monitors.

Increased definition of the extent and possible generation of the ozone minimum region (<10 ppbv) in the equatorial Pacific was obtained.

Confirmation was obtained that ozone monitors based on UV absorption at 253 nm give variably (0–8 ppbv) higher readings than the ECC monitor, which is based on chemical oxidation of iodide. Volatile organic compounds are believed to contribute to the ozone signal.

Methyl iodide was measured throughout the ozone minimum region at concentrations of 0.2–2 pptv which are the same or lower than had been reported before. Since the sunlight photolysis of methyl iodide to I radicals, which react with ozone, is rapid, and the recycling of the resulting I0 has been shown to be too slow, it is unlikely that this process contributes to maintaining low ozone levels in the region.

Observations of significant chloride loss from sea-salt particles as a function of particle size confirmed results obtained on a 1988 cruise in the North Atlantic. This suggests that the phenomenon may not be limited to relatively polluted regions of the marine atmosphere.

Continuous shipboard measurements of boundary layer peroxyacetyl nitrate (PAN) were obtained, the first in the equatorial Pacific. Mixing ratios were exceedingly low and lacked correlation with sunlight, indicating very little local generation of PAN.

Elevated surface water nitrite (NO_2 .) was found, extending from 130°W to the date line. Samples from this region were tested for gaseous nitric oxide (NO) to determine the possible role of equatorial upwelling on the remote marine nitrogen cycle.

Marine Sulfur and Climate

AOML's Marine Sulfur and Climate (MS&C) research emphasis is on field measurements of compounds involved in the atmospheric S cycle, with the objective of quantifying the contribution of marine biogenic versus terrestrial S emissions to aerosol particle production. Analyses of atmospheric samples collected during a 1988 AOML research cruise in the North Atlantic were completed. Because AOML's capabilities to measure gas-phase and rainwater dimethylsulfoxide (DMSO) and dimethylsulfone ($DMSO_2$) concentrations are unique, the resulting data represent the first simultaneous inventory of all five recognized end products of dimethylsulfide (DMS) oxidation in the marine atmosphere. Other sulfur compounds measured were sulfur dioxide gas, particulate methane sulfonic acid (MSA), and sulfate. These data allowed us to assess the role of DMSO and $DMSO_2$ in the marine atmospheric S cycle. The results indicated that DMSO and $DMSO_2$ concentrations were 1 to 3 orders of magnitude lower than those of sulfate, and that these compounds were almost entirely in the gas phase. This suggests that DMSO and $DMSO_2$ are minor players in the marine atmospheric sulfur cycle over the North Atlantic and that they probably have an insignificant effect on particle formation there.

Analysis of a similar suite of samples collected during an AOML research cruise in the tropical Pacific from Panama to 180°W longitude in January and February 1990 is still under way. Analyses indicate that DMSO and $DMSO_2$ may be more important relative to sulfate over the remote tropical Pacific as opposed to the North Atlantic, in terms of the flux of sulfur out of the atmosphere. The $DMSO_2$ was most correlated with the DMS fluxes.

A major objective of MS&C research on the tropical Pacific cruise was to investigate the particle size distribution of MSA. The majority of 14 measured distributions showed no pronounced maximum on submicrometer particles, as has been observed elsewhere. Analysis of the data indicated that MSA was distributed essentially uniformly with the effective surface area of particles larger than about 0.5 μm in radius, which were primarily sea salt. Less MSA was found in smaller particles, which were composed primarily of sulfate and ammonium. These results are consistent with various experimental studies reported in the literature in suggesting that MSA, produced from photochemical oxidation of DMS, condenses on pre-existing particles in strong preference to nucleating into new particles. This suggests that MSA may not contribute appreciably to new particle production in the remote tropical marine atmosphere.

Ocean-Atmosphere Carbon Dioxide Exchange Study

- Completed planning of a cooperative program with other ERL Laboratories and academia to continue the above described research for the period 1990 through 1993.
- Participated in a cooperative PMEL–AOML cruise on the NOAA ship *Malcolm Baldrige* to determine carbon parameters along 170°W from the latitude of Hawaii to 65°S during austral summer.

WOTAN

A substantial effort was carried out in the analysis of WOTAN data from FY–88 and FY–89 deployments. The results continue to be encouraging; correlations between radar, rain gauge, anemometer, and acoustical data were found. Examination of U.S. Navy data obtained using acoustical devices operating at frequencies similar to WOTAN was also carried out for both rainfall- and wind-generated acoustical signals.

Plans FY 91

TOGA–EPOCS

AOML activities for the TOGA and EPOCS Programs are expected to continue much the same 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 resume work at a modest level, and oceanographers from France and Japan will continue releasing substantial numbers of buoys for the study. The drifting buoy program will be expanded to global coverage for the World Ocean Circulation Experiment (WOCE) during 1991–1996, beginning with extension into the North Pacific during 1991. Much of the global coverage will come about from releases of drifting buoys by scientists in several additional countries, and a larger NOAA contribution will be funded from the Climate and Global Change Program. AOML will continue to function as the data center for the global program for WOCE. 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 working with Lagrangian analyses. Use of the data in evaluation and improvement of ocean circulation models will receive new emphasis at AOML.

The Geostationary Earth-Orbiting Satellite (GEOS) ceased operation in early 1990. Slightly more than 3 years of unclassified data from this satellite are available to support investigation of the variability of sea surface height and currents. 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 low-frequency variations of the North Equatorial Countercurrent and other regional features.

Work will continue on development of the four-dimensional data assimilation methodology. Verification runs will be made to learn the practical feasibility of the conjugate gradient method. The first runs will be by collaborators from the Massachusetts Institute of Technology (MIT) who have access to computer resources at the National Center for Atmospheric Research.

A new thrust in ocean circulation modeling for EPOCS will be completed. Through collaboration with NASA scientists an alternative modeling strategy is being 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 predicting El Niño .

Atlantic Climate Change

AOML will participate very substantially in a major new component, Atlantic Climate Change, of the Climate and Global Change Program funded by NOAA. Some activities, such as monitoring sea level and electrical potential across the Straits of Florida, begun a decade ago under the banner of the Subtropical Atlantic Climate Studies (STACS), are essential to the larger scale program and will be continued. Structure and variation of the extended Western Boundary Current region as an index to the "overturning" circulation in the North Atlantic Ocean will be investigated during the preparation for and conduct of WOCE. Research vessel cruises will be used to sample the waters and currents of the region, and to place and service moored sensor systems.

The voluntary Observing Ship Program will be brought up to strength and will provide a synoptic description of upper-ocean climate conditions in the Atlantic Basin. The new data and historical data will be used to investigate the role of oceanic processes in forcing Atlantic sea-surface temperature (SST) anomalies. These investigations will be aided by results from a project, originated for the EPOCS Program, to develop a sophisticated method for assimilating observations in general circulation models for the ocean.

By early 1990, tide gauges had been restored or established on all but three of the sites recommended by an International Oceanographic Commission Workshop. It is planned to establish the remaining three sites in 1991, prior to the launch of the BRS–1 and TOPEX satellites.

In cooperation with NOS, the University of Miami, the University of California, and the U.S. Naval Observatory, AOML will use current developments in geodetic measurement technology and geophysical modeling to observe and interpret absolute sea level trends in order to improve the prediction of climate response to human activities. Beginning with sites in Miami and the Bahamas, the program will gradually expand to encompass first Florida and ultimately the entire Caribbean Sea–Gulf of Mexico–Bahamas region, and the western Atlantic domain from the U.S. east coast to Bermuda.

Finally, to facilitate collection of current data with minimal cost in ship time, a new instrument for unattended measurement of current profiles in the deep ocean will be developed and tested.

RITS

The FY–91 field program will focus on a cruise to the South Atlantic Ocean from the Equator to ~55°S. The cruise will include two staggered meridional transects and a cross-ocean transect, to investigate atmospheric transport, transformation, and deposition processes in both the trade wind regime and westerlies of the South Atlantic. These transects will occur before and during the biomass burning season in central Africa and Amazonia in order to investigate the potential global effect of the burning practices.

The observation of significant chloride losses from sea-salt particles over both the North Atlantic and tropical Pacific oceans has led to a hypothesized mechanism for the loss initiated by reaction of ozone at sea-salt particle surfaces, generating molecular chlorine (Cl_2), followed by rapid photochemical conversion of Cl_2 to hydrochloric acid (HCl), and eventual recapture of the HCl by the sea-salt particles. Simulations with a zero-dimensional photochemical model suggest that (1) oxidation by Cl may be an important tropospheric sink for DMS and hydrocarbons, and (2) under low NO_x conditions, the rapid cycling of this "reactive" chlorine would provide a catalytic loss mechanism for ozone, which would possibly explain the low ozone concentrations often observed above the world's oceans. An investigation into this challenging hypothesis will be initiated.

Marine Sulfur and Climate

AOML's MS&C research during FY 91 will focus on two field efforts. The first will be part of the third Pacific Sulfur/Stratus Investigation (PSI–3) experiment off the coast of Washington State. AOML plans to make real-time shipboard measurements of atmospheric radon and black carbon, and to collect samples for later analysis of DMSO and $DMSO_2$ gases and MSA particle size distribution. The second field effort will be conducted as part of the RITS South Atlantic Ocean cruise mentioned above. Sampling for all five DMS oxidation products will be conducted.

Ocean-Atmosphere Carbon Dioxide Exchange Study

- Participate in cooperative NOAA–Department of Energy (DOE) intercalibration of measurement protocols.
- Conduct a cruise to determine carbon parameters along WOCE lines A-16–A-23 from the Equator to as far south as possible during austral winter.

WOTAN

Future deployments of the AOML WOTAN system are planned, to obtain a diverse-as-possible rainfall data set. A possible joint NOAA–USN–NASA field effort and program is in discussion stages. A WOTAN deployment within or near a large Naval hydrophone installation is being considered together with weather radar, wind, surface wave, and conventional rain gauge measurements.

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 uses NOAA research aircraft to acquire unique data sets.

Accomplishments FY 90

Hurricane Modeling Research

The goal of this research is the understanding and predicting of the motion, intensity, and structure of hurricanes. To achieve this goal, the complex problem of interactions between different dynamic regimes and physical processes in the three-dimensional moist atmosphere must be addressed. To proceed, a general-purpose base model (code name, QVADIS) was developed that uses an accurate and flexible numerical method called the spectral application of finite element representation (SAFER) method. Two-dimensional versions of QVADIS, on nested multiple domains, are in use in other HRD projects (see below).

Synoptic-Scale Aspects of Hurricanes

This research studies the synoptic-scale flow on the periphery of mature hurricanes and its effect on hurricane tracks. Omega dropwindsondes (ODWs) released from the NOAA P–3 research aircraft are used in experiments 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 NHC in the preparation of official forecasts and at NMC in the initialization of dynamical hurricane track prediction models.

A program of experimental hurricane track forecasting, using a multiply nested barotropic numerical model (nicknamed VICBAR) based on the SAFER method, is in progress. SAFER provides very-high-quality grid nesting and minimal truncation errors. VICBAR can, and has been, run in real time. The input data are processed and analyzed using a nested spline analysis code developed at HRD. Winds and geopotential heights at 850, 700, 500, and 200 mb are analyzed, and VICBAR is initialized with vertically averaged winds and heights to produce a 72-h track forecast.

Data for about 120 forecasts were collected in real time during the 1989 hurricane season. Track forecasts for about 30% of these cases were run in real time and made available to the forecasters at NHC. The remaining cases were run after the season. The results showed that VICBAR had smaller track forecast errors than other dynamical models and had forecast skill comparable with the statistical-dynamical model known as NHC83. NHC83 has been NHC's most skillful model for several years.

A three-layer, multiply nested SAFER model was developed to investigate certain aspects of hurricanes. The three-layer model is the simplest formulation that can incorporate the effect of boundary layer dissipation, convective heating, momentum transports, and vertical variation in the large-scale environment. The three-layer model was tested with a symmetric vortex on an f-plane. Idealized experiments were carried out to evaluate the model sensitivity to adjustable parameters.

Observational Studies of Hurricanes

Analysis of Hurricane Hugo (1989) shows that it experienced three eyewall replacements: the first, as it approached the Lesser Antilles; the second, while environmental shear inhibited intensification in the open Atlantic; and the third, as it approached the Carolina coast. The first two replacements conform with experience; the hurricane weakened as the eye expanded discontinuously. The last was different; the hurricane strengthened as the eye expanded and continued to strengthen afterward. This seemingly anomalous development can nevertheless be understood empirically in terms of the convective ring model.

Severe turbulence was encountered during a NOAA P–3 flight into Hurricane Hugo on 15 September 1989. A detailed analysis of the data from this flight showed that the severe turbulence was related to the penetration of an intense minivortex on the scale of 2–3 km embedded along the inside edge of the eyewall. The vortex was positioned at a radius of 7 km from the geometric center of the radar eye, between the inside portion of the radar eyewall and the cloud boundary.

Atlantic Tropical Climate Studies

Research on Atlantic hurricane cycles and tropical wind variability associated with interseasonal oscillations is in progress. Wind observations for 1980–1989 from NHC's tropical analysis are being used. The data are filtered to remove periods shorter than about 15 days and are then sampled once every 5 days. The tropical analyses include winds at both an upper (200 mb) and a lower (near-surface) level, from the Equator to about 45°N and from about 5°W to 125°W. The winds are filtered into three bands: The "monthly" band (50–85 days) includes variability on the month-to-month (60-day) time scale; the 30–55 day band corresponds to the time scale of the well-known global tropical oscillation; the "intermediate" band (18–29 days) comprises shorter period oscillations.

The modes in the monthly band were found to be dominated by three events. The structure of the dominant mode (a nonpropagating dipole) corresponds to global and regional modes of intraseasonal variability that have been found by others. Teleconnection patterns and the first two dominant modes of variability in the intermediate band during winter represent east-west oriented wavetrains, which have also been found by others. The second mode, however, shows evidence of southeast propagation. This has not been found in earlier studies.

An objective index of the global tropical 30–55 day oscillation shows that this signal is strong in the tropical eastern Pacific, but is generally weak over the Atlantic. Thus, the signal is only weakly correlated with Atlantic tropical storm activity. In fact, no significant spectral peak is found in Atlantic tropical storm activity on intraseasonal time scales.

Plans FY 91

Hurricane Modeling Research

The present phase of building QVADIS by components is near completion. Tests of the assembly of components will begin soon. Preliminary tests of the modeled physical processes will be carried out with a two-dimensional model representing the stratified atmosphere in a vertical plane. In addition to the new formulation of reversible moist processes, the modeled physics must include irreversible processes. The latter are subject to various degrees of approximation; the adequacy of the approximations will be tested.

Synoptic-Scale Aspects of Hurricanes

VICBAR, with modifications based upon results from the 1989 season, will be run during the 1990 hurricane season. The new version includes an additional analysis level (400 mb), the inclusion of Southern Hemisphere data (to 27.5°S), and time-dependent boundary conditions from NMC's global spectral model. Real-time forecasts will be made from 1200 UTC data. The 0000 UTC forecasts will be run the following morning. Cooperative studies with NHC and NMC to examine the effect of ODW data on the NMC operational analyses and the NMC hurricane track models will continue.

Further experiments with the new three-layer model will be designed to evaluate the effect of internal and external sources of heat and momentum on the evolution of the hurricane. Specifically, the effects of vertical wind shear on vortex evolution will be investigated. The three-layer model will also be used in real-data experiments. Data from Hurricanes Josephine (1984) and Gloria (1985) will be used to test the model's ability to make 72-h hurricane track forecasts. Comparisons will be made with VICBAR forecasts.

Observational Studies of Hurricanes

Collection of flight-level data will continue for the purpose of broadening experience with hurricane evolution. Flights into weak tropical systems are planned, over both the Atlantic and the eastern Pacific, during a cooperative investigation with MIT scientists. These flights will focus on the role of middle-level moistening in the evolution of convection.

If an appropriate hurricane landfall case arises, low-level wind analyses similar to those carried out for Hugo will be started. Completion of a long-awaited additional loran station in the southwestern United States will allow a joint effort with the National Severe Storms Laboratory. Its mobile Cross-Chain Loran-C Atmospheric Sounding System (CLASS) launch facilities will be used to study wind and thermodynamic profiles during hurricane landfalls on the Gulf of Mexico coast.

Atlantic Tropical Climate Studies

Study of interseasonal variability over the tropical Atlantic will continue. The results for the 50–85 day and the 30–55 day bands will be compared with a combined 30–85 day analysis. Complete spectra will be made of the unfiltered Atlantic tropical winds for selected years for both the summer and winter seasons.

The analysis will be extended to include outgoing longwave radiation (OLR) to relate convective activity to the wind fields. Sea-surface temperature variability may also be included in some aspects of the study. The relationships of the dominant modes of variability during the summer to tropical storm cycles in both the Atlantic and eastern Pacific will be studied. The relationship of the global tropical 30–55 day oscillation to eastern Pacific tropical storm activity will be evaluated.

MARINE RESEARCH

AOML studies in Marine Research concern processes occurring in seafloor ridges, the effects of the environment on fishery populations, carbon and nutrient enhancement of productivity in coastal areas, and the dispersion of wastewater in the ocean environment.

VENTS studies evaluate the effects on the global ocean environment of seafloor hot springs as major agents of chemical and thermal exchanges between the seafloor and the ocean. The studies are performed at representative segments of the Gorda–Juan de Fuca Ridge System in the Pacific and the Mid-Atlantic Ridge in support of NOAA's global ocean environmental mission. The studies are collaborative with PMEL, the NOAA Undersea Research Program (NURP), and a network of leading scientists funded by other U.S. and foreign government agencies and universities. The external funds multiply NOAA funding 5 to 10 times and increase scientific productivity. These efforts contribute to the NOAA VENTS program, 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) involve NOAA scientists at PMEL, AOML, and NMFS as well as academic contractees. 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 has been field study 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 has been to document the temporal changes in spatial distribution of both eggs and larvae in relation to physical processes (e.g., advection and dispersion). Field studies conducted during cruises in FY 86–89 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.

FOCI represents an important scientific and technical contribution toward NOAA's increasing focus upon fisheries oceanography. The information obtained to date indicates that models including physical-biological interactions can lead toward prediction of the variation of populations of commercially harvested marine species. This ability is essential both for managing our natural resources efficiently and for distinguishing natural from anthropogenic variability.

The Nutrient-Enhanced Coastal Ocean Productivity (NECOP) Program is a component of the NOAA Coastal Ocean Program designed to accomplish the following: (1) Determine quantitatively the degree to which coastal primary productivity has been enhanced in areas receiving high terrestrial nutrient inputs; (2) determine the effect on water quality (especially dissolved oxygen demand) of this enhanced productivity; and (3) determine the fate of the carbon fixed in coastal areas of enhanced productivity and its effect on living resources within the coastal ocean and upon the global marine carbon cycle.

The Coastal Zone Oceanography/Ocean Discharges Program studies the interaction of water mass types and the processes that occur at their boundaries. Wastewater plumes constitute one category of water mass type in which turbulent flow is released into oceanic waters. Understanding the dilution that such plumes undergo is an extremely important environmental concern, and dilution is a process for which very limited data are available. The knowledge and techniques developed in this research are now being applied to oceanographic problems and phenomena in the coastal zone.

Accomplishments FY 90

VENTS

Gorda–Juan de Fuca Ridge

- Completed the first quantitative determination of the total heat flux from a seafloor hydrothermal field, comprising both the discrete component of heat flux from individual vents and the diffuse component from relatively large areas of the seafloor, based on measurements made at the ASHES vent field on the Juan de Fuca Ridge. The study revealed that the diffuse component is 1 order of magnitude greater than the discrete component of heat transfer from the hydrothermal field.

- Began development and application of a submersible-borne sonar system to acoustically image hydrothermal plumes. This was accomplished in collaboration with the Naval Research Laboratory (NRL; engineering and signal processing), and by securing funding support from NOAA's Office of Undersea Research. The joint effort with NRL included designing and producing the prototype plume sonar system, obtaining Navy submersible time for an engineering test, organizing a scientific team to perform the work, and preparing for a field experiment at black smokers on the East Pacific Rise. The plume images obtained will be used to elucidate the dynamics of the dispersion of heat and chemicals into the ocean and to guide further chemical sampling of plumes.

- Confirmed our hypothesis that a diagnostic signature of magnetic profiles of the seafloor can be used to identify new hydrothermal sites. Additional studies of magnetic properties of rocks and inverse modeling of magnetic intensity lows at hydrothermal sites allow the inference of circulation characteristics of hydrothermal systems beneath the ocean floor.

- Compiled an interactive, computerized bibliography of scientific publications on oceanic ridge processes for use by VENTS investigators.

Mid-Atlantic Ridge

AOML organized, led, and executed a multidisciplinary, international cooperative diving cruise of the R/V *Atlantis* II and DSV *Alvin* in January 1990 to characterize thermal and chemical effects on the ocean of hydrothermal venting from the TAG and Snakepit hydrothermal fields on the Mid-Atlantic Ridge. The cruise included scientific teams from NOAA, WHOI, MIT, University of Cambridge (England), Canadian Geological Survey, University of Toronto, and IFREMER (France). This was the first intensive dive series at the recently discovered Mid-Atlantic Ridge hydrothermal sites. The chemical, thermal, and biological data collected are the basis for definitive studies of Atlantic hydrothermal processes.

FOCI

- Delineated the fine-scale distribution of pollock eggs, using in-situ photographic data.

- Confirmed the closely coupled relationship between coastal eddy formation and structure and critical plankton processes such as grazing and primary production.

- Confirmed the relationship between the Alaskan Coastal Current front and a downwelling-induced concentration of plankton along a front between Sutwik and Semidi Islands.

NECOP

- Completed planning of the initial NECOP study in the Mississippi-Atchafalaya outflow area.

- Established a NECOP data servicing center at AOML in cooperation with NODC.

- Conducted a series of cruises to document the spatial and temporal extent of the occurrence of hypoxia along the Louisiana Inner Shelf.

- Conducted a coordinated experiment with the NOAA ship *Malcolm Baldrige*, R/V *Gyre*, R/V *Pelican*, and the NASA Lear Jet in the Mississippi-Atchafalaya outflow and adjacent shelf area during the summer low-flow season.

Coastal Zone Oceanography/Ocean Discharges

Analysis of acoustical and other data gathered on oceanic, anthropogenically generated plumes revealed a complex spatial and temporal variability within the plume boundaries. Estimates were derived for the levels of variation to be expected for chemical and biological samples gathered from within such plumes.

Plans FY 91

VENTS

- Perform sea trials of the prototype hydrothermal plume-imaging sonar system at black smokers at the East Pacific Rise early in FY 91 by an AOML–NRL–University of Hawaii scientific team using the Navy submersible DSV *Turtle*. The plume-imaging sonar will undergo further development jointly with NRL (addition of Doppler capability to measure fluid flow rates) and will be applied to studies in the megaplume area of the Juan de Fuca Ridge planned with DSV *Alvin* late in FY 91, contingent on results of the sea trials and funding.

- Execute a comparative study of the southern Juan de Fuca Ridge and northern Gorda Ridge, using existing multidisciplinary data sets to determine how differences in structure and volcanism control differences in the nature and distribution of hydrothermal activity on the two ridge segments.

- Contingent upon funding, begin development of a prototype probe to measure, for the first time, conductive heat flow through bare rock seafloor (prior seafloor heat flow measurements were limited to sediment-covered areas). This will be done jointly with the University of Miami and applied to the megaplume area of the Juan de Fuca Ridge.

- Continue collaborative scientific studies of hydrothermal processes at the Mid-Atlantic Ridge including planning for a joint IFREMER–NOAA dive series using the French submersible DSV *Nautile*.

FOCI

- Complete analysis of data on physical-biological relationships within a weak coastal eddy.

- Complete development of a multiple-frequency acoustic sampling system and test in local sea trials and mesocosm simulations.

- Develop requisite software permitting real-time estimation of size frequency histograms from multiple frequency acoustic backscatter data.

NECOP

- Conduct analysis and synthesis of data from 1990 cruise and aircraft field program.

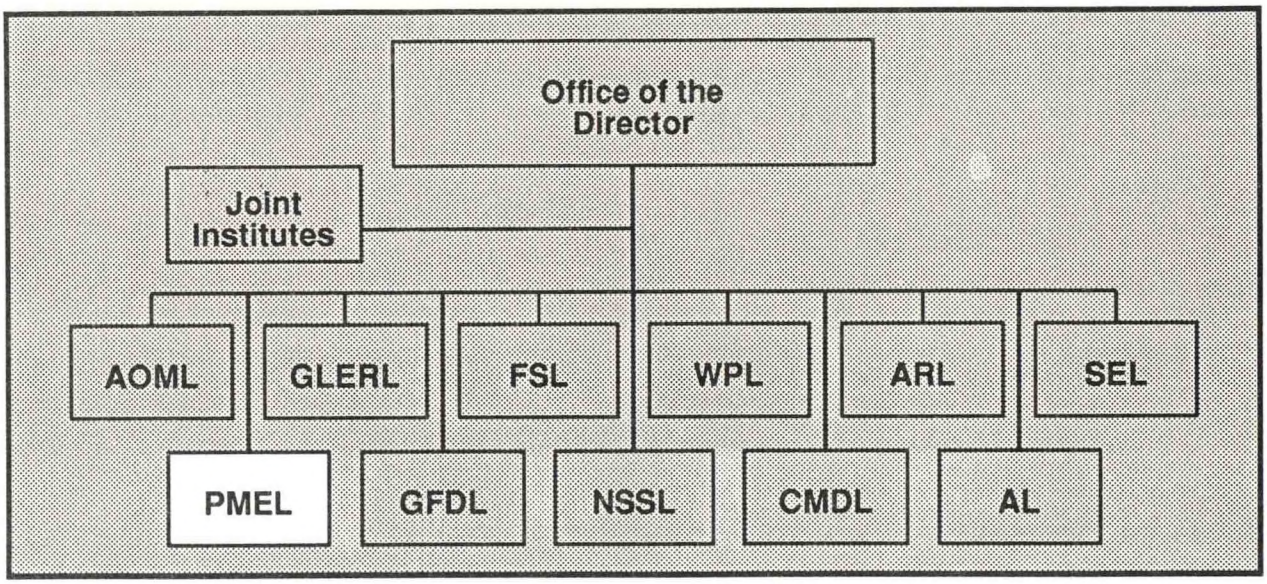
- Conduct a major interdisciplinary cruise to the Mississippi-Atchafalaya outflow area during the winter wind-mixed season just prior to spring runoff and high discharge.

- Conduct a synthesis workshop.

Coastal Zone Oceanography/Ocean Discharges

- Conduct a major experiment spanning at least a 1-year period for the study of the mixing and dispersion of plumes in the coastal ocean environment.

- Obtain one of the most extensive data bases on coastal ocean currents, water column stratification and changes therein, and coastal ocean plume mixing and dispersion. This data set will serve to assist in source function definitions for larger scale coastal ocean circulation, mixing, and environmental consequence models.



PACIFIC MARINE ENVIRONMENTAL LABORATORY

Seattle, Washington
(206) 526–6810
Eddie N. Bernard, Director

The Pacific Marine Environmental Laboratory (PMEL) carries out 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 (JISAO), with the University of Washington; and the Joint Institute for Marine and Atmospheric Research (JIMAR), with the University of Hawaii. PMEL also complements its research through NOAA's National Marine Fisheries Service (NMFS) and the Cooperative Institute for Marine Resources Studies (CIMRS), a joint organization with Oregon State University.

CLIMATE RESEARCH

NOAA's 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. More recently, NOAA has initiated the Climate and Global Change (CGC) Program to study oceanic thermohaline circulation and its climatic impact in coordination with other Federal agencies. These two major NOAA programs form the backbone of much of the research conducted at PMEL.

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 climate and global change 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.

Man's addition of chemical constituents to the atmosphere and the potential consequences of these changes create a need for improved understanding of the ocean's absorption, transport, and emission of the important trace gases. PMEL research in these areas focuses on the carbon cycle in the ocean-atmosphere system and the air-sea exchange of other radiatively important trace species. These studies involve integrated chemical and physical measurements of the oceanic and atmospheric boundary layer.

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 90

Equatorial Dynamics

In support of the Equatorial Pacific Ocean Climate Studies (EPOCS) and Tropical Ocean and Global Atmosphere (TOGA) programs, PMEL maintains an array of moored and island stations in the tropical Pacific. Twenty-four moored stations measure the vertical distribution of 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. The moorings transmit wind velocity, air temperature, SST, currents at 10 m, and the off-equatorial temperature profiles in real time.

Automated wind stations are also maintained on islands in the western and central Pacific (Kapingamarangi, Nauru, Baker, and Christmas islands). Data from these stations are used to diagnose oceanic and atmospheric processes in the tropical Pacific, to validate the operational general ocean 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.

Equatorial SST Variations

A central focus of the TOGA and EPOCS programs is to understand the mechanisms responsible for variations in the equatorial Pacific Ocean on El Niño–Southern Oscillation (ENSO) time and space scales. During 1986–1988, EPOCS, TOGA, and the U.S.-People's Republic of China bilateral undertook 12 research cruises and maintained the array of current meter moorings, Automated Temperature Line Acquisition System (ATLAS) wind and thermistor chain moorings, and island wind stations. Data from these and other sources were merged into a comprehensive description of variability on daily to interannual time scales over approximately 100 of longitude (110°W to 155°E) in the equatorial Pacific. As a result of these efforts, the 1986–1988 ENSO event is the best documented ever, based on in-situ wind, ocean current, and temperature data. The descriptive analyses of these data provided the necessary background for more detailed studies now under way in which specific dynamic and thermodynamic hypotheses are being tested. In addition, these analyses have provided the observational framework needed for the design and implementation of a basin-wide, tropical Pacific observing system, the TOGA Tropical Atmosphere-Ocean (TOGA–TAO) array, required for the second half of the TOGA decade. Within this array, detailed process studies will examine dynamic air-sea interactions critical for modeling ENSO.

TOGA–TAO Project Office

In support of the Climate and Global Change Program, the TOGA–TAO Project Office was established jointly by the Oceanic and Atmospheric Research (OAR) and the National Ocean Service (NOS) arms of NOAA. The project office will be responsible for maintaining the TOGA–TAO array, which is planned to include 65 ATLAS moorings spanning the equatorial Pacific from 110°W to 145°E. By the end of FY 90, the array was 29% completed with 19 moorings in place. Expansion of TOGA–TAO is the highest priority for the ocean-observing system in the second half of the TOGA decade.

PROTEUS Mooring System

A new mooring system, Profile Telemetry of Upper Ocean Currents (PROTEUS), was developed which has the capability of transmitting profiles of ocean currents in real time, using a moored acoustic Doppler current profiler. This system was successfully deployed on the Equator at 140°W in April 1990 and has operated flawlessly since then. Data from this and other moored arrays are used to study low-frequency dynamics and thermodynamics in the upper equatorial Pacific Ocean.

Modeling of the Tropical Pacific

The effect of westerly wind bursts in the western Pacific on SST in the eastern Pacific was evaluated using the Geophysical Fluid Dynamics Laboratory (GFDL) ocean circulation model. Results indicate that these bursts could be important in the onset of ENSO events. This study also led to an empirical study of island wind data to categorize types of westerly wind events. Both these analyses are critical for the planning of the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE).

Western Boundary Currents

Estimates of transport by the Florida Current are derived from observations of the cross-stream cable voltages between Jupiter, FL, and Settlement Point, Grand Bahama Island. Eight years of data have been scrutinized for errors, edited using improved estimates of the geomagnetic and tidal variations, and adjusted for secular change in the Earth's magnetic field. The new magnetic station at Settlement Point now permits measurement of, and compensation for geomagnetic variations on a daily to weekly basis. Use of similar cable for transport measurements is an integral part of the emerging Atlantic Climate Change Program.

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 participated in three major field programs in 1990 to study trace gases and aerosols that affect climate.

The third Soviet-American Gas and Aerosol experiment (SAGA–3) was conducted on the Soviet R/V *Akademic Korolev* and included five Equator crossings between Hilo, Hawaii, and American Samoa during February and March. The major objectives of the cruise were to study (1) factors controlling the background photochemistry of the remote tropical marine boundary layer, (2) the flux of biogenic trace gases (CO_2, CH_4, CO, and dimethyl sulfide) from the ocean, and (3) the formation of particles in the remote marine atmosphere.

The second expedition was aboard NOAA ship *Malcolm Baldrige* along 170°W from Western Samoa to 60°S and north to Hawaii. PMEL measured carbon cycle trace gases (CO_2, CO, and CH_4) in the atmosphere and in surface waters by gas chromatography, filling in some of the major data gaps for the South Pacific that hinder accurate assessment of global carbon fluxes.

The third major field project, the Pacific Sulfur/Stratus Investigation (PSI), is a multiagency (NOAA, NASA, DOE, DOD, NSF) program to study the effect of the sulfur cycle on marine stratus clouds and climate. PSI–2, the second in an annual series, was conducted off the Washington coast in April, and included measurements from NOAA ship *McArthur,* a coastal research station at Cheeka Peak, and a University of Washington research aircraft.

CFC tracer program

Chlorofluorocarbon (CFC), salinity, temperature, dissolved oxygen, nutrients, carbon dioxide, and helium-tritium were measured on a 2-month-long NOAA Climate and Global Change cruise in the southwestern Pacific in the spring of 1990. These measurements document the evolution of CFC transients in the thermocline and intermediate waters of the southwestern Pacific since the first NOAA CFC tracer cruise in this region in 1984. CFCs were also detected along the Tonga-Kermadec Ridge and east of New Zealand in the deep western boundary current, which is the major source of inflow into the interior of the deep Pacific. The PMEL CFC tracer group also participated in the World Ocean Circulation Experiment (WOCE) CFC Intercalibration Cruise in December 1989. Careful intercomparisons between PMEL, Scripps Institution of Oceanography, and Woods Hole Oceanographic Institution CFC groups during this cruise will facilitate the exchange of tracer data sets and aid in collaborative efforts.

Plans FY 91

Equatorial Dynamics

- Continue implementation of TOGA–TAO array.
- Continue development and deployment of PROTEUS moorings.
- Complete analysis of the dynamics of the North Equatorial Countercurrent.
- Complete analysis of the annual cycle in the eastern, central, and western equatorial Pacific Ocean.
- Complete studies of the mechanisms of seasonal warming and cooling in the equatorial waveguide, using model and observational data.

Western Boundary Currents

- Continue to improve the cross-stream measurements of the Florida Current.
- Develop a strategy for expanding the use of cables for transport measurements in the Atlantic Climate Change Program.

Marine and Atmospheric Chemistry for Climate Change

- Conduct a CO_2–RITS–CFC transect in the northern Pacific Ocean along 150°W in coordination with CGC and WOCE programs.
- Participate in the U.S.-Australian WOCE cruises in the tropical and circumpolar regions of the southwestern Pacific Ocean.
- Conduct a pilot study of the ventilation of deep waters in the Greenland-Norwegian seas, using CFCs and other tracers.
- Conduct a third multiagency PSI study off the Washington coast to study the effect of the marine sulfur cycle on stratus clouds and climate.

MARINE RESOURCES

Accomplishments FY 90

VENTS Program

The VENTS Program was established in 1984 to focus NOAA interdisciplinary research on the oceanic effects of hydrothermal activity along seafloor-spreading centers. At that time, hydrothermal venting had been directly observed by means of submersible along the Galapagos Ridge, the East Pacific Rise, and the Juan de Fuca Ridge. The accelerating rate of spreading-center hydrothermal discoveries has resulted in an increasing recognition of seafloor hydrothermal venting's importance as a fundamental process whereby mass and heat are transferred from the Earth's interior to its surface along the entire 60,000-km-long global spreading-center system.

Recent results from both national and international mid-ocean ridge research projects show that hydrothermal activity along seafloor-spreading centers significantly affects oceanic chemical and thermal budgets at scales ranging from local to global. VENTS Program research is directed toward determining, and then understanding, hydrothermal processes that may have large-scale ocean environmental effects, in some cases over periods of years to centuries.

In carrying out this research mission, the VENTS Program strategy has been to focus on a limited, but significant, segment of the global spreading-center system and to study impacts of hydrothermal activity within a single oceanic basin. VENTS research has therefore been concentrated on the isolated seafloor-spreading centers in the northeastern Pacific. In FY 90, VENTS research focused on two principal tasks:

- Determination of the patterns and pathways of the regional transport of conservative and nonconservative hydrothermal emissions. This research addresses the composition, variability, and fate of specific hydrothermal chemicals, minerals, and gases that are both dissolved and suspended in

hydrothermal effluent, as well as the chemical, physical, and biological reactions associated with hydrothermal fluids that result in the removal of certain elements from seawater.

- Determination of the source strengths of hydrothermal emissions and their relationships to volcanological and tectonic factors that influence the location, vigor, and duration of hydrothermal venting.

Transport of hydrothermal emissions

An intensive surface ship and submersible program was carried out to map the distributions of hydrothermally derived Si, ^{3}He, Mn, Fe, CO_2, and heat along the ridge axis of Cleft Segment. Results show that hydrothermal emissions from the southern Juan de Fuca Ridge form an elongated plume, recognizable several tens of kilometers beyond the ridge crest by unique elemental signatures in suspended particles. Fe- and P-enriched particulate matter were traced more than 50 km to the west along the southern edge of the Vance Seamount chain. A similar hydrothermal plume has been observed southwest of the Endeavour Segment. It is possible that these plumes coalesce west of the Cobb-Eickelberg Seamount to form the hydrothermal "megaplume" that extends west of the ridge axis for at least 1,500 km.

Comprehensive analysis of the hydrothermal particulates indicates that phosphorus is being scavenged from solution by the newly formed iron oxyhydroxides, which settle to the seafloor. Similarly, geochemical evidence for scavenging of vanadium, chromium, and arsenic by hydrothermal iron oxides was also observed in the water column and underlying sediments. These findings demonstrate the important role of hydrothermal emissions as scavengers of chemicals from seawater. Mass balance calculations suggest that hydrothermal emissions account for approximately 10–30% of the phosphorus sinks in the oceans.

During FY 90, work began on the development of an in-situ chemical analysis system designed to operate in a real-time scanning mode in order to map the distribution of iron and manganese in seawater–vent fluid mixtures as a function of vent temperature. Vent water composition and temperature are key parameters that affect chemical reactions in the hydrothermal plumes.

The first systematic investigation of zooplankton biology in a neutrally buoyant hydrothermal plume was completed. In collaboration with VENTS scientists, researchers from Woods Hole Oceanographic Institution made six near-bottom tows through the megaplume vent field. The primary goal of this research was to test the hypothesis that hydrothermal plumes are effective dispersal agents for the larvae of benthic vent animals.

Eleven moorings were deployed around the megaplume vent field to study temporal variability of venting, integrated heat flux from the field, and the near-field deposition of hydrothermal particles. The moored instruments included 44 current meters, 20 sediment traps, and 9 transmissometers.

Long-term moored-array current measurements show that plumes may be advected along the Cleft Segment of the southern Juan de Fuca Ridge before being deflected west or east by bathymetric features such as the Cobb-Eickelberg Seamount chain or the Vance Volcanoes Chain. The background flow into which plumes are ejected is more energetic than expected, and variations can reverse flows on several different time scales. Temperature variations with periods of 1–2 months can be as large as plume thermal anomalies.

A three-dimensional map was made of the neutrally buoyant warm plume overlying the megaplume vent field. The plume was mapped around and within the moored array in order to obtain a high-resolution initial description of the plume that will be monitored over year-long intervals by the moored instruments.

Source strengths of hydrothermal emissions

Geological surveys carried out during the VENTS FY–90 *Alvin* dives on the southern Juan de Fuca Ridge resulted in the discovery of an extensive high-temperature hydrothermal vent field that appears to be the

source of the megaplume, a very large, steady-state hydrothermal plume observed in this region for the past several years.

Other dives confirmed the existence of a new volcanic mound on the seafloor in the megaplume region. The mound was first noted as a bathymetric discrepancy in a comparison of VENTS Sea Beam maps compiled in 1981 and newer maps resulting from repeat surveys carried out in 1987. The volcanic activity that created this mound may have been associated with the generation of the 1986 megaplume events.

Results from the second year of the bottom pressure recorder (BPR) experiment at Axial Volcano showed no obvious evidence of volcanic deflation. One observed event, which is too small to be positively identified as deflation, emphasizes the need for enhanced, multi sensor monitors. Data from a third-year BPR deployment are currently under analysis.

An analysis system for classifying seafloor terrain, based on the spectral content of Sea Beam bathymetry, was developed and is currently being applied to the Juan de Fuca Ridge. In addition, a terrain correction system for sidescan sonar imaging was developed and is being tested. A data base system for all VENTS Sea Beam bathymetry was implemented and allows ready access to all such data for use in contour mapping.

A surface gravity and magnetics survey of the southern Juan de Fuca Ridge was successfully completed from the NOAA ship *Discoverer.* The area covered included Cleft and Vance Segments and was especially centered on the source region of the megaplume events.

During FY 90, studies were completed on the magnetic properties of rocks and modeling of magnetic lows at the Sea Cliff hydrothermal field on the northern Gorda Ridge. The studies support the original interpretation that the magnetic lows are produced primarily by hydrothermal alteration of the magnetic mineral component of basaltic rocks.

Permission was granted by the U.S. Navy for VENTS to access certain SOFAR hydrophone arrays for the purpose of establishing an event detection system capable of determining when and where episodic events such as submarine volcanic eruptions and megaplume bursts occur. Detailed plans for the detection instrumentation have been provided to the Navy, and initial equipment installation is expected to begin as early as January 1991.

Fisheries Oceanography Coordinated Investigations (FOCI)

Effective management of the commercially valuable stocks of pollock (*Theragra chalcogramma*) in Alaskan waters could be improved with better knowledge of how coupled physical-biological interactions affect year-to-year changes in recruitment. The goal of FOCI is to understand the processes that lead to variations in fishery recruitment. Research was conducted in support of the paradigm that such variations occur as a result of events during fishes' early life history. Our focus has been to elucidate physical and biological phenomena and to understand how complex interactions between these two phenomena affect rates of mortality.

To date, nearly all research has been conducted in the Shelikof Strait region of the Gulf of Alaska. This stock of pollock was selected because it met the criteria of being commercially important and having a tractable early life history.

During FY 90, seasonal and interseasonal variation of pollock in the western Gulf of Alaska was examined using 5 years of current, water discharge, and climatological data. An important finding was that an index of storm activity in the northeastern Pacific (northeastern Pacific pressure index) has important regional manifestations in both winds and currents. Thus there is a direct link between this climate-scale function and local physics. This helps to establish a cause-and-effect basis for the relationship between the pressure index and the abundance of adult pollock.

A model of time-dependent larval dispersion was used to simulate observations. There were two surveys of larval pollock in spring 1988. The first survey data were used as an initial condition, together with estimates

of advection and diffusion, to generate a prediction of the distribution of larvae observed during the second survey. The success of this approach clearly indicates the importance of improving our knowledge of the velocity field input.

The fate of larvae carried into the Gulf of Alaska by the Alaska Coastal Current has been elucidated. Between 1986 and 1987, 26 satellite-tracked buoys were drogued at 40 m in the vicinity of the highest concentration of spawning; 17 buoys remained over the continental shelf and 9 buoys were transported off the shelf and entered the oceanic Alaskan Stream. The off-shelf buoy trajectories showed a well-formed, narrow, high-speed current. All but one of the buoys went aground in the Aleutian Islands or entered the southern Bering Sea. Larvae that follow a similar path would probably be lost to recruitment in the Gulf of Alaska stock. Additional observations in the Alaskan Stream have revealed a narrow, extremely stable flow. This result has helped to verify previous inferences and is in excellent agreement with a recent hydrodynamic model of the northeastern Pacific Ocean.

Most of the pollock larvae remain on the Gulf of Alaska shelf. How they are retained and what factors affect their survival are important PMEL research topics. During spring 1990, three satellite-tracked buoys deployed in a high-density patch of larval pollock were caught in an eddy. This was the first time buoys had clearly described such a marked feature in the circulation of the region. Speeds around the eddy were 20 to 30 cm s^{-1}, and the eddy had an apparent diameter of 25 km. After remaining stationary for many days, the eddy began to move southwestward, lose rotational energy, and apparently dissipate as the waters shoaled. The three buoys passed thorough the Semidi Islands and continued along the coast. It is in such coastal waters that the highest concentrations of young-of-the-year fish have been observed in the past.

FOCI began to implement a new data management and analysis system, known as Extensive PMEL Information Collection (EPIC). This system allows efficient access to many forms of data, including traditional physical oceanographic observations, and less standard biological observations. EPIC also permits easy implementation and use of modern analysis programs and display routines.

Plans FY 91

VENTS Program

- Reduce and analyze the current meter, sediment trap, and transmissometer data sets obtained during the FY –90 mooring experiment at the megaplume vent field.
- Continue the decadal-scale monitoring of venting variability on the Cleft Segment of the Juan de Fuca Ridge.
- Conduct reconnaissance surveys of venting activity on the north and south Axial Volcano rift zones.
- Undertake a synthesis of venting distribution and geologic structure along the Juan de Fuca Ridge in order to understand the large-scale control exerted by geology on the occurrence of venting.
- Integrate off-axis CTD observations and current meter measurements collected over the past several years in order to determine a regional circulation pattern and its variability.
- Conduct an *Alvin* dive at Cleft Segment, Juan de Fuca Ridge, with the objectives of describing high-temperature venting chemistry and modeling the mixing behavior of seawater with heat and major elements in hydrothermal fluids within the buoyant plume.
- Continue the development of in-situ, scanner-mode measurements of the concentrations of dissolved Mn, Fe, and Si in vent fluids and hydrothermal plumes.

- Continue analyses of heat-^{3}He-Si relationships in off-axis regions to determine the effects of steady-state and episodic venting on the regional distributions of these constituents in the North Pacific.

- 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.

- Compare bottom roughness statistics derived from Sea Beam backscatter information with those generated by spectral techniques and fractal measures.

- Analyze data from the FY–90 test of the newly enhanced BPR (E–BPR), which incorporates three pressure sensors to account for drift, short baseline tilt sensors, a time-integrating vertical-axis seismometer, and a dynamic pressure gauge to monitor harmonic tremor.

- Deploy the gravimeter-based instrument and four E–BPRs equipped with electromagnetic current meters to monitor a 40-km length of the Cleft Segment.

- Continue development of a semi-quantitative model of the behavior of a phase separated reservoir at the Axial Seamount Hydrothermal Emissions Study (ASHES) vent field in collaboration with a postdoctoral student in the Civil Engineering Dept. at Oregon State University.

- Continue implementation of a T-phase event detection system in collaboration with the U.S. Navy.

- Conduct 20 *Alvin* dives at the megaplume site for the purpose of establishing the relationships between the newly discovered high-temperature venting, a new constructional volcanic mound, and the generation of megaplume events.

Fisheries Oceanography Coordinated Investigations (FOCI)

- Adapt a hydrodynamic model to the topological constraints of the Shelikof Strait region and begin initial testing.

- Conduct a field experiment to provide upstream boundary conditions for the hydrodynamic model and observations in interior regions for verification of results from this model.

- Continue long-term observations, including water properties, currents, pollock eggs, larvae; continue acquisition and processing of satellite images.

- Provide measurements of water properties and motion for process-oriented studies of survival and secondary production within a larval patch.

- Begin a Bering Sea FOCI program. Emphasis will be on describing and modeling the general circulation over the basin. A cruise will be conducted jointly with Soviet scientists to provide the first synoptic view of the major transport features and flow through the deep western passes. Detailed data on nutrient distributions will also be obtained.

MARINE OBSERVATION AND PREDICTION

Accomplishments FY 90

Arctic Research

Exchanges through Barrow Canyon

The analysis of recent measurements in Barrow Canyon and supporting oceanographic and meteorological time series was completed. No hypersaline plumes, such as would be expected to result from intensive sea ice formation along the Alaskan coast, were observed to exit through Barrow Canyon during the intensive measurement year 1986–1987. Instead, cold and fresh waters advected down-canyon by the mean flow alternated with up-canyon flow of warm and saline water upwelled onto the shelf. At times the latter resulted in onshore heat and salt fluxes large enough to be of possible local significance, e.g., to the surface heat budget. Contrary to earlier findings, the flow was only weakly correlated with the wind and the atmospheric pressure gradient. Instead, both upwelling and flow reversals were coherent along the shelf at sites 400 km apart, with phase differences corresponding to a speed of 2.3 m s^{-1}. The majority of these events therefore appear to be manifestations of remotely forced shelf waves propagating eastward along the Arctic Ocean margin.

Investigations in the Greenland Sea

The Greenland Sea is one of the few regions in the world capable of ventilating the deep ocean. Of particular interest is the role of the western boundary current in supplying the deep Atlantic's interior region with buoyancy and salt, thereby controlling both the surface driven convective regime and deep mixing. To assess the supply of buoyancy, two instrumented moorings were recovered and a new one deployed in the recirculation region of the southern Greenland Sea. Meanwhile, analysis of recent data sets concentrated on the contribution of saline sources to the deep mixing regime. Multiple sources of slightly different density, all originating in the Arctic Ocean, can be shown to compete with the cold and fresh deep water produced in the central convective gyre of the Greenland Sea to determine the deep structure of the basins that overflow into the North Atlantic. During most of the 1980s, a failure to drive deep convection in the Greenland Sea has resulted in a significant warming and a slight salinization of the deep water in the formative region.

Joint U.S.-U.S.S.R. Chukchi Sea circulation study

Plans for a joint U.S.-U.S.S.R. field investigation of the shelf circulation from Bering Strait northward are being implemented with two cruises during the latter part of the 1990 field season, one on the *Professor Khromov* and the other on the *Surveyor*. Sixteen instrumented moorings were deployed for a year to provide a detailed time history of currents, sea surface elevation, temperature, and salinity. In addition, each cruise conducted extensive mapping of water properties, including nutrients and dissolved oxygen and a number of trace substances such as chlorinated organics and stable isotopes. Satellite-tracked surface buoys were used to determine ice drift and meteorological forcing. This joint research program will provide the first comprehensive measurements of a vital arctic shelf area, which has one of the largest biological production rates in the world and which plays a pivotal role in the climatology of the Arctic Ocean.

Tsunamis

The primary objective of the PMEL Tsunami Project is an improved understanding of the dynamics of tsunami generation, propagation, and shoreline inundation. To meet this objective, the Pacific Tsunami Observation Program (PacTOP) was established to provide high-quality tsunami measurements in the deep ocean and coastal environment. Three oceanographic cruises were carried out this year to recover and re-deploy bottom pressure recorders (BPRs) as part of the continuous PacTOP network maintenance.

A comparison of PacTOP tsunami measurements with numerical simulations was completed in collaboration with JIMAR scientists. A finite-difference implementation of the nonlinear shallow water equations was used; source terms were based on a rectangular fault plane model of seafloor deformation. This study is the first comparison of a generation-propagation model with truly appropriate field observations, and deals with two small tsunamis generated in the Gulf of Alaska on 30 November 1987 and 6 March 1988; the results illustrate the sensitivity of such tsunami models to errors in source specification.

More recently, another small tsunami was generated on 5 April 1990 by a magnitude 7.6 earthquake in the Marianas Trench. Remarkably, a tsunami wave packet less than 0.5 cm in amplitude was clearly measured by a PacTOP instrument situated more than 800 km distant from the source.

Plans FY 91

Arctic Research

- As part of the Atlantic Climate Change Program, begin monitoring the fresh water flux from the Arctic Ocean through Fram Strait.
- Complete the first set of cruises in the Chukchi Sea in support of the Joint U.S.-U.S.S.R. circulation study, and calibrate and process the resulting hydrographic data sets.

Tsunamis

- Complete a detailed comparison of existing analytic theories with tsunami waveform measurements.
- Maintain the PacTOP network by the recovery and re-deployment of all deep-ocean BPRs.

MARINE ENVIRONMENTAL ASSESSMENT

Accomplishments FY 90

Biogeochemistry

During 1990, two biogeochemical studies were undertaken on copper (Cu) cycling in marine systems to address problems associated with trace metal pollution including toxic and noxious algal blooms. In the first study, a cathodic stripping voltametry technique (CVS) was improved and tested in Puget Sound. Preliminary results showed three maxima in Cu complexing ligands: in the near surface; at 50 m, the depth of the West Point Sewage Treatment Plant's outfall, which is located just north of the sampling site; and at the bottom. The ligand concentrations and the stability constants were comparable with other coastal water determinations

by investigators using cupric ion bioassay and Sep-Pak equilibration. It is apparent that 99% of the dissolved Cu is complexed with organic matter. A model of Cu complexation will contribute to determining whether Cu availability is regulating the severity and frequency of toxic and noxious algal blooms, which have become major problems in many regions of North America.

In the second study, the role that complexation plays in controlling the fate of anthropogenic Cu in estuaries was investigated in a series of radiochemical experiments. The results indicate that biological processes are controlling the adsorption of Cu, either by active biological uptake of Cu or the excretion of Cu-complexing ligands. Cu adsorption onto particles controls the fate of anthropogenic Cu discharge into marine environments, a subject of considerable interest within the Toxic Chemical Contaminants component of the Coastal Ocean Program.

Estuarine Circulation Modeling

A principal accomplishment over the past 12 months has been the development and use of models of physical and chemical processes in estuaries, which are central to the goals of the Coastal Ocean Program. Models of time-dependent estuarine circulation and chemical scavenging have been completed. Model distributions have been compared with observations both to evaluate model parameters and to check model completeness and accuracy.

The main focus has been on modeling the fluid circulation of Puget Sound. Intrusions of dense water, important to bottom-water renewal in Puget Sound, were shown to be controlled by four factors: the horizontal salinity difference across the sill region, the intensity of mixing there, the supply of riverine discharge in the inlet, and the strength and direction of the wind. The model suggests that a difference in salinity of at least 1.3 $^{0}/_{00}$ between the entrance and inner lip of the landward sill is required for the initiation of an intrusion. This difference depends on the entrance salinity, controlled by winds in the Strait of Juan de Fuca and along the coast, and on the salinity in the basin, regulated by runoff and earlier density intrusions. About 20% of the runoff during the winter months is retained in the main basin, freshening it as much as 0.8 $^{0}/_{00}$. As the salinity of the main basin declines in the spring months, the salinity outside the entrance rises toward a summer peak, and the cross-sill salinity gradient reaches a maximum. This phenomenon coupled with reduced summertime river runoff, a factor in regulating intrusions, explains why the strongest intrusions occur during the summer.

Surprisingly, vertical mixing at the Admiralty Inlet entrance is advective rather than turbulently diffusive and occurs every tidal cycle, providing a mechanism for surface freshets to dilute bottom water. This weakens the effective cross-sill salinity gradient and dampens the intrusion, an effect not recognized previously in Puget Sound.

Winds affect intrusions in a number of ways besides their effects on the entrance salinity already mentioned. Northward winds transport surface water out of the estuary with a compensating landward bottom flow that hastens the dense-water traverse of the sill region. Southward winds have the opposite effect.

Particulate exchange rates and time scales in Puget Sound were modeled by an analysis of radioisotope data. Particulates were estimated to sediment vertically to a depth of 220 m, in 10–15 days. These are the first such data for an estuary and are an important step toward a complete model of contaminant transport and fate. The values were integrated into a preliminary model of the water column distribution of the "unresolved complex mixture of hydrocarbons" (UCM), a chemical marker of anthropogenic input of material into Puget Sound.

Knowledge of the particulate exchange rates has also allowed the creation of a preliminary model to simulate vertical profiles of small and large particle concentrations as measured optically and fluxes as measured by sediment traps. This will lead to an understanding and quantification of contaminant transport

in the coastal ocean, and is one of the Laboratory's contributions to improving the environmental health of the nation.

Chemical Modeling

A model of trace metal behavior in water masses moving along the bottom of deep estuaries has been applied to manganese (Mn) in the main basin of Puget Sound. The model shows that the concentration of dissolved Mn, an important scavenger of toxic metal contaminants in the water column, tends toward a concentration near the bottom that is controlled by the outflux of dissolved Mn from the underlying sediment and the oxidation rate onto particles in the water column. The instantaneous concentration of particulate Mn varies greatly near the bottom as near-bottom currents periodically resuspend metal-bearing bottom sediment. This research contributes to the understanding of the behavior of estuarine contaminants, an element in the NOAA Coastal Ocean Program.

Tidal Currents

Also contributing to the understanding of processes affecting estuarine contaminants, an analysis of tidal currents in the southern reaches of the main basin of Puget Sound shows that the diurnal currents increase in strength toward the bottom. This region includes the southern part of East Passage, heavily contaminated Commencement Bay, and the deeper parts of Dalco Passage. Both the amplitudes and phases of these currents are very sensitive to the density variations in Puget Sound, causing the tidal currents and their effects on contaminants to vary substantially in time. During rare summer conditions when the water is vertically homogeneous, these currents become uniform with depth.

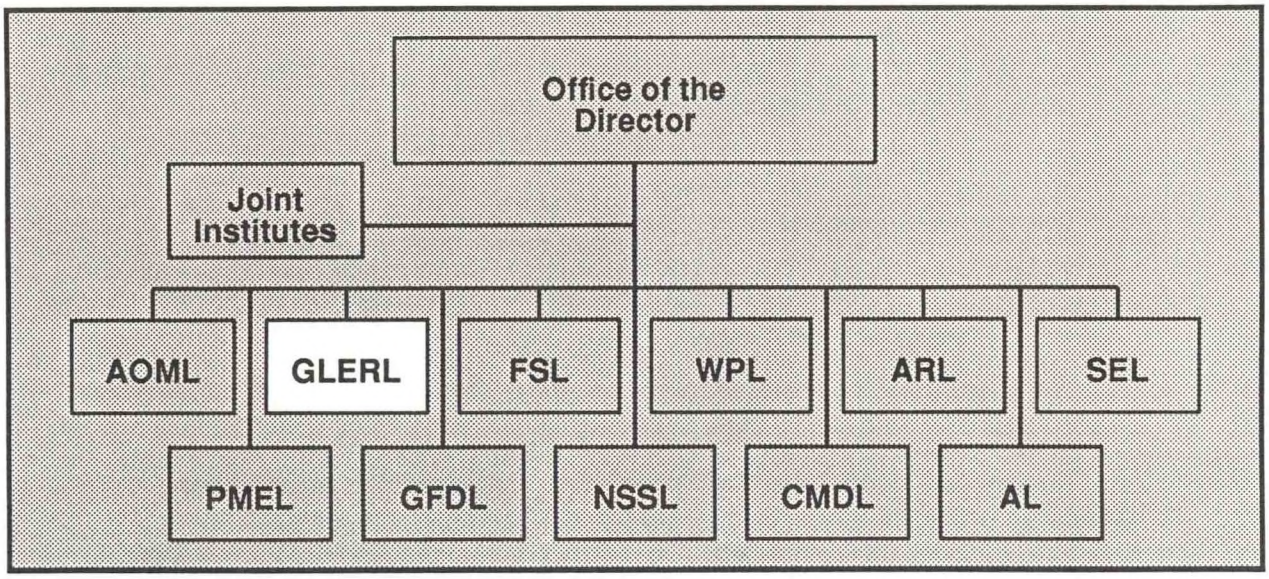
Sea Level Climatology

In support of both the physical impacts element of NOAA Coastal Ocean Program and the NOAA and Climate Global Change Program, an ongoing study of sea level variations shows that sea level fluctuations observed in Puget Sound propagate into the Sound from the Pacific Coastal region. For signals with periods greater than those of the tides, the squared coherence is greater than 0.95 between observed sea level at Seattle in Puget Sound and that at Neah Bay, near the coast. There is a landward decrease in the amplitudes of these signals (20% decrease at Seattle), due possibly to the spreading of the signals throughout the extensive inland waters of the region. The 90-year time series at Seattle is therefore a useful surrogate for coastal sea level and, indirectly, the historical weather and steric ocean (e.g., El Niño) signals since these are the main causes of sea level variations along the U.S. West Coast.

Plans FY 91

- Complete Mn precipitation studies and apply to dynamical chemical models for estuaries.
- Investigate density intrusions during summer months, using a numerical model.
- Implement a scavenging model of suspended matter that describes profiles, fluxes, and resuspensions of interactive size classes.

- Analyze sea level in Puget Sound for the period 1899–1988 including extreme events, interannual variations, and trends.



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 water, with special emphasis on the Great Lakes. GLERL's scientific programs are organized into six coordinated research programs considered critical to the NOAA mission and Great Lakes problems (Non-indigenous Species, Coordinated Ecosystem Research, Climate Variability and Global Change, Pollutant Effects, Marine Hazards and Water Management, and Green Bay Coordinated Research), The Nutrient-Enhanced Coastal Ocean Productivity (NECOP) program, The Great Lakes Coast Watch Program, and several independent research projects.

NON-INDIGENOUS SPECIES

The goal of this program is to expand our knowledge of the biology and the ecological effects of non-indigenous species in the Great Lakes.

Recently, two non-indigenous species were introduced into the Great Lakes that have the potential to dramatically alter trophic relationships of the entire ecosystem: the zebra mussel (*Dreissena polymorpha*), and the spiny water flea (*Bythotrephes cederstroemi*). *Dreissena* is capable of increasing in numbers very rapidly. This species is likely to have a profound effect on the cycling of materials and the implications to other species. *Bythotrephes* has become a dominant member of the plankton in all the Great Lakes. Our own preliminary work suggests that *Bythotrephes* is a voracious selective predator. Recent shifts in zooplankton community structure from *Daphnia*, the favorite food of *Bythotrephes*, to copepods in Lake Michigan have been hypothesized to be caused by *Bythotrephes*.

Accomplishments FY 90

The Zebra Mussel Dreissena polymorpha

Effects on lower food web of Saginaw Bay

- Samples for phytoplankton, zooplankton, and benthos were taken at stations throughout the bay. Conductivity-temperature-depth (CTD) casts were made (vertical profiles) at the same stations, and primary production was determined.

Metabolic physiology

- Zebra mussels were collected in Lake St. Clair (one site with high abundance and one with low abundance).
- A diver survey of unionids and zebra mussels was conducted in Lake St. Clair.

Toxicokinetics and bioaccumulation of organic contaminants

- Toxicokinetics for accumulation from water by zebra mussels will be examined for selected polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyl's (PCB's) congeners.
- The respiration rate will be determined for comparison with uptake clearance of the contaminants.
- The lipid content of the mussels will be examined for effects of lipid content on elimination of the contaminants.

The Spiny Water Flea Bythotrephes

Physiological ecology and its direct effect on food web structure

- Analyzed results of in-situ feeding experiments performed over past 2 years.
- Initiated weekly *Bythotrephes* sampling for population dynamics study.

Effect on Fish: Aversion conditioning, recruitment, and food web structure

- Set up aquaria and fish-holding tanks, and videotaped a series of experiments that demonstrated the development of aversion conditioning in perch to *Bythotrephes*.

Plans FY 91

- Analyze the data from the mussel survey in Lake St. Clair.
- Analyze *Bythotrephes* population data collected June–December 1990.

- Collect bloater chubs and *Bythotrephes* for a series of experiments.
- Collect zebra mussels from various locations in Lake St. Clair throughout the March–December field season. On each sample date, quantify individual zebra mussel oxygen consumption, nitrogen (ammonia) excretion, lipid content, dry weight, ash-free dry weight, and C:N ratio in soft tissue.
- Continue to sample the same variables in Saginaw Bay, but at additional sites. Anticipated funding will allow more samples to be collected on both spatial and temporal scales and will allow the study to expand into examining nutrient changes and developing eutrophication models.

COORDINATED ECOSYSTEM RESEARCH

The dynamics of Great Lakes ecosystems, including those of their fish populations, are controlled by the actions of humans and nature.

Long-term observations of ecosystem components (e.g., the abundance of fish, plankton, nutrients) demonstrate that they can be highly variable in time and space. Identifying the cause(s) of this variability is, therefore, a worthy goal because it will lead to an understanding of the relative importance of different influences on ecological dynamics. The goal of the Coordinated Ecosystem Research program is to improve predictions of ecological change that result from natural and anthropogenic perturbations. The early part of this program will focus on improving predictions of food web dynamics that support a $2 to $4 billion per year Great Lakes salmonine fishery. A key aspect of the program is to understand relationships between the dynamics of forage fish, the lower food web that supports their growth, and characteristics of the physical environment. Specific studies will be conducted to (1) quantify temporal and spatial trends and variability; (2) identify first-order relationships among fish populations, lower food web, and physical factors; and (3) provide estimates of biotic biomass for use in ecological simulation models.

Accomplishments FY 90

Microplankton in the Great Lakes

- Conducted a cruise in Lake Ontario to collect preliminary data to provide whole-lake estimates of phytoplankton biomass, primary production, and total microplankton biomass.

Whole-Lake Physical Variability

- Compared METOCEAN platform performance against National Data Buoy Center (NDBC) meteorological data and data obtained from Mini-TOD drifters.
- Conducted several Lagrangian cluster experiments in Lake Ontario with the CSS *Advent*.
- Participated in designing and implementing a fully portable platform for acoustic Doppler current profiler (ADCP) measurements.

The Microbial Food Web in the Great Lakes

- Finished analysis of data collected on *Synechococcus*.
- Compared cellular production rates of picoplankton populations in the Gulf of Mexico and in the Great Lakes with differential filtration and autoradiography.
- Finished the analysis of red fluorescing communities in the Great Lakes.
- Conducted in-situ experiments on the division cycle of *Synechococcus* (phototrophic picoplankton) to estimate growth rates. This organism is the most abundant phototrophic organism in the Great Lakes.

Whole-Lake Estimates of Macrobenthos Production and Biomass

- *Diporeia* and *M. relicta* samples collected in southern Lake Michigan in 1986–1987 were picked and sorted.

Pelagic-Benthic Energy Transfer and Bioenergetics Models of Macroinvertebrates

- Plans were developed to (1) elucidate the seasonal input rates and composition of "new carbon" reaching the Great Lakes' benthos, (2) estimate the fate of the incoming particulate carbon, (3) examine the biochemical partitioning of the carbon in the organisms, and (4) develop a carbon budget to quantify the input, alteration, and burial rates of carbon from settling particles.
- A sediment-trap program was established to characterize the quality and quantity of organic carbon, nitrogen, biogenic silica, and diatom species at the sediment-water interface.

The Influence of Ice Cover and Spring Weather on Northern Lake Michigan Whitefish

- Ice cover models were developed for three areas of northern Lake Michigan.
- A stepwise regression approach was used to select model parameters and to construct whitefish recruitment models.

Food Quality in Pelagic Food Webs

- Work on feeding mechanisms of *Diaptomus* and other copepods was continued using high-speed microcinematography and traditional feeding experiments.
- We discovered that copepods could use mechanical cues to perceive particles. Our results also showed that it is probable that both mechanical and chemical cues are used and that mechanoperception dominates in large particles, whereas chemoperception dominates in small particles.

Plans FY 91

- Provide preliminary examination of the spatial and temporal abundance of microplankton in Lake Michigan by initiating a synoptic whole-lake sampling program.
- Provide preliminary examination of the composition of microplankton during the whole-lake cruises.
- Conduct airborne imaging spectrometer survey at Lake Michigan test site for estimates of surface temperature and chlorophyll.
- Begin development of data assimilation methods for shipboard and satellite data bases and for satellite data validation of surface temperature and chlorophyll.
- Continue exploring the use of flow cytometry to characterize phototrophic picoplankton communities in the Great Lakes.
- Initiate and develop the use of image analysis in the study of phototrophic picoplankton and its potential for studying phytoplankton populations.
- Finish experiments that compare differential filtration and autoradiography experiments for estimating species-specific production.
- Initiate development of a carbon-based microbial food web model.
- Measure and weigh *Diporeia* and *M. relicta* samples collected in 1986–1987; identify species when possible, and estimate biomass. Additional samples will be collected.
- Experimentally measure carbon transfer from large diatoms to the benthic Lake Michigan amphipod *Diporeia* sp.
- Examine the biochemical partitioning of the carbon from large diatoms (*Melosira* sp.) to the Lake Michigan amphipod *Diporeia* sp.
- Quantify seasonal input rates and determine composition of "new carbon" reaching the Great Lakes benthos.
- Develop carbon budget to quantify the input, alteration, and burial rates of carbon from settling particles in Lake Michigan.
- Determine whether copepods' preference for nutrient-sufficient cells as food over nutrient-deficient cells, at high algal concentration, will hold at low algae concentrations.
- Using microcinematography, observe feeding mechanisms of tethered copepods to make generalizations about appendage use patterns and sensory cues.

CLIMATE VARIABILITY AND GLOBAL CHANGE

For climate change to be understood more adequately, the processes included in General Circulation Model (GCM) analyses must be extensively studied. In the Great Lakes region, some of these processes include vertical dynamical heat fluxes, heat transport by deep lake currents, deep lake convective dynamics, deep water circulation, biogeochemical cycling, and the effect of ice. By better understanding these processes and the regional aspects of climate change, GLERL's coordinated research program on Climate Variability and

Global Change in Large Lakes will contribute to the immense problem of understanding global climate change. A few ongoing studies have been internally funded and are currently producing results. Additional studies have been proposed for outside funding both by GLERL researchers alone and by GLERL researchers jointly with scientists from the Cooperative Institute for Limnology and Ecosystems Research (CILER).

GLERL's activities in this area include planning for involvement with the NOAA Ecological Systems & Dynamics Project, NSF Long-Term Ecological Research Sites and Global Change Research, the Freshwater Initiative, the Global Exchange and Water Cycle Experiment, U.S.-U.S.S.R. Working Group VIII, and the Joint U.S.-Canadian Study on the Impacts of Climate Change on the Great Lakes.

Accomplishments FY 90

Water Resources and Climate Change Contingency Planning

- A number of potential adaptive strategies for Great Lakes water management were developed.
- From a review of existing Great Lakes institutions and policies that have relevance to water quantity management and/or climate change, a number of strengths and weaknesses were identified, and several themes concerning barriers to further progress in contingency planning were discerned.
- Previous accomplishments provided a basis for identifying necessary conditions for fostering regional climate change contingency planning, appropriate institutional attributes and mechanisms for conducting a contingency planning process, and specific elements that should be included in contingency plans.

Effect of Climate Change on Large-Lake Ice Cycles

- The monthly ice cover concentrations typical of severe winters and mild winters on Lakes Erie and Superior between 1897–1898 and 1982–1983 were identified.
- Average 700-mb heights and associated circulation patterns coincident with contemporary severe and mild winters were identified.

Ecological Monitoring

- Ecological Lake Michigan monitoring data, collected between 1982 and 1990, were compiled and statistically tested for the specific purpose of developing an accessible data base that can be used for both model verification and trend studies.
- Biweekly collections of the ecological monitoring parameters at one deep-water station in Lake Michigan were completed. Results from this study, added to the current historical data, support the refinement and development of the technical design of the monitoring program and support relevant process studies.

Thermal Structure Studies

- A monitoring site was established in Lake Michigan. One subsurface mooring consists of five VACMs recording hourly temperature and velocity data. The second contains 11 thermistors recording temperatures at 3-h intervals. The third mooring is deployed on the surface and will be retrieved in the fall.

Environmental Radiotracers

- In the Lake Erie Reference Sites study, nearly all cores (90%) have now been analyzed for gamma emitters. In the study concerning Biogenic Silica Accumulation in Lake Erie Since 1800, timed extractions using LiOH were accomplished. In Radiotracer Methods Development, intercalibration of the new detector for Pb-210 was completed. Samples were collected and cores dated for Great Lakes carbon geochemistry. Samples were also collected for the Coastal Marine Carbon Budget and Geochemistry portion of the NECOP program.

Plans FY 91

- Begin evaluation of Lake Ontario water regulation plan adjustments as a strategy for reducing regional effects of climate change.
- Continue to compile U.S.S.R data from the Caspian Sea basin to determine hydrological effects on climate change for large lakes of the world.
- Begin to adapt and calibrate GLERL's runoff model to parts of the Caspian Sea basin.
- Collect GCM climate warming scenarios over the U.S.S.R. from the National Center for Atmospheric Research (NCAR) and continue, with NCAR, to assess GCM simulations for studying hydrological aspects of climatic change on large lakes over the U.S.S.R. and the Laurentian Great Lakes. GLERL will participate in mesoscale atmospheric modeling for selected large-lake regions of the world, through interagency cooperation under the Cooperative Institute for Limnology and Ecosystems Research (CILER), with NCAR, the University of Michigan Department of Atmospheric, Oceanic, and Space Studies (AO&SS), and Ohio State University.
- Through these joint efforts, continue to study effects of GCM-GLERL model and mesoscale model linkages, and continue to compare hydrological and GCM outputs and mesoscale outputs.
- Retrieve, refurbish, and redeploy temperature and current instruments from the Lake Michigan monitoring site.
- Procure two additional thermistor strings and establish a second thermal monitoring site in northern Lake Michigan.
- Conduct at least three CTD cruises on Lake Michigan to (1) supplement thermistor string data, (2) investigate inshore-offshore temperature structure, (3) assemble data for verification and testing of a hierarchy of hydrodynamic and thermodynamic models, (4) make contributions to a Lake Michigan climatological data base.
- Develop plans that address the more immediate overall strategy for sampling, laboratory analysis, and quality control in ecological monitoring.

- Continue developing a computer program capable of compiling and presenting the monitoring data in a manner easily accessible to interested scientists and agencies.

- Conduct 15–20 field trips to Lake Michigan to collect ecological data on temperature, zooplankton composition, secchi depth, bacterial abundances, chlorophyll *a*, carbon, phytoplankton, conductivity, and nutrients.

- Complete radiometric analyses of 1988 sediment cores, and process data using existing sedimentation-mixing models. Collect additional cores with special emphasis on long (10-m) cores, which extend into 16th century sediments.

- Begin analysis of primary, Pb-210 dated core from the 1988 collection for BSi.

- Analyze selected sediment cores for carbon isotopes including C-14; develop whole-lake models for carbon cycling.

- Apply models to radionuclide and stable-element sediment profiles as data become available.

POLLUTANT EFFECTS

The goal of the pollutant effects coordinated research program is to increase understanding of the dynamics, fate, and effects of contaminants in the ecosystem. The research effort is a combination of process studies and mathematical modeling. The results contribute to improved forecasting of the effects of contaminants, and support choices of management approaches. The program addresses the following questions: (1) For a given load of toxic contaminant, what level of exposure can be expected for various biota? (2) What is the assimilative capacity for toxic contaminants defining no-effect loads for both species and communities? (3) What kind of prediction can be applied to catastrophic events to ensure best management decisions? (4) What are the effects of long-term low-level contaminant exposures?

Accomplishments FY 90

Sediment-Associated Toxic Organics: Fate and Effects

- Initial examinations of many of the major variables that could affect the bioavailability of sediment-associated contaminants were completed.

- The 28-day mortality bioassay and the sediment/avoidance preference bioassay were employed as a portion of the U.S. EPA's program for Assessment and Remediation of Contaminated Sediments (ARCS).

- An approach was investigated with some of the very toxic sediments to establish the amount of toxicity equivalents by diluting the sediments with either a reference sediment or clean sand.

- Characterization of the amphipod *Diporeia* was advanced by examining responses to stressors, salinity, temperature, and cadmium (Cd).

- The experiment to examine the role of contact time between the contaminant and sediment particles used selected PAHs as the model contaminants. The bioavailability of compounds was generally reduced with increased aging (contact time between the sediment and the contaminant).

- The first studies were completed on the role of organic carbons on the bioavailability to *Diporeia* exposed to contaminated sediments containing three levels of organic carbon, plus a fourth sediment where only the fine fraction was dosed.
- A mechanistic model to describe the bioaccumulation of sediment-associated organic contaminants was developed.
- The bioavailability of selected chlorinated hydrocarbons sorbed to sediments was investigated with *Diporeia.*
- A study to investigate the effect of aging, changes in contact time between sediments, and contaminants on the partition coefficients between sediment particles and interstitial water was performed.

Physiological and Biochemical Measures of Contaminant Effects

- The O:N ratios for *Diporeia* sp. were examined on both a north-south and an east-west transect.
- The method for measuring catecholamines in invertebrates by high-performance liquid chromatography with fluorescence detection was perfected.

Long-Term Trends in Benthic Populations

- In the Saginaw Bay samples, all chironomids were identified to species and oligochaetes were identified to species in two of the six data sets.
- Samples of *Pontoporeia* abundances in the nearshore waters of Lake Michigan were collected for fish exclosure experiments.
- The data on long-term trends in mussel populations in western Lake Erie were analyzed.

Bioenergetics of the Great Lakes Amphipod Diporeia sp.

Assembled and began use of a personal-computer-based microscope-digitizer system that allowed for rapid and reliable completion of *Diporeia* body length measurements needed for production estimates.

Plans FY 91

- Complete data analysis for Saginaw River bioassays.
- Complete sample analysis for the bioavailability of sediment-sorbed chlorinated hydrocarbons to *Diporeia.*
- Continue to evaluate the utility of O:N ratios as a measure of stress. Specifically examine source of variability in O:N measurements in the field to better establish the range to be expected.
- Perform laboratory exposures of *Diporeia* to stressors such as food depravation and specific contaminants.

- Document catecholamine research progress.
- Continue identifying oligochaetes from Saginaw Bay.
- Pick and sort organisms collected in Whitefish Bay as part of the fish exclosure experiments.
- Continue periodic sediment-grab sampling at 45-m and 100-m sites to determine if *Diporeia* production is still declining.
- Test sediments of opportunity with the 28-day mortality bioassay where comparisons can be made with existing chemistry or other bioassay results for improved calibrations of the bioassay.
- Calibrate the 28-day mortality bioassay with standard contaminants to better understand the bioassay results.
- During the calibration with standard contaminants, gather data in an attempt to define the temporal, exposure, residue, effects relationship.
- During the studies with standard contaminants, follow the avoidance response to better understand the avoidance/preference bioassay under development.
- Study the effects of contaminants on bioturbation, using the Gamma Scan system. Additionally, studies will be initiated on the effect of particle size on bioavailability of contaminants and the role of particle size in bioturbation studies.
- Develop methods to determine the assimilation efficiency of sediment-associated toxins by *Diporeia* sp.

MARINE HAZARDS AND WATER MANAGEMENT

Natural hazards encompass a wide variety of environmental phenomena that pose threats of loss of lives or property and social or economic disruption. Large waves, high and low lake levels, heavy snowfalls, ice, and erosion are important natural hazards in the Great Lakes system and (with the exception of low lake levels) in other coastal areas as well. Human-caused hazards also pose serious threats, especially spills of petroleum products and chemicals. The program comprises four broad components: Prediction, Climatology and Statistics for Decision Making, Process Studies, and Interface With Policy and Decision Makers.

Accomplishments FY 90

Great Lakes Water Level Statistics for Decision Making

- Developed a resampling strategy for estimating Great Lakes water level statistics on month-to-month differences, structured according to lake level intervals, month of occurrence, and prevailing precipitation regime.
- In coordination with the Great Lakes Commission and the U.S. Army Corps of Engineers, organized and conducted a 2-day symposium and workshop. More than 70 experts attended, representing the region's scientific, academic, and policy leadership.

Great Lakes Evaporation, Forecasting, and Simulation

- Developed shallow- and deep-water concepts of heat storage and tested them against observed heat storage and surface temperature data.
- Incorporated water surface temperature observations as boundary conditions in lake evaporation simulations and forecasts.
- Incorporated revised lake evaporation model into the forecast package
- Developed the Great Lakes hydrological cycle package for use on personal computers, to make the entire package available to other agencies.

Objective Analysis of Great Lakes Marine Meteorological Observations

- Implemented a system for acquiring and storing routine meteorological observations from NDBC buoys, Coastal Marine Automatic Network (CMAN) stations, Coast Guard and other coastal stations, and ships.
- Examined two methods for objective analysis of wind data. An inverse power law method is preferable over the two-step exponential method for use in the Great Lakes.

Assessment of Shallow-Water Effects on Wind Waves in the Great Lakes

- Implemented the state-of-the-art third-generation Wave Attenuation Model (WAM) for wave prediction, for application to Great Lakes waves studies.
- Participated in the annual WAM model workshop and the planning workshop of the Surface Wave Dynamics Experiment (SWADE).

Plans FY 91

- Publish and distribute proceedings from Great Lakes Water Levels Symposium.
- Investigate evaporative response of each of the Great Lakes to variations in meteorology, heat storage, and other factors.
- Assess water balance groundwater fluxes and other water balance questions by using the improved (and independent) evaporation models.
- Finish modifying water supply forecasting algorithm.
- Integrate 1–D flow routing models for the St. Lawrence River.
- Continue analysis of wind and wave data recorded in Lake Erie, Lake St. Clair, Saginaw Bay, and Green Bay, as well as data recorded from NDBC buoys in the Great Lakes.

GREEN BAY COORDINATED RESEARCH

The presence of toxic organic materials in the water, sediment, and biota of Green Bay has long been a cause for concern and has severely affected the bay's fishery. In order to address the problems in the bay, the EPA has undertaken the Green Bay Mass Balance Study with two major objectives: (1) To provide information to aid and support regulatory activities in Green Bay, and (2) to pilot the use of the mass balance approach to regulation of toxic substances in Green Bay.

Accomplishments FY 90

Sediment Resuspension and Particle Settling Velocities

- Sediment traps were deployed and retrieved at five EPA stations in Green Bay.
- Samples were dried, weighed, and stored frozen. Organic carbon analysis was completed.

Sediment Transport in Green Bay

- The summer data on sediment transport were edited, filtered where necessary, and corrected for fouling of the sensors.

Water Volume Transport Measurements

- All current- and temperature-measuring instruments were removed from Green Bay.
- An acoustic Doppler profiler was redeployed and operated during winter.
- Data were edited and archived.
- Several differing algorithms were developed and tested to compute water volume transports on key Green Bay cross sections.

Plans FY 91

- Complete the analysis of trap samples for organic carbon.
- Provide trap samples for PCB analysis.
- Begin development of an empirical model of sediment resuspension in the bay.
- Calculate horizontal flux of sediment in and out of the southern bay.
- Compute volume transports through key bay cross sections.
- Direct scientific analyses of the data sets at discovery and conceptual modeling of the fundamental processes of lake physics governing bay dynamics.

- Complete the analysis of trap samples for organic carbon.
- Provide trap samples for PCB analysis.
- Complete entry of all data for analysis.
- Complete final report to EPA.

NUTRIENT-ENHANCED COASTAL OCEAN PRODUCTIVITY (NECOP)

This is one of a series of NOAA-wide programs dealing with major problems in the coastal ocean. The central hypothesis is that the increased nutrient input from the Mississippi River has led to increased productivity, with undesirable consequences. GLERL is involved in the following studies, all of which began in FY 90.

Accomplishments FY 90

The Fate and Effects of Riverine (and Shelf-Derived) Dissolved Organic Nitrogen on Mississippi River Plume–Gulf Shelf Processes

- Samples and data were collected on the first NECOP cruise.
- A high-performance liquid chromatography technique for the analysis of NH_3 and a procedure for gas stripping dissolved inorganic carbon from sea water were implemented and used on the first NECOP cruise.

Suspended Sediment on the Louisiana Continental Shelf: Concentrations, Compositions, and Transport Pathways

- Vertical profiles from three of the four cruises were digitized.

Retrospective Analysis of Nutrient-Enhanced Coastal Ocean Productivity in Sediments from the Louisiana Continental Shelf

- A core collected in 1984 and partially analyzed was selected for further analysis.
- Cores were collected on the first NECOP cruise.
- A technique was implemented for the analysis of lignins (terrestrial organic matter).

Plans FY 91

- Analyze the collected NECOP samples for carbon and nitrogen stable isotopes.

- Participate in the second NECOP sediment core collection cruise.
- Participate in two NECOP *Laser* and two NECOP RV *Baldridge* cruises in the Gulf of Mexico.
- Analyze current meter and CTD records from first NECOP cruise.
- Analyze the cores for carbon and nitrogen stable isotopes, alkanes, and lignins.

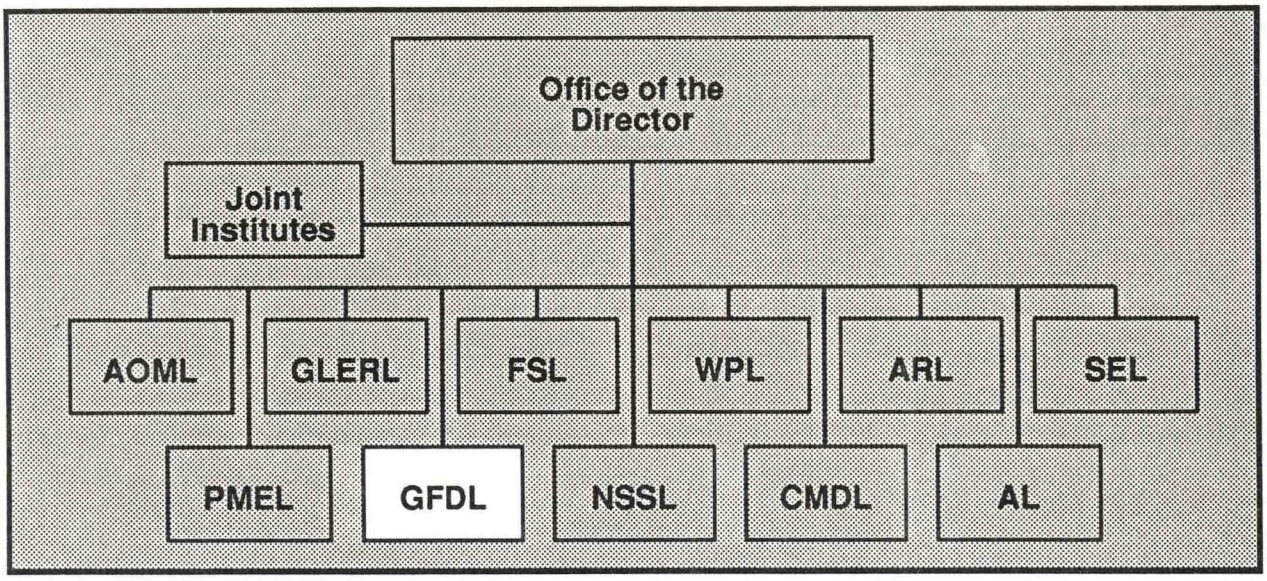
GREAT LAKES COASTWATCH

Accomplishments FY 90

- A computer initiative for a Great Lakes Regional NOAA Ocean Communication Network (NOCN) Node (RNN) was developed, and computer equipment for communications, data display, data storage, and data analysis was purchased.

Plans FY 91

- Computer equipment for operation of Great Lakes RNN will be installed and tested at GLERL.
- The Center for Great Lakes Studies (CGLS) (Milwaukee) personnel will be trained on operation of the Interactive Digital Image Display and Analysis System (IDIDAS) workstation and a prototype CoastWatch user site will be established at CGLS (Milwaukee).



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 systems 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 (AOS) 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 higher 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 to years? 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 90

- A successful 12-month forecast of the 1982 El Niño was reported last year. The 1982 case was further examined using five different versions of the air-sea model in terms of surface heat flux corrections. In all the forecasts, the El Niño signature emerged 9 months later. Subsequently, 9-month forecasts have been tested for two additional cases, (i.e., 1983,1984), with and without flux correction. The 1982 and 1983 El Niño cases were successfully forecast, but the 1984 La Niña case was not well predicted. A possible reason is that the initial condition of ocean heat content was not well represented.

- The sensitivity of the 30-day mean radiative response of an extended-range prediction model to a new method of cloud prediction vs. fixed clouds was investigated. Incorporation of the new cloud prediction scheme dramatically enhances the model's longitudinal structure of the Earth's radiation budget in the tropics and subtropics, producing results that are consistent with observations. Marked longitudinal structure is also found in the predicted distribution of cirrus clouds and corresponding longwave radiative heating in the tropical upper troposphere, where the zonal mean cold bias of the model is reduced by 2 K.

- Results from experimental predictions for Hurricane Gloria, using GFDL's Movable-Mesh Mesoscale model, indicated that high-quality forecasts with the hurricane model could be extended out to 132 hours. Need for an improved specification of the initial vortex was strongly suggested because of slowness of the vortex spin-up in the model.

- In response to the above discovery, a methodology to specify the initial tropical system in high-resolution hurricane models was developed. In the new method, observed or assumed data on the storm structure are used to construct bogus vortices, which consist of a model-generated symmetric component and a diagnostically determined asymmetric component. Results from preliminary experiments using bogus vortices are very promising.

- Analysis of the rapidly deepening cyclone that occurred over the South Pacific on 5 September 1987 was completed. Sensitivity experiments were used to investigate the role of surface processes in the development. The analyses showed that the intensification of the storm was somewhat sensitive to surface frictional effects, but not very sensitive to surface heat fluxes (aside from preconditioning the unstable environment), orography, or land mass distribution.

- Analyses of the energy budget of extratropical cyclones revealed that, although waves grow initially through baroclinic processes, they do not necessarily decay by transferring energy by means of barotropic processes as previously thought but rather by radiating energy away from the disturbance. It was found that ageostrophic geopotential fluxes are the dominant mechanism for the removal of energy from the wave, exporting it downstream where, given favorable conditions, it can trigger the development of a secondary disturbance.

- A simplified time-dependent numerical model was used to investigate the role of the initial wind profile in determining whether squall lines may develop in preference to isolated cumulonimbus. It was found that squall lines are more likely to develop if the forced subsidence from the initial convective updraft is able to move ahead of the surface outflow boundary, where the forced ascent is concentrated. This implies a requirement for a minimum vertical shear normal to the incipient squall line.

- A nested-grid calculation was carried out to simulate deep moist convection that was observed on 10–11 April 1979 in north-central Texas. The mesoscale group's regional-scale model was used to supply the initial large-scale flow and side boundary conditions for the convective-scale model. This latter model produced strong convective cells in a region where severe storms were observed to occur.

Plans FY 91

- High-resolution versions of the global spectral and air-sea model will be developed and run for forecasts as long as 1 year.

- Improved physics packages involving surface boundary layer processes as well as those in the free atmosphere will be compared with earlier, more simple physical parameterization schemes.

- Seasonal forecasts using the air-sea model will be applied using different initial conditions. An investigation of the causes for the systematic biases in the air-sea model will be further pursued.

- Prediction experiments of hurricanes will be conducted for additional cases with improved initial conditions. Additional data will be provided by The National Meteorological Center (NMC), The European Centre for Medium-Range Weather Forecasts (ECMWF), and other institutes.

- Environmental flow and surface boundary effects on hurricane genesis processes will continue to be studied.

- Downstream energy transport processes will be further investigated to delineate their role in extratropical wave evolution.

- New case studies will be initiated to determine the role of surface fluxes in the intensification of extratropical cyclones.

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 millennia; and to evaluate the climatic effect of human activities such as the release of 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 Southern Oscillation–El Niño (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 models are constructed to study and simulate the ocean, the atmosphere, the coupled ocean-atmosphere-cryosphere system, and various planetary atmospheres.

Accomplishments FY 90

- A fully coupled ocean-atmosphere model was subjected to two opposite CO_2 forcings: a gradual increase and a gradual decrease of the atmospheric CO_2. The downward penetration of the thermal anomaly into the model ocean is significantly deeper in the CO_2-decrease experiment than in the CO_2-increase experiment, owing to the difference in the changes of salinity and temperature in the upper layer of the ocean.

- A detailed radiative transfer model was used to clarify the contributions of "other" greenhouse gases (e.g., nitrous oxide, methane, and the chlorofluorocarbons) on the expected temperature changes in the lower stratosphere. The results indicate that these greenhouse gases provide a heating effect to offset partially the cooling effect due to increasing CO_2 in the lower stratosphere.

- A highly variable forcing of stratospheric and tropospheric climate is produced by volcanic aerosol injected into the stratosphere. Heretofore, it has been difficult to establish the relative importance of this variable forcing. Detailed radiative transfer calculations using both small-size and mixed-mode particle distribution assumptions were used with available stratospheric satellite data to investigate this question. The results indicate that the volcanic injections and their variations are comparable with or even exceed the longwave flux changes due to added greenhouse gases over the past decade. Thus, a quantitatively important source of decadal-scale climate variability has been identified.

- Preliminary comparisons were made between GFDL and ARL global atmosphere temperature data sets that are based on very different analysis procedures and data coverage. The comparisons show a remarkable agreement in the tropospheric temperature variations for the two hemispheres and the globe. The good agreement suggests that the large-scale temperature variations during the last 30 to 40 years can be determined well on the basis of the present rawinsonde network.

- An atmospheric general circulation model (GCM) coupled to a motionless slab ocean was shown to reproduce realistic sea level pressure and sea surface temperature anomaly patterns in the extratropical zones. This finding illustrates that the essence of middle-latitude air-sea interaction on monthly time scales can be captured by local heat interchange between the ocean and atmosphere, whereas ocean dynamics have a minor role. The oceanic changes in this simplified coupled system appear to be driven by the atmospheric circulation anomalies.

- The dynamical interactions between winter storm tracks and the monthly averaged (stationary) circulation were diagnosed using the three-dimensional distributions of eddy-induced geopotential height tendency and vertical motion. The barotropic effects of the synoptic-scale eddies are stronger than the baroclinic effects in the upper troposphere, so the net eddy forcing acts to reinforce the quasi-stationary flow in which the disturbances are embedded.

- The vorticity dynamics and heat budget of observed tropical synoptic-scale disturbances were documented using a multi-year global data set. The relationships of these features with both intense vortices and more slowly varying tropical fluctuations were established. The salient properties of these observed phenomena were employed to assess the fidelity of tropical GCM simulations.

- Experiments with idealized atmospheric GCMs showed that the large changes in the eddy momentum flux that occur when the model's resolution is increased are due to increased meridional, and not zonal, resolution.

Plans FY 91

- The time-dependent response of climate to gradual changes of atmospheric CO_2 will be re-examined by use of a coupled ocean-atmosphere model with higher computational resolution.
- Analysis of the radiative effects of the greenhouse gases will continue, with a focused effort to develop simple, but accurate, parameterizations for use in GCMs.
- The nature of the air-sea interaction in the equatorial Atlantic and Indian Oceans and the effect of the seasonal cycle on the simulated ENSO events and other low-frequency phenomena will be investigated with data from coupled GCM experiments.
- The time integration of the coupled ocean-atmosphere model will be extended to a millennium, to investigate the very-low-frequency variability of climate.
- In collaboration with other institutes, additional conventional and satellite data will be analyzed in order to increase the GFDL observational upper-air analysis to a 40-year period and to analyze the consistency between various objective analyses.
- A series of calculations will be performed with a low-resolution atmospheric model coupled to a mixed-layer ocean to study the sensitivity of climate to orbital perturbations and the creation of permanent snow cover (embryonic ice sheets) over North America.
- A consortium of scientists at several universities and government laboratories has been formed to study experiments performed at GFDL with atmospheric models. The experiments focus on the ways in which the dynamics of storm tracks and stationary waves control regional climates and their variability. Initial integrations in this series of experiments will be performed in FY 91.
- The various modes of interaction between the synoptic-scale features and intraseasonal phenomena in the tropics will be scrutinized in further detail.
- Satellite extinction data will be investigated further to narrow the remaining uncertainties of radiative effects due to the particle size distribution of stratospheric aerosol.

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. This involves attack on such central problems as the transport of quasi-conservative trace gases; the biogeochemistry of climatically significant long-lived trace gases, such as carbon dioxide, methane, nitrous oxide, and the chlorofluorocarbons; the chemistry of ozone and its regulative trace species, such as the families of reactive nitrogen, hydrogen, chlorine, and hydrocarbons; and the effects of clouds and aerosols on chemically important trace gases. Such research 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 90

- The GFDL Global Chemical Transport Model (GCTM) was used to reevaluate the behavior of reactive nitrogen (NO_y) in the troposphere due to transport from the stratosphere. This is part of a longer-term study to understand the behavior of NO_y, a controlling agent for tropospheric chemistry. The GCTM experiments indicate that stratospheric production of NO_y, and its subsequent transport to the troposphere, have a minimal effect on NO_y amounts in even the remote lower troposphere. However, injection from the stratosphere is an important mechanism for maintaining NO_y levels in the middle-latitude middle and upper troposphere of both hemispheres.

- One of the most significant challenges for modeling climate and atmospheric chemistry is the proper simulation of the planetary boundary layer. A new diurnal cycle version of the GFDL SKYHI GCM with new boundary layer mixing parameterizations was tested by including radon, a natural substance with a ground source and simple rapid radioactive decay. The simulated diurnal cycle of radon matches closely with observations of radon in surface air. This indicates that the SKYHI GCM may be used with greater confidence in lower tropospheric chemical transport studies.

- A GFDL SKYHI GCM experiment was completed that allows investigation of the chemical-transport-radiative-dynamical response of the stratosphere to the Antarctic "ozone hole." In addition to the substantial polar vortex cooling and concomitant polar jet strengthening previously reported, further analysis shows evidence of dynamically induced sinking motion over the entire polar region. In addition, a cooling of about 1°C in the 50–100 mb middle-latitude Southern Hemisphere summer appears due to meridional spreading of ozone-depleted air into these regions. The model predicts only small Northern Hemisphere effects due to the influence of the Antarctic ozone hole phenomenon.

- A study of the effect of cyclone activity on ozone transport in high latitudes in the Southern Hemisphere was completed. A limited-area simulation suggests that cyclones on the periphery of Antarctica can produce so-called ozone mini-holes. The model-generated mini-hole and observations for the same time show remarkable similarity.

- The project undertaken to study the transfer of tritium from the stratosphere to the ocean surface due to deep moist convection has been completed. A two-dimensional calculation was carried out, and a 24-hour integration shows that about two-thirds of the tritium enters the ocean through vapor diffusion and one-third by rainout. This is the first simulation that has identified a plausible mechanism by which surface water vapor diffusion dominates, even in rainy, convective environments.

Plans FY 91

- Model simulations with the GCTM will be used to conduct a systematic analysis of various sources on the tropospheric budget of reactive nitrogen, NO_y. This will involve modeling investigations of the contribution of biomass burning, fossil fuel combustion, lightning, and biogenic sources, as well as comparison with available observations. Preliminary multiple species simulations of the global distribution of natural ozone (unaffected by anthropogenic emissions) are the next step through the use of the NO_y fields previously generated.

- Model simulations aimed at clarifying the source-sink distributions for CO_2 will be initiated. Transport studies of the tropospherically inert gas, CFC11, will also be conducted for comparison of the GCTM with other models.

- The development of a fully consistent ozone chemistry for the SKYHI GCM will undergo preliminary testing on the Cray Y–MP computer.

- Analysis of the GFDL SKYHI GCM ozone hole experiment will be completed.

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 (tritium, chlorofluorocarbons, etc.) in the world oceans, and the modeling of the oceanic carbon cycle and trace metal geochemistry. For regional coastal studies two- and three-dimensional 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 90

- The extent of global warming will be determined largely by the degree to which the ocean can absorb large amounts of anthropogenic CO_2. The ocean's capacity to take up anthropogenic CO_2 was studied with a 3–D global circulation model of the ocean which provided a lower limit for oceanic uptake capacity. For 1980–1989, the estimated CO_2 fossil production was 5.4 Gt C/yr; only 1.9 Gt C/yr was taken up in the 3–D ocean simulation.

- The ocean's biological processes are a critical but poorly understood part of the ocean's carbon system. Members of the marine geochemistry group, in collaboration with several outside investigators, constructed, for the first time, a seasonal basin-scale simulation of the biological production and nutrient cycling in the North Atlantic, using an idealized seven-component ecosystem model incorporated into a $2^\circ \times 2^\circ$ ocean circulation model.

- During the past decade, a primary effort has been directed toward gathering and measuring a representative data set for radium isotopes, covering the entire Atlantic Ocean from the Arctic to the Antarctic. Analysis of a variety of radium isotope data sets began. Data interpretation includes studies of oxygen and nutrient budgets, western boundary currents, thermocline ventilation, and abyssal circulation. Modeling studies began, using a combination of tracers.

Plans FY 91

- Plans include incorporation of seasonality, the natural carbon cycle, and an investigation into iron fertilization effects upon oceanic uptake as well as migration to a more sophisticated atmosphere-ocean model.

- The ocean tracer measurement group will participate in the World Ocean Circulation Experiment in the Pacific Ocean by collecting and analyzing volume samples for ^{14}C.

- The analysis of results from the North Atlantic biological production experiment will continue.

- A model will be used in an attempt to simulate Equatorial Pacific circulation.

OCEAN SERVICE

Various models that can be used to predict oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, one-dimensional models of the turbulent surface layer of the ocean predict the sea-surface temperature and heat content of the upper ocean. More complex three-dimensional 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 sea-surface temperature anomalies, such as those observed in the tropical Pacific Ocean during ENSO phenomena.

Accomplishments FY 90

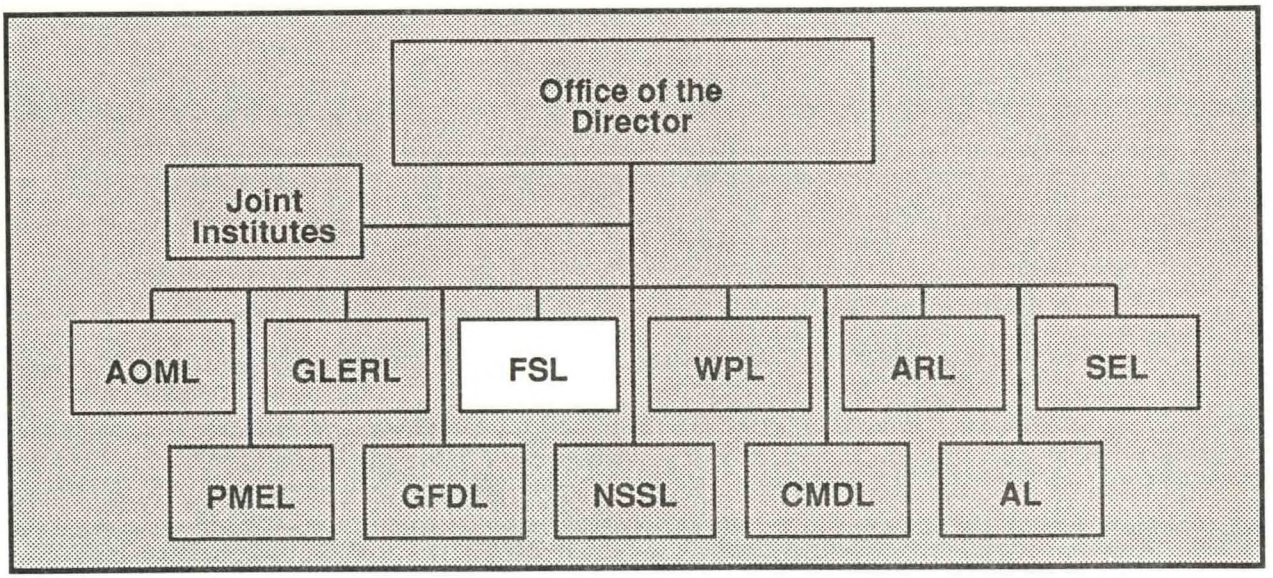
- The GFDL coupled ocean-atmosphere model used in greenhouse warming projections was evaluated by a simulation of chlorofluorocarbon (CFC) uptake by the oceans. A comparison with measurements made by PMEL provides observational support for the large-scale air-sea interaction in the model.
- Atmospheric models coupled to high- and low-resolution models of the ocean indicate two quite different types of large-scale air-sea interaction on the El Niño time scale, providing one explanation for the great variety of El Niño scenarios actually observed.
- A 200-year integration of a coupled ocean-atmosphere model exhibits temporal variations of the thermohaline circulation in the North Atlantic Ocean on time scales of a decade to a century. They are accompanied by the fluctuation of near-surface temperature and salinity with similar time scales.
- A 10-year series of circulation analyses was obtained using the oceanic GCM. These model results are being compared with an ocean data assimilation technique for the same period. The observed data set consisted of SST observations from COADS (Comprehensive Ocean-Atmosphere Data Set), subsurface data from MOODS (Master Oceanic Observation Data Set), and NMC atmospheric surface data. A 6-year assimilation for 1979–1984 was completed. Preliminary results of the comparison appear promising.
- Regional basin and coastal models were developed and used for investigations of Gulf Stream dynamics, ice-ocean interaction in the Arctic Ocean, and the general circulation of the Mediterranean Sea.

Plans FY 91

- The air-sea coupled models are being recoded to exploit fully the capabilities of the new Cray supercomputer. Once the recoding is completed, the ocean-atmosphere interactions involved in the seasonal cycle will be explored.
- An ocean GCM with higher resolution will be developed, and systematic errors will be investigated. The ocean data assimilation will be extended.
- A simulation of tropical Atlantic variability with a GCM will provide detailed information about changes in the currents and heat budgets and their role in interannual variability.
- The analysis of various ocean-models and the oceanic component of global coupled air-sea climate models incorporating CFCs and other tracers will continue. Model experiments with finer grid

resolution and integrations covering longer periods of time will be conducted. Collaborations with PMEL will continue in order to increase the size of the observed CFC data sets available for comparison with the models.

- Long-term simulations using the 3–D Arctic model will be performed. The research will simulate the seasonal cycle of the large-scale oceanic circulation in the Arctic region, and water mass modification in various basins.



FORECAST SYSTEMS LABORATORY

Boulder, Colorado
(303) 497–6818
Alexander E. MacDonald, 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: Developing and validating information systems to satisfy NOAA's operational services.
- Research Applications: Utilizing advances in understanding atmospheric and oceanic processes to develop improved data management systems, forecasting systems, and analysis systems for geophysical data.
- System Validation: Testing systems in realistic environments to assess their usefulness in improvement of NOAA's services.
- Technology Transfer: Facilitating transfer of new techniques and systems to operations, working directly with users.

ARTIFICIAL INTELLIGENCE

The Artificial Intelligence (AI) Project seeks to inform the environmental science community about applications of interest to NOAA, and to apply that technology in selected areas.

Accomplishments FY 90

- Results from Shootout-89 were analyzed. Shootout-89 was a 3-month-long 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/judgment analysis tradition were tested. Two of the expert systems showed promising results; however all systems were poorly calibrated, so overall skill results were low.

- Two joint Artificial Intelligence sessions at AMS conferences were arranged. The first occurred jointly with the 11th Conference on Probability and Statistics, and the 12th Conference on Weather Analysis and Forecasting. The second will occur at the 16th Conference on Severe Local Storms.

- The data-gathering phases of the WISE (Weather Information and Skill) experiment were completed. Twenty-nine forecasters from NOAA, the National Center for Atmospheric Research, The State University of New York at Albany, and Hanscom Air Force Base made 60-min nowcasts of significant or severe convection and tornadoes under three information conditions. In two of the conditions, information was severely limited. Results indicate that (1) forecasts based on full information were more skillful than forecasts based on limited information, (2) experienced forecasters generally show a greater skill than inexperienced forecasters, (3) individual differences among forecasters were significant; that is, the most skillful limited-information-based forecasts showed more skill than the least skillful full-information-based forecasts. These results indicate that forecaster training is necessary if the full capability of new meteorological data sources and workstations is to be realized. Results have been reported to the participants.

- The Metalog program, a system to maintain and manage scientists' comments about data, was ported to the UNIX operating system. In addition, an experimental version of Metalog that employs an external database was developed. Metalog continues to be used in field experiments and in data-management operations. Feedback from users indicates that Metalog provides a more useful and efficient vehicle for recording relevant and timely information than do traditional hand-written notebooks.

- An improved version of the Forecaster's Intelligent Discussion Expert System (FIDES) prototype was demonstrated at the 6th 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 help provide training for graduate students and novice weather forecasters.

Plans FY 91

- Conduct Shootout-91, an expanded version of Shootout-89 taking place in both Colorado and Oklahoma. Several upgraded systems from Shootout-89 and several new entries will be evaluated.

- Complete analysis of the WISE experiment and submit an article on the results.

- Working with CMDL scientists, use the Metalog program to capture and maintain metadata about CMDL's Comprehensive Ocean-Atmosphere Data Set (COADS), in order to develop a sophisticated COADS automated "help" system that will serve as a prototype for similar systems involving other environmental data sets.

ANALYSIS AND PREDICTION

The Analysis and Prediction (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 90

Many advances have been made in recent years in the understanding of mesoscale phenomena. However, the extension of this understanding into the operational environment has been difficult. Application of conceptual or theoretical advances to local problems in forecasting high winds and flash floods has been tested at several NWS forecast offices.

- The occurrence of severe (Taku) winds in southeastern Alaska was found to be the manifestation of an amplified mountain wave that is often coincident with gap flow through the nearby Coast Mountains. An analysis of historical events and a unique set of wind records from a nearby ridge show the separate identity of these concurrent phenomena, and indicate that more restrictive conditions are required for Taku winds than for gap winds. A set of parameters for forecasting Taku and gap winds has been developed and is being tested at the Juneau NWS Forecast Office.

- The synoptic pattern associated with most December and January Front Range Colorado windstorms has strong northwest flow aloft ahead of a diffuse Pacific front and an upper-level short-wave trough. Analyses of operational NWS data and special Mobile Cross-Chain Loran Atmospheric Sounding System (MCLASS) soundings on the most severe windstorm of the 1988–1989 season (9 January) indicate the role of the synoptic scale in creating and then eliminating atmospheric conditions favorable for the occurrence of high wind. Results from this case and others have been used to refine a high-wind decision tree used by the National Weather Service Forecast Office (WSFO) in Denver.

- Although the meteorological setting for a flash-flood-producing storm closely resembled that of a mesohigh-type flash flood and displayed characteristics of a quasi-stationary mesoscale convective system (MCS), operational forecasts did not reflect the magnitude of the problem or the potential for flash floods during a 23 July 1987 event in Minneapolis. From a joint FSL–NWS examination of both the meteorology of and the operational response to this multifaceted weather system, it appears that forecasters were overburdened with issuing both severe thunderstorm and tornado warnings, and did not have the time to perform the necessary analyses and diagnoses needed to keep abreast of other weather developments and anticipate trends. A review of operational procedures suggests that automated analysis and diagnosis to emphasize severe thunderstorms and heavy rainfall could improve Weather Service response to future multihazard situations.

Other accomplishments include the following:

- First measurements of the structure of an MCS-induced mesoscale vortex by wind profiler, Doppler radar, and satellite observations. Peak vortex-relative tangential winds of 15 m s^{-1} and maximum relative vorticity of 2.5–3.0 x 10^{-4} s^{-1} were estimated for the vortex.

- Installation of an isentropic analysis package and the development of analyses on isentropic surfaces (e.g., Richardson number, quasi-geostrophic diagnostics) to improve the forecasting of clear air turbulence.

- Development of a research-quality, 40-year data base of hourly precipitation data for the United States and accessing software.

- Inclusion of two state-of-the-art modules in FSL's participation in the NWS Training Center's Flash Flood Course; these modules discuss the use of quasi-geostrophic diagnostics and GOES water vapor images for flash-flood forecasting.

Plans FY 91

The frontogenetic/frontolytic formulation of quasi-geostrophic diagnostics for predicting winter storm development will be evaluated for selected cases from winter 1989–1990.

Forecast diagnostic packages (such as quasi-geostrophic diagnostics and isentropic analyses) will be interfaced with a real-time personal computer workstation for performing forecasting research.

PROGRAM FOR REGIONAL OBSERVING AND FORECASTING SERVICES (PROFS)

Accomplishments FY 90

Forecast Research Group

The Forecast Research Group (FRG) is involved in two specific activities designed to improve weather services: quantitative data integration and forecaster training. The group is developing a Local-scale Analysis and Prediction System (LAPS) to provide an even-higher-resolution refinement of the MAPS anlayses, but covering only a single forecast office's area of responsibility. A limited portion of the LAPS suite of gridded analyses was implemented on FSL's DARE–II workstation. Several months of routine execution of the LAPS software has provided opportunities for informal evaluation and presentation at daily weather briefings. This has resulted in refinements to LAPS and new ideas for further developments. This has also resulted in the essential "debugging" of the system, required prior to the installation of LAPS at the Denver WSFO. Formal evaluation of several products aimed at improving forecasts of convective precipitation was conducted.

LAPS, and the participation of FRG meteorologists, were important elements of the Winter Icing and Storms Project (WISP) conducted Jan.–Mar. 1990. The forecasters provided predictions of snow and aircraft icing conditions with 1- and 2-day lead times, which were used for efficiently deploying research aircraft. LAPS was used to produce gridded estimates of supercooled cloud water, an essential ingredient of aircraft icing. Evaluation of these forecasts was under way in late FY 90. Also during WISP, FRG conducted studies on the use of a 2–D cross-section model for predicting winter downslope windstorms.

FRG supported a preliminary program to establish an Experimental Forecast Center (EFC) with local WSFOs, including Denver and Cheyenne. This program includes seminars and workshops, research meteorologists working on shift, and identification of forecast problems to be addressed in cooperative research efforts. Two researchers worked forecast shifts at the Denver WSFO.

Mesoscale Analysis and Prediction System

The Mesoscale Analysis and Prediction System (MAPS) has been developed by FSL scientists over the past 5 years. MAPS provides frequent, detailed analyses of diverse surface and tropospheric data over the contiguous United States and very-short-term numerical forecasts (out to 12 hours) in support of aviation and local nowcasting. MAPS has been running in real time on a 3-h data assimilation cycle at FSL for more than

2 years. It exploits automated aircraft reports and experimental wind profiler data in addition to conventional data.

The National Meteorological Center (NMC) has agreed to test MAPS on its own computers and to make MAPS the basis for a "Rapid Update Analysis Cycle." This new service will be implemented operationally in time for the National Weather Service's Modernization and Associated Restructuring Demonstration (MARD).

Several modifications and improvements were made to MAPS in preparation for porting it to NMC.

- The fully isentropic version of MAPS was completely revamped. The new version now employs a hybrid coordinate system, with terrain-following coordinates in the lowest 200 mb and isentropic coordinates above. The addition of terrain-following coordinates gives better vertical resolution when the lapse rate is steep in the lower atmosphere (as on most summer days). Moist physics is now a part of MAPS. The prognostic variable is condensation pressure, which is conserved in adiabatic flow. Stable (stratiform) precipitation and a parameterization for convective precipitation are both now in the MAPS forecast model. Early comparisons of analyses and short-range forecasts with observed cloudiness, water vapor imagery, and precipitation indicate substantial skill.

- All MAPS computer codes—for data ingest, quality control, objective analysis, and model forecast—were converted to the FORTRAN 77 standard. The code was ported in two steps: everything through objective analysis in May 1990, and the forecast model in September 1990. The codes are running initially on NMC's NAS 9000 computer, but they will eventually be ported to NMC's new Cray Y–MP computer.

Advanced Traffic Management System (ATMS)

The Advanced Traffic Management System (ATMS) Project conducts research and development to validate the utility of weather information for strategic planning and management of the National Airspace System (NAS). The ATMS Project emphasizes the development of real-time meteorological data sets for integration into the FAA's prototype ATMS.

- A prototype ATMS Aircraft Situation Display was installed at FSL, providing researchers with real-time flight data of all aircraft within the NAS. A product generation and distribution system was implemented on FSL's PROFS VAX cluster to disseminate real-time data sets to the Transportation Systems Center (TSC).

- A satellite ground station and two-way communication link between FSL and the Transportation Systems Center (TSC) in Cambridge, Massachusetts, was installed to facilitate the exchange of data.

- Real-time national Radar Summaries and Legends were integrated into the ATMS environment for use on the Aircraft Situation Display.

- A Winds Aloft product and a Jet Stream product derived from the Mesoscale Analysis and Prediction System have been developed to enhance planning and management of enroute aircraft. The Winds Aloft product will be used in TSC's Metering And Spacing models; the Jet Stream product will be used by traffic managers on the Aircraft Situation Display.

- LAPS is being used to derive terminal area traffic management products, using Denver's Stapleton Airport as the validation site. A Surface Winds product and a Cloud Ceilings product have been developed to address terminal area traffic management needs.

System Design and Implementation (SDI)

The System Design and Implementation (SDI) branch is responsible for assisting other PROFS branches in specifying the architecture for major new meteorological systems. The branch also designs the system software, develops major portions of the software, and manages the system integration.

The Denver Advanced Weather Interactive Processing System for the 1990's (AWIPS–90) DARE–II workstation was completed and installed in the Denver WSFO. The system includes two full-function, one limited (no animation) and five text (only) workstations. Thirteen processors perform data acquisition, management, processing, and display functions. SDI also supported the installation of DARE–II workstations at the National Severe Storms Laboratory (NSSL) and NWS Techniques Development Laboratory.

The communication links for the Information Stream Project for AWIPS/NOAAPORT (ISPAN), which will provide data from the National Environmental Satellite, Data, and Information Service (NESDIS) and National Weather Service Telecommunications Gateway (NWSTG) to the AWIPS–90 contractors, were connected to PROFS for initial evaluation. Satellite and national guidance products have been received over the links, decoded, reformatted, and displayed on the workstations.

The personal computer workstation project successfully completed its initial milestone to provide a basic real-time and review capability. PROFS' Local-scale Analysis and Prediction System (LAPS) was demonstrated on the personal computer at the IIPS Conference in Anaheim, CA, in February. Subsequently, the workstation was demonstrated at the NWS managers conference, the mesoscale conference, and the radar conference held in Boulder, CO.

The Navy-NOAA Joint Ice Center (JIC) system was enhanced to improve its reliability and provide additional functionality. The system, which was developed by PROFS, is being used to support operational ice forecasting.

SDI provided technical consultation to the USAF Mark IV–B program in reviewing Lockheed's design of the Mark IV–B workstation system. As part of this consultation, SDI developed a prototype of key elements of the user interface.

Exploratory Development Facility (EDF)

The EDF acquires, pre-processes, stores, and makes available to FSL a wide variety of meteorological data for research and applications. EDF provides the capabilities for using, testing, and evaluating advanced weather information systems.

Computer facility

- The central computing facility was upgraded with a DEC VAX 6400–20 with a vector processor, a development workstation system, a connection to the Internet WAN, and additional servers, routers, and computer peripherals. Upgrades of system software include the acquisition of CASE software (VAXSET) and electronic bulletin board software (VAXnotes).

- The number of VAX processors increased to 73. Operating system upgrades have been accomplished for these computers (version 5.2 to 5.3) as well as many versions of layered products (VAX ELN, FORTRAN, PASCAL, C, PSI, and RDB). System software written or upgraded include PROFSmon monitor system, Continuous Backup, X-window, and Ramtek driver.

- The real-time portion of the facility was operational 97% of the time and achieved 95% availability of products to the workstation in Denver.

Data ingest

- Continued to support the Denver WSFO for both Cool Season and Convective operations, using the Mile-High Doppler Radar. During the 1990 WISP project, experimental snowfall accumulation products were generated. Two hydrology algorithms, Precipitation Projection and Flash Flood Potential Assessment, became operational.
- Upgraded TIROS software. Image products are now routinely generated.
- Replaced mesonet dew point instruments with more reliable relative humidity instruments.
- Developed software to transfer Profiler Hub data to NWS.
- Rewrote the surface aviation observational (SAO) storage process. Upgraded the pilot report (PIREP) data acquisition system to decode Northwest Airlines reports.
- Completed an acquisition system to receive NWSTG data for the ISPAN project.

Research support

- Real-time PROFS Mesonet, conventional and Doppler radar, upper-air sounding, surface aviation observations, profiler, and satellite data and products were provided to researchers at the National Center for Atmospheric Research (NCAR), Colorado State University (CSU), the Department of Energy's Rocky Flats operations, and ERL groups through dedicated or dial-up communication links. Real-time data and products were also supplied to workstations at CSU and NCAR.

Experimental Forecast Systems (EFS)

DARE–II

The DARE–II system was commissioned in March 1990 at the Denver WSFO. It supports all the forecast functions in the office and replaced AFOS as the operational system. It is a functional prototype of the Advanced Weather Interactive Processing System for the 1990s (AWIPS–90), which is scheduled for nationwide deployment during the mid-1990s. It provides powerful display and manipulation capabilities and integrates a wide variety of data including Doppler radar, satellite, and profiler. Automated monitoring of aviation terminal forecasts and state-of-the-art hydrometeorological techniques were added in FY 90.

Norman

Development of the initial system for Norman, Oklahoma, was completed and tested in preparation for installation in early FY 91. The basic system is identical to DARE–II. Data for Norman will come from the National Environmental Satellite, Data, and Information Service (NESDIS) and NWS Telecommunications Gateway; from the Twin Lakes, Oklahoma, WSR–88D radar; and from other sources in Oklahoma. Interfaces to ingest these data have been developed. A local product generation facility has also been developed to transform these data into displayable products.

Plans FY 91

Forecast Research Group

FRG will be involved in another WISP experiment in early 1991, and will again provide the operational weather forecasting. FRG will also be testing several new features of the LAPS system, including "tuned" versions of the supercooled liquid water algorithms, and a new quantitative snowfall estimation algorithm based on cloud microphysical principles. As in last year's test, a snowfall estimation algorithm, based on a revised version of the NEXRAD precipitation accumulation algorithm, will be running. A summertime test of the LAPS system is planned. The experiment will test and validate human forecasts and several new nowcasting algorithms for convective weather.

FRG also plans to begin a cooperative effort with the Colorado State University (CSU) Department of Atmospheric Science on using LAPS and MAPS to initialize CSU's Regional Atmospheric Modeling System, a state-of-the-art primitive equation numerical model. Significant progress is expected toward using FSL's gridded information to produce real-time model simulations for weather forecasting purposes. Cooperative work will continue with a modeling group at the Université Blaise Pascal, France, to improve the FRG version of a 3–D full-physics model.

Work will proceed on the production of forecaster training materials with the Cooperative Meteorological Education and Training staff. Creation of computer-based learning modules is planned for FY 90. EFC activities will be expanded by occasional service of two more individuals at the Denver WSFO.

Mesoscale Analysis and Prediction System

During FY 91 the MAPS Team's work will include the following:

- Work with NMC to assure that MAPS runs smoothly on NMC's NAS 9000 computers; prepare MAPS for operational implementation on NMC's Cray Y–MP computer. Operational implementation is expected in FY 92.

- Incorporate ARINC Communications Addressing and Reporting System (ACARS) aircraft data and data from the Wind Profiler Demonstration Network as new profilers come on line.

- Incorporate a diurnal cycle and simple boundary-layer physical processes into MAPS.

- Experiment with a 1-h assimilation cycle. (The current cycle is 3 h.) For mesoscale applications, it is desirable to incorporate data into MAPS every hour. There are enough data over the United States to justify this assimilation frequency; a major problem will be to minimize gravity-wave noise in 1-h forecasts.

Advanced Traffic Management System

- Additional hardware provided by TSC will be installed at FSL to enhance our computing needs for traffic management product development.

- The Winds Aloft, Jet Stream, Terminal Area Surface Winds, and Cloud Ceilings products will be integrated into the Aircraft Situation Display.

- Development will begin on an automated Instrument Flight Rule (IFR) Area Outline, which delineates IFR conditions over the United States. The IFR Area Outline will be used on the Aircraft Situation Display.
- Development will begin on an Airspace Volumes Avoidance product that will delineate areas of severe weather hazardous to en route aircraft.
- A Surface Aviation Observation/Terminal Forecast monitor, which analyzes visibility and cloud ceilings at the Nation's 28 pace-setting terminals, will be developed and integrated into the Aircraft Situation Display. This product will be used to notify traffic managers when ceiling or visibility at major airports is expected to go below Visual Flight Rule (VFR) minimums.

System Design and Implementation

SDI will support installation and upgrades to the workstation system in Norman, OK. SDI will also continue to maintain the workstation software at the Denver WSFO.

The personal computer workstation will receive additional functionality to meet the Cooperative Program for Operational Meteorology Education and Training (COMET) requirement. The initial operating capability of the COMET configuration is scheduled for November 1990. Major activities include integration of additional application programs, creation of a compact disk containing two severe weather events, and development, with FSL researchers, of new workstation capabilities.

Technical guidance will be given to the Taiwan Central Weather Bureau (CWB) in developing a central data acquisition and processing facility in Taipei. CWB staff will assist SDI in developing new capabilities for the personal computer workstation.

SDI will start to implement and evaluate three-dimensional displays of radar, satellite, and other meteorological parameters on its recently acquired Stardent workstation.

The branch will support the USAF Space Division by developing a Mark IV–B user guide, preparing test plans, and assessing meteorological products.

Exploratory Development Facility

Upgrades will include a significantly faster processor and additional disk storage, network redesign and implementation, and the replacement of obsolete servers, routers, and controllers.

Data acquisition tasks will include design and implementation of the GOES-NEXT ingest subsystem and ground station, implementation of a subsystem to read Mile-High radar tapes, completion of the Mesonet software upgrade, design of a new Mesonet hardware system, software to ingest buoy and hydrology data, and the upgrade of PIREP and Automation of Field Operations and Services (AFOS) subsystems.

Experimental Forecast Systems

DARE–II

DARE-II will continue to support the Denver WSFO in FY 91. The text workstation will be upgraded to use commercially supported "X windows" software. Automated monitoring and relational query capabilities will be added for forecaster use. A graphic editing facility will be developed to allow forecaster annotation and manual graphic creation.

Norman

The WSR–88D processor will be enhanced to provide more products and capabilities including an improved plate stack or weak echo region request product. New interfaces will be developed to ingest Automated Surface Observing System (ASOS) data and the Oklahoma mesonetwork. In addition, the interface to NESDIS will be upgraded to 1.54 mbps (million bits per second). Support will also be provided for an extensive evaluation effort at Norman.

Modernization Program

Two major new efforts in FY 91 will concern AWIPS Deferred Capabilities and Advanced Development Facility. AWIPS Deferred Capabilities are those that will not be available initially but are needed by the mid-1990s for NWS to fulfill its mission with projected resources. The main component is a four-dimensional gridded representation of weather from which all products will be generated. Planning, research, and prototyping work will occur in FY 91. The Advanced Development Facility will allow NOAA to establish in-house expertise with computer hardware and software used by AWIPS–90. During FY 91, evaluation support will be provided to the AWIPS–90 program, a UNIX-based minicomputer system will be procured for development and prototyping, and plans will be made to set up an AWIPS system. In addition, planning for an orderly evolution from current FSL facilities to those needed in the coming decade will begin.

PROFILER PROGRAM

The Profiler Program Office (PPO) directs the procurement, installation, operation, maintenance, 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 NWS and major scientific and meteorological field experiments, and (2) foster advances in atmospheric research and weather prediction.

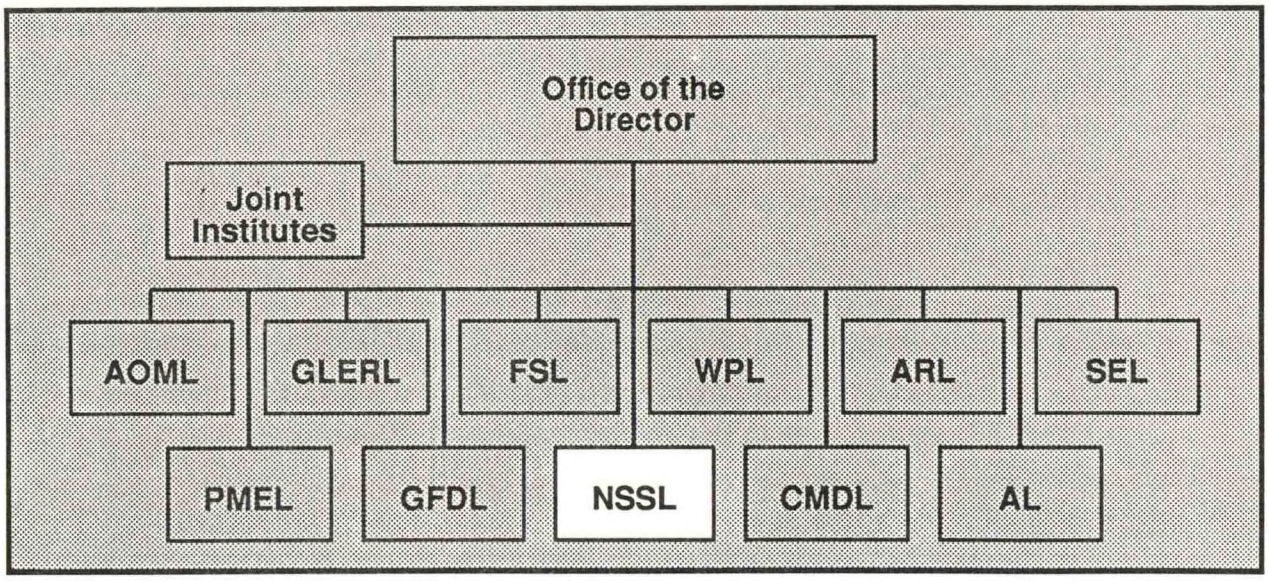
Accomplishments FY 90

- Concrete and steel work for the antennas was completed for all sites.
- The first six production profilers were installed and began operating.
- On-line delivery of data from the Platteville prototype profiler to NWS Gateway began.
- RASS temperature profiling was successfully tested on the Platteville prototype profiler.
- The wind profiler portion of the emergency response plan for Mount Redoubt, Alaska, volcano was developed.
- The PPO's Profiler Control Center was established and procedures were developed; the center was staffed and is ready for the operational control of the network.
- System integration (profiler, communications, Hub) was completed for two profilers.
- Hub acceptance testing, system integration testing, and maintenance documentation were completed.
- Data acceptance criteria were developed and approved.

- The communications contract was awarded and the first installation and Hub interface were accepted.
- An agreement was signed with NCDC to accept, archive, and distribute retrospective profiler data.
- The development of the Hub was completed; the system was accepted by the Profiler Control Center.

Plans FY 91

- Install the remaining production profilers in the network.
- Accept and deliver real-time data to NWS and the NESDIS National Climatic Data Center from all profilers that have been accepted and integrated with the Hub.
- Use the Bloomfield, CT, prototype profiler to test the Unisys prototype RASS add-on.
- Design advanced retrospective data management capability jointly with NCDC.
- Distribute network data via Unidata to Unidata users and to National Climate Data Center for permanent archiving and retrieval.



NATIONAL SEVERE STORMS LABORATORY
Norman, Oklahoma
(405) 366–0427
Robert Maddox, Director

The National Severe Storms Laboratory (NSSL) develops the scientific basis for improved weather forecasting through studies of mesoscale weather processes and numerical and conceptual modeling of storm phenomena. 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 airborne and ground-based Doppler radar, instrumented mobile laboratories, and lightning-mapping systems. In coming years, wind profiler and digital satellite data will be incorporated into case study analyses, and data from diverse observing systems will be blended and used in mesoscale numerical prediction models.

Through relationships with other government agencies and universities, NSSL participates in many field research projects. In FY 90 for example, NSSL staff collaborated with the Federal Aviation Administration (FAA) and the National Center for Atmospheric Research (NCAR) in terminal radar development activities at Orlando, FL. During July the Laboratory worked closely with the National Weather Service (NWS), Mexican scientists, the University of Arizona, Arizona State University, and the Salt River Project to gather data for studies on the role of organized convective storms within the southwestern United States monsoon flow.

MESOSCALE RESEARCH DIVISION

Accomplishments FY 90

Research within the Mesoscale Research Division of NSSL continued to focus primarily on the analysis and interpretation of observational data of mesoscale convective systems (MCSs), thunderstorms, and related phenomena. A major field project, the Southwest Area Monsoon Project (SWAMP), was successfully carried

out during July and August 1990. Planning continues for a spring 1991 Cooperative Oklahoma Profiler Studies (COPS) project. Analysis continues of data sets collected during the Preliminary Regional Experiment for STORM-Central (PRE–STORM).

Mesoscale Convective Systems Research

- A multi-scale analysis of the 3–4 June PRE–STORM MCS was completed that illustrates an intricate, symbiotic interaction of convective-scale and frontal processes within this storm system. A closely related study (done partly in collaboration with researchers at Colorado State University) provides unprecedented insight into the mechanisms responsible for the intense "wake low" surface pressure feature associated with many MCSs. A particularly intriguing result is that locally intense downdrafts developed along the trailing edge of an otherwise benign stratiform rain region.

- A study of the generation and redistribution of momentum within an evolving squall line observed on 17 July 1981 during CCOPE was completed. Principal results showed that the vertical transport of momentum remained nearly constant during the evolution because decreasing transport in weakening convective updrafts was offset by increasing internal generation of momentum by mesoscale pressure forces.

- A study to determine the basic recurring mesoscale patterns of convection and their frequency of occurrence in the southern high plains, using PRE–STORM data, was completed. Although the data set was small, three primary types of mesoscale organization of convection were seen: linear, occluding, and chaotic or largely unorganized.

- Analysis of the PRE–STORM 10 May 1985 severe weather event revealed features related to the onset of convection. Computation of surface-based positive and negative buoyant energy at each supplementary sounding site shows that the convection did not occur until the negative energy was reduced to less than 50 J kg^{-1} (about 10 m s^{-1} updraft velocity). Once initiated, convection was able to continue in regions with negative energy in excess of 200 J kg^{-1} (20 m s^{-1}). The decrease in negative energy is shown to be related to synoptic-scale upward motion as well as surface heating.

- A study of the electrical structure of the stratiform cloud that trailed the Oklahoma squall line of 18 June 1987 was completed. A balloon-borne electric field meter launched immediately behind the convective line revealed a charge structure comparable in both complexity and intensity with those analyzed previously for thunderstorm cores.

- Horizontal patterns of cloud-to-ground lightning were determined for four MCSs in the PRE–STORM region on 3–4 June 1985. The patterns showed that severe weather was located primarily on the south side of the regions and that negative flashes occurred in convective echoes early in the MCS life cycle.

- A study of the precipitation and kinematic structure of a convective system observed by the P–3's airborne Doppler radar during the Taiwan Area Mesoscale Experiment (TAMEX) project was completed. A momentum budget reveals substantial acceleration of line-perpendicular flow results from mesoscale pressure gradients set up by the convection. This finding is in agreement with other studies, both in middle-latitude squall lines and in tropical squall lines.

Cooperative Oklahoma P–3 Studies (COPS–89)

- Analysis of airborne Doppler radar data in the fore-aft scanning mode shows the utility of the method. Comparisons of dual-Doppler derived wind fields from Cimarron and NEXRAD were compared

with wind fields derived from the fore-aft mode. The results indicate the robustness of fore-aft techniques and also demonstrate inherent advantages of a mobile platform in mitigating some of the geometric uncertainties associated with dual-Doppler radar.

- Dual-Doppler synthesis of NEXRAD and Cimarron data was successfully completed. It was found that routine, operational NEXRAD scanning sequences, although not optimal, are useful for researching mesoscale flow fields within MCSs. Possible modifications to the NEXRAD scans will be suggested to the NEXRAD test facility prior to COPS–91.

Microburst Handbook

- The handbook on visual identification of microbursts was printed in a second edition referencing the English units used in aviation. Several drafts of a poster version were developed.

Studies at the Kennedy Space Center

- A special cooperative endeavor was initiated with the NWS Forecast Office in Melbourne, Florida, to furnish this new office with improved techniques and aids for thunderstorm prediction in central Florida. It included distribution of a collection of papers and reports on convection.

Plans FY 91

The Division will continue to analyze and interpret special observational data sets collected during past field projects (e.g., PRE–STORM, COPS–89, SWAMP) and to prepare for the COPS–91 project.

Mesoscale Convective Systems Research

- Decompose pressure and buoyancy forces derived from Doppler radar data to show what parts of the forces are causing mesoscale convective system evolution and how the forces are responsible for unusual system motion. Test hypotheses on COPS and other data sets.

- Analyze electric field meter, cloud microphysical, and dual-Doppler synthesized wind data collected during COPS–89 to investigate further the charge distribution and electrification processes of middle-latitude MCSs.

- Conduct COPS–91, focusing on scientific evaluation of the profiler data on MCSs and electrification mechanisms of MCSs' dryline morphology.

Southwest Area Monsoon Project (SWAMP)

Substantial efforts will be made to analyze airborne Doppler radar data in conjunction with satellite imagery, dropwindsonde data and flight-track measurements to describe MCSs observed over the southwestern United States and Mexico during the 1990 SWAMP program. Early work will focus on reconstructing the precipitation and airflow fields within these storms, which appear to evolve very differently from

analogous systems previously documented over the central United States. Those environments conducive to intense convection over the southwestern United States and Mexico will be analyzed and documented.

Microburst Poster

A full-color poster version of the Microburst Handbook will be completed for distribution throughout NWS and to various aviation groups.

FORECAST APPLICATIONS RESEARCH GROUP

Accomplishments FY 90

NEXRAD

NEXRAD follow-on test and evaluation, October–December 1989, was supported by radar data quality and algorithm evaluation. Input was prepared for the Norman-based Operational Support Facility. Enhancements were added to experimental versions of NEXRAD mesocyclone and hail algorithms. Improvements in both algorithms have resulted in increased detection capability and in fewer false alarms.

An experimental Tornadic Vortex Signature algorithm, independent of the mesocyclone algorithm, was developed and tested on radar data from other parts of the United States. Initial results suggest good probability of detection and low false alarm ratio for tornadic storms relatively close to the radar.

An experimental version of the NEXRAD velocity de-aliasing algorithm was enhanced by adding a wind field model to the algorithm; the algorithm now correctly de-aliases radial velocities for most clear air, high vertical wind shear cases.

Training

Remote training modules on convective storms and radar were prepared. The modules include the use of numerical simulations to illustrate thunderstorm structure. Support to the NWS Doppler Training Unit continued. Assistance was given to the training unit and to Unisys Corporation during preparation of the NEXRAD Operations training course. Lectures were given to pre-course training classes. Seminars and workshops on mesoscale and radar meteorology were presented at several NWS Offices and at other locations.

Weather Hazards to Aviation

A gust front detection and tracking algorithm, which will be used for both the Terminal Doppler Weather Radar (TDWR) and NEXRAD systems, was enhanced by adding techniques to detect azimuthal shear and reflectivity thin lines. Other more rigorous techniques that detect and forecast the speed and direction of movement of gust fronts were also added to the algorithm. A separate study showed that gust fronts can be detected up to 100 km from the radar; beyond that range the radar beam will overshoot most gust fronts.

Experimental Forecasting

In cooperation with the Norman NWS Forecast Office, mesoscale forecast exercises continued. Forecast skill levels for severe thunderstorms, mesocyclones, and MCSs were documented, and errors were investigated in order to improve forecast techniques. For the first time in Oklahoma, short-term (6- and 12-h) quantitative precipitation forecasts were made. NSSL archives of tornado proximity soundings were used to derive a new tornado forecast parameter, storm-relative helicity—the tendency for low-level, vertical wind-shear to be tilted into horizontal rotation. The tornado forecast method and accompanying display products were coded into a local applications program, which was tested in real time at the Norman Forecast Office.

Forecast Verification

In collaboration with the Doppler Radar and Remote-Sensing Research group, a new approach to verification of rare events was formulated and applied to the severe thunderstorm and tornado watches issued by the NWS National Severe Storms Forecast Center. The new technique uses an updated and improved data base on severe thunderstorm and tornado watches to create forecasts that are more specific than those created by the old technique, applying to an area of only ~1600 km^2 for 1 h, instead of the typical watch area of about 80,000 km^2 that lasts for more than 5 h. This modification permits a more detailed depiction of variations in forecast quality over both space and time.

Plans FY 91

- Participate in follow-on testing of the first NEXRAD units as they are installed.
- Further improve and test enhanced NEXRAD algorithms for detecting weather hazards (tornadoes, mesocyclones, hail, gust fronts, and tropical cyclones).
- Prepare additional training modules on Doppler radar. Continue support to the NWS Training Unit as the NEXRAD Operations course is taught.
- Continue cooperative forecast exercises with the Norman NWS Forecast Office as deployment of new mesoscale sensors begins in Oklahoma. Special attention will be given to improved techniques derived from profiler and NEXRAD wind data.
- Explore the utility of lightning data for improving mesoscale forecasts.
- Complete a study to examine the utility of NEXRAD, surface network, and rawinsonde data for detecting the initiation of thunderstorms in the vicinity of Kennedy Space Center.
- Complete a study examining the kinematics of "ring" gust fronts around microbursts.
- Examine the forcing mechanisms and structure of microburst-producing storms and their relationship to outflow strength.

METEOROLOGICAL RESEARCH

Accomplishments FY 90

Center for Analysis and Prediction of Storms (CAPS)

Scientists at NSSL worked with professors and scientists at the University of Oklahoma, Pennsylvania State University, AOML, WPL, Florida International University, University of Wisconsin, NOAA Cooperative Institutes; Ecole Polytechnic and University of Claremont in France, and Forschungszentrum Geesthacht in Hamburg, Germany, on problems of four-dimensional mesoscale data assimilation. The work concentrated on variational techniques using the adjoint method and was approached by several avenues: Use of simple barotropic and shallow-water models to study hurricane prediction; nonhydrostatic modeling of dryline and associated data assimilation; automatic adjoint-code generation; theory of adjoint assimilation. The interdisciplinary approach involved meteorologists, applied mathematicians, and computer scientists.

- The parallel processing of the track forecasts of hurricane Elena (1985) was accomplished on the University of Oklahoma Alliant Computer. This involved decomposition of wind fields into streamfunction and velocity potential, using a variety of methods, and development of an adjoint code for assimilation.

- The study of multi-minima in conjunction with adjoint data assimilation was investigated using simple nonlinear dynamical models.

- Indeterminacy of solutions due to data sparcity was studied using the adjoint method and simple nonhydrostatic models.

- The use of weak constraints in adjoint data assimilation was investigated using the barotropic model.

Initiation of Cloud Models From Observations

As part of a research project funded by CAPS and in collaboration with investigators from the University of Oklahoma, preliminary experiments were carried out involving insertion of velocity data into a numerical cloud model. Other model variables were adjusted to the inserted velocity data, owing to constraints imposed by the model equations. These experiments were run in preparation for later experiments that will include combining dynamic and microphysical retrieval concepts in the assimilation process. The dynamic retrieval code was transferred to the National Center for Supercomputing Applications CRAY-2 and successfully tested using data from a past case study.

Mesoscale Convective Systems Studies

A 3–D, time-dependent mesoscale kinematic model was used to generate temperature and water substance fields in the 7 May 1985 PRE–STORM mesoscale convective system. The microphysical parameterization was modified to improve the diagnoses of clouds and precipitation as inferred from satellite and radar measurements.

Storm Electrification Research

Preliminary runs of the NSSL kinematic Storm Electrification Model were conducted for the case of the tornadic storm in Binger, Oklahoma. The model calculations reveal the simultaneous distribution of space charge and electric fields in the main updraft region as well as the anvil and associated stratiform precipitation region.

Dryline Research

Preliminary analyses of data collected in the dryline environment during the COPS–89 field experiment were completed. A proposal entitled "Numerical Simulations of the Dryline over Western Oklahoma" was accepted by NCAR. A suite of 2–D simulations of the 24 May 1989 dryline was completed.

Modeling Study of a Precipitating Anvil Cloud

A simple, one-dimensional model was developed to examine the potential for a sublimation-initiated mesoscale downdraft to influence the dynamics of the sub-anvil region by transporting horizontal momentum from the base of a high-level precipitating anvil cloud to the middle or lower troposphere. The study was motivated by an examination of data from a 50-MHz radar wind profiler on 24 June 1985. Downward momentum transport from anvil base may have produced unbalanced flow at middle levels, owing to strong flow within the anvil and weak middle-level geostrophic winds. The similarity between the evolution of the simulated and observed wind fields emphasizes the importance of ice microphysics to the dynamics of regions below precipitating anvil clouds.

GUFMEX

The research phase of the Gulf of Mexico project (GUFMEX) involved scientists at government laboratories and universities as well as forecasters in the NWS Southern Region. A symposium sponsored by NOAA's new Cooperative Institute at Texas A&M will take place in January 1991 at Galveston, concentrating on air mass modification and air-sea interaction. Eight of the seventeen presentations will be based on data collected during project GUFMEX.

In collaboration with the NESDIS Satellite Data Applications Branch in Madison, WI, microwave and infrared satellite measurements from the Special Sensor Microwave/Imager (SSM/I) instrument aboard the Defense Meteorological Satellite F8 and from the GOES VISSR Atmospheric Sounder (VAS) were used to estimate precipitable water, augmenting the sparse coverage of rawinsonde sites in the vicinity of the Gulf of Mexico. Microwave data provide more uniform coverage than VAS since they are relatively free from contamination by most clouds. Also, the moisture fields derived from microwave data appear to be less noisy than those derived from the infrared. Surface wind speeds obtained from the microwave data are in qualitative agreement with surface observations. Analyses from satellite data appear to add considerable information to the moisture and wind analysis over the Gulf of Mexico and should help in forecasting moisture changes, particularly moisture return near the surrounding coastal areas.

Earth Radiation Budget Experiment

The goal of this project is to assess, from regional satellite observations, the feedback of clouds and Earth surface characteristics on the Earth-atmosphere radiation budget. Feedback of clouds is an important factor in anticipating the effect of increasing greenhouse gases on climate. In collaboration with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) in Madison, WI, the effect of deep convective clouds on the radiative energy absorbed over North America was examined during a portion of a warm season. The net effect of these clouds was found to be sensitive to the diurnal distribution of cloud cover.

Plans FY 91

- Microwave data from the SSM/I will be applied to the retrieval of total precipitable water in the Gulf of Mexico for other periods during the GUFMEX experiment (1988) and cases of interest to NWS from the winter of 1989–1990. Statistics on the temporal-spatial variability of water vapor will be developed for the purpose of developing a climatology of water vapor from satellite measurements.
- The Klemp-Wilhelmson cloud model will be used in conjunction with retrieval methods to investigate the sensitivity of convective cloud simulations to various quantities and qualities of initializing data.
- Mesoscale convective system interactions and their influence on system movement will be explored using the Penn State–NCAR mesoscale model.
- The relations of buoyancy and precipitation distributions to the development of rotation in the 7 May PRE–STORM mesoscale convective system will be investigated.
- Two-dimensional dryline simulations will be completed and three-dimensional experiments will begin, using the Colorado State University RAMS model.
- COPS–91 data will be gathered to investigate the validity of the Rotunno theory for maintaining the character of squall lines.
- The feasibility of estimating upper tropospheric moisture response to changes in temperature and convective activity from VAS satellite data will be determined. The response of upper-level moisture to global warming and associated changes in convection are now recognized as critical factors in determining the atmospheric effect of increasing greenhouse gases.
- The role of land surface characteristics (vegetation, soil moisture) and cloud cover on the Earth-atmosphere radiation budget will be investigated jointly with CIMSS and NESDIS.

DOPPLER RADAR AND REMOTE-SENSING RESEARCH GROUP

Accomplishments FY 90

Storm Studies

Analyses began of three splitting thunderstorms that occurred in southern North Dakota on 27 June 1989 during the North Dakota Thunderstorm Project. Two of the storms were sampled intermittently with a ground-based and airborne dual-Doppler radar configuration.

Aircraft Turbulence

A case study concerned severe turbulence encountered by an aircraft on 26 April 1984 during an attempted landing ahead of a squall line gust front. Wavelike patterns in Doppler radar reflectivity and radial velocity measurements suggest that the turbulence was caused by a shearing instability associated with a low-level jet that fed the squall line. Evaporative cooling beneath the squall line's forward anvil also may have contributed to the destabilization.

Mesoscale Circulations

A generalized Q vector was developed, starting from the primitive equations and using minimal assumptions. The associated theory unifies several well-known works on the forcing of vertical motion in a general context.

The utility of Doppler radar for monitoring the kinematic properties of nonprecipitating cold fronts was examined. Despite operation at low antenna elevation angles, short radar ranges, and low signal-to-noise ratios, the radar depicted a sequence of events consistent with other instrumentation. Mean flow deformation and convergence, calculated by the VAD technique, for a weak, dry cold front were of order 10^{-4} s^{-1}; local maxima in the frontal zone, calculated from dual-Doppler radar data, were of order 10^{-3} s^{-1}.

A study of vertical vorticity generation and amplification in the PRE–STORM case of 6–7 May 1985 began. Preliminary results indicate that the primary vorticity tendency mechanisms, in order of magnitude, are the tilting of horizontal vorticity, the stretching of pre-existing vertical vorticity, and the stretching of Earth spin vorticity.

Polarization Studies

We explored the utility of polarimetric measurements for discrimination of hydrometeor types, with emphasis on detection of hail and discrimination between sizes. Specifically, we examined the differential propagation constant, the correlation coefficient between vertically and horizontally polarized echoes, and the differential reflectivity, from a storm at close range. The case demonstrates the complementary nature of these polarimetric measurements. Self-consistency among them allows qualitative and some quantitative discrimination between hydrometeors. It appears that a region of negative differential reflectivity contains vertically oriented hail, and that is corroborated by a noticeable increase in the differential phase. This increase is caused by differential phase shift upon Mie scattering.

Plans FY 91

- Collect polarimetric data from springtime storms to relate polarimetric signatures from a stratiform region of an MCS to the observed hydrometeors.
- Complete study of splitting thunderstorms that occurred on 27 June 1989 during the North Dakota Thunderstorm Project.
- Develop an extensive treatise on the basics of objective analysis.

- Continue analysis of vertical vorticity generation in the 6–7 May 1985 mesoscale convective system. Factors important for producing the large vertical wind shear and horizontal vorticity at the rear of the storm system will be examined.
- Examine the kinematic properties of tornadic storm inflows in an attempt to explain the wavelike reflectivity and wind bands seen in the inflow regions of some storms.
- Attempt to solve the "alternative balance" equations numerically.

STORM ELECTRICITY AND CLOUD PHYSICS GROUP

Accomplishments FY 90

With the Office of the Federal Coordinator for Meteorology, we helped develop strategy and plans for using lightning data, especially the ground strike location maps, in various NOAA missions and research.

Hypotheses of Charge Generation in MCSs

In this new area of research, we are looking for basic understanding of physical principles and correlations among the storm structure, air motions, and electrical activity of these significant weather systems. Measurements of in-situ electric fields in MCSs more than tripled the data available, and also yielded the first simultaneous measurements of electric field and precipitation microphysics. Three hypotheses were developed pertaining to electrification of the stratiform region: (1) Charge is carried from the convective cores into the stratiform by the internal wind; (2) charge is created and separated by colliding precipitation in the region; (3) convective cells embedded in the region add charge. These hypotheses will be applied in modeling efforts and will be used to plan future field programs.

Radiosonde and MCLASS Performance

We developed a test plan to assess the operation of radiosondes used with NOAA's MCLASS (Mobile Cross-chain Loran Atmospheric Sounding System) in the following four categories: clear air; near storms, but outside storm clouds; stratiform precipitation regions; and convective cells. A new antenna design and receiver module (developed in collaboration with NCAR) improved performance significantly. Reliable thermodynamic (temperature, pressure, dew point) and wind information were obtained in the first two categories.

Balloon-Borne Instrumentation

We developed, tested, and made initial flights with an electro-optical instrument to measure the charge and size of precipitation particles. This instrument was flown into severe storms and MCSs. The data will be used to define the electrical nature of the storm systems and to provide constraints for models.

Plans FY 91

- Investigate, in collaboration with the Forecast Applications Research Group, how to incorporate lightning ground strike data, wind profiler data, and Doppler radar wind profiles in new diagnostic products to support improved prediction of severe weather.
- Develop enhanced capabilities for the NSSL balloon-borne electric field meter.
- Provide new information on the electrical characteristics of storms and MCSs from analysis of MCLASS and mobile laboratory data and from analysis of ground strike data relative to satellite infrared imagery.
- As part of the anticipated COPS–91 program, measure the electric field in storms that form in a dryline environment.

SCIENTIFIC SUPPORT DIVISION (SSD)

Accomplishments FY 90

Computing

An Uninterruptible Power System was added to protect the computing facility and workstation room from short power outages. Additional disk drive systems were added to both the VAX and Concurrent systems to bring total storage capacity to 5.8 gigabytes and 3.3 gigabytes, respectively. An additional computer (VAX 8700) was purchased to improve MRD's computing capabilities. A new 8mm tape system was added to the Concurrent along with a Versa Module Europa (VME) Bus interface to connect the system to the Cimarron radar. Three Stanford University Network Microsystems, Inc. (SUN) workstations were added, and the SUN Server was upgraded with an additional 2.5 gigabytes of disk space and a 150-mb 1/4-inch tape system. Additional personal computers were purchased upgrading several to 386s, and a new 33-MHz machine for graphic processing was obtained. Graphics output was improved by the addition of a high-resolution color camera and additional color plotting capabilities.

Cimarron Doppler Radar

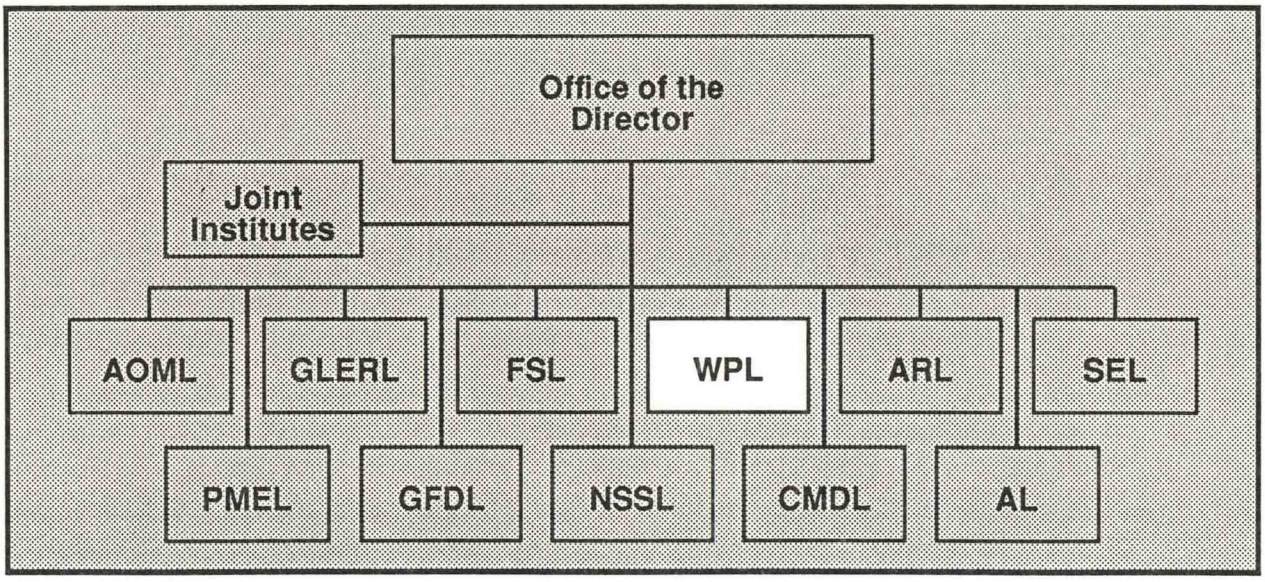
Progress continued on the Cimarron Doppler radar system. The new signal processor is producing reflectivity, mean velocity, and spectrum width data in both staggered and regular Pulse Repetition Time (PRT) modes. The microwave link is operational, and components were purchased to implement remote operation of the radar.

Mobile Laboratories

NSSL now has two fully operational mobile laboratories capable of MCLASS operations along with two additional MCLASS units, one of which will be configured for dropsonde operations on the P–3 aircraft. The mobile laboratories were used in the SWAMP program in Arizona and provided support to the FAA TDWR program and NASA research in Florida. Improved communication methods, including 800-MHz truck and satellite communications, were tested on NSSL2.

Plans FY 91

- NSSL will continue to upgrade its mobile laboratory capabilities.
- Cimarron Doppler radar will become fully operational with full remote control capability.
- New high-speed workstations will be added to complement the current computing capabilities.



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.

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

Accomplishments FY 90

Sensor Development

- By using Doppler lidar turbulence measurements, the sensible heat flux in the mixed layer was measured and determined to be a residual in the kinetic energy budget equation.
- WPL continued the development of several instruments and techniques for remote sounding of temperature, water vapor, and clouds:

  FIRS (Fourier Transform Infrared Sounder)
  Acoustic source and shielding for RASS (Radio Acoustic Sounding System)
  Dual-channel radiometer for aircraft deployment
  Millimeter-wave radiometry for water vapor profiling (evaluated)
  State-of-the-art, six-channel microwave radiometer (completed)

The development of an integrated sounding system for TELESONDE continued by combining data from RASS, MWSRs (Microwave Water Substance Radiometers), and FIRS with data from polar-orbiting satellites.

Research

- The 915-MHz wind profiler was used to observe the morphology of drop size distributions in liquid precipitation. The scattering targets were identified in the Doppler spectra of the vertically pointed antenna beam. The time-continuous records of Doppler spectra as a function of height provided information on the precipitation particles, size distribution, and temporal evolution.
- Significant advances were made in understanding the origin of radar refractive index structure in the lower troposphere. A stochastic model was developed for gravity-wave-induced turbulence to predict the generation of thin turbulent strata from autoconvective overturning. A top-down/bottom-up diffusion model was applied to separate temperature and humidity contributions to radar backscatter in a cloud-free convective boundary layer. Subsequent experimental analyses suggested a strong correlation between radar reflectivity and the humidity structure function at the top of the marine boundary layer.

Plans FY 91

- Begin development of a coherent Nd:YAG lidar for measurement of small-scale turbulent parameters and fluxes.
- Apply combined Differential Absorption Lidar (DIAL)/Doppler lidars for studies of water vapor and trace species fluxes.

MESO-BETA AND -GAMMA SCALES

Accomplishments FY 90

Sensor Development

- A demonstration of temperature profiling by the Radio Acoustic Sounding System (RASS) technique was conducted on the prototype radar of the NOAA wind profiler network. This demonstration showed that vertical profiles of virtual temperature could be measured in the lower troposphere by these 404.37-MHz network radars with the same time and space resolution used for wind profiling. In a series of tests, virtual temperature profiles were measured from 500 m altitude (the lowest height observed by the radar) to 3.5–5.2 km altitude with a measurement every 250 m. Profiles were measured every 6 min. These results show that the NOAA wind profiler network could provide local forecasters and research meteorologists with continuous wind and lower tropospheric temperature data. Temperature measurements made by the profilers, when combined with those retrieved from passive satellite radiometers, improved the resolution and accuracy of the overall profile. The profiler-satellite combination may provide temperature profiles that meet the requirements for many meteorological applications.

- WPL constructed and tested the transmitter and local oscillator lasers for a compact, high-pulse-repetition-rate CO_2 lidar utilizing state-of-the-art RF discharge technology. The frequency stability of these lasers appears superior to that of the current pulsed Doppler lidar. An RF-driven power amplifier is now under construction.

- Development continued on an acoustic transmitter and acoustic shielding for RASS; these efforts led to an application for a patent. Construction was completed and testing was started for microwave radiometers operating at 23.87, 31.65, 53.85, and 56.02 GHz. Construction was started for the dual-frequency receiver that operates at 23.87 and 31.65 GHz for aircraft deployment. Flight and electromagnetic testing of the airborne radiometer antenna continued. Additional airborne instrumentation development concerned the scanning radar altimeter (SRA) mode of operation for the NASA Multimode Airborne Radar Altimeter (MARA) for measuring the directional wave spectrum of the ocean and a compact antenna system. To aid in deriving temperature and water vapor profiles as a part of an integrated sounding system, a Fourier Transform Infrared Sounder (FIRS) was purchased. Data analysis software, using MODTRAN, was developed to calculate radiance, transmission, and weighting functions.

Research

- The technique for Tracking Air with Circularly polarized Radar (TRACIR) was demonstrated during a snowstorm by releasing chaff from a ground-based station during the Lake Ontario Winter Storms (LOWS) experiment. Chaff was detectable in the presence of snow by means of its large circular depolarization ratio.

- An analysis of data taken with our 3-cm-wavelength Doppler radar during the North Dakota Thunderstorm Project has documented an intense nocturnal jet in excess of 25 m s^{-1} that was only 400 m above the surface. This mesoscale feature is believed to have set the stage for severe weather events on the following day.

- Lidar data, taken during a severe downslope windstorm, were used to make a video documentary of the event. The data defined the gust structure, movement, and evolution. However, the anima- tions

made from the data did not support current theories of gust development. It appears that these lidar observations and animations will lead to a new understanding of downslope wind structure.

- Experimental data and numerical model simulations clarified the role of ocean-land temperature contrasts and nocturnal slope flows in the formation of a coastal mesoscale circulation, the Santa Barbara Eddy.

Plans FY 91

- The theory that predicts how well RASS will perform in a given meteorological situation is not complete. A theoretical formulation that incorporates the effects of winds, turbulence, humidity, temperature, and their gradients will be developed for RASS.

- Operational RASS temperature profiles must measure both the speed of sound and the vertical wind in the same height interval and at the same time because a 1 m s^{-1} vertical wind causes a 1.6°C temperature error if vertical wind is ignored. Simultaneous measurement of both velocities will be added to WPL's RASS temperature profilers.

- WPL will develop and test a small, high-pulse-repetition-rate CO_2 lidar system for measurement of winds and gas species from airborne and ground platforms.

SYNOPTIC AND MESO-ALPHA SCALES

Accomplishments FY 90

Sensor Development

- The performance of the 404.37-MHz prototype wind profiler system was studied in detail during a 300-h test of continuous operation. Comparisons were made between horizontal wind components, measured by the new UHF radar, those measured by a nearby VHF research profiler, and winds from NWS radiosondes launched about 50 km from the profilers. The network (UHF) and WPL (VHF) wind profilers had standard deviations of 2.30 m s^{-1} and 2.16 m s^{-1} for the differences of the u- and v-components, respectively. However, the research profiler ignores vertical velocity, whereas the network radar measures it and removes its effects from the u- and v-component measurements. The network wind profiler and the NWS rawinsondes have standard deviations of 3.65 m s^{-1} and 3.06 m s^{-1} for the differences of the u- and v-components, respectively. These results are similar to those found in earlier comparison studies. The new network wind profiler demonstrated excellent sensitivity, consistently reporting measurements at all heights from 2 to nearly 18 km msl with very few outages.

- WPL participated in experiments at NASA Ames (Moffatt Field), prior to the Global Backscatter Experiment (GLOBE) I and II missions, to intercompare and validate backscatter-measuring instruments aboard the DC–8. On the basis of WPL results, several major problems with the onboard lidars were discovered during the initial study. Resolution of the problems was verified during a follow-up intercomparison.

Research

- A radar technique called Imaging Doppler Interferometry was studied to determine its potential applicability to tropospheric wind profiling. This technique uses multiple receiving antennas to find the angular location and the radial velocity of persistent scattering centers in the radar resolution volume. The technique is unproven in the troposphere, but it is important because the antennas required are small enough that compact, mobile profilers may be feasible. An additional advantage of this technique over other wind profiling methods is that a high-resolution image can be made of the wind field in the radar resolution volume. A disadvantage is that higher transmitted power may be required.

- The synoptic-scale and mesoscale analysis of the Energetics of Rapidly Intensifying Cyclones over the Atlantic (ERICA) was completed for the extratropical marine cyclone of 4-5 January 1989. The analysis incorporated special aircraft and dropwindsonde observations to resolve the detailed structure of fronts and associated precipitation systems. Results revised the Norwegian conceptual model of frontal evolution during explosive cyclogenesis.

- Numerical simulations of the above-described cyclogenesis study were carried out with a high-resolution, full physics, numerical prediction model. Numerical results were verified against the detailed mesoscale analyses, revealing both the realism and shortfalls of the simulated cyclone evolution and its parameterized sub-grid-scale physical processes.

Plans FY 91

- Continue to assess the application of profile-RASS-radiometer (ground-space) observing systems to synoptic-scale and mesoscale meteorological diagnostics and numerical simulations.

- Continue the analysis and numerical simulation of extratropical cyclogenesis and its associated internal mesoscale structure and processes.

- Continue applying WPL Doppler lidar expertise to assess issues, such as backscatter and technology feasibility, relating to eventual deployment of a space-based lidar system for global wind measurements.

AIR QUALITY

Accomplishments FY 90

Sensor Development

- The characterization process began for the $ZnGeP_2$ crystals obtained from the U.S.S.R. Institute of Atmospheric Optics for doubling and mixing radiation from carbon dioxide and carbon monoxide laser sources. These crystals have high potential for producing usable radiation in the 3–5 m spectral band for measuring trace species.

- The effectiveness of arrays of Aeronomy Laboratory-designed 915-MHz wind profilers was demonstrated in studies of mesoscale transport in Grand Canyon National Park and in the San Joaquin Valley of California. Improvements such as portable clutter screens and real-time data transmission to a central hub were made.

- A new sodar system was developed and transferred to the Colorado Department of Health to be used for air quality nowcasting with real-time remote color facsimile displays and laser printer digital facsimile recording.

Research

- It was demonstrated through analytical simulations and field measurements that simultaneous lidar and radar backscatter data from cirrus provide useful information on particle sizes.

- A major field project was conducted to study air flow in the Grand Canyon during January–March. Perched on the South Rim, the Doppler lidar scanned down into the canyon opening from the north and obtained data on flow in the canyon. Such data, available only through remote sensing, are providing information on flow characteristics in the vicinity of the canyon, which are responsible for transporting pollutants into the canyon.

Plans FY 91

- Development efforts will begin on a lidar system that will measure profiles of tropospheric ozone and ozone fluxes.

CLIMATE

Accomplishments FY 90

- A new lidar concept was examined for measuring properties of cirrus cloud particles that affect the Earth's radiation budget. A laser beam with sufficient power can reorient nonspherical cirrus particles, whose size and shape distributions can then be determined using an appropriate probing lidar. Detection with a ground-based lidar would be marginal, but an airborne lidar might be feasible.

- Mathematical foundations were developed for recovering path-average ocean sound-speed (temperature) profiles from acoustic time-of-flight data. Both ray and normal mode representations of underwater propagation permit application to the wide range of acoustic frequencies and transmission distances of interest in ocean climate studies. Networks of such acoustic paths can map three-dimensional mesoscale ocean temperature structure by tomographic inversion, and "acoustic thermometers" can monitor path-average ocean temperatures on basin and global scales.

- An optical inner-scale scintillometer was developed for accurately measuring heat and momentum fluxes in a horizontally uniform atmospheric surface layer over horizontal paths as long as 500 m. This instrument will form the basis for a suite of instruments to monitor surface fluxes of climatically important trace constituents, such as carbon dioxide, methane, and water vapor. A millimeter-wave scintillometer has been designed, which, in concert with the inner-scale scintillometer, will measure humidity flux.

- The first comparisons were made of global, long-term, satellite-based measurements of surface solar irradiance with those simulated by atmospheric general circulation models (GCMs). Significant differences were found between the simulated and observed fields. The differences give modelers the quantitative information they need to improve surface solar irradiance simulations. Because

surface solar irradiance variability is related to cloudiness, the measurements can also lead to improved cloud parameterizations in these GCMs.

- A new offset Cassegrain antenna was constructed for the WPL 8-mm-wavelength cloud-sensing radar that will give it significant capability for use in microphysical studies of radiatively important cloud systems (i.e., cirrus and stratocumulus clouds). Scattering calculations were performed to evaluate the ability of the new antenna to measure the depolarization of radar signals scattered from cirrus clouds. Results indicate that polarization measurements with this antenna will provide useful information about ice crystal types and their orientations in cirrus clouds.

- During the Cloud Lidar and Radar Exploratory Test (CLARET I), it was demonstrated that microwave radar can provide microphysical and dynamical information about optically thick cirrus clouds that is unobtainable by other means. These initial tests illustrated the value of combined lidar and radar measurements of clouds that play a key, but as yet unquantified, role in the global radiation budget.

- WPL analyzed the performance of, designed, and began construction of an ultraviolet differential absorption lidar (DIAL) for measuring profiles of ozone and ozone flux in the lower troposphere.

- It was experimentally determined that lidar backscatter from nonspherical ice cloud particles at 10.6-μm wavelength (where absorption is strong) is low, whereas at visible wavelengths (where scattering dominates) it is high, in agreement with theoretical expectations.

Plans FY 91

- An underwater acoustic receiving station will be operated at Ascension Island in the South Atlantic Ocean in concert with the Heard Island Feasibility Experiment. For two weeks in early 1991, a 57-Hz coherent sound source in the southern Indian Ocean will insonify the world's oceans. Worldwide measurements of sound intensity, stability, and reverberation will tell whether it is feasible to monitor global ocean warming by measuring the time of flight of sound pulses across the world's ocean basins.

- The variability of surface solar irradiance will be correlated with meteorological and oceanographic parameters (such as sea surface temperatures) to investigate possible cloud radiation feedback mechanisms. An understanding of these mechanisms will contribute to a reduction in the uncertainty of climate predictions.

- With respect to climate and global change research, WPL plans to complete the analysis of remote-sensing data from CLARET I and conduct a second-phase CLARET experiment as the Laboratory begins to apply the new cloud-sensing radar to study microphysical properties of clouds having the greatest impact on the global radiation budget.

- In order to address the shortcomings of cloud parameterizations now used in general circulation models, WPL will continue to upgrade radar capability to sense microphysical properties of radiatively important clouds such as cirrus and stratus clouds.

- Development will start for the creation of compact, robust, unattended lidar systems for application in atmospheric process studies and monitoring.

OCEANS AND GREAT LAKES

Accomplishments FY 90

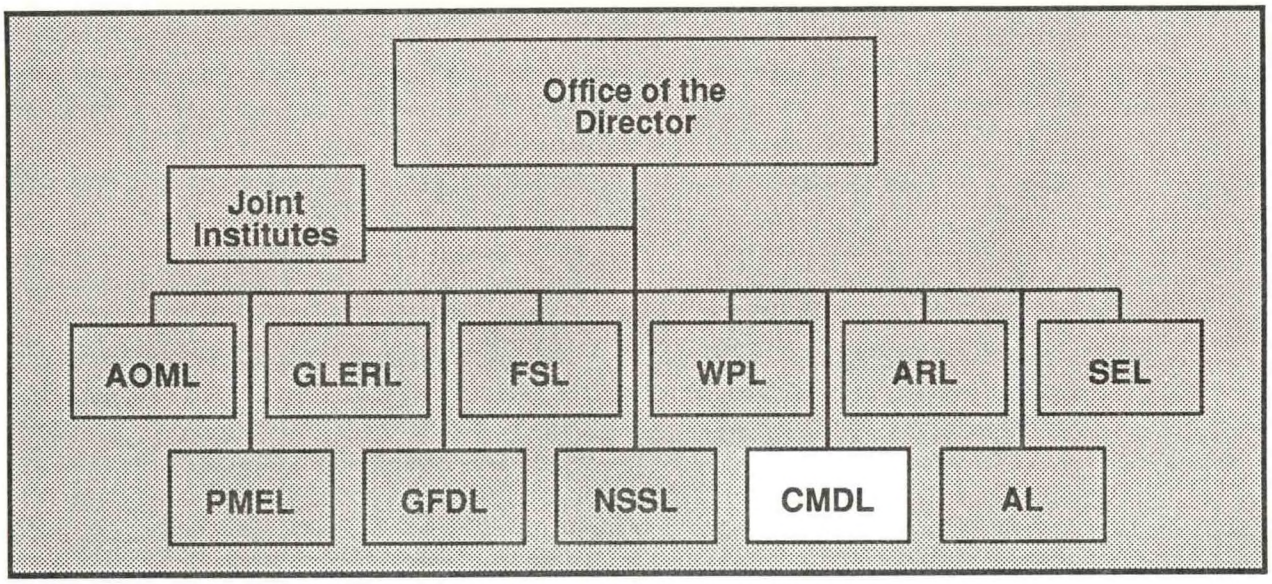
Sensor Development

With regard to the Combined Oceanic and Atmospheric Sensing Technique (COAST), the sensing of ocean currents with existing microwave weather radars, we determined that a stepped-frequency transmission sequence at a single frequency would be more versatile, less costly, and simpler to implement than the simultaneous transmission of two frequencies.

Plans FY 91

Research

- Implement and evaluate COAST for measurement of high-resolution ocean surface currents and marine boundary layer winds.



CLIMATE MONITORING AND DIAGNOSTICS LABORATORY

Boulder, Colorado
(303) 497–6966
Eldon E. Ferguson, Director

The Climate Monitoring and Diagnostics Laboratory (CMDL) was formed in December 1989 from two divisions of the Air Resources Laboratory, Climate Research and Geophysical Monitoring for Climatic Change (GMCC). The GMCC Division was subsequently reorganized and absorbed into CMDL.

CMDL conducts research to measure atmospheric constituents and assess climate fluctuations on a variety of time scales. The Laboratory operates remote baseline observatories at Point Barrow, Alaska; Mauna Loa, Hawaii; Cape Matatula, American Samoa; and South Pole, Antarctica. Here, and at numerous cooperative sites, long-term, background monitoring of trace gases and particles and solar and infrared radiation takes place. These atmospheric and oceanic data are analyzed to determine the species' budgets, sources, sinks, and trends. The Laboratory also analyzes real-time and historical climate information to develop climate indices, predictive techniques, and evaluations of predictions.

Much of the Laboratory's research focuses on three contemporary issues: greenhouse gas climate warming, stratospheric ozone depletion, and El Niño–Southern Oscillation effects on larger space-scale weather and climate. Concentration levels are increasing for the gases that cause changes in the atmosphere, namely, carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. In response to international concerns, new, less-damaging but not damage-free species are being introduced. CMDL is responsible is for long-term monitoring of these species and associated research on their global budgets.

CARBON CYCLE

Accomplishments FY 90

In-situ monitoring of CO_2 continued at the four CMDL baseline observatories as well as in-situ monitoring of CH_4 at Point Barrow and Mauna Loa. CO, CO_2, and CH_4 were also measured in samples from the global cooperative flask sampling network.

An improved battery-powered pumping unit for flask sampling of air has been successfully tested and is gradually replacing older units in the network. A new design for glass flasks, with better stability for CO_2 and especially CO, is also being phased in. To improve sampling quality at cooperative sites, each new sample taker is given personalized training at either Boulder or the field site.

Recent analyses of CO_2 from the flask samples, surface ocean CO_2 partial pressure (pCO_2) data, and global-scale carbon cycle modeling strongly suggest that terrestrial ecosystems in the Northern Hemisphere are responsible for the uptake of most of the CO_2 that is observed to be removed from the atmosphere each year by natural processes. In addition, a detailed study has been made of statistical and systematic errors affecting in-situ and flask measurements of CO_2, leading to quantitative error estimates.

We began a collaborative program with the University of Colorado at Boulder to measure the stable isotopic composition of CO_2 in samples from the flask network. The global budget of CO_2 still remains somewhat of an enigma. Isotopic data from northern high-latitude sites appear to contradict the observed pCO_2 patterns in the surface waters of the northern oceans. Isotopic data suggest that northern oceans take up most of the carbon. The isotopic signatures of CH_4 also contain important information with respect to source apportionment. We are also collaborating with the Institute of Nuclear Sciences in New Zealand and the National Center for Atmospheric Research (NCAR) to collect, extract, and analyze air samples for $^{14}CH_4$ content.

The CH_4 concentrations resulting from selected scenarios, of global sources and sinks, as calculated with a three-dimensional atmospheric transport model, were compared with CH_4 measurements from the global network. This work was done in collaboration with NASA's Goddard Institute for Space Studies. An unequivocal determination of the contributions of major suspected sources to the global budget is not possible from the present distribution of measurements. However, because network sites are far away from the sources and sinks, we found that some postulated sources could be exchanged for others without seriously affecting the modeled concentrations at our sites. In separate analyses, we established that the global growth rate of CH_4 (about 0.8% per year) is slowly decreasing.

A gravimetric calibration scale for CO has been established and has been compared with other calibration scales currently in use. The construction of a facility for the volumetric calibration of primary standards for CO_2 has started. This will be part of the new CO_2 Central Laboratory of the Global Atmospheric Watch of the World Meteorological Organization (WMO).

Plans FY 91

- Continue monitoring CO_2, CH_4, and CO through in-situ measurements and the cooperative flask network. Gradually expand the flask measurement program to regular sampling aboard aircraft, to improve estimates of sources and sinks of these carbon cycle gases over the continents, as well as to provide better constraints on the parameterization of vertical transport in three-dimensional atmospheric transport models. Expand flask sampling aboard ships (South China Sea) to get closer to a very important source region of CH_4.

- Install an in-situ gas chromatograph for CO monitoring at Point Barrow.

- Continue measurements of stable isotopes of CO_2 in samples from the flask network, in collaboration with the University of Colorado.

- Initiate a study of the high-frequency variability and correlation of CO_2 and CH_4 at Point Barrow and Mauna Loa, with emphasis on sources and sinks.

- Complete implementation of improved battery-powered pumping units and new-design glass flasks at cooperative field sites.

NITROUS OXIDE AND HALOCARBONS

Accomplishments FY 90

Installation of automated gas chromatographs (GCs) for the atmospheric measurement of N_2O, CFC-12 (CCl_2F_2), CFC-11 (CCl_3F), CH_3CCl_3, and CCl_4 was completed at all NOAA/CMDL baseline observatories. An automated GC was installed at Niwot Ridge, CO, in the spring of 1990 to examine continental sources of these gases. The frequency of GC measurements was increased from once every 3 hours to once every hour. In addition to the automated measurements, pairs of flasks were collected once a week from Alert, Canada; Point Barrow; Niwot Ridge, CO; Mauna Loa; and Cape Matatula. Flasks were taken at South Pole only during the austral summer. All flasks were returned for analysis in Boulder, CO, for N_2O, CFC-12, and CFC–11. These flasks were sampled once a month for atmospheric HCFC-22 ($CHClF_2$), CFC-113 (CCl_2F–$CClF_2$), and halons H-1211 (CF_2ClBr) and H-1301 (CF_3Br), using EC–GC and cryogenic trapping of 250-cc samples.

Work continued on developing trace gas standards for N_2O, CFC-12, CFC-11, CFC-113, CH_3CCl_3, CCl_4, HCFC-22, HFC-134a (CH_2FCF_3), HCFC-123 (CF_3CHCl_2), and halons H-1211 and H-1301. Our calibration scales for CFC-11 and CFC-12 were finalized. Work continued on the preparation of atmospheric standards of CO in collaboration with the Carbon Cycle group.

An automated, airborne GC was designed and constructed for the analysis of atmospheric N_2O and the CFCs in a vertical profile, where pressure and temperature can vary rapidly as a function of altitude. From airborne measurements in the plumes of power plants and laboratory investigations of combustion, we estimated that the source strength for N_2O from direct combustion of fossil fuels is smaller than previously obtained.

Atmospheric and surface water concentrations of N_2O, CFC-11, CFC-113, CH_3CCl_3, and CCl_4 were measured hourly aboard the Soviet research vessel *Akademik Korolev*, over a cruise track in the central and western Pacific crossing the Equator six times during the third Soviet-American Gas and Aerosol (SAGA–III) experiment. Dissolved N_2O at depth was measured with a head space sampler and electron capture gas chromatograph (EC–GC). A main purpose of this experiment was to quantify changes in the gradient of the concentration of these gases as a function of latitude and time across the Equator to estimate the interhemispheric exchange time.

Plans FY 91

- Continue routine monitoring in situ and by flask at six sites for N_2O, CFC-12, CFC-11, CFC-113, CH_3CCl_3, CCl_4, HCFC-22, and halons H-1211 and H-1301.

- Complete testing of a new automated GC system for measuring N_2O, CFC-12, CFC-11, CH_3CCl_3, and CCl_4 in flasks. Add new flask sampling stations at Bermuda, Harvard Forest (Harvard University), MA, and Cape Grim, Australia (CSIRO), in collaboration with scientists from those locations. Construct and install automated GCs at Harvard and Cape Grim to quantify the continental sources of trace gases.

- Improve the airborne GC system for measuring vertical profiles of long-lived gases to participate in polar missions.

- Develop mass spectroscopy and enhanced EC–GC technology to measure the new substitute chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), in the atmosphere.

- Develop an independent calibration scale using gravimetric standards for H_2 and CH_4 at relevant atmospheric concentration levels in collaboration with the Carbon Cycle group.

ATMOSPHERIC RADIATION

This project is devoted to the long-term monitoring of surface aerosol light scattering and condensation nuclei, global and direct solar and ultraviolet radiation, global terrestrial radiation, participation in organized aerosol and radiation field experiments, radiative transfer analysis, and UV remote sensing of ozone profiles from satellite and the surface. As part of the internal reorganization associated with the formation of CMDL, most of the aerosol research historically associated with the Group was transferred to the Aerosols, Ozone, and Water Vapor Group.

Accomplishments FY 90

Comparisons of stratospheric aerosol optical thickness inferred from lidar observations obtained at Mauna Loa and Boulder with SAGE–II satellite observations showed good agreement, thus improving confidence in the use of lidar data to correct Umkehr and satellite measurements of ozone profiles.

Stratospheric aerosol error corrections to Umkehr ozone profiles were calculated on a monthly basis from 1984 through 1988 for 10°-wide latitude bands centered at 30°S, 20°N, 30°N, and 40°N. A priori statistical ozone profile data for upgrading the Umkehr ozone profile inversion algorithm were derived from the SAGE–II global ozone data set. Tests with SBUV and SAGE–II statistical information were performed and results were evaluated.

Solar radiation pyranometers in the 31-station U.S. network were calibrated and cycled into the network. A comparison of NOAA and Solar Energy Research Institute (SERI) calibration methodology was completed. Results indicated that the two calibration methods differed in small, systematic ways and that the difference was dependent upon instrument manufacture. A group of Eppley precision spectral pyranometers differed negligibly in scale factors, but the average difference for a group of 18 Spectro Sun pyranometers was 0.90%.

Two new automated photometric remote-sensing instruments were installed on the roof of building RL3 in Boulder and are being evaluated for their potential to provide routine data on column precipitable water and aerosol optical depth.

Characteristics of the diurnal and annual variations in the surface radiation budget as measured from the top of ERL's Boulder Atmospheric Observatory tower were determined. The net solar radiation observations were used to validate an algorithm for determining surface net solar radiation from ERBE satellite observations of net radiation at the top of the atmosphere. Preliminary analysis of nearly 1 year's surface radiation measurements from Kwajalein, M.I., has provided the basis for qualifying the suitability of that site for long-term monitoring for studies of the tropical surface energy budget, and for validating satellite determinations of the same quantity.

Initial steps toward organization of the World Climate Research Programme's Global Baseline Surface Radiation Network (GBSRN) have been completed. The WMO has issued an announcement and plan for international participation.

Analyses of surface solar radiation measurements at the South Pole showed a positive trend in late summer cloudiness during the 12-year record. Similar analyses of measurements outside the village of Barrow gave strong evidence that the annual date of snowmelt has not changed since at least the 1940s, compared with the apparent trend toward earlier snowmelt times noted in the Barrow village meteorological reports.

Procedures were established to characterize the response function versus wavelength and to calibrate the 15 Robertson-Berger meters used in the NOAA network. Laboratory apparatus was assembled and tested, and full network operations including data acquisition and archiving were re-implemented.

Plans FY 91

- Verify lidar measurements above 30 km and near the tropopause with SAGE–II global aerosol profile data. The tropopause is the customary region where lidar measurements are normalized. Produce a climatology of best-estimated lidar backscatter near the tropopause and the variations with latitude.

- Begin implementation of the World Climate Research Program's GBSRN. The NOAA contribution will consist of two to four sites, one of which will be the Boulder BAO site with upgraded instrumentation. Evaluate the feasibility and utility of new automated photometric remote-sensing instruments for column precipitable water and aerosol optical depth, for possible deployment at the BAO site. Establish a test GBSRN site on Bermuda, where the radiation budget is expected to be representative of the central southwestern Atlantic Ocean.

- Examine the quasi-biannual oscillation in the amplitude of the annual cycle in the 33-year record of atmospheric transmission data from Mauna Loa for its relationship to other atmospheric oscillations and its potential for climatic impact. Investigate the effects of late summer cloudiness trends on the surface radiation budget at the South Pole.

- Undertake a joint U.S.-U.S.S.R. surface radiation budget project involving exchange of data and instruments at South Pole and Vostok sites, to determine the degree of homogeneity in the radiation balance among these two Antarctic Plateau sites.

- Investigate relationships between SBUV, Umkehr, and SAGE remote-sensing devices in terms of the ozone profiles resulting from their respective mathematical inversion algorithms.

- Complete the characterization and calibration of the NOAA Robertson-Berger meters. Perform investigations to determine the long-term stability of the meters and to develop a quantitative understanding of the effects of ozone, aerosols, and clouds on the transmissivity of solar UV radiation, using 1-nm spectrally resolved UV measurements.

- Test improvements to the Umkehr algorithm. Study Umkehr ozone profile errors produced by stratospheric aerosol concentrations at different altitudes. Assess the usefulness of zenith-sky cloud detector data for determining overhead sky conditions during an automated Dobson Umkehr measurement.

AEROSOLS, OZONE, AND WATER VAPOR

The Aerosols, Ozone, and Water Vapor Group was formed with the reorganization of GMCC and the formation of CMDL. The group is composed of all components of the former Monitoring Trace Gases (Ozone) Group along with most aerosol research from the Aerosols and Radiation Group.

Accomplishments FY 90

Aerosols

The group participated in the Desert Aerosol Lifting Experiment, a U.S.-U.S.S.R. cooperative experiment in the desert region south of Dushanbe, U.S.S.R., and organized a workshop in Boulder to discuss the results of the experiment. Multi-wavelength sunphotometer measurements, condensation nucleus measurements, and single-wavelength nephelometer measurements were obtained to characterize dust production, movement, and interaction with the local radiation field. Two large dust events were recorded with visibilities as low as 2 km. Meteorological and satellite analyses indicated that the source region for the dust was outside the local area, probably to the southwest over Afghanistan.

Through participation in a NASA cooperative circum-Pacific airborne aerosol experiment, high-sensitivity three-wavelength nephelometer measurements were obtained on the NASA DC–8 aircraft as part of a survey of background tropospheric and stratospheric aerosols for comparison with similar satellite-derived aerosol measurements. Several aerosol profiles were obtained with lidar and aircraft in-situ sampling. Agreement between the two methods was good, including clean regions in the upper troposphere.

New butanol-based condensation nucleus (CN) counters were installed at the Barrow and South Pole CMDL observatories. These instruments replace the General Electric CN counters that have operated at these stations since 1974.

With colleagues from the University of Wyoming, WPL, and ARL, the group obtained lidar, aircraft, and balloon-borne measurements of aerosol profiles near Boulder to provide a calibration for lidar measurements in a clean region of the atmosphere. At White Sands, New Mexico, aerosols were measured with an automatic condensation nucleus counter, a high-sensitivity nephelometer, and an aethalometer on the NOAA King Air aircraft to further investigate laser propagation. Agreement between the balloone-borne instrument and the aircraft instruments was excellent. A clean region was found just below the tropopause over Boulder.

High-sensitivity three-wavelength nephelometer measurements were obtained on the Wyoming King Air aircraft, and condensation nucleus and single-wavelength nephelometer measurements were obtained on the NOAA WP–3D aircraft as part of the California state-sponsored San Joaquin Valley experiment designed to assess air quality.

Ozone

Total-ozone and Umkehr vertical profiles were collected from the seven-station Automated Dobson Network. Total ozone was measured with the Dobson spectrophotometer at nine additional locations. World standard Dobson spectrophotometer No. 83 was operated at Mauna Loa Observatory during June–August 1990 in an ongoing determination of the calibration of this standard. This series of calibration measurements going back to 1972 has been particularly useful in helping to characterize measurement drift of TOMS and SBUV satellite ozone-measuring systems. A wavelength pair justification method was developed for reprocessing the satellite total-ozone record to give long-term trend results at Mauna Loa within 1% of those obtained with the Dobson instrument.

Dobson instruments from 17 countries were intercalibrated at an international intercomparison at Arosa, Switzerland. NOAA secondary standard Dobson No. 65, which had been extensively intercompared with instrument No. 83 at Mauna Loa in 1989, was the reference instrument. Twelve of 16 instruments were found to have remained essentially unchanged in their calibration since the previous intercomparison in 1986.

Soundings were made every 3 days at South Pole, using lightweight, balloon-borne ozonesondes, during the springtime stratospheric ozone depletion season from September to November. In addition, weekly ozone profile measurements continued at South Pole and Hilo. During the spring of 1989, ozone depletion over

South Pole was substantial; ozone amounts were nearly as low as the all-time low in 1987. However, recovery began by mid-November (earlier than in 1987).

Surface ozone data were obtained at the four CMDL observatory sites and at three locations in the North Atlantic that are part of the Atmosphere-Ocean Chemistry Experiment (AEROCE) network. A nearly 1% per year increase in summer ozone concentration has occurred at Point Barrow over the past 17 years, perhaps as a result of an increase in reactive nitrogen over the north slope of Alaska. The steady decline in the seasonal minimum of surface ozone at South Pole that occurs during the summer may be related to the shifting pattern of storm-related transport to the South Pole.

Water Vapor

Monthly measurements of the water vapor profile to 25 km were continued at Boulder. Profiles of water vapor at Alert, Canada, and South Pole were measured cooperatively with University of Wyoming scientists. At South Pole, the profiles documented the dehydration of the lower stratosphere during the period of formation of polar stratospheric clouds.

Plans FY 91

Aerosols

- Install instruments to measure aerosol size and chemistry at Mauna Loa and South Pole. Install a butanol-based condensation nucleus (CN) counter and an aethalometer at Samoa.
- Develop airborne CN counters, including both the modified TSI counter for aircraft studies and the initial design and laboratory research on a small, expendable CN counter for balloon-borne applications.
- Host an international symposium on Tropospheric Chemistry of the Antarctic Region in Boulder. This symposium will bring together Antarctic specialists from around the world to present research results and recommend topics for future research.

The NOAA–NASA initiative Network for Detection of Stratospheric Change (NDSC) has designated the Mauna Loa Observatory as its first station. CMDL's contribution will be an upgraded ruby lidar, similar to one that has observed stratospheric aerosol at Mauna Loa since 1976, and a new temperature lidar. These instruments will provide long-term measurements to detect changes associated with the ozone layer.

Ozone

- As part of the ongoing calibration program of Dobson No. 83 at Mauna Loa, operate a second spectrophotometer to investigate the light-scattering effects within the instrument on the absolute accuracy of Dobson measurements.
- At the AEROCE site at Mace Head, Ireland, install upgraded equipment to allow measurements from the sampling tower. Calibrations of the ozone instruments at the other AEROCE sites and two of the CMDL observatories as well as an intercomparison of the CMDL and NIST standards are scheduled.
- Complete a digital version of the electrochemical ozonesonde. This instrument, which uses the field-tested sonde developed by the University of Wyoming, will make three ozone soundings per

week at the South Pole Station during the ozone hole period and one sounding per week during the remainder of the year.

- Begin ozonesonde measurements at Mauna Loa with the digital instrument. Thus, a continuous record of stratospheric ozone profiles since 1987 will be available when the new NDSC facility begins operation, providing an ozone climatology and correlative measurements for NDSC ozone lidars.

Water Vapor

- Expand applications of CMDL's balloon-borne frost-point hygrometer. In addition to continuing the long-term record of stratospheric water vapor at Boulder, correlative flights will be conducted following the Upper Atmospheric Research Satellite (UARS) launch, and the hygrometer will be compared with the NOAA Aeronomy Laboratory's Lyman Alpha hygrometer on the ER–2 stratospheric aircraft over California. Water vapor measurements in collaboration with the University of Wyoming at South Pole and McMurdo Stations in Antarctica will continue, and a new collaboration in the Arctic, at Kiruna, Sweden, will begin with the University of Wyoming and the Max Planck Institute for Nuclear Physics (Heidelberg, Germany). These measurements will help us to understand the formation of polar stratospheric clouds and accompanying springtime ozone depletion in the polar regions.

CLIMATE RESEARCH

Accomplishments FY 90

Data Set and Workstation Development

Significant progress was made toward the next release of the Comprehensive Ocean-Atmosphere Data Set (COADS) in cooperation with NCAR and NOAA's National Climatic Data Center. Systematic differences in data values from different data sources and errors in data formats were examined, and corrections proposed. The effect of trimming (i.e., removing erroneous data) has been explored. The original trimming algorithm produced a data set that distorted the largest climate signals, such as major El Niño–Southern Oscillation events, by excessive discarding of good data. A new trimming procedure is being developed to produce more reliable data for these climate events.

A package of computer software has been developed to enable scientists to examine COADS data in a simple, user-friendly environment. The software allows the user to choose particular fields, to specify a particular region, and to calculate standard statistics. Results of calculations are displayed on the workstation screen as contour maps or images. The user can produce statistics at the workstation console, an enormous improvement in efficiency in the preliminary data analysis phase of research.

Climate Diagnostics Studies

Studies of tropical–middle-latitude interactions were performed. Outgoing Longwave Radiation (OLR) data were filtered to separate fluctuations on time scales of weeks, months, and longer. These filtered data were used to define particular periods of convection in the tropics. Composites of geopotential height were calculated on the basis of occurrence of tropical convection in specific regions, and the resulting teleconnection patterns studied. The results show interesting patterns in which tropical convection can have a definite effect on middle-latitude weather events.

Simple model studies were performed to improve our understanding of the effect of tropical heating on the circulation. In one study, the tropical heating was prescribed and allowed to oscillate with a 40-day period over a restricted area of the tropical Pacific. The resulting middle-latitude teleconnections were compared with observations and found to be quite good. This study has improved understanding of the frequency-dependence of tropically generated weather fluctuations. Another study concerned the effect of changes in the vertical distribution of tropical heating on middle-latitude teleconnections. By simply raising the level of maximum heating from 500 mb to 300 mb, the amplitude of the middle-latitude teleconnections was doubled. The results of this study will be helpful in designing observational systems to determine the vertical profile of the components of tropical heating.

A general circulation model was used to study the circulation effects of the sea-surface temperature (SST) anomalies associated with the El Niño–Southern Oscillation warm event of 1986–1987. Five different experiments were performed using identical SST forcing. The model responses were different, however, because of unstable atmospheric flow. The results of this study so far show that the climate signal forced by the SST anomalies is one of the observed teleconnection patterns. However, the model response has substantial differences from case to case. Investigations are under way to determine the primary cause(s) of these differences.

Plans FY 91

Data Set and Workstation Development

- Continue progress toward the next update and release 2 of COADS. An improved trimming procedure will be developed and applied, with documentation of its effects.
- Expand workstation software. The number of on-call statistical routines will be increased; new data sets will be incorporated; and, most important, the software will be modified to run on a variety of scientific workstations.

Climate Diagnostics Studies

- Begin a study of climate variability and the mechanisms of long-term climate change over the Atlantic Basin. The goal of the study is to examine and document decadal time-scale fluctuations over the past century and to relate fluctuations in surface fields such as sea level pressure, surface winds, sea surface temperature, and cloudiness to one another.
- Continue model studies of the effects of changes in heating on middle-latitude circulation. The issues to be examined include the relative importance of tropical versus middle-latitude heating in generating middle-latitude climate anomalies.
- Continue general circulation model experiments on the effects of sea surface temperature anomalies. The causes of variation from case to case will be a major emphasis.
- Continue observational studies linking changes in tropical heating and middle-latitude circulation. The focus will shift to relating tropical heating anomalies to classes of middle-latitude weather events, such as intense cold fronts.
- Relate the annual cycle of low clouds in the eastern equatorial Pacific to changes in surface fields, such as SST and sea level pressure. Boundary layer structure and energy fluxes at the ocean surface will be examined.

SPECIAL PROJECTS AND OBSERVATORY PROGRAMS

Accomplishments FY 90

The Arctic radiosonde data archive activity was expanded with the acquisition of a nearly complete series of soundings from the Soviet ice stations and digitizing of the U.S. Ptarmigan dropwindsonde files. The archive now holds nearly 1 million soundings starting in the 1930s. Of these, less than 20% have been analyzed for climate trends.

Two successful airborne research programs were undertaken for the U.S. Army White Sands Missile Range where some of the first high-resolution vertical profiles of aerosol soot carbon were obtained. These profiles showed the presence of layers of soot in the free troposphere.

In August the group instrumented and flew the NOAA WP–3D for 50 flight hours in the San Joaquin Valley Air Quality Study. This large program has the goal of determining the distribution and causes of crop-damaging ozone in the central valley of California in summer.

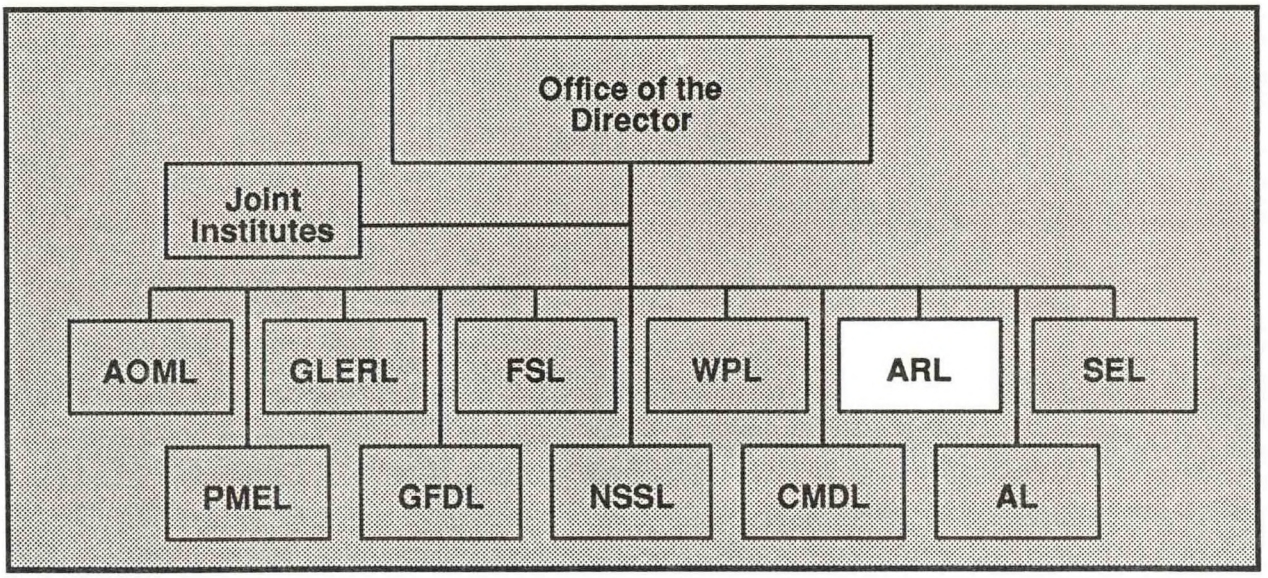
As part of an ongoing study of arctic climatology, monthly mean tropospheric temperatures were calculated from the thickness of the 850–700 and 700–500 mb layers for each of 1977 points in an octagonal grid centered on the North Pole for the period 1960 to 1989. Temperature trends were estimated by comparing mean values of the first and last 13-year periods of the record. Temperature increased an average of 0.5°C in the 850–700 mb layer and 0.2°C in the 700–500 mb layer. Changes in the winter season dominated, with warming of as much as 3°C in the 850–700 mb layer over Alaska and the Tibetan plateau and cooling in the northern Pacific and over western Europe. The warm-cool couplet associated with the mean position of the Aleutian low indicates a systematic winter season change in its position and/or strength.

At the four baseline observatories, we hosted numerous cooperative research projects operated by outside agencies, universities, and institutions. These cooperative projects complement in-house CMDL monitoring. During the past year, 36 such projects were conducted at the observatories, including 7 for aerosol research, 8 for greenhouse gases, 6 for isotopes, 3 for precipitation chemistry, and 4 for solar and terrestrial radiation. Examples include detection and characterization of PSCs over the South Pole (University of Rome and University of Wyoming), isotopic characterization of atmospheric carbon for defining sources and sinks of CO_2 and CH_4 (University of Washington, Scripps Institution of Oceanography, and CSIRO), characterization and detection of long-range transport of atmospheric aerosols as an indicator of regional and hemispheric exchange (University of Washington, University of California at Davis, University of Miami, and USDOE/EML), and detection and characterization of tropospheric chemical processes (University of Rhode Island and NCAR).

Plans FY 91

- Complete analyses of the AGASP–III NOAA WP–3D arctic haze research data. Continue planning, instrument development, and aircraft preparation for the international AGASP–IV/LEADEX arctic leads program, Alaska coast to the North Pole, March–April 1992.
- Conduct two airborne field programs (NOAA King Air and NCAR Saberliner) to measure aerosol light absorption and scattering above White Sands Missile Range for the Department of Defense High Energy Laser Program.
- Compute and analyze predictive air trajectories for blast debris transport, and conduct in-situ airborne aerosol measurements for the Defense Nuclear Agency High Energy Test Blast project, Yucca Flats, NM.

- Complete error checks and make available to the climate research community in a single, user-friendly format a computerized radiosonde and dropwindsonde data archive comprising all available soundings (through 1989) taken in the Arctic, including all Soviet and ship soundings.
- Continue analyses of the NOAA WP–3D airborne data collected on the San Joaquin Valley Air Quality Study.
- Continue sampling and analyses of Antarctic and Arctic phyloplankton for bromine production and document further results of the bromine ozone destruction phenomenon in both polar regions.
- Update historical analysis of Arctic temperature to 1990, using 850–500 mb thickness; recomputate trends at each grid point for better resolution of the geographical distribution of interannual changes, and extend the analysis to the 1000–850 mb layer.
- Continue the program of cooperation with universities, research institutions, and other government agencies. A major project (MLOPEX) at Mauna Loa will involve several institutions in a second extensive series of photochemical gas measurements. Requests to establish cooperative research programs at the baseline observatories should be addressed to the director of the Laboratory.



AIR RESOURCES LABORATORY
Silver Spring, Maryland
(301) 427–7684
Bruce Hicks, Director

Air Resources Laboratory (ARL) research is geared to needs both of NOAA and of other Federal agencies with related missions. These other agencies include the Department of Energy (DOE), the Department of the Interior, the Department of Defense, the Nuclear Regulatory Commission, the Federal Aviation Administration (FAA), and the Environmental Protection Agency (EPA). The general areas of study relate to Air Quality and Climate, with research focusing on turbulence and diffusion in the atmosphere, global transport of pollutants, meteorology of air pollution, air-surface exchange (including both wet and dry deposition), and global climate change. The work includes observational and theoretical studies as well as instrument and model development. ARL is the official government source for information on atmospheric transport and diffusion to guide emergency responses.

ARL consists of a Headquarters Group in Silver Spring, MD; the Field Research Division in Idaho Falls, ID; the Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, TN; the Atmospheric Sciences Modeling Division (ASMD) in Research Triangle Park, NC; and the Aerosol Research Section (ARS) in Boulder, CO. Integrated research programs among the various ARL organizations focus on Air Quality and Dispersion, Fluxes and Air-Surface Exchange, and Emergency Response and Preparedness, with an evolving theme on Global Climate Change.

AIR QUALITY AND DISPERSION

FIELD STUDIES

Accomplishments FY 90

The Western Atlantic Ocean Experiment (WATOX) came to a close in FY 90. The results show that about 30% of the emissions of sulfur in North America leave the continent by transport across the Atlantic coast.

Much of ARL's recent field research on air quality has been directed to improving understanding on the sources and sinks of ozone near the surface, especially in remote environments. Surface, aircraft, and tethered-balloon ozone observations were gathered as a part of DOE's ASCOT (Atmospheric Studies in Complex Terrain) field study conducted in Oak Ridge, TN, early in 1990. Experimental teams from Argonne, Los Alamos, Lawrence Livermore, and Pacific Northwest National Laboratories and from the University of Kansas participated. The observations involved the measurement of eddy fluxes using the aircraft and tower systems recently developed by ATDD, as well as profiles of ozone concentration measured using tethersondes. The data are of special interest because the ridge-valley terrain complicates the way in which various chemical and physical processes cause local changes in ozone concentrations. ATDD provides the field directorship of the ASCOT program.

A similar field program was conducted as an ARL contribution to the Rural Oxidants in the Southern Environment (ROSE) field program in Alabama, led by the ERL Aeronomy Laboratory during summer 1990. ATDD provided tethersonde/ozonesonde observations, tower-based meteorological and flux measurements, and airborne flux measurements using a new mobile flux facility. Extensive time records and spatial averages of eddy fluxes of sensible and latent heat, momentum, O_3, and CO_2 were determined; more than 45 flight hours of eddy flux data were obtained.

The Field Research Division had a leading role in the study of ozone and oxidants during 1990 in the San Joaquin Valley, CA. The program had two goals: (1) to provide decision makers with an improved understanding of the causes of excessive ozone concentrations in the valley, and (2) to provide estimates of the consequences of different emission control strategies. About 75 measurement sites were set up; hourly meteorological and air quality data were collected from 55. Intensive measurements were collected during 11 selected days between 13 July and 6 August. The Aerosol Research Section also participated in the San Joaquin study, through a contract with the University of Wyoming. On one day of intensive measurement, ozone concentrations exceeded 200 ppbv at some locations.

ARS was involved in the Lake Michigan Ozone Study conducted during July 1990. The NOAA King Air flew 15 research flights during the experiment. Each flight mapped a vertical cross section of the atmosphere above Lake Michigan from the surface to 2.5 km above the lake.

ASMD conducted field tests of the Regional Acid Deposition Model (RADM). The second field effort in the Acid Model Evaluation Study (ACID–MODES II) began in April 1990, in Columbus, OH. The NOAA King Air aircraft was operated as one of two aircraft participating. The results of this field evaluation are critical to the acceptance of the integrated assessment of effects of acid rain, now being finalized by the National Acid Precipitation Assessment Program (NAPAP).

Evaluation of micrometeorological flow data and tracer data obtained by ASMD in the Integrated Air Cancer Program experiment in Boise, ID, led to new theories of drainage flow in valleys. This development will aid modeling of pollutants from low-level sources such as wood fires and foundries in nighttime, stagnant conditions.

ATDD participated in the first field experiment of the Mexico City Air Quality Research Initiative (MCAQRI), 10–12 September 1990. MCAQRI is a 3-year program jointly funded by the Mexican Petroleum

Institute (IMP) and DOE to study the air pollution problems of Mexico City, train IMP personnel in data collection techniques, and help Mexican authorities identify options for improving Mexico City air quality.

Plans FY 91

DOE's ASCOT program is shifting attention to the flows emerging from the Front Range of the Rocky Mountains onto the plains south of Boulder. ATDD will participate in an initial study during December or January, timed to coincide with gaseous tracer and tetroon releases near DOE's Rocky Flats facility. WPL will use several radar profilers to determine winds aloft; winds closer to the surface will be measured by a tower network, several mini-sodars, and low-altitude tethersondes. Work on the 1990 study near Oak Ridge will also continue.

The role of gravity waves as modifiers of atmospheric dispersion will be examined in a series of coordinated modeling and field experiment projects. As a component of these studies, ATDD will join a National Center for Atmospheric Research (NCAR) field program this fall at a site in Wyoming to measure the turbulent kinetic energy balance in a horizontally homogeneous surface boundary layer. ATDD will operate a microbarograph network to observe the effects of gravity waves on planetary boundary layer (PBL) turbulence.

The second MCAQRI field experiment will be conducted in Mexico City during February. ATDD will again measure ozone and meteorological profiles. This study may include remote-sensing equipment (lidar) and aircraft sampling of atmospheric constituents.

MODELING STUDIES

Accomplishments FY 90

The influence of biogenic nonmethane hydrocarbon (NMHC) emissions on regional ozone is of steadily increasing interest. Tests using the Regional Oxidant Model (ROM) showed that the relative effects of biogenic compared with anthropogenic NMHCs on ozone production vary spatially over the northeastern United States. In regions where biogenic NMHC emissions dominate and where anthropogenic NO_x emissions are high, reductions in anthropogenic NMHC emissions may not be very effective in lowering O_3 levels. In areas where biogenic NMHCs are less important, reduction of anthropogenic NMHCs may be quite effective in reducing O_3 concentrations.

A joint multiyear project was initiated between the Atmospheric Sciences Modeling Division and the Aeronomy Laboratory (AL). A protocol was developed for a joint model intercomparison program; this includes diagnostic and operational model evaluations for RADM, ROM, and the AL regional models.

A set of computer programs was developed to enable the photochemical Urban Airshed Model to be driven by various outputs of the Regional Oxidant Model. ROM simulations for the northeastern United States provide initial and inflow boundary concentrations for UAM applications in major metropolitan areas in support of ozone reduction strategies. The interface programs also incorporate gridded meteorological parameters, surface characteristics, and biogenic emissions data.

A major evaluation of long-range transport and dispersion models across North America using the ANATEX data base (generated by ARL) was completed. Transport errors for state-of-science models were calculated for the first time on continental scales, permitting more realistic warnings to be issued in the event of accidental releases of hazardous materials into the air, for example.

An advanced state-of-the-science aerosol chemistry and dynamics module was developed, and incorporated into the RADM system. The modified RADM will be used to study and assess regional aerosol levels

and particle size distribution. The assessment version of the RADM was completed and documented for the NAPAP Integrated Assessment. The model was used to provide answers to key scientific questions of acid transport and deposition, including the investigation of nonlinearity of emissions versus deposition reduction.

An aggregation approach was integrated into the RADM to obtain annual average deposition values of sulfate from 5-day episodic calculations for use in the NAPAP Integrated Assessment. The technique was also shown to be usable for nitrate deposition.

Gravity waves in the PBL generated by two- and three- dimensional terrain features were investigated, using a linear wave theory model that includes energy reabsorption at a critical level. It was found that, for even mild terrain perturbations, the Reynolds stress and surface drag caused by these waves can be as large as those associated with surface friction, for typical values of wind speed and thermal stratification in the stable PBL. A climatological study over both simple and complex terrain showed that wave breakdown events and resulting wave-turbulence interactions account for much of the nighttime exchange of momentum, heat, and pollutants between the atmosphere and the ground.

ATDD developed an improved Gaussian puff model, VALPUFF, as a practical tool for modeling dispersion of pollutants released into the drainage flow in a deep valley. This model uses vertically averaged winds and dispersion parameters based on on-site turbulence measurements, and provides a physically realistic simulation of the mean transport for highly variable emission rates and heights or meteorological conditions near the source. The model was evaluated against the 1984 ASCOT tracer data. Concentration fields appear to be simulated well, but more work needs to be done to improve predictions of rates of movement of puffs of pollutants.

Special attention was devoted to the issue of toxic pollutants in several important environments (e.g., Chesapeake Bay, the Great Lakes, and Antarctica). For Antarctica, the issue concerns trash disposal practices by the scientific stations operating there.

A new chemistry module was developed for the HY–SPLIT long-range transport model. The module is constructed to permit consideration of gas and aqueous phase oxidation of sulfur dioxide, and dry and wet removal of sulfur dioxide and sulfate particles in a Lagrangian framework. The model has been tested with data collected at State College, Pennsylvania.

Plans FY 91

The ROSE data will be used to investigate differences in existing regional oxidant photochemical models. Field study data bases from the summer 1988 eastern United States (Eulerian Model Evaluation Field Study) and the upcoming Southeast Regional Oxidant Network campaigns will also be used.

Wind data collected in the meteorological survey of the Oak Ridge region during a 3-week period in February–March 1990 (coinciding with the ASCOT field experiment) will be analyzed. Statistical tools and model simulations will be used. The analysis is aimed at developing useful techniques to ensure that discrete observations adequately represent pollutant transport in puff-trajectory models. The models can be particularly useful for assessing risk of hazardous material releases.

ATDD will include wind shear, terrain, and density effects in TRIAD (or another suitable model) to investigate pollutant transport in coastal areas and complex terrain. Random walk modeling of turbulent dispersion in complex terrain will be explored using a Lagrangian particle model.

Modeling studies will also focus on regulatory model needs identified in recent workshops:

- An applied model to assess effects of NO_x emissions from small, as well as large, isolated point sources.

- Improved complex terrain models. Available models such as the expanded ASMD complex terrain dispersion model CTDMPLUS can be used in some situations, but further work is needed to cover other topographic circumstances.
- Models for stagnation (wind speeds less than 1 m s^{-1}) situations. There is no currently approved applied model that can adequately assess pollutant effects from dispersion in light and variable wind conditions.
- A model capable of assessing effects of particulates from strip mining operations, taking into account such specific problems as terrain complexity, deposition, and time of day as related to mining activities (e.g., explosions, mining, transport).
- A capacity to include effects of building wakes. Existing models are not applicable close to buildings.
- Direct meteorological research support to EPA will include continued development and evaluation of air quality dispersion models for inert and reactive pollutants and the associated meteorological predictive models. Emphasis will be on the following:
- Modifying the existing puff dispersion model INPUFF to account for dispersion around terrain obstacles.
- Evaluating RADM Version 2.5, and the development of a nested version (grid size reduced from 80 to 20 km) to handle toxic deposition to the Great Lakes and coastal estuaries.
- Incorporating aerosol chemistry and dynamics modules into RADM to convert it to a Regional Particulate Model, and evaluating the new model and its application to western U.S. visibility.
- Developing and evaluating an improved version of the meteorological predictive scheme MM4, previously developed by Pennsylvania State University and NCAR.
- Nesting the Urban Airshed Model into the Regional Oxidant Model to permit "handoff" of regional background conditions to the urban model.
- Determining the contribution of biogenic emissions to ozone loading on rural and urban scales.

ASMD will begin to address human exposure and dose. Efforts will include investigating multi-zone within-building contaminant dispersion simulation models, and techniques to estimate the time series of ambient concentration levels in human exposure modeling.

AIRCRAFT VORTICES

Accomplishments FY 90

A new sensor system was set up to measure vortices from low-flying aircraft, made up of a ground array of 50 sensors extending in a line 1600 m long, and 200 sensors mounted on a tower. New instrumentation was installed, and appropriate calibrations were completed. New smoke canisters were fabricated to accommodate the 4800 smoke grenades to be used in the planned study.

Wingtip vortices will be measured as aircraft fly past the array of instruments. A computer program will plot the measured velocities in a 3–D display. Initial tests of the new sensor system were completed, and experiments were conducted to quantify differences in the vortex patterns left during straight and level flight and 3-degree glide slope flight for a Boeing 727 aircraft.

Plans FY 91

Studies of aircraft wakes will be expanded under an interagency agreement to provide meteorological support to FAA's turbulence program. Cooperative work is also planned with the Frankfurt [Germany] Airport Authority, Lufthansa German National Air Lines, the German Air Traffic Control Service, the Meteorological Institute at the Technical University in Hanover, and the German National Aerospace Research Establishment.

BACKGROUND MONITORING

Accomplishments FY 90

Under the sponsorship of the World Meteorological Organization (WMO), a small group of international experts met in Silver Spring, MD, to discuss the status of WMO's Background Air Pollution Monitoring program (BAPMoN), especially the precipitation chemistry part. As a result, these recommendations were presented to the WMO Executive Council:

1. Establish a new system for site accreditation.
2. Develop one-to-one monitoring ties between developed and third-world countries.
3. Improve the archiving system by adopting new data insertion techniques.
4. Strengthen WMO control of the network day-to-day operations.

ARL participated in an extensive review of global turbidity monitoring programs, under the auspices of WMO. The conclusions are being refined, but it is clear that existing routine turbidity measurement programs need to be modified.

Plans FY 91

A summary of the status of precipitation chemistry measurements made under the auspices of WMO will be completed. A report to WMO concerning the operation of global turbidity monitoring networks will also be completed.

FLUID MODELING

Accomplishments FY 90

Wind-tunnel measurements were conducted to simulate downwash in the immediate lee of a stack when the effluent speed is small compared with the windspeed. Under a Cooperative Research and Development Agreement with the Georgia Institute of Technology, models were used to study the design of effluent discharge risers proposed for use in Boston harbor. It was concluded that 45 risers, instead of 80, would suffice. This reduction should result in a savings to Massachusetts of $25 million.

Plans FY 91

Wind tunnels, a convective tank, and a water channel/towing tank will continue to be used to study flow in complex terrain, flow around buildings and other such obstacles, basic characteristics of boundary layer flow, and dispersion of gas plumes in air and water. Dense gas jet behavior will be investigated (in cooperation with the University of Hamburg) and concentration fluctuations in plumes will be studied (in cooperation with the Los Alamos National Laboratory).

Wind tunnel experiments on turbulent mass transfer near structural components (walls, columns, etc.) and on monuments will continue, in collaboration with the National Park Service. Flow visualizations will be emphasized, to aid in interpretation of the mass transfer results and improve understanding of the contributing processes.

FLUXES AND AIR-SURFACE EXCHANGE

DEPOSITION (INCLUDING ACID DEPOSITION)

Accomplishments FY 90

Wet Deposition

An analysis of event precipitation chemistry data revealed that background levels of rainfall acidity across the northeastern United States ranges between pH 5.0 and 5.2, a single value of 5.3 being found for a high-altitude site. The methods rely on statistical examination of data obtained at locations where the weekly-averages yielded by routine monitoring networks are not appropriate. Efforts were initiated to ensure the continued operation of the existing network of event-monitoring locations (the so-called MAP3S network), since these provide the only opportunity to investigate the detailed characteristics of precipitation chemistry and the causes of any changes that might occur.

The influence of urbanization on precipitation chemistry was assessed by comparing two neighboring locations in Mississippi. The results indicate that the urban area was slightly more affected by pollution than a nearby rural region, but that the concentration difference was less than 10% for sulfate, nitrate, and hydrogen ion concentrations.

Results obtained in the operation of the Global Precipitation Chemistry Network (operated by the University of Virginia for ARL) revealed that organic acids are likely to have an increasingly important role as the effects of proposed sulfur emission regulations and controls are felt across North America. Once again, intensive event monitoring of precipitation chemistry is needed to measure the presence of these organic acids; weekly accumulations of deposited rainfall are not adequate.

Plans FY 91

Wet Deposition

Plans for a possible remote precipitation monitoring site in the Soviet Union will be refined.

Dry Deposition

The site-specific inferential approach for estimating dry deposition will be extended to characterize dry deposition across 80x80 km areas in the vicinity of each measurement site. Starting in FY 92, the ARL inferential approach will be used by the EPA's National Dry Deposition Network for reporting annual dry deposition amounts of sulfur dioxide, ozone, sulfate, and nitric acid.

ATMOSPHERE-SURFACE EXCHANGE

Accomplishments FY 90

There is a growing recognition that the terrestrial sink of CO_2 might now be underestimated. In early 1990 ARL held a workshop on detecting terrestrial sinks for CO_2. The purpose was to bring together the global-scale modelers who are trying to infer fluxes of CO_2 over small scales, and the experimentalists who measure fluxes on a small scale. The primary question addressed was —How do we measure and describe the surface sink associated with specific regions of the Earth in global-scale numerical models and in global budget calculations? Research projects have been proposed to address several issues related to the areal integration of air-surface exchange relationships, such as the effects of topography and changes in vegetation. In essence, the homogeneous-surface relationships that are commonly used in numerical models will necessarily lead to an underestimate of the exchange rates.

A new fast-response water vapor and CO_2 sensor developed at ARL performed well in field tests. The sensor was used with a new aircraft turbulence package to measure eddy fluxes over land, for comparison with tower data. Initial tests showed good agreement for sensible heat, water vapor, ozone, and CO_2 fluxes.

From 8 to 23 June, a trial experiment was conducted in the Florida Keys to evaluate the performance of several ARL instrument systems, and to measure fluxes of momentum, heat, water vapor, and CO_2 over the sea, on a beach, and over the intervening water. The primary objectives of the experiment were to demonstrate the ability of the infrared gas analyzer to measure CO_2 fluctuations over the sea, and to test the feasibility of deploying the Mobile Flux Platform system on a pontoon boat. The original system was mounted on a light airplane to traverse the path between the moored boat and the tower on the beach. Preliminary comparisons between flux systems show agreement to within 20% for the sensible and latent heat fluxes, which were about 30 W m^{-2} and 140 W m^{-2}, respectively.

ARL is playing a strong part in the planning of the international Marine Aerosol and Gas Exchange (MAGE) program, a component of the International Global Atmospheric Chemistry Program. A highly successful symposium (The Role of the Oceans as a Source and Sink of Trace Substances That Influence Global Change) took place at the 70th Annual Meeting of the American Meteorological Society under ARL sponsorship; the first global estimates of deposition of nutrients, trace metals, and organics to the world oceans and inland seas were presented.

Tests were conducted by ATDD to evaluate the ability to measure eddy fluxes within forest canopies. Data on forest floor SO_2 and O_3 deposition indicate virtually no surface uptake resistance for SO_2 during wet conditions. An attempt is being made to quantify the total aerodynamic resistance, so that the surface resistance for dry conditions can be evaluated. The O_3 data, on the other hand, show virtually no effect of surface wetness on the deposition rate. The results from this work will be used to refine the ARL multi-layer inferential model of air-surface exchange. Work is continuing on the analysis of CO_2 efflux data from the soil at the Walker Branch Watershed. An analytical box model has been developed to describe the processes influencing soil evaporation.

Plans FY 91

More tests will be conducted of the new Mobile Flux Platform. Specific tests will be conducted to assess our ability to minimize the consequences of ship motion, and to provide an improved absolute verification of the fluxes that are measured. The studies will focus on the fluxes of sensible heat, water vapor, momentum, ozone, carbon dioxide, methane, and various sulfur and nitrogen gases.

The multi-agency Atmosphere/Ecosystem Gas Interchange Study (AEGIS) proposes to measure momentum, heat, water vapor, CO_2, and methane fluxes over a peat bog in northern Minnesota; such areas are common in northern latitudes, but little is known about their capacity as sources and/or sinks for radiatively important and climatically relevant trace gases. If funding is available, work will begin in FY 91, and continue for two more years. A wide variety of measurement systems (enclosures, towers, and aircraft) will be used. Mathematical models of the various transfer processes will be developed and exercised. ATDD will participate in flux measurement and modeling.

During the spring of 1991, ATDD will participate in a field experiment with Southwest Sciences, Inc. (Santa Fe, NM) to evaluate the performance of a new open-path infrared instrument for direct eddy correlation measurement of fluctuating methane concentrations. This instrument is being developed with Phase II Small Business Innovative Research funding.

EMERGENCY RESPONSE AND PREPAREDNESS

EMERGENCY ASSISTANCE

Accomplishments FY 90

ARL has a historic involvement in advising other agencies (and in providing direct warning to the public) in the event of accidents involving nuclear materials. ATDD provides emergency assistance to DOE's Oak Ridge Operations Office. A principal goal is to ensure DOE ready access to reliable dispersion models that are appropriate for the terrain and other conditions of specific sites. During 1990, an intensive site survey of the Oak Ridge area was conducted. This involved the erection of an array of meteorological towers to investigate local dispersion, as might affect response strategies in the event of an atmospheric release of hazardous materials.

The Oak Ridge site survey study provided background information for an intensive study of transport and diffusion across the area, conducted as a major field investigation of the DOE complex terrain dispersion community (the ASCOT program, with field operations led by ATDD), conducted in March 1990.

Work started on setting up an advisory service to work with the headquarters of the Nuclear Regulatory Commission. The intent is to provide objective guidance in planning for response to nuclear accidents, and to provide expertise in the event of an atmospheric release.

Plans FY 91

A new computer system will be developed to bring together the site-specific modeling capabilities of the Oak Ridge group and the larger-scale trajectory modeling capabilities of the Silver Spring group.

GLOBAL CLIMATE CHANGE

CLIMATE DIAGNOSTICS

Accomplishments FY 90

The ARL record of global tropospheric and low-stratospheric temperatures, beginning in 1959, was updated through the summer of 1990. Between 1979 and 1988 there was a correlation of 0.98 between these global temperatures and the tropospheric temperatures obtained from satellite microwave sounding, showing the robustness of both data sets. 1989 was a cooler year than 1988, but when the adjustments were made for the influence of sea-surface temperatures in the eastern equatorial Pacific, 1989 was the warmest year of the record.

The 300-mb north-polar vortex was more contracted in 1989 (6% less than average size) than in any year since the record began in 1963, which is consistent with adjusted 1989 warmth.

Rocketsonde data were updated through 1989 and continue to show a stratospheric cooling of about 1$C per 10 years. There is a good in-phase relation between these rocketsonde temperatures and sunspot number.

During 1962–1989, there were six years when the June-July-August (JJA) sea-surface temperature in the eastern equatorial Pacific, and the JJA average of 50-mb and 30-mb temperatures at Singapore both increased from one year to the next. On all six occasions these increases were accompanied by a decrease in October–November total ozone at the South Pole (i.e., the Antarctic ozone hole deepened). It is likely that the JJA sea-surface temperature will increase between 1989 and 1990 (nascent El Niño) and that the average of 50-mb and 30-mb JJA temperatures at Singapore will increase between 1989 and 1990, owing to the phase of the quasi-biennial oscillation. Accordingly, on the basis of this limited sample, the Antarctic ozone hole would be expected to be even deeper in 1990 than in 1989.

The records of U.S. cloudiness and sunshine, beginning in 1950, were updated through spring 1990. Both quantities were near their long-term averages in 1989.

A collaborative program to study tropospheric humidity was initiated with GFDL. Global radiosonde data sets are being compared, and also the techniques used to process them. Initial results indicate about a 20–25% increase in specific humidity if CO_2 concentrations double, but no substantial change in relative humidity.

The first stage of a WMO international survey on radiosonde instruments and practices, proposed by ARL, was completed. This is an effort to unearth information about past changes in the radiosonde network that could influence interpretation of archived radiosonde data and confound efforts to study climate variations. ARL is providing a WMO Rapporteur on Historical Changes in Radiosonde Instruments and Practices. Some responses to initial inquiries of national meteorological authorities have already been received in Geneva, and the second, more detailed survey is in preparation.

Global total ozone and ozone profiles were updated through 1989. Global total ozone increased by about 3% between 1985 and 1989 in association with the increase in sunspot number during that period. Recent data suggest that the global total ozone has begun to decrease as the sunspot number declines. During the last 11-year sunspot cycle the total ozone decreased by about 2% globally.

ASMD staff conducted a study of the agreement between model predictions of climate of the recent past and actual climate records. The first task was to compare winds and surface pressure produced by the present-climate GFDL simulation with contemporary observations, spanning the years 1950–1979. To make this comparison, a "correction" to the GFDL surface pressures was applied, to convert to sea level pressures. A climatology of wind and pressure data in coastal areas of the United States was prepared, using COADS data; additional maps of wind and pressure fields are now being prepared.

Plans FY 91

The temperature, cloudiness and sunshine, and ozone monitoring programs will continue, as will the monitoring of tropospheric water vapor. The effects of changes in U.S. radiosonde instrumentation and practices on humidity records will be completed and a similar study of worldwide radiosonde data undertaken. A study of the relations among the changes in moisture variables over time will be initiated.

ARL has become more involved in the study of global climate change and its effects on regional climate and air quality. Future activities will include the evaluation, use, and linkage of global circulation, regional air quality, and biospheric models; and the development of appropriate exposure and climate scenarios for use in assessing the ecological effects of climate change.

AEROSOLS AND RADIATION

Accomplishments FY 90

Monitoring aerosols and radiation is no longer a major ARL activity; this work was moved to the new ERL Climate Monitoring and Diagnostics Laboratory set up in FY 90. A new ARL Aerosol Research Section (ARS) was created at Boulder, with a focus on the sources and sinks of aerosols rather than on their concentrations and time trends.

The ARS participated in the 8th U.S.A.-P.R.C. cooperative research cruise, operated under the NOAA/TOGA program. The 50-day cruise of the western Pacific Ocean began at Guangzhou on 25 May 1990. The intent was to investigate linkages between marine biomass, air chemistry, cloud microphysics, radiation budget, and precipitation amount and quality. Measurements included concentrations of dimethyl sulfide in seawater and in the air, sulfate aerosols, condensation nuclei, cloud cover, solar radiation, rainfall, and precipitation chemistry.

The sensitivity of broad-band ultraviolet measurements to aerosols and total column ozone was examined in cooperation with scientists from the Universities of Michigan, Florida, and North Carolina. This was an effort to determine the limitations of broad-band measurements for determining trends in the ultraviolet regime at the Earth's surface.

Plans FY 91

ARS will collaborate with the U.S. Department of Agriculture on the long- range transport of wind-blown dust, in the context of "Climate and Global Change." Agriculture Canada may also become involved.

The NOAA King Air research aircraft will sample orographic clouds near Price, Utah, in an early 1991 field study. The aircraft will measure meteorological variables, cloud liquid water content, sulfur hexafluoride (a tracer), and silver iodide (a cloud seeding agent).

Work will continue, to evaluate instrumentation needed for making UV-B measurements to detect long-term trends for the assessment of human and ecological exposure. A report on the results of instrument comparison studies will be prepared during FY 91.

ATDD will continue work in DOE's new program for Atmospheric Radiation Measurements. A number of elaborately instrumented sites will be established to evaluate and parameterize surface energy budgets and fluxes for a wide variety of surface types and atmospheric conditions. ATDD staff serve on the Site Operations Committee, and will also participate in experiments.

TRACER STUDIES

Accomplishments FY 90

A year-long plume trajectory study was started for DOE at its Rocky Flats (Colorado) facility. The intent is to produce a representative climatology of plume transport during all times of day and all seasons. Each tracer test involves releases of constant-density tetroons, tracked for distances of up to 80 km, using ground-based radar. The program is also supporting ongoing analyses of the "Denver Brown Cloud," an air pollution phenomenon of great concern in the same area. In July three Brown Cloud studies took place, with release of 21 tetroons, some from downtown Denver and some from the Greeley area.

A meteorological transport and deposition interpolation model was developed to estimate deposition of radioactive iodine (^{131}I) in areas remote from the Nevada test site. Use was made of the predicted position and distribution of the radioactive cloud and precipitation scavenging. The source of the ^{131}I was the nuclear weapons test series at the Nevada test site between 1950 and 1970. Precipitation scavenging coefficients were determined statistically. Every county in the United States can be assigned a deposition value of ^{131}I, for use in assessing likely health effects.

Plans FY 91

Tracer studies conducted at the Rocky Flats facility will continue through April 1991. Balloon tests will also be conducted for comparison purposes as part of a major tracer study in December 1990 through January 1991.

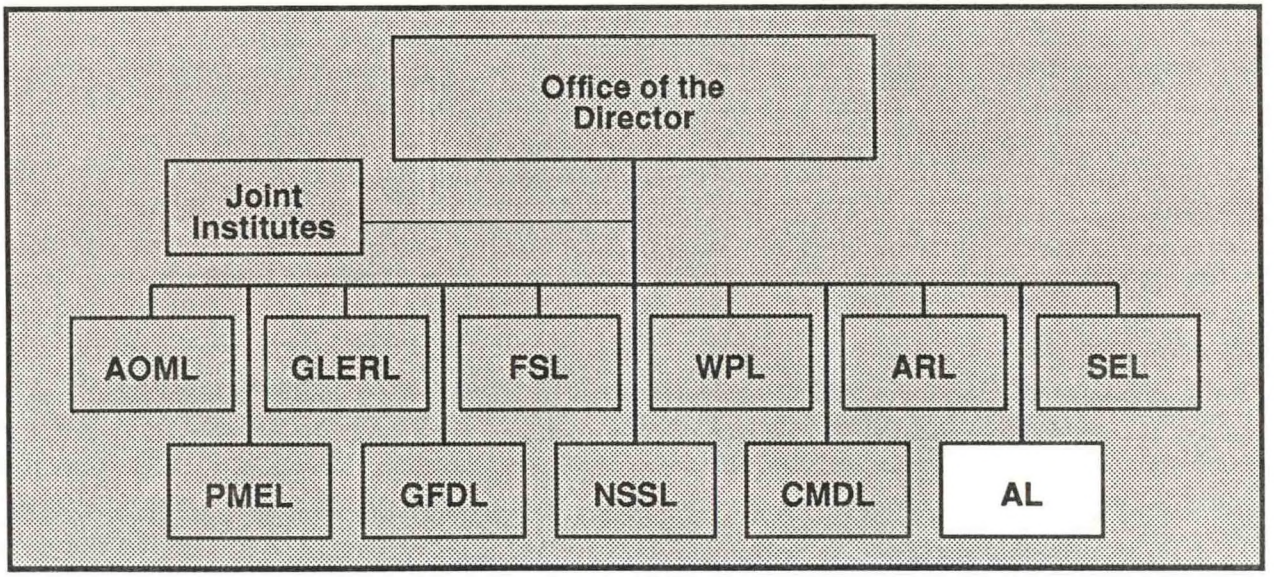
A capability for making horizontal dust flux measurements near the surface will be developed, to provide a better understanding of the regional sources and sinks of desert dust. In addition, a vertical flux capability will be developed, for selected chemical trace species (gaseous and particulate) aboard aircraft. Two approaches are envisioned. First, the new eddy flux system will be adapted to the NOAA King Air research aircraft. Second, ARS and NCAR will develop and test a new intermittent chemical flux sampling system.

In cooperation with CMDL, ARS will measure aerosol black carbon, condensation nuclei, and aerosol backscatter over White Sands, NM, at altitudes as high as 12 km above sea level. Previous measurements have extended to only 6 km altitude.

ARS will participate in a NOAA-supported winter cloud physics research project, based in Provo, UT. The purposes are to study the turbulent flow over mountainous terrain, to measure the amount of liquid water available for conversion to ice in orographic clouds, and to determine whether a cloud- seeding agent (AgI) can convert the available liquid water to ice in these clouds.

Participation in the Lake Michigan Ozone Study will continue, to determine why occasional high-ozone episodes occur along the urbanized western shore of Lake Michigan. The NOAA King Air will be used to map the concentrations of ozone and its precursors above and across Lake Michigan. Aerosol emission models will be improved and applied to the problem of detecting land degradation that might result from climate change. The most critical parameters affecting dust emissions are wind stress, vegetation (expressed as the ratio of frontal area of the vegetation to the total ground area), and the size distribution of soil particles. Field programs will be conducted to test the existing model, and to provide a basis for its improvement.

ARS plans several research cruises to measure atmospheric aerosols and gases along coastal waters and over open ocean to improve our understanding of the biogeochemical cycles of S, N, Fe, and Si compounds; these are of interest in the context of global climate, air quality, and ecology.



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 (ENSO), 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. The phenomena are basic to many areas of geophysics, including meteorology, climatology, pollution dispersal, oceanography, and space physics.

Wave and turbulence fluctuations have a striking effect on transport of pollutants and were intensively observed as long as 3 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 90

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:

- A new, unique theory of turbulence was developed. This work vastly simplifies existing theories and makes it possible to derive analytic formulas of turbulence details for the first time. This theory is a major advance of our principal goal.
- Our pressure strain (correlation of pressure and velocity) formula was generalized to include time-varying turbulence.
- The diffusivity of stably stratified turbulence was determined and tested.
- The first theory for the effect of spatially varying advection on turbulence spectra was initiated. The effect is critical for boundary layer predictions.

Atmospheric Gravity Waves

- The first nonlinear theory was developed for the spectrum of many interacting gravity waves — the wave condition most typical of troposphere, stratosphere, mesosphere, and oceans. It is based on a new concept of scale-dependent diffusion.
- This theory was applied to predict the total energy of gravity waves at every height.
- A theory was initiated to explain the ubiquitous -3 spectral power law of stratospheric and oceanic variability.
- With Utah State University, a new kind of radar (Imaging Doppler Interferometer) was used to study gravity wave breaking.
- A major dissipation mechanism of gravity waves was discovered.

Plans FY 91

Turbulence Modeling

- Apply new (turbulence) theory to derive analytic formula of wind shear turbulence.
- Initiate calculations of the correlations between pressure and energy.
- Continue theory for prediction of turbulence spectra in boundary layers — the most difficult task in our (major) program to derive a reliable model of planetary boundary layer turbulence.

- Complete theory for the effect of height-varying advection on turbulence spectra.

Atmospheric Gravity Waves

- Determine the spectrum of saturated (maximum amplitude) gravity waves.
- Determine the source of atmospheric waves in the atmosphere.
- Investigate Stokes drift and its relation to transport.
- Complete the theory of -3 spectral power law.
- Continue major effort to determine the nonlinear properties of gravity waves from a rigorous approach. It is this nonlinearity that ultimately governs transport.

ATMOSPHERIC CHEMICAL KINETICS

This program investigates chemical and photochemical reactions that take place in the Earth's atmosphere. These processes are studied in the laboratory under chemically isolated conditions to obtain data for individual reactions. These data are used in understanding the effects of both natural and anthropogenic chemicals on the environment. Environmental problems such as photochemical air pollution, acid precipitation, global warming, and stratospheric ozone depletion are addressed. Most atmospheric reactions involve free radicals, which are highly reactive molecular fragments. Radical reactions are studied directly, using a variety of production and detection methods to investigate isolated chemical processes. Reaction rate coefficients, optical absorption coefficients, quantum yields, and reaction mechanisms are examples of the products of this program.

Accomplishments FY 90

- The vibrational line positions and intensities of the OH radical were determined. These spectroscopic parameters improve our knowledge of this key atmospheric molecule and assist in its study in the laboratory and in the atmosphere.
- The fundamental infrared band of the BrO radical was measured and analyzed to determine the spectroscopic coefficients and absorption coefficients. The results have direct application to the measurement of BrO in the laboratory and in the stratosphere.
- Measurements were completed on the OH reactions and UV absorption cross sections of several of the halocarbon compounds being considered as replacements for the ozone-depleting chlorofluorocarbons. These data provide the basis for evaluating the environmental effects of the replacement compounds and for choosing the best alternatives.
- The rate coefficient for the reaction of OH with methane was measured over a large temperature range. A significant error of 25% in the previous values was discovered, resulting in a reevaluation of the atmospheric lifetime and budget of this important trace gas.

- The mass accommodation coefficients of OH and HO_2 radicals on a liquid water surface were measured and found to be very large. These results indicate that the radicals can be rapidly taken up by water droplets.

- The mass accommodation coefficients of N_2O_5 and $ClONO_2$ on ice and solid nitric acid trihydrate were measured. Some of the accommodation coefficients were found to be much larger than previous measurements indicated. These results have important application to the formation of the polar ozone hole.

- A critical evaluation was completed of many important mechanisms needed to model the atmospheric chemistry of sulfur.

- The rate coefficient for the reaction of OH with HONO was measured as a function of temperature. The results indicate that the reaction is not very important in the atmosphere.

Plans FY 91

- The kinetics and mechanisms of the reactions of $O(^1D)$ with the chlorofluorocarbon replacements will be studied.

- The photochemistry of ozone in the 190–240 nm wavelength region will be evaluated.

- The mass accommodation coefficients of $ClONO_2$ and N_2O_5 on sulfuric acid and water mixtures will be measured.

- The effects of D atom substitution in CH_4 on the kinetics of the OH reaction with methane will be determined.

- The spectroscopy of HO_2 in the near infrared will be studied.

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 research contribute to improvements in weather forecasting and the transfer of advanced meteorological measurement technology.

Much of our research is based on data obtained with wind profiler radars (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 velocity.

Accomplishments FY 90

The second phase of development of our Flatland radar near Champaign-Urbana, Illinois, was completed by installing four oblique beams, in addition to the existing vertical beam, so that the horizontal wind as well as the vertical air motion could be measured. The radar has been observing almost continuously since November 1989. We also installed a surface meteorological station and a balloon launching and telemetering system.

We continued our systematic studies of the properties of the atmospheric gravity wave field. Comparison of vertical and oblique measurements of wind fluctuations by the Flatland radar showed that over flat terrain the fluctuations at periods shorter than 6 h are entirely or almost entirely due to gravity waves. We also showed that the fluctuations due to gravity waves consist of bursts of energy from fronts and convection superimposed upon a low background level. Preliminary comparisons with the Urbana MST radar, 23 km to the northeast, were made.

We found that the mean measured vertical air motion in the troposphere is a few centimeters per second downward in all months. We are intensively investigating this surprising result, since whether or not it represents a true vertical motion is very important to the utility of wind profiling radars.

Plans FY 91

Eight sensitive air pressure sensors will be installed in an array around the Flatland radar to detect the passage of fronts and to measure the wavelength and velocity of gravity waves.

We will use oblique wind measurements to calculate the vertical flux of horizontal momentum and wind acceleration in the troposphere and lower stratosphere over very flat terrain. The oblique wind measurements will permit assessment of the relative contributions to the wind acceleration of mountainous and very flat terrain (which, including the oceans, represents at least 80% of the surface of the Earth).

TROPICAL DYNAMICS AND CLIMATE

The research goals of Tropical Dynamics and Climate are an improved understanding of tropical circulations systems and their effect 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 90

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 climate bulletins.

We completed an analysis of the first 4 years of wind observations from Christmas Island. The results reveal an important year-to-year variation in the zonal winds over the central Pacific. The winds observed at Christmas Island depend on the strength of the Walker Circulation, and their variation is related to the phase of the Southern Oscillation.

Substantial progress was made in the construction of a trans-Pacific network of wind-profiling Doppler radars. The Pohnpei, Micronesia, wind profiler was upgraded and now operates with five beams. Additional wind profilers were constructed on Saipan and Darwin, Australia, in collaboration with the Australian Bureau of Meteorology Research Centre. The Saipan wind profiler was used to provide wind observations for the U.S. Navy's Tropical Cyclone Motion Experiment. Construction began on a wind profiler site at Biak, Indonesia.

We deployed several UHF wind profilers in the field for lower tropospheric wind measurement. The first system was installed at Mount Isa, Australia, with the support of Mount Isa Mines Ltd. In late February we

installed a similar system at Christmas Island. A third system was used in cooperation with the National Center for Atmospheric Research (NCAR) for the Hawaiian Rainband Project (HARP).

Lower tropospheric wind profiling technology was transferred to the Wave Propagation Laboratory. WPL has used the 915-MHz wind profiler in several field programs and the two Laboratories have begun the process of technology transfer to the private sector through a Cooperative Research and Development Agreement (CRDA).

Plans FY 91

Our Operations at Christmas Island will continue with TOGA funding, 6-hourly data will be transmitted via satellite to the scientific community, and the high-resolution tapes will be archived by AL.

We plan to complete the construction of a trans-Pacific network of VHF wind profilers. The VHF wind profiler at Biak, Indonesia, will be brought into operation.

Pending additional TOGA support we plan to install with NCAR the first land-based Integrated Sounding System at Manus Island. A lower tropospheric wind profiler system will be installed in the Galapagos Islands.

Collaborative research with the Australian Bureau of Meteorology Research Centre will continue and focus on analysis of the vertical motion data obtained during the first year of operation of the Darwin VHF radar.

We will continue to use the available tropical Pacific rawinsonde data base in studies of coupling mechanisms between the ocean and the 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 and from collaborative experiments. In recent years the principal research activities were focused on problems and issues of global change and regional air pollution such as radiatively important trace gases, tropospheric oxidants, and acid precipitation. The ultimate goal of the program is to attain an understanding of the composition and energy budgets of the atmosphere so that trends can be accurately predicted.

Accomplishments FY 90

In a three-dimensional mesoscale model (60x60 km resolution) study of rural ozone pollution over the eastern United States, we found that convective transport associated with cumulus clouds has a major role in determining ozone buildup. Model calculations that neglect convective transport tend to consistently overpredict surface ozone concentrations that are due to the accumulation of ozone precursors, viz. non-methane hydrocarbons and nitrogen oxides (NO_x). Cumulus convective transport is a subgrid process that has to be parameterized in the model; it is a major source of uncertainty in the model-predicted ozone concentrations.

The budget and photochemistry of ozone and NO_x were studied in collaboration with scientists from our Tropospheric Chemistry program, NCAR, CMDL, and universities. Extensive observations of trace species and meteorological parameters important for evaluation of the budgets of ozone and NO_x were made at CMDL's Mauna Loa Observatory in May and June of 1988 during the Mauna Loa Observatory

Photochemistry Experiment (MLOPEX). The observations provide critical ambient input parameters for model calculations, as well as realistic constraints for testing model results. By modeling the budget balance of CH_2O, CH_3OOH, HNO_3/NO_x, H_2O_2, and NO_2/NO, we found a major discrepancy in model-calculated odd hydrogen (HO_x) concentrations and values inferred from the observations. A new experiment is proposed because the discrepancy may have a fundamental effect on the budget of tropospheric ozone.

Plans FY 91

Research will focus on two projects: (1) three-dimensional model studies of the effects of anthropogenic emissions on the OH levels in the boundary layer over the eastern United States, (2)a study of the tropospheric ozone budget over the western Pacific, in collaboration with our Tropospheric Chemistry Program, CMDL, NASA, NCAR, and universities.

OPTICAL AERONOMY

The Optical Aeronomy Program uses spectral measurements to study fundamental atmospheric processes. The center for the observational program is the Fritz Peak Observatory in the mountains west of Boulder, CO.

Accomplishments FY 90

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 laser light is now being used to measure spectroscopically the OH molecular absorption in the near ultraviolet round trip between Fritz Peak and Caribou Mine 11 km away. The new 2-m echelle spectrograph used for spectral line analysis passed both laboratory and field tests, and has now reached operational capability. A new double reticon array detector was developed and tested for use on the spectrograph and is now becoming operational. OH abundance determinations were made in the summer of 1990; operational measurements are expected in 1991.

Tropospheric Long Path

Recognizing that the chemistry of OH cannot be understood from a single species measurement, we 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. This experiment is now operational at Fritz Peak and producing very-high-quality data.

Stratospheric OH Radical

The ground-based absorption measurements of stratospheric OH continued through FY 90 at Fritz Peak. The average level of OH increased significantly in FY 90 over previous years, and the seasonal behavior of

OH was observed to co-vary with solar activity over the past 10 years. An instrument was deployed in New Zealand and is producing new Southern Hemisphere data. New theoretical analysis indicates an effect of lower stratospheric OH on total column OH.

Plans FY 91

A program started in 1989 to develop a new observing system to measure stratospheric trace gases by using spectroscopic absorption of light in the ultraviolet and visible portions of the spectrum will come to fruition. The prototype instrument, including a new spectrograph and telescope system, will be completed in spring 1991 and field tested at Fritz Peak. An intercomparison campaign in France will occur in July 1991. The instruments developed as part of the program will be installed at several global locations as part of a joint NOAA–NASA program for early detection of stratospheric change.

Routine measurements of tropospheric OH are anticipated in FY 91. Full seasonal determinations of ozone, water vapor, nitrogen dioxide, formaldehyde, SO_2, and other molecules in support of the OH experiment are under way. The OH Pesios interferometer in Lauder, New Zealand, will produce a full year of data for the Southern Hemisphere. Prototype testing of the new trace gas measurement system is expected to begin. An intercomparison campaign will take place in France next summer. A new IR instrument is under construction for determination of tropospheric OH sink species.

METEOROLOGICAL CHEMISTRY

This program examines the combined effects of chemical and meteorological processes in determining the chemical composition of the upper troposphere and lower stratosphere. This composition is central to global change, from both the scientific and the policymaking points of view. Major efforts are in two areas, (1) the chemical and meteorological state of the lower stratospheric vortex at both poles in winter and spring, and (2) the exchange of air between the lower stratosphere and the upper troposphere, particularly in the tropics.

Accomplishments FY 90

Instrument Development

Encouraging progress has been made in laboratory feasibility studies for a laser ionization mass spectrometer for aerosols, and toward the design of an airborne instrument for simultaneous measurements of NO, NO_2, and NO_y. A new airborne data system was designed and constructed. Some consideration was given, through liaison with Boeing, to the potential of the Condor high-altitude unmanned aircraft as an instrument platform.

Plans FY 91

Data Analysis

Study of data will continue through to publication on the three previous airborne missions: the Airborne Antarctic Ozone Experiment, the Airborne Arctic Stratospheric Experiment, and the Tropical Cloud Mission

from the Stratosphere-Troposphere Exchange Project. Global analyses of potential vorticity from the European Centre for Medium-range Weather Forecasts (ECMWF) will be incorporated.

Instrument Development

Laboratory investigation of the laser ionization mass spectrometer for aerosol measurement will continue. Construction of an airborne instrument for simultaneous measurement of NO, NO_2, and NO_y will proceed. There will be continued investigation of the far infrared laser magnetic resonance approach for OH and HO_2.

Mission Planning

The group is planning extensive involvement of its airborne instruments in the NASA–NOAA ER–2 mission scheduled for October 1991 to October 1992, including the scientific leadership for the Southern Hemisphere phase of the mission from April to December 1993.

TROPOSPHERIC CHEMISTRY

Accomplishments FY 90

Regional Ozone Production

Ozone is formed in the lower atmosphere by photochemical reactions with precursor nonmethane hydrocarbons (NMHCs) and nitrogen oxide (NO). The presence of these compounds accounts for ozone abundances that in summer 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 ozone is formed, and (3) the influence of small- and large-scale meteorological processes on ozone distribution.

The potential role of natural NMHCs was noted in experimental and theoretical ozone studies carried out in the Aeronomy Laboratory in the mid-1980s. Since then a major research emphasis of the Laboratory has been to understand 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 to measure ozone precursors and other key photochemically active trace species that shape ozone 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 1990, a major field campaign, Rural Oxidants in the Southern Environment (ROSE), was undertaken to study the process responsible for ozone formation at a rural location in the southeastern United States. This study focused on three key questions: (1) Do the oxides of nitrogen (NO_x) or the NMHCs control the formation of ozone? (2) Do natural or anthropogenic NO_x and NMHCs control the formation of ozone? (3) Does the formation of ozone occur regionally or locally?

To answer these questions, a full suite of instruments was installed at an isolated rural site in Alabama. In addition, height profiles of O_3 and NMHCs were measured from tethered balloons. Finally, to study the regionality of the ozone formation processes, O_3, NO_x, total reactive nitrogen (NO_y), and NMHCs were measured from an aircraft. Preliminary analyses indicate that natural NMHCs dominate and that the oxides of nitrogen are anthropogenic. At this site, the formation of the ozone appears to be limited by the available

NO_x. As a consequence, we predict that increased NO_x levels as a by-product of increased human activities in this area will lead to increased ozone levels.

Global Ozone Production

Ozone has two very important roles in the troposphere: (1) Ozone controls tropospheric photochemistry; (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 comprehensive measurements of ozone and its precursors in the remote free troposphere.

Nitric acid (HNO_3), particulate nitrate (NO_3^-), and NO_y were measured simultaneously as part of MLOPEX, at the NOAA GMCC station (3.4 km elevation, 19.5°N, 155.6°W) on Mauna Loa, HI. The data obtained have now been analyzed. Measured NO_y mixing ratios were low (the median was 263 pptv in free tropospheric air), reflecting the remote location of the site. HNO_3 was found to be the dominant reactive odd nitrogen species, accounting for 43% of NO_y. Approximately 20% of NO_y was unaccounted for in these measurements obtained in free tropospheric air. The amount of NO_y in ozone-producing active forms such as NO and nitrogen dioxide (NO_2) is somewhat larger than expected, and the NO_y contained in reservoir species such as HNO_3 is less than expected. This finding is important to our understanding of the factors that control ozone production in the remote free troposphere.

Biosphere Atmosphere Exchange

As noted above, NO_x has 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 soils as a by-product of natural biological activity. Although this is an important natural source, at present it is poorly characterized. During the ROSE campaign in Alabama, emissions of NO_x from soils were measured. The sandy loam soils at this site are characteristic of soils found in the extensive, previously unstudied pine forests of the southern United States. The measured NO_x emission rates were small, similar to those measured in other forest soils. These results indicate that NO_x emissions from soils in forest regions are not a major source of NO_x.

The emissions from forests are the principal natural sources of NMHCs. Isoprene from deciduous trees, principally sweetgum, and terpene emissions from coniferous trees, principally loblolly pine, were measured in detail. These are the first comprehensive measurements of the emissions from these important forest species.

Development of Measuring Capability

A key element in developing an understanding of atmospheric photochemistry is the ability to obtain unequivocal measurements of photochemically active trace compounds. Particularly important are partially oxygenated hydrocarbons because these species can be further oxidized in the process forming ozone.

A new gas chromatographic technique was used to measure selected oxygenated hydrocarbons in the ROSE campaign. Acetaldehyde, acetone, methacrolein, methyl vinyl ketone, methyl ethyl ketone, methanol, and ethanol were measured on an hourly basis over the 6-week time period. By use of the new technique, 85–90% of the local atmospheric burden of detected oxygenated hydrocarbons were identified by species.

Plans FY 91

Regional Ozone Production

A workshop will be held in Boulder in January 1991 to discuss the results obtained during the first ROSE campaign. These results will provide the data base to be used for a joint NOAA–EPA intercomparison of model simulations of regional ozone production.

Global Ozone Production

Plans will be made for a second mission to Mauna Loa to study the production of ozone in the remote free troposphere. In addition, plans will be formulated to measure ozone production and transport over the Atlantic Ocean from the North American continent. This program is in response to the growing concern that long-range ozone transport may influence air quality on an interhemispheric scale. This study is part of the North Atlantic Regional Experiments (NARE), which are a component of the International Global Atmospheric Chemistry (IGAC) project.

Biosphere Atmosphere Exchange

The NO_x emissions measured from soils will be inventoried for the United States. This will be the first attempt to produce such an inventory for the United States and will indicate those areas and seasons in which these emissions can contribute substantially to the NO_x background.

Development of Measuring Capability

In collaboration with NCAR, we will begin a 5-year program to intercompare NMHC measurement techniques and evaluate the standards.

MIDDLE ATMOSPHERE STUDIES

The objective of the Middle Atmosphere Studies Program is to undertake theoretical and field studies aimed at a fuller understanding of chemistry and transport processes in the 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 in Antarctica and Fritz Peak, Colorado. 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. Ozone chemistry of polar regions is a major research focus.

Accomplishments FY 90

Field Measurements

Over the past two decades, the Aeronomy Laboratory has pioneered measurements of the column abundance of stratospheric species by means of ultraviolet and visible absorption spectroscopy. A new

observation strategy has been developed which additionally returns information about the vertical distribution of rapidly photolyzing stratospheric species, such as NO_3. The approach consists of taking observations of NO_3, using the moon as a light source while the Sun rises. The rising Sun photolyzes the stratospheric NO_3 in time-dependent fashion from the top downward through the atmosphere. Detailed measurements of the rate of NO_3 decline coupled with calculated photolysis rates allow the vertical profile of NO_3 to be inferred.

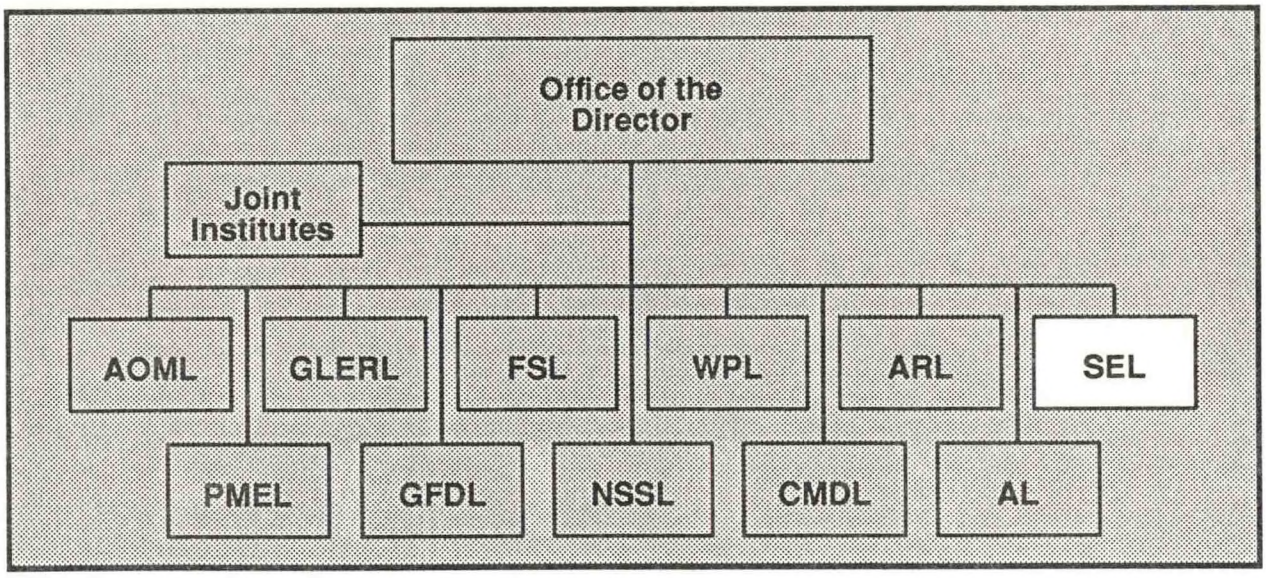
In another study, measurements of the column abundances of OClO and ozone from the Antarctic were used to obtain information regarding the diurnal photochemistry of OClO, and, more importantly, to show that coupled chlorine-bromine chemistry accounts for about 20% of the observed rate of column ozone decline during Antarctic spring. The remainder of the observed ozone loss is due almost entirely to reactions involving chlorine alone. Studies of ozone depletion due to chlorine and chlorine-bromine chemistry are important for policy decisions regarding regulation of halogenated compounds.

Stratospheric and Mesospheric Modeling

In polar regions, substantial enhancements in particle surface area occur as a result of polar stratospheric clouds, which form when temperatures get very cold. These are believed to engage in heterogeneous reactions that perturb the chlorine and nitrogen chemistry, thereby leading to polar ozone depletion. However, the connection between polar stratospheric clouds and ozone depletion has been based largely on indirect evidence consisting of laboratory measurements of polar stratospheric clouds and observations of perturbed gas phase abundances within the stratosphere. During the Airborne Arctic Stratosphere Expedition (AASE), aircraft measurements of polar stratospheric clouds were obtained along with observations of chemical species including chlorine monoxide, a key player in photochemical ozone destruction. By combining these observations with a trajectory model including both photochemical effects and cloud microphysics, it has been shown that rapid development of a polar stratospheric cloud was accompanied by a large enhancement in chlorine monoxide, in quantitative agreement with theory. Not only did the observed latitude gradient of the observed cloud material and chlorine monoxide indicate chemical processes on cloud surfaces, but also a clear diurnal variation was observed, providing strong evidence for the influence of clouds on reactive chlorine radicals. This study has provided the first in-situ evidence supporting the view that important heterogeneous reactions previously identified only in laboratory and theoretical studies occur in the lower stratosphere. Such interpretive studies are critical to attempts to quantify stratospheric ozone depletion in polar regions.

Plans FY 91

Observational and theoretical studies will continue. Near-term observational studies will focus on measurements of ozone, NO_2, and OClO in the Antarctic during February–November 1991. These will be the first observations of the evolution of chlorine chemical species throughout the Antarctic winter and spring, allowing a detailed study of the annual cycle of stratospheric ozone and its depletion. Several theoretical projects are also in progress. A major focus is the study of the stratospheric and mesospheric chemistry of the hydrochlorofluorocarbons (HCFCs). HCFCs are fast becoming the substitutes for ozone-destroying CFCs in many applications. As HCFCs come into greater and greater use, it is important to understand their middle-atmosphere chemistry to evaluate their influence on stratospheric ozone. Prior studies of the ozone depletion potential of HCFCs have used models extending only to stratopause levels. The present study will be the first examination of the possible influence of chlorine release over the entire atmosphere for the ozone depletion potential of HCFCs.



SPACE ENVIRONMENT LABORATORY

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

The Space Environment Laboratory (SEL) continued in FY 90 to provide space environment services to a variety of customers, to improve the quality and amount of its services, to improve the efficiency with which it provides services, and to perform research to better understand the basis on which predictions of space environment conditions are made. At the same time, SEL sought to develop new sources of data on space environment conditions. SEL also began to plan its participation in the Solar Influences portion of NOAA's Climate and Global Change Program.

Some highlights of these efforts include greater-than-99% up-time for the Forecast Center, and the shifting of customers from outmoded communication channels to newer, computer-to-computer links. A User Conference was held at SESC to inform customers about SESC services and to solicit feedback from them regarding those services. SEL put into operation an automated forecast verification system; over time, this system will allow individual forecasters to recognize if they have been characteristically over-forecasting the occurrence of some phenomena and under-forecasting the occurrence of others. The process of data ingest, processing, storage, and display for the forecasters was modernized by using distributed (small, linked rather than centralized) processing, thus minimizing the danger of overloading that can cause single-point failures. Daily interplanetary scintillation (IPS) data from England became available; analysis of and research with these data are expected to show that they will contribute to the improvement of geomagnetic storm forecasting.

SEL plans are contingent upon adequate funding, but they include improvements in each of the areas noted above. Specifically, SEL intends to continue to provide high-quality monitoring and forecasting services and to improve them. The upgrade to SEL's Data Acquisition and Display System (SELDADS) will be completed; this should put more information in front of forecasters, which should lead to better forecasts. Also, users should find easier access to SEL's holdings of current time series and image data about the space environment. A source of real-time solar wind data will be sought, analysis and interpretation of IPS will continue, and flow of IPS data from Japan will begin; all are aimed at improving predictions of geomagnetic activity. Solar X-Ray Imager (SXI) fabrication will begin, and SEL will participate in oversight of the vendor's progress.

Not least, SEL will emphasize Climate and Global Change research related to the variation of energy deposited in the upper atmosphere as a result of changing space environment conditions.

SPACE ENVIRONMENT SERVICES

Accomplishments FY 90

SESC Operations

The Space Environment Services Center (SESC), the national space weather service, is operated jointly by NOAA and U.S. Air Force personnel. SESC maintains a continuous, up-to-the-minute watch on storms and disturbances in the solar-terrestrial environment and receives real-time data from other Federal agencies as well as public and foreign institutes. These data are used at SESC to monitor key variations in solar activity, solar radiation, and effects on Earth's environment. The resulting indices are compiled, activity is summarized, and forecasts are made. These products are then issued to users whose activities are affected by variations in space weather. SESC functions as the World Warning Agency for the International URSI-gram and World Days Service, providing international exchange of space weather data, products, and daily forecasts.

In FY 90, a new algorithm for calculating energetic proton fluxes from measurements taken on the GOES spacecraft was developed and made operational. The new algorithm provides more accurate conversion from observed counts to physical fluxes, and consequently allows users to make better calculation of radiation effects. This algorithm replaces an older one that did not adequately handle spurious counts and gave artificially high values.

A verification system to evaluate space weather forecasting at SESC was implemented. The new verification products provide forecasters with an overview of SESC's forecasting capability; this allows them to evaluate their skills and provides management guidance to improve forecast quality.

The first SESC Users Conference was held in May 1990. Users of SESC's solar-terrestrial data met to discuss effects on navigation, communications, and electric power distribution systems and to express their needs for existing and proposed services.

Solar Cycle 22, which began in September 1986, is now at maximum, a period which could last through 1993. During this phase, the frequent major solar events often result in detrimental effects to systems sensitive to the space environment. In addition to routine products and services, more than 750 requests for special support were processed in SESC.

On-Line Services Group Operations

Phase I of an upgrade to the Space Environment Laboratory Data Acquisition and Display System (SELDADS) was completed. This phase consisted of hardware and software acquisition, familiarization of the staff with a new operating environment, and initial equipment testing and development.

Backup facilities for the primary Geostationary Operational Environmental Satellite (GOES) ground station were tested and made operational.

A new Dual Port Interface Device (DPID) Sun-follower interface, power module, and supporting software for the telescope and dome systems at SESC were developed and installed. This new system allows remote control of the dome from either the observatory or the Forecast Center by use of keyboard commands.

A new approach was developed for creating and disseminating new SESC products. Alternative methods were established to encourage users to access SESC products through real-time satellite broadcast, direct

access, or electronic data networks. A plan to switch customers of SESC's expensive teletype service to low-cost, high-speed systems such as electronic mail began to be implemented in FY 90, reducing teletype communication costs by approximately 30% and improving customer service.

Technique Development

SESC began receiving geomagnetic data through Intermagnet, a global geomagnetic data network. Data are being received from U.S., Canadian, and United Kingdom stations in the form of 1-min averages.

Arrangements were made for SESC to obtain near-real-time solar wind data from NASA's Pioneer Venus Orbiter. These data are made available to the international community by means of SESC's daily Solar Coronal Disturbance Report.

SEL is exploring the possibility of a standard definition of a geomagnetic storm; standardization is important when data sets are to be shared among different organizations. A draft definition was published as a first step toward achieving an internationally approved definition.

Plans FY 91

SESC Operations

- Implement the remaining verification products; provide forecaster training in interpretation and use of the verification system.
- Analyze recommendations from the Users Conference; determine what changes to SESC products and services are needed, and examine the possibility of developing special-interest customer groups and targeted publications.
- Work on the analyses of IPS data for use in the Forecast Center and on the integration of IPS data into SESC operations and products.
- Celebrate the 25th anniversary of NOAA's routine space environment forecasts.

On-Line Services Group Operations

- Use NESDIS Wallops Island or NIST Suitland satellite down-link facilities for SESC GOES backup, and shut down the GOES receiving station at Table Mountain.
- Complete phase II of the SELDADS upgrade.
- Convert the High Latitude Monitoring Station (HLMS) to an unmanned, automated operation. Install an auroral radar there, with U.S. Air Force funds.
- Improve current satellite broadcast services and develop a strategy to send/receive data and products to/from overseas users via satellite.
- Start operations with Air Weather Service Space Forecast Center, when it becomes operational at Falcon Air Station, Colorado Springs.

- Implement new computer file server, with U.S. Air Force funds, to improve services to customers wishing to access the SELDADS data base.

Technique Development

- Work with the U.S. Geological Survey to expand the geomagnetic data network, both in number of reporting stations and in global coverage.
- Work with the University of Alaska in its installation of 12 new magnetometer sites.
- Develop new geomagnetic displays and analysis tools.
- Develop a prototype and begin testing of a new geomagnetic probability forecast process.

RESEARCH

Accomplishments FY 90

Climate and Global Change—Solar Influences

A theme, called Solar Influences, was developed for inclusion in the NOAA-wide Climate and Global Change Program. Initial work emphasized the need for creation of long-term data bases involving energetic particles and solar ultraviolet radiation measured by NOAA/TIROS and GOES satellites.

Ionospheric Studies

After several years of preparation, the book *Ionospheric Radio* was published. It concerns the effects of the ionosphere on radio waves, over the frequency range from extremely low frequencies to super-high frequencies, and the associated solar-terrestrial physics. An SEL employee was the sole author of the 580-page book.

The total electron content of the ionosphere has been measured by two methods, Faraday rotation and time delays from the global positioning system (GPS) satellites, with excellent agreement.

Magnetospheric Physics

A quiet-time model, or description of the geostationary magnetic field, was constructed from GOES-based magnetometer observations for 1980–1984. Preliminary comparison between the analytic magnetospheric field model results and the measurements field model gives good agreement.

Data from the Space Environment Monitor (SEM) aboard the NOAA/TIROS satellites have been processed to produce synoptic particle flux maps at satellite altitude with a spatial resolution of 5° in both latitude and longitude. The procedure permits the characterization of the low-altitude particle flux environment and its time variations, and provides a low-altitude normalization for traditional radiation belt models. The solar cosmic ray events of 29 September and 19, 22, and 24 October 1989, produced significant proton fluxes of sufficient energy to penetrate Earth's atmosphere. During FY 90, dose-equivalent radiation rates were calculated for travelers on the Concorde supersonic transport and at ground level.

A preliminary analysis of data from the High Energy Proton and Alpha Detector (HEPAD) aboard the GOES–6 satellite was completed. The HEPAD measures protons and alpha particles that are principally responsible for the production of ionization in the lower atmosphere and for the radiation environment at air craft altitudes. Initial comparison of the HEPAD data with other data indicates that the HEPAD data are reasonably accurate and that it will be possible to make a real-time assessment of the HEPAD's energy range.

Studies continued on chaotic particle motion in the geomagnetic tail current sheet. Plasma wave measurements during ISEE–3's deep passes through the geomagnetic tail showed that moderate-to-intense electric field turbulence occurred in association with the major plasma and magnetic field regions.

Interplanetary Physics

Assessment of the 2 1/2–dimensional interplanetary global model (2 1/2–D IGM) as an operational numerical model for simulating disturbed and undisturbed solar wind continued. Parametric studies with the 2 1/2–D IGM included simulating solar-flare-generated shocks and the erupting and corotating phases of coronal-hole-generated solar wind streams. Specific major solar flares were studied using the 2 1/2–D IGM. In most cases, good agreement was found between the model's predictions and in-situ observations.

Our collaboration with Tel Aviv University continued to develop a model of "helmet streamer" configurations in the solar wind. This 2 1/2–D analytic/numeric study determines self consistently the correct currents, magnetic fields, and near-Sun solar wind conditions. Therefore, it can be used to initialize simulations of high-speed streams from coronal holes between the streamers.

A numerical, 3–D simulation of solar-ejected plasmoids traversing interplanetary space was developed to determine the draping of the interplanetary magnetic field (IMF) around plasmoids, deformation of the IMF due to a plasmoid, and the generation of a bow shock around a plasmoid. This work also enhanced the production of IPS all-sky "g-maps" at SEL.

The 3–D shapes of solar-flare-generated shock waves were studied using interplanetary scintillation (IPS) observations (see below). This work suggests that the fastest part of a shock is oriented along the heliospheric current sheet and not, as previously thought, in the helioradial direction from the flare site.

SEL participated in the refurbishment of an antenna system at Cambridge, England. The antenna is used to monitor varying scintillation of radio waves from small-diameter, extragalactic radio sources, waves that scintillate (IPS) because of variations in the interplanetary medium through which the waves must propagate to reach the antenna. Maps of areas of this increased IPS can be used to monitor the earthward progress of solar disturbances. Data display routines were developed, including a simple geometrical model for projecting a solar wind disturbance onto the celestial sphere. Also, two IPS radio receivers were built, using Indian funding, at the planned IPS measurement site near Ahmedabad, India, and are being tested preparatory to building the remainder necessary to populate a 10,000-square-meter array.

A new algorithm was developed in late 1989 to improve the accuracy of the measurement of solar energetic particles from GOES–6 and –7 satellites; after a "beta test" of several months duration, it was placed into operation in mid-January 1990.

Researchers started examination of solar wind data from ISEE–3, situated 1.5 million km upstream of Earth, to study the ability of such data to give lead times of up to 1 h in the prediction of major geomagnetic activity.

Solar Physics

Solar irradiance variability studies continued, and empirical models of UV irradiance were further developed. Photometric measurements indicate that network contribution to irradiance variability is overes-

timated in the present irradiance models, and that the network contribution is not constant in time, as is also assumed in the present models. Periodicities of 154 and 51 days were found in solar irradiance indices whose variations are related to strong magnetic fields; a 300-day periodicity was identified in those indices, some variation being caused by weaker magnetic fields.

The temporal variations of solar UV radiation were derived from May 1986–April 1990 observations with the Solar Backscatter Ultraviolet (SBUV2) Monitor on the NOAA–9 satellite. Comparing these results with earlier NIMBUS–7 satellite data showed that the peak UV flux of Solar Cycle 22 approximately equalled that of Cycle 21. A model of solar extreme ultraviolet (EUV) and UV radiation as a function of time and wavelength, called SERF2, was published.

An international collaborative program, the Solar Electromagnetic Radiation Study for Solar Cycle 22 (SOLERS22), was initiated with strong SEL participation. SOLERS22 efforts will determine the daily flux values of solar spectral irradiance in the x-ray, EUV, UV, visible, and infrared wavelengths, and the total solar irradiance during Solar Cycle 22.

A large computer software base for dynamic power spectral analyses of solar time series was developed. The software uncovers how periodic components in solar time series change over time; it will form the foundation for future statistical and physical studies correlating different solar time series measurements. Solar variability, on time scales of days to months, was found to be quasi-periodic and quasi-stationary.

A 22-year data base of solar synoptic charts that record patterns of large-scale solar features was taken to Australia for collaborative research into the evolution of large-scale solar magnetic fields, coronal holes, and "active" solar longitudes. New computer programs were created to use this data base to calculate the daily values of coronal-hole area.

Of special concern was the significance of reduced sunspot activity, leading to speculation of an unusually early maximum for Solar Cycle 22. Long-term forecasting data were re-evaluated in view of recent events.

The THEO expert system for solar flare prediction was also re-evaluated. Adjustments were made to improve performance and to extend THEO's ability to instruct the operator and give self explanation for its decision making.

A study continued on the comparison of solar soft x-ray measurements from sensors on the Soviet Union's PROGNOZ and NOAA's GOES satellites, to determine the properties of coronal plasmas without the instrumental and environmental bias found in any single data set. A related study concerned simultaneous stereoscopic measurements of several solar flares from the same two satellites. This method of observation produced new data on the geometry of flares, indicating that the highest-temperature plasma was at very great heights.

A continuing study of high-temperature flares yielded new information on the concentration of these flares in particular active regions.

The study of solar active region evolution known as TELSAR (Tracking and EvoLution of Solar Active Regions) produced results useful as the first step in improving 2- to 7-day flare forecasts.

Max '91 is a program devoted to the study of solar activity during the present solar maximum. It is jointly funded by NASA and the National Science Foundation for the development and use of long-duration balloon payloads and new, ground-based instrumentation. SEL continued to provide real-time solar data, communications, and computer services for Max '91. The coordinated observing efforts that are the centerpiece of the program were coordinated from SEL. SEL staff helped to organize the first Max '91 Workshop and continued to support the production and mailings of Max '91 literature, which is distributed to more than 400 solar scientists worldwide.

Plans FY 91

Climate and Global Change—Solar Influences

- Establish the necessary parameters and develop the format and computer code for creation of appropriate and accessible long-term energetic particle and solar ultraviolet radiation data bases from NOAA/TIROS and GOES satellites.

Ionospheric Studies

- Measure and analyze ionospheric total electron content.

Magnetospheric Physics

- Refine the fit of the empirical, quiet-day model to the laboratory model, with the expectation that the analytic model may be used as an algorithm to extend the results of the observational model to all satellite longitudes.
- Improve the existing algorithm to estimate—from GOES measurements—the dose-equivalent rates of cosmic rays at arbitrary altitudes, from the ground to low Earth orbit.
- Reduce HEPAD observations into a data base useful as input to climatological and radiation models.
- Continue chaos and tail current sheet studies for a model of a magnetosphere with a neutral line; look for other data sets with which to compare model results.

Interplanetary Physics

- Continue the study of energetic particle propagation with the use of the 2 1/2–D IGM for flares occurring on the western solar hemisphere; compare these western flux and anisotropy predictions with those expected for eastern and central-meridian flares.
- Refine the 2 1/2–D helmet-streamer models to accomplish self-consistent currents, their associated interplanetary magnetic fields, and the solar wind flows.
- Study the initiation of non-flare-associated coronal mass ejections (CMEs) as predicted by 2 1/2–D numerical calculations of sheared magnetic field configuration.
- Generate maps of synthetic IPS disturbances described by the 3–D IGM, for comparison with IPS observations of real disturbances.
- Continue international collaborations on use of IPS data, attempting to arrange the daily provision of IPS data to SEL from sites in India, Japan, Russia, and, possibly, China (in addition to England).
- Evaluate the ability of solar wind measurements obtained at the L_1 Lagrange point to predict subsequent levels of geomagnetic activity.

- Develop, with the National Environmental Satellite, Data, and Information Service (NESDIS), a NOAA-wide initiative for establishing a new series of satellites, located 1.5 million km upstream of Earth, for the purpose of predicting geomagnetic activity with up to 1 h lead time.

Solar Physics

- Continue research on solar irradiance variability, to understand the relative importance and variation of the contributions of various solar features to irradiance.
- Develop techniques for estimating intermediate-term solar UV irradiance variations back to 1947.
- Conduct a SOLERS22 workshop in Boulder in the early summer of 1991.
- Complete development of a new Solar Extreme Ultraviolet Radiation Function (SERF) model.
- Investigate nonlinear, frequency-domain techniques for analyzing observed solar variability; periodicities of other regularities found will be related to fundamental solar physics.
- Continue study of the evolution of solar active regions, intending to improve flare forecasts; there will be concentration on treatment of observational errors and interpretation of the resulting evolutionary statistics.
- Publish a catalog of solar active regions that have produced strong x-ray flares, as a resource for developing improved medium-term predictions of solar activity.
- Continue to produce H-alpha synoptic charts for archiving and as an aid to research on long-range solar predictions
- Continue to study the association of high-temperature flares with specific solar active regions.
- Continue investigation of flare data from PHOBOS and GOES satellites.
- Coordinate a second Max '91 campaign in December 1990 and expand schedule of coordinated observations to approximately four per year by the end of FY 91.

SYSTEMS SUPPORT

Accomplishments FY 90

Operational Satellite Instrumentation

SEL continued to supervise the contract for the SEM systems for the NOAA/TIROS–K, –L, and –M spacecraft, which will fly in the early 1990s. The design of the SEM systems was nearly completed; the delivery of the instruments for the spacecraft is on schedule.

Funding was secured, and preparations continued during FY 90 for the Solar X-Ray Imager, which will fly on the GOES satellites within the next few years.

SEL Scientific Work Station System

The planned replacement of the oldest SEL scientific work stations was completed in FY 90. The first module of a new application software for solar map automation was completed. A new forecaster work station interface neared completion.

Artificial Intelligence Technique Development

The evaluation of neural networks and other alternative "learning" systems, for use in the forecasting of solar flares and other solar-terrestrial phenomena, yielded the finding that all methods compared generated very similar verification scores. This is thought to be due to inherent properties of the data set used as well as the data encoding scheme. An investigation of data properties and alternative encoding schemes began.

Wide-Area Networking

Computer networking was very important to SEL as a means of communication between cooperating scientists and institutions, disseminating SEL data, and acquiring data from other institutions and data centers. The joint effort to improve the connectivity of all DOC agencies at the Broadway site resulted in all SEL systems' becoming connected to the new NSF–NASA Internet Domain "BldrDOC."

Interplanetary Scintillation Observations

The IPS antenna array at Cambridge, England, was reactivated. Data from this system show promise of significantly improving our ability to predict geomagnetic disturbances caused by the arrival of solar wind density disturbances. The data system software developed in SEL was completed and installed at the site; routine data acquisition began in February 1990. Routines for computer-to-computer transfer of the data from Cambridge to SEL were developed and are in use. The Indian IPS site was visited, and an engineering review was performed. This review resulted in several recommendations to the Indian engineers.

Plans FY 91

Operational Satellite Instrumentation

- Continue contractor and subcontractor reviews of the programs to develop and fly SEM systems on the GOES and NOAA satellites; support the publication of specifications and selection of the fabrication contractor for the Solar X-Ray Imager.

SEL Scientific Work Station System

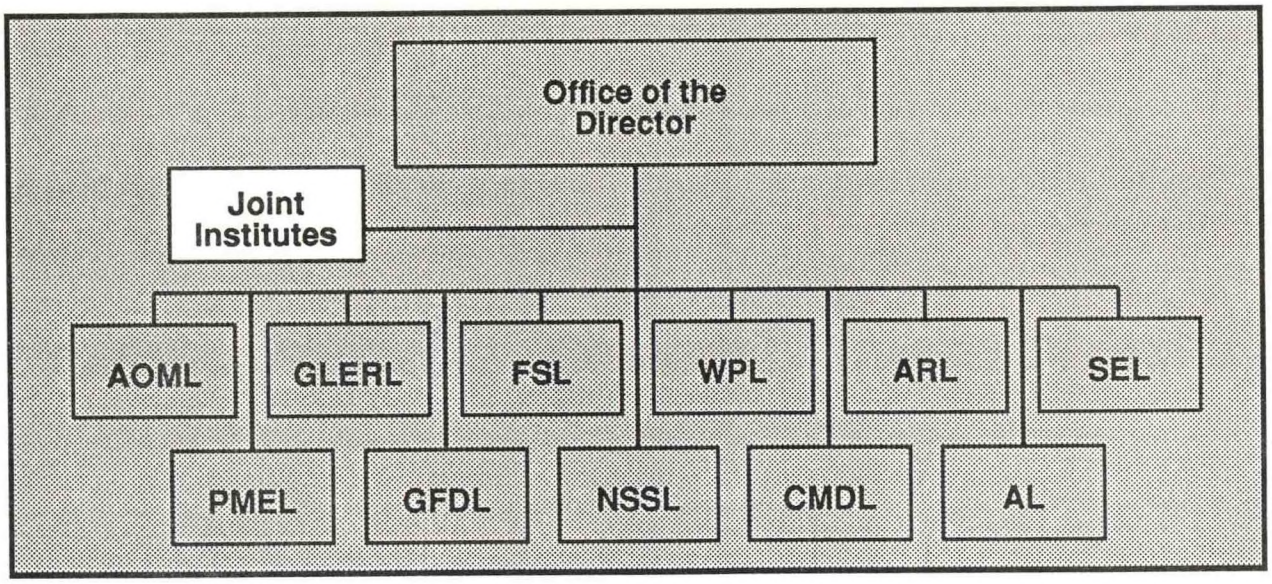
- Complete the replacement of first-generation work stations and the conversion to full UNIX compatibility.

Artificial Intelligence Technique Development

- Complete the study of "neural net" and other experience based computer reasoning systems and methods for making solar terrestrial predictions; verify these systems' and methods' predictions by comparison with observations.

Wide-Area Networking

- Plan, procure, and install a networked data server for better service to SELDADS users, if U.S. Air Force funding is received.



JOINT INSTITUTES

Under the Joint Institutes program NOAA and seven universities have signed Memorandums of Understanding to create Joint (or Cooperative) Institutes.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, limnologic 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. ERL has these Joint Institutes at present:

- CIRES (University of Colorado)
- CIMAS (University of Miami)
- CIRA (Colorado State University)
- JISAO (University of Washington)
- CIMMS (University of Oklahoma)
- JIMAR (University of Hawaii)
- CILER (University of Michigan)

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

Boulder, Colorado
(303) 492–7943
Robert E. Sievers, Director

The Cooperative Institute for Research in Environmental Sciences (CIRES), is a joint enterprise of the University of Colorado and NOAA's Environmental Research Laboratories (ERL). CIRES serves as a mechanism to foster collaborative research between university and NOAA personnel and to train graduate students and postdoctoral scientists in the sciences of the environment. Active collaborations during FY 90 at CIRES concerned the broad program areas of Atmospheric and Climate Dynamics and Environmental Chemistry and Biology. They involved eight ERL Laboratories: the Aeronomy Laboratory (AL), the Air Resources Laboratory (ARL), the Climate Monitoring and Diagnostics Laboratory (CMDL) 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, in Solid Earth Sciences, is not directly related to ERL missions. This report concerns CIRES activities in the first two of the program areas as well as in CIRES 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 departments: Aerospace Engineering Sciences; Chemistry and Biochemistry; Electrical and Computer Engineering; Environmental, Population, and Organismic Biology; Geography; Geological Sciences; Mechanical Engineering; and Physics. In addition to the National Geophysical Data Center (NGDC) of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), NOAA scientists on the Council are affiliated with AL, CMDL, and WPL.

ERL support of CIRES research was supplemented by approximately equal funding from the university and outside sources during FY 90. 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

CIRES collaborates with AL and CMDL in Environmental Chemistry and Biology research. Accomplishments relating to the following topics are discussed in the Laboratories' reports:

- Laboratory studies of the chemical kinetics of reactions relevant to atmospheric chemistry.
- Field measurement programs aimed at maintaining the global data base of atmospheric carbon dioxide and methane measurements.
- Investigations of the role of chemical kinetics in the polar "ozone hole" phenomena.
- Studies aimed at understanding the formation of oxidants in rural areas.

Accomplishments FY 90

Climate and Global Change

Methane Flux Studies: In addition to ongoing studies of the global methane problem in collaboration with scientists in NOAA's Geophysical Monitoring for Climatic Change (GMCC) program, CIRES scientists worked with the Center for Limnology to study methane emission rates from Rocky Mountain lakes and wetlands. During FY 90, methane emissions were measured for the first time in the extensive wetland and mountain lake areas of the Central Rockies. Because the global methane budget is so poorly understood, it is important to examine the various biotic zones that are likely to emit significant amounts of methane. The cold, boggy areas and shallow lakes found in the Central Rockies are among the least understood biotic zones, and this work is designed to provide basic information on the associated emission rates.

Results from the FY 90 work indicate that montane meadows emit more methane (per unit area) than lakes do, and that emissions from meadows correlate strongly with the organic content of the soil. Absolute emission rates exceeded those documented for Alaskan tundra and were as high as those observed in Florida swamps.

Biogeochemical Cycling: Studies of the cycling of carbon were conducted in the floodplain of the Orinoco River in Venezuela, using stable isotope techniques to test the hypothesis that food webs are almost exclusively dependent on carbon from unicellular algae, rather than from the extensive inventories of carbon that are produced by aquatic and terrestrial vascular points in the floodplain. Analysis of the stable isotope signatures for all the major food web components, including fishes, benthic invertebrates, zooplankton, etc., has only recently been completed. Preliminary results show support for the original hypothesis, which will change the perspective on energy flow pathways within tropical floodplains.

Stratospheric Ozone Depletion

The discovery of the Antarctic "ozone hole" several years ago led to intense research on its morphology and chemical interactions, and CIRES scientists, in collaboration with AL scientists, have played a large role in this research. FY 90 was a banner year for publication of results from these studies. In addition, the CIRES-AL team announced the discovery of a similar, although less intense, depletion of ozone in the Arctic. Depletion in the Arctic was previously unexpected, because it was thought that the Arctic stratosphere was not cold enough to form the ice particles on which the ozone-destroying heterogeneous chemical interactions occur. However, measurements from high-altitude research aircraft revealed saturation to ice at the polar tropopause. Thus, early indications are that mechanisms responsible for the Antarctic ozone hole are at work in the Arctic as well.

Regional Air Quality

Hydrocarbon Emission Studies: The role of nonmethane hydrocarbons (NMHC) in the formation of ozone in both urban and rural environments continued as a topic of investigation. Photochemical/dynamical modeling studies used observations from previous field programs as validation tools. In addition, a baseline case was established for further studies of emission reduction strategies.

Field Measurements: FY 90 saw the participation by CIRES scientists in a major field project, Rural Oxidants in the Southern Environment (ROSE). A central question addressed is the source of NMHCs; early indications are that natural sources (particularly coniferous forests) are particularly important.

Plans FY 91

Methane Flux Studies: During FY 91, the studies of methane emission in Rocky Mountain lakes, bogs, and meadows will be expanded to include quantification of methane oxidation rates. Data collection will be expanded to include other potential correlates of methane emissions, including nitrogen availability and carbon/nitrogen ratios.

Biogeochemical Cycling: The Orinoco floodplain data will be analyzed in detail to determine whether the initial results can be verified with the complete data set.

Field Measurements: A second experiment will be conducted as a followup to the 1988 Mauna Loa Observatory Photochemistry Expedition to study further the photochemistry of the remote troposphere. Analyses of data from the ROSE and the Arctic expeditions will continue, and planning for a second Arctic campaign will commence.

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 collaborations in Atmospheric and Climate Dynamics with the ERL Laboratories. Highlights include the following:

- Development of new methods to understand the propagation of waves in random media, with applications to lidar remote sensing of the atmosphere and to ocean acoustic tomography and ocean current remote sensing, new applications of profiler data, and improvements in interpreting satellite data, with WPL scientists.

- Statistical studies of tropical-extratropical interactions and data quality of Comprehensive Ocean Atmosphere Data Set, 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 CMDL and SEL scientists.

- Development of improved data assimilation techniques for mesoscale modeling, design and implementation of a profiler data management system, design and implementation of a pilot balloon network to monitor the southwest North American monsoon, and analysis of aerosol data sets obtained by research aircraft to determine aerosol size distributions in relation to water volume concentration, with ARL, FSL, and NSSL scientists.

- Studies of atmospheric variability at the Shelikov Strait (Alaska) as a part of the Fisheries Oceanography Coordinated Investigations, with PMEL scientists.

In addition to these ERL collaborations, CIRES Atmospheric and Climate Dynamics research during FY 90 concerned 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 90

Cryosphere-Climate Interaction

The polar regions are very sensitive to changes in climate, and understanding how these regions respond to and, in turn, influence climate change is a focus of research at CIRES. Much of this work takes advantage of the resources provided by the snow and ice data centers (discussed below). Because in-situ observations are difficult in these extreme environments, remote sensing data are crucial to this research.

During FY 90, the role of sea ice in the polar climate system received increased attention. Sea ice constitutes a dynamic system that strongly affects the transfer of heat between atmosphere and ocean, because much of the heat transfer probably occurs through leads (open water) in the sea ice cover. Studies at CIRES were aimed at developing better techniques to diagnose the extent of sea-ice cover and to determine conditions under which various levels of ice concentration vary with differing atmospheric forcing. Changes in that forcing were investigated by examining the radiosonde data base for the Arctic basin. An important part of this work is improving the ability to discriminate between low Arctic stratus clouds and sea-ice cover in satellite imagery; artificial intelligence techniques were investigated for this purpose. This work has taken on added importance with the discovery, based on analyses of submarine sonar data, that the overall thickness of the sea ice in the Arctic basin may be decreasing on a time scale of decades.

Climatological Analyses

The Comprehensive Ocean-Atmosphere Data Set (COADS) continues to be an important tool for climatological research at CIRES, particularly when its surface-based observations are combined with satellite data sets. However, because the COADS data are so inhomogeneous, it is necessary to continue to develop improved tools for their use. Two studies, conducted during FY 90, concentrated on optimal methods to use COADS to calculate sea-air heat and moisture fluxes and on quality-control of the raw data from which the COADS products are developed. In addition, development of multivariate statistical techniques for COADS analysis continued.

Application of these techniques during FY 90 centered on relationships among tropical and subtropical circulation systems, including long-term variability associated with changes due to El Niño / Southern Oscillation variability, changes in the Indian and Australian monsoon systems and their relationships to convective systems and sea-surface temperature patterns, and the role of atmospheric wave phenomena in the development and propagation of tropical cyclones. The sensitivity of these circulation systems to changing sea-surface temperature patterns was also investigated using general circulation model studies.

Similar studies were used to investigate the sensitivity of the global climate system to varying continental configurations. In addition, a statistical forecasting technique based on neural networking was developed for climatological forecasting of El Niño.

Plans FY 91

Cryosphere-climate interaction: Satellite sounding data will be used to complement the radiosonde data base, with the goal of further improving and validating satellite discrimination techniques and understanding how sea ice varies with changing forcing. The artificial intelligence studies will be extended to the use of neural networking to assimilate data sets based on diverse information sources.

Climatological analyses: The general circulation model studies of atmospheric sensitivity to changes in sea-surface temperatures and continental configurations will form the basis for the development of simpler

models that should help to elucidate the fundamental processes and dynamics involved. Multivariate analyses of COADS will be extended from the Pacific to the world ocean. El Niño–Southern Oscillation sensitivity studies will be extended to examine teleconnections to middle-latitude climate variability.

NATIONAL SNOW AND ICE DATA CENTER
WORLD DATA CENTER-A FOR GLACIOLOGY [SNOW AND ICE]

The NSIDC and the co-located WDC–A are operated, in part, under a contractual agreement between CIRES and NESDIS/NGDC. The role of NSIDC and WDC–A is to acquire, archive, and disseminate data relating to all forms of snow and ice. NSIDC is the primary U.S. archive for snow and ice data. NSIDC's scientific discipline focuses on snow and ice processes and interactions of snow and ice with the atmosphere and ocean. The data archival and distribution activities of NSIDC and WDC–A are closely related to Cryosphere-Climate Interaction research.

Accomplishments FY 90 and Plans FY 91

Distribution of Brightness Temperature Data

The NSIDC continues to distribute 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. Subsequent SMMR data are being distributed by the NASA Goddard Space Flight Center.

SSM/I Snow Cover Studies

NSIDC continues to develop and distribute Special Sensor Microwave/Imager (SSM/I) snow cover and climate data products under the NASA Program for Interdisciplinary Research in the Earth Sciences. The study has three 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; preparation of a prototype snow cover climatology from the first three years of SSM/I data; assessment of its utility as a climate system index in conjunction with SSM/I-derived sea-ice products. As with the SMMR data, the distributions are using CD–ROM as the primary medium.

Distributed Active Archive

Beginning in FY 91, NSIDC will be funded as an Earth Observing System Data and Information System (EOSDIS) Primary Distributed Active Archive Center for Snow and Ice (SI.DAAC) to serve the polar oceans and ice research community with data products generated primarily from low bandwidth satellite instruments. In particular, NSIDC has the responsibility for processing, archiving, and distributing sea-ice parameters derived from passive-microwave sensors.

The SI.DAAC will provide a test bed and developmental path for the early EOSDIS program. The goal will be to continue to support scientists by providing cryospheric data and information services, assisting in

locating and manipulating data not archived at NSIDC, and serving as a point of contact for the development and implementation of new geophysical algorithms.

CENTER FOR THE STUDY OF EARTH FROM SPACE (CSES)

CSES research activities focus on the use of satellite remote sensing of Earth's atmosphere and land surfaces with emphasis on spectral imaging techniques. In FY 90 CSES research concentrated less on instrumental techniques and more on geophysical applications of spectrometric data sets.

Accomplishments FY 90 and Plans FY 91

Cloud Area Determination From AVIRIS Data

The Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) is an aircraft-borne prototype of the High-Resolution Imaging Spectrometer (HIRIS) that is to be a part of the Earth Observing System polar orbiter. A number of CSES research projects use AVIRIS data sets to develop new techniques for using spectrometer data, with application to HIRIS in the future. AVIRIS provides a large number of spectral bands in the visible and near infrared; it was found that cloud area could be inferred from ratios of the signals in these bands. The method has been applied to various AVIRIS data sets and found to be more sensitive to clouds, and less sensitive to spurious surface features, than the traditional threshold reflectance methods for cloud determination. This technique is also being applied to the determination of surface reflectance.

Factors Limiting Carbon Balance in Arid and Semi-Arid Lands

AVIRIS data are also being used to study changes in plant chemistry in response to stress induced by changing climatological factors. Both in-situ and remote-sensing data of individual plants and simple, manipulated ecosystems subjected to stressful conditions are used to develop models of the relationships between spectral reflectance and ecosystem health. Emphasis on plant chemistry, particularly trace-gas emissions, in arid and semi-arid environments makes this research especially relevant to the regional changes anticipated for the Colorado Front Range with changing climate. The ultimate goal of this research is to develop techniques for hyperspectral analysis of HIRIS data to monitor Earth's biosphere.

Remote Sensing of Leaf and Canopy Water Status

The goal of this research is to develop methods for remotely measuring leaf water status and canopy photosynthesis/primary production. This is critical to monitoring the health of vegetation, which may be affected by changes associated with the buildup of atmospheric trace gases. During FY 90, measurements of willow canopies were obtained in order to develop relationships among spectral reflectance and vegetation indices. These relationships will be used to develop a remote-sensing method to infer primary productivity.

Scales in Geophysical Systems: Mathematical Approaches

With increases in the resolution of remote-sensing instruments comes the need for improved data handling and interpretation. Many geophysical systems exhibit self-similar behavior on a wide range of scales, and there is evidence that much of this behavior can be represented as fractal or multifractal processes. During FY 90 two CSES research projects were initiated to investigate self-similar phenomena, with the goal of explaining the relationships between the simple, fractal, models and the complex geophysical systems. A theoretical investigation into the use of multifractal descriptions of rainfall and runoff seeks to combine analytic and numerical simulations, based initially on the binomial model, with spectral parameters estimated from hydrological data sets to improve understanding of the scaling behavior of rainfall and runoff. A related investigation involved the use of both these theoretical techniques and satellite data to study the three-dimensional structure of river networks. Because (upstream-wise) branching in a river system has characteristics of fractal behavior in a two-dimensional sense, it remains to include the third dimension (topography) for a complete description of the river network. This inclusion will improve understanding and predictability of sediment transport and erosion.

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 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 have been or 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 90

Each year CIRA hosts at least two workshops, one of which is for all CIRA research personnel. This year's workshop was held 20–22 June 1990 and was well attended by a large portion of the CIRA research staff (which includes employees of CIRA, Colorado State University, the RAMM Branch of NESDIS, 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.

A second workshop, sponsored jointly by CIRA and its Center for Geosciences, was held on 23–25 August 1989 at the Pingree Park Campus. The topic was Precipitation Measurement and Modeling. Included were

participants from outside universities, NOAA, the Army, Colorado State University, and the National Center for Atmospheric Research (NCAR).

The Center for Geosciences also held a Regional Atmospheric Modeling System (RAMS) Workshop in October 1989 on the main campus of Colorado State University. There were 53 participants.

A very successful Fellowship Program supported scientists from Italy, Canada, and Mexico. In addition to the formal Fellowship Program, many prominent scientists visited and gave seminars.

Plans FY 91

In addition to the regular research, CIRA will continue cooperating with the Army Research Office at the Center for Geosciences. CIRA will also hold a general research workshop and an invitational workshop. Some special events will be incorporated to celebrate the tenth anniversary of CIRA.

CIRA will continue its Fellowship Program with the scientists from Italy and Canada and will be supporting an additional polar lows scientist from Denmark. CIRA will continue to host visiting scientists and support the seminar program.

SATELLITE CLOUD CLIMATOLOGY PROJECT

Accomplishments FY 90

CIRA participated in the International Satellite Cloud Climatology Project (ISCCP) (part of the World Climate Research Programme) as a Sector Processing Center. It collected GOES–6 satellite data and contributed to the ISCCP validation program.

- CIRA obtained more than 90% of the data required by ISCCP.
- A calibration estimate was prepared by correlating Indian Satellite (INSAT) and Meteosat or GMS ISCCP B3 data. This allowed conversion from INSAT to the ISCCP standard AVHRR radiances and eventually reaching an absolute calibration scale.
- Analysis of INSAT data continued.

Plans FY 91

The Sector Processing Center will continue to collect and process GOES raw data into B1 and B2 resolution data sets. Research examining the diurnal variation of clouds from INSAT data will continue. Planning preparation of histograms in support of the World Climate Research Programme rainfall estimation project will begin. Analysis of ISCCP C1 and C2 products in the context of climate model simulations will continue.

SEVERE WEATHER RESEARCH

Accomplishments FY 90

Studies supported NOAA's severe weather prediction mission in the areas of mesoscale analysis and forecast product development.

- The very large and consistent diurnal variation of deep convection associated with tropical cyclones was documented.
- Mesoscale cloud climatologies were developed and their uses were explored.
- Utilization of a PROFS Storm Education and Research System (SERS) enabled CIRA to interact with NOAA elements in the areas of TIROS Microwave Sounding Unit (MSU) data uses, mesoscale soundings with VAS data, and forecasting with expert systems.
- An expert system forecast (Nowcast) application was developed and tested at the Cheyenne WSFO.
- Analysis of VAS sounding data revealed that optimum fields of view for averaging for sounding derivation may be determined by structure function analyses.
- Deconvolution of GOES–IR data to show true scene radiance contined.

Plans FY 91

- Investigate the utility of polar-orbit data, especially microwave, for regional and mesoscale applications.
- Continue focus on the determination of the spatial and temporal variability in VAS radiance measurements so that these 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.
- Investigate the precursor states of intense convective systems.
- Develop products for use in extending advance warnings of severe weather.
- Develop training aids and participate in field forecaster training.
- Evaluate and develop nowcast products for VAS Data Utilization Center (VDUC) and other state-of-the-art interactive forecast systems.
- Improve satellite monitoring techniques and the acquisition of mesoscale data bases.

AIR QUALITY—JOINT RESEARCH WITH THE NATIONAL PARK SERVICE

Accomplishments FY 90

A cooperative effort with the National Park Service and NOAA continued, to determine, evaluate, and analyze the visual effects of pollutants on specific scenic vistas.

- Developed photographic imaging techniques to depict slight changes in visibility due to layered and regional hazes.

- Produced videos showing the effect of pollution on various parks; generated park service training films; developed custom graphic materials for presentation purposes.
- Developed capability to produce video presentations of research results.
- Developed a series of reports summarizing the results of recently completed investigations of the applicability of various radiation transfer models to the real world.
- Validated e-o devices under controls.

Plans FY 91

- Continue development of software to digitize color slides, real-world images, and projected images in laboratory situations.
- Continue work on 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.
- Develop and use receptor models to determine transport pathways and estimate the proportion of a measured pollutant that can be attributed to each of several sources.
- Investigate the effect that various sulfur emission reduction scenarios would have on visibility.

WMO SHARE PROGRAMME

CIRA has contracted with WMO to participate in the WMO SHARE Programme. SHARE 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. Participating scientists from Argentina, Brazil, Jamaica, Kenya, Niger, People's Republic of China, Trinidad, and Turkey have visited CIRA.

Accomplishments FY 90

- Assisted participating countries in training and installation of the VAX VMS Version 1.0 software produced by CIRA to enable participating scientists to instruct their countrymen in use of an IBM PC/AT for their specific research needs.
- Provided software routines to process and display forecast products.

Plans FY 91

- Continue to train scientists of Third World countries to install software and to train others upon return to their respective countries.
- Correct any problems associated during and after installation.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

Norman, Oklahoma
(405) 325–3041
Douglas K. Lilly, Director

The University of Oklahoma (OU) and the National Oceanic and Atmospheric Administration (NOAA) established the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) in 1978 as a means to promote greater cooperation and collaboration on problems of mutual interest among research scientists in the NOAA Environmental Research Laboratories (mainly NSSL), and faculty, postdoctoral scientists, and students in the School of Meteorology and other academic departments at OU. Through CIMMS, OU faculty and NSSL scientists also collaborate on research supported by other NOAA programs and Laboratories as well as other agencies such as the National Science Foundation (NSF) and the Federal Aviation Administration (FAA). The NSF-sponsored Center for Analysis and Prediction of Storms (CAPS) was originally proposed through the mechanism of CIMMS. That the NSF chose to fund the CAPS as one of only 11 Science and Technology Centers established in 1989 is a result, at least in part, of the CIMMS 10-year record of accomplishments.

During FY 89–90, OU and NOAA negotiated a new 3-year cooperative agreement for CIMMS funding that took effect on 1 July 1990. Under the new agreement CIMMS will concentrate its efforts and resources on three principal research themes for the next 3 years: (1) Basic Convective and Mesoscale Research, (2) Forecast Improvements, and (3) Climatic Effects of Mesoscale Processes. Accomplishments for FY 90 are presented here in terms of the themes of the FY 90 plans, whereas FY 91 plans are presented in terms of the research themes of the new 3-year agreement.

Accomplishments FY 90

Mesoscale Modeling

Short-term forecast model

Development of a 3–D nonhydrostatic model for short-term prediction continued in collaboration with CAPS scientists. Principal contributions of CIMMS scientists and graduate students were in development of single-Doppler retrieval techniques of the types that will have to be incorporated into the model in order for it to take advantage of the data that are expected to be widely available from the network of WSR–88D radars in the next several years.

Convective cloud model

A 3–D nonhydrostatic model of a convective cloud with detailed description of the principal warm-rain cloud microphysical processes was used to study the limitations of the bulk microphysical parameterizations and the possibilities for their improvement. Precipitation development in single-cell and multicellular clouds was also investigated. Another numerical model with very high resolution for cloud droplet distribution functions has been developed to study microphysical schemes applicable to stratocumulus cloud models.

4–D data assimilation

The model developed by a CIMMS postdoctoral scientist was used by two doctoral candidates to continue the work. One student is pursuing a theoretical investigation of multiple minima associated with variational assimilation, using nonlinear dynamics and the anelastic 3–D convection model. The other student will study the assimilation of data in conjunction with the dry line.

Mesoscale Dynamics

The previously derived viscous Sawyer-Eleiassen (S-E) equation was developed into a prognostic model in combination with the tendency equations for momentum, potential temperature, and equivalent potential temperature. This model has been used to study the formation of stable frontal rainbands and the evolution of potential vorticity (PV) anomalies. The results of model simulations suggest that there are two types of feedback mechanisms between rainband and frontogenetic forcing which explain the growth of stable rainbands under different stability conditions.

The semi-geostrophic (SG) omega equation finite element model was further developed for use with real data. The model has been tried on Alpine Experiment (ALPEX) data and National Meteorological Center Eta-model data. The results indicate that the SG model is significantly better than the conventional omega equation, but when the number of grid points is large, the Gaussian elimination method used for solving matrices costs too much in computer time. Thus an efficient iteration method needs to be developed for the model. Currently the effect of stratiform latent heating and PBL effect have just been incorporated into the model. Preliminary tests indicate an improvement in the diagnosed low-level wind field.

Mesoscale Observations

The GUFMEX project

It is generally accepted that the Gulf of Mexico is the primary source of water vapor for both general precipitation and severe storms in the central United States; yet there have been relatively few investigations of the details of moisture transport from the Gulf, or the modification processes that occur when continental air plunges southward over this body of water. The GUFMEX project was designed to study those events in late winter and early spring when polar air (of Pacific or continental origin) plunges into the Gulf of Mexico and subsequently returns to the continent.

As part of GUFMEX, a CIMMS graduate research assistant completed a study on the problem of air-mass modification over the loop current, using ideas from the theory of mixed-layer modeling. The student analyzed special upper-air data over the loop current obtained on 21 February 1988 when a cold-air mass plunged into the eastern Gulf and subsequently returned to the continent. He showed that the simple mixed-layer model accurately describes the air mass modification in this case. This work is being compared with operational models that use more sophisticated boundary-layer parameterizations.

Electrical Aspects of Mesoscale Convective Systems

Scientists at CIMMS and NSSL have been searching for relationships between the locations of strike points of cloud-to-ground (CG) lightning flashes and radar, satellite, surface, and rawinsonde observations of mesoscale convective systems (MCSs). In many cases, the maximum convective precipitation and the

maximum negative CG flash activity occur at nearly the same time. The most intense period of positive CG activity occurs at nearly the same time as the maximum stratiform rainfall.

Principal contributions by CIMMS scientists and graduate students were the following: (a) results that show a close association between amount of rainfall in convective systems and amount of CG lightning they produce, and (b) observational studies that indicate the distribution of electric charge in MCS is more complex than the long-accepted dipole model.

Remote Sensing

Weather hazards to aviation

Scientists at CIMMS had an important role in the improvement of the gust-front detection and tracking algorithm for both the Terminal Doppler Weather Radar (TDWR) and the WSR–88D systems. Techniques to detect azimuthal shear and reflectivity thin lines were added to the algorithm. Other more rigorous techniques that detect and forecast the speed and direction of movement of gust fronts were also added to the algorithm.

The TDWR gust-front algorithm was tested in a real-time environment in Orlando, Florida, during the summer of 1990. Scientists from CIMMS participated in the test by monitoring the algorithm as it ran and by observing how the output was used by air traffic controllers to help route aircraft around hazards in the vicinity of the terminal.

Polarization studies

Through CIMMS, scientists and students from the OU School of Meteorology and a visitor from India collaborated with NSSL scientists to study the utility of polarimetric measurements for discrimination of hydrometeor types. The emphasis was on the detection of hail and estimation of its size. In one case study of a storm at close range, the differential propagation constant, correlation coefficient between vertically and horizontally polarized echoes, and differential reflectivity turned out to be complementary observations such that consistency among them allowed qualitative and some quantitative discrimination between hydrometeors. In particular, it appears that a region of negative differential reflectivity in this case contains vertically oriented hail that is larger than 2 cm in diameter.

Plans FY 91

Basic Convective and Mesoscale Research

Dynamic and synoptic meteorology

The CIMMS adaptive finite-element diagnostic model will be run on real data to diagnose the components of vertical circulation that are forced by the large-scale flow, stratiform latent heat, and boundary layer processes.

Atmospheric physics

Very limited modeling studies and field observations of cloud electrification will be undertaken by students supported by NSF and NSSL through CIMMS, in conjunction with NSSL scientists.

The numerical model for warm convective clouds, with detailed microphysics, will be used to determine the sensitivity of convective systems to the distribution of nuclei in the environment, and to try to explain evolution of raindrop size distributions in multicellular cloud systems.

Boundary layer meteorology and turbulence

Analysis of GUFMEX data will continue.

Development of new techniques for analysis of Doppler radar and profiler data, as well as large quantities of surface data, will continue, toward the goal of mapping boundary layer divergence and moisture with sufficient detail to allow accurate prediction of storm-generation regions.

Forecast Improvements

Observing-system technology

Scientists and students at CIMMS will work with NSSL scientists on developing new techniques for retrieval of thermodynamic properties and winds from single-Doppler radar observations. These techniques will be extremely important to the eventual development and implementation of better short-term, storm-scale numerical prediction models.

The forcing mechanisms and structure of microburst-producing storms and their relationship to outflow strength will be examined. An improved version of the gust-front algorithm, incorporating new techniques developed in FY 90, will be thoroughly tested and made ready for real-time tests in Oklahoma and Florida during the spring and summer of 1991. If funds become available, further polarization studies will be pursued in conjunction with the planned Cooperative Oklahoma Profiler Studies 1991 (COPS–91) field observation program.

Forecasts and warnings

CIMMS will participate in improvement of forecasts through its support, albeit at a low level, of the Geosciences Computing Network (GCN) at OU. In conjunction with the CAPS program and other research needs in the College of Geosciences, the GCN is building a capability in visualization and graphics display of real data as well as numerical model output. The improvement of forecasts and warnings in the next several years will depend to a great extent on the improvement of visualization and display techniques. Through CIMMS, new visualization platforms and display techniques will be available to NSSL scientists and OU faculty working on these problems.

Climatic Effects of Mesoscale Processes

Cloud-topped boundary layers

A proposal to the NOAA Climate Office to apply the CIMMS warm-cloud model with detailed microphysics to the study of the cloud-topped mixed-layer environment, in which marine stratocumulus forms, has been recommended for funding. CIMMS scientists hope to begin the work during FY 91.

Effects of lightning

Scientists at NSSL and OU, through CIMMS, will submit a proposal to pursue lightning studies specifically addressed to the question of NOx production.

COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH

Ann Arbor, Michigan
(313) 764–2426
Russell A. Moll, Director

The University of Michigan and NOAA signed a Memorandum of Understanding in 1989 creating the Cooperative Institute for Limnology and Ecosystems Research (CILER). This new institute is intended to encourage collaborative research between scientists at NOAA's Great Lakes Environmental Research Laboratory (GLERL) and other research institutions, especially universities, in the Great Lakes Basin. Although the administration of CILER is assigned to The University of Michigan, a special bilateral agreement between The University of Michigan and Michigan State University brings the latter institution into CILER as a full partner of the joint institute.

The primary research focus of CILER is in three areas: Climate and Global Change, Coastal and Nearshore Processes, and Large-Lake Ecosystem Structure and Function. CILER is the only joint institute with direct responsibilities for freshwater research, but its sphere of interest is not restricted to the Laurentian Great Lakes of North America; research programs under CILER also include estuarine and coastal marine environments.

The initial activity under CILER was the selection of its first Director by the Executive Board in late October 1989. Since then, an infrastructure has been established to enable CILER to support collaborative research. Significant milestones in FY 90 included the selection of the first group of Fellows, with representation from throughout the Great Lakes Basin; preparation of the first 3-year research plan; selection and hiring of the first two Visiting Fellows; and receipt of funds from the United States Environmental Protection Agency (EPA) to commence activity on the first major CILER research project.

CLIMATE AND GLOBAL CHANGE

Accomplishments FY 90

The CILER research program in Climate and Global Change was developed through several meetings with Fellows. This program focuses on four related projects: Regional Great Lakes Mesoscale Climate

Models, Lake World Climate Studies, Paleoclimate Studies, and Climate-Induced Food Web Changes. Research proposals were prepared in each project area in FY 90 to solicit funds to begin Climate and Global Change investigations. The proposals were submitted to the Office of Global Programs, NOAA. One of the proposals was also submitted to the National Park Service per the request of that agency. A small portion of one project, Lake World Climate Studies, was funded with University of Michigan funds in FY 90, and research will begin in 1991.

Plans FY 91

Lake World Climate Studies

The primary objective of Lake World Climate Studies is to use large lakes throughout the world to study regional climates. The structure and dynamics of lake ecosystems and their components are responsive to environmental factors that change with regional climate. However, unlike ocean basins, the basins of large lakes are not interconnected and thus each lake responds primarily to regional climate and not to integrated global climate. The problem with deciphering the information from large lakes is that in order to understand how the signals differ among lakes, a similar set of measurements is required from several basins scattered throughout the globe. Once such a data base has been developed, the response of large lakes to regional climates may be identified.

The initial plans for this project call for placing strings of moored instruments in basins of large lakes, which have been selected as candidate study sites, within North America, Asia, South America, and Africa. A group of collaborators have agreed to work together on eight different large lakes. These studies will begin in FY 91 at Lake Victoria in eastern Africa. Lake Victoria was selected because the current data base from African lakes is small compared with data bases for other large lakes of the world. A moored instrument array which includes a thermistor string, sediment trap, and current meter will be installed in a mid-lake region of Lake Victoria in early 1991.

COASTAL AND NEARSHORE PROCESSES

Accomplishments FY 90

The initial 3-year plan identified three research projects: Shoreline Responses to Forcing Functions, Wetland/Estuary Structure and Function, and Coastal Exchange Processes. In conjunction with the Visiting Fellows Program, research began on coastal exchange processes in FY 90. Staff scientists at GLERL have a prominent role in the NOAA-supported Nutrient-Enhanced Coastal Ocean Productivity (NECOP) program. This multi-institution program includes investigation of the exchange and transport of materials from the Mississippi River into the Gulf of Mexico. The CILER Visiting Fellows are especially interested in the transport of critical nutrients from the river outfall into the gulf and the reaction of the food web to that nutrient enrichment.

Plans FY 91

Shoreline Responses to Forcing Functions

For several years GLERL and University of Michigan scientists have collaborated in the study of waves in the nearshore environment. The current location for these studies is the east coast of Lake Michigan. In conjunction with the new GLERL facilities at Muskegon, Michigan, plans are now under way to construct an instrument tower within 6.5 km of the Muskegon facility. This tower, which will be a semi-permanent structure standing in 10 m of water, is designed to fold down during the winter to prevent damage or destruction from ice. The tower will support instruments such as wave directional spectra-sensing devices and pressure gauge/electromagnetic current meters. Data will be transmitted from the tower by means of telemeter link.

Plans for FY 91 call for drafting of engineering plans, securing Federal and State permits for tower installation, constructing the tower, and installing the tower. Many of the instruments scheduled for deployment on the tower are available for use as soon as the tower is installed.

Coastal Exchange Processes

Studies of the Mississippi River outfall under the NECOP program are ongoing. Primary production of organic carbon from the Mississippi River and adjacent shelf waters will continue to be investigated as well as the fate and effects of riverine dissolved organic nitrogen. Visiting Fellows will participate in research cruises aboard NOAA vessels in the Gulf of Mexico during the summer of 1991.

LARGE-LAKE ECOSYSTEM STRUCTURE AND FUNCTION

Accomplishments FY 90

CILER Fellows identified five areas for research: Comparative Limnology, Limnological Ecosystem Structure and Function, Ecosystem Stresses From Toxic Substances, Impacts of Exotic Species Invasions, and Fisheries Recruitment Dynamics.

Through a cooperative arrangement with the EPA Great Lakes National Program Office, funding was received in late FY 90 for a 1-year interdisciplinary study of the lower 10 km of the Saginaw River. This study focuses on the sources and fate of heavy metals and PCBs and lies within the Ecosystem Stresses From Toxic Substances project.

Another CILER project in FY 90 focused on Impacts of Exotic Species Invasions. As a result of the Great Lakes invasion by the zebra mussel (*Dreissena polymorpha*), public concern over the effects of exotic species has reached a high level. Given the increase in awareness of this problem, there have been numerous calls for research into the generic problem of exotic species invasions in the Great Lakes. In response to several NOAA requests, CILER and GLERL have taken a leadership role in drawing the Great Lakes community together to develop a coordinated research plan for such a study.

Plans FY 91

Ecosystem Stresses From Toxic Substances

Overall, water quality in the Great Lakes ranges from good to excellent. However, there are problem areas that suffer from the accumulation of toxic substances including heavy metals and synthetic organic compounds. These problem areas have been designated Areas of Concern (AOC) and are the subject of special studies. One such area is the lower Saginaw River and Saginaw Bay. Working in conjunction with several government agencies, the EPA has commissioned numerous projects in this AOC with the purpose of determining the fate and effects of toxic materials, especially PCBs and several heavy metals (copper, lead, and zinc).

Beginning in the fall of 1990, samples will be collected for a year in the lower Saginaw River. The result of analyzing these samples is a data base that will be used to drive several models that estimate the fate of PCBs and metals dissolved in the water and adsorbed to particles. The models will attempt to determine if a significant amount of PCBs and metals that have accumulated in the sediments of the lower river, disperses into Saginaw Bay adjoining the river outfall, and/or enters the food web in the lower river. Water and particulate samples will be analyzed for a suite of variables including PCBs and heavy metals. The measurements will serve several purposes including the basis of near-field and far-field dispersion models of toxic substances. Biological samples will also be collected and analyzed to indicate if significant transfers of toxic materials from the water column into the fish take place by means of bioaccumulation in the food web. Finally, automated sampling will be used in an attempt to relate high flow conditions in the Saginaw River to massive mobilization of PCBs and heavy metals.

Impacts of Exotic Species Invasions

A result of CILER and GLERL leadership in this area is the development of a plan for a coordinated program of research throughout the U.S. portion of the Great Lakes Basin. The initial framework of that plan, completed in late summer of 1990, calls for the establishment of a committee to implement the plan. Both CILER and GLERL will have principal roles on that committee in FY 91. Pending legislation may provide funds to initiate several research projects in FY 1991 through CILER in the area of exotic species invasions in the Great Lakes.

COOPERATIVE INSTITUTE FOR MARINE AND ATMOSPHERIC STUDIES
Miami, Florida
(305) 361–4185
Claes G.H. Rooth, Acting Director

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is an association between NOAA and the University of Miami'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 the laboratories of NOAA's Environmental Research Laboratories (ERL) and of the National

Marine Fisheries Service (NMFS). CIMAS also provides partial support for visiting collaborating scientists who augment the expertise at RSMAS and the cooperating ERL and NMFS laboratories.

Activities under the cooperative theme of Fisheries Ecology and Ecosystem Dynamics are supported in cooperation between NMFS and ERL and administered by ERL.

CLIMATE VARIABILITY

Research on climate variability is conducted in cooperation with the Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA/ERL with a focus on those aspects of ocean dynamics that are considered important for understanding our climate and predicting climate change. Most FY 90 activities were within two major NOAA programs: Subtropical Atlantic Climate Studies (STACS) and Equatorial Pacific Ocean Climate Studies (EPOCS). Plans for future work are aligned within the priorities of the Global Change Initiative of NOAA, with special emphasis in observational work on the Atlantic Climate Change Program (ACCP), and in analysis and data assimilation on the ACCP as well as on TOGA (Tropical Ocean and Global Atmosphere) and EPOCS. The Tropical Ocean-Atmosphere Newsletter, which includes news of the International TOGA Program, was published by CIMAS through May 1990 when the TOGA program office terminated its publication.

Time series of transport observations in the Florida Straits and in the western boundary region of the subtropical Atlantic deep basin (at 27°N latitude, off the island of Abaco) are maintained in support of the STACS objective to develop the basis for designing efficient climate monitoring systems. Several complementary techniques are applied to this task. High time resolution is achieved by a limited number of current meters, complemented in the Straits of Florida by transport monitoring through submarine-cable-based measurements of the electromagnetic induction effects due to the Florida Current. High vertical resolution of current structure is provided, intermittently, by current profilers deployed from research vessels, accompanied by observations of water mass properties. We now have almost a decade of continuous time series of cable-derived transport estimates, intermittently calibrated by current profile sets. These observations are yielding new insights into the nature of annual and multiyear fluctuations in oceanic transports. Trace chemical distributions (concentrations of dissolved oxygen and of chlorofluorocarbons) complement the direct transport observations with information about water mass source characteristics. When combined, these diverse observations represent an indispensable tool for testing how well the fluctuations generated in advanced ocean models represent the actual oceanic processes. In order to determine the degree to which transport conditions at 27° N latitude (Abaco Section) represent global or local Atlantic processes, the STACS observation domain has been extended into the western tropical Atlantic.

These studies have been planned and executed in close cooperation between AOML and University of Miami scientists. The Atlantic field studies, in particular, have involved joint shipboard campaigns as well as shared responsibilities for data analysis and interpretation between CIMAS members from both cooperating institutions.

Accomplishments FY 90

Subtropical and Tropical Western Atlantic.

In the Florida Current, several current profiler sections were acquired, aimed at maintaining calibration control for the electromagnetic monitoring. The data time series has now been extended to 8 years; it is increasingly feasible to test hypotheses about which regions in the Atlantic are most directly responsible for the coupling of atmospheric (wind) variations to fluctuations in Florida Current transport. Evidence is

beginning to emerge that wind variability along the U.S. east coast has a significant role in this regard on seasonal time scales.

East of Abaco, in the Bahamas, the STACS investigation of the structure and variability of the Deep Western Boundary Current (DWBC) with moored current meter arrays was continued through June 1990. A three-mooring array deployed in October 1988 was recovered in June 1990. Analysis of approximately 5 years of moored current meter data and current profiler sections taken to date shows a broadened mean expression of the DWBC, relative to its structure at any single time. This is mainly due to a pronounced meandering of the DWBC on 100-day time scales. The meandering is also responsible for much of the observed transport variability in the immediate vicinity of the deep basin wall.

Analysis, in the context of the ocean current observations of conductivity-temperature-depth (CTD) and chlorofluorocarbon (CFC) data from STACS cruises conducted off Abaco in previous years, shows that the tracer data have more complex vertical structure than that found in the current pattern. A bimodal high-latitude injection pattern for CFCs with regard to depth is suggested by the presence of two distinct CFC concentration maxima associated with the upper and bottom parts of the DWBC. The main implication of this is that the observed current patterns probably relate to a longer-time-scale average forcing than do the tracer core patterns. That is, they represent oceanic responses to longer time scales of the climatic forcing patterns than those which dominate the vertical structure of the tracer concentration patterns.

Extension into the western tropical Atlantic Ocean of the observed CFC concentration pattern was previously (in 1986) noted from Abaco (27° N) as far south as Barbados (13° N). A new CTD–CFC section was acquired in the western tropical Atlantic Ocean during February and March 1989 on the NOAA ship *Albatross*. Results from this cruise confirm the multiyear persistence of the bimodal CFC distribution and also demonstrate its enhanced extension eastward, albeit with decreasing amplitude, monotonically from the western boundary out to the mid-Atlantic ridge. Similarly, a section extending northwestward from Brazil (8° N) shows significant penetration of CFCs into the basin interior.

These observations indicate not only a fast response in the western boundary region at middle and low latitudes to water mass formation processes occurring at high latitudes, but also that the interior basins of the tropical western Atlantic acquire imprints of these processes by communication with the western boundary. By virtue of their large mass, and hence large inertia against composition changes, these interior regions are promising candidate sites for monitoring long-term variability in the composition of those subpolar water masses that replenish the interior deep waters and thereby drive the large-scale deep water circulation.

Data from the western tropical Atlantic boundary region, acquired in the period September 1987 to September 1988 as part of the NOAA STACS effort to determine transport pattern connections between the subtropics and the tropics have been analyzed and interpreted. A three-mooring array across the Demerara Rise off French Guiana from about 7° to 8.5° N latitude was complemented by CTD surveys and Pegasus (free-fall current profiler) measurements. Analyses of these data sets have yielded the following results:

- Flow velocities in the North Brazil Current (NBC) show a strong seasonal variability throughout the upper water column (approximately the upper kilometer), with maximum northwestward flow in September through December and minimum flow (also northwestward) in March through June. Seasonal variability at the farther offshore mooring, at the base of the continental rise, shows a correspondingly strong offshore flow in the upper layers during September through December and weak, variable flow during March through June. These findings are consistent with numerical model predictions of an intensification and retroflection of the NBC during late summer and fall. This deflected current, in turn, feeds the seasonally enhanced eastward transport in the North Equatorial Countercurrent.

- Both the NBC and the offshore (eastward) flows in the upper 1000 m were modulated throughout the year by an energetic 50-day oscillation with peak-to-peak meridional velocity fluctuations in excess of 1 m s^{-1}. Analyses of satellite-derived coastal zone color scanner images and of numerical model results indicate that these 50-day fluctuations result from large (400-km diameter) eddies that

are shed from a pulsating northwest extension of the eastward-curving NBC in the retroflection region.

- Deep currents below 3500 m at the offshore mooring were not noticeably influenced by the energetic upper layer variability. Rather, they showed a strong and remarkably steady Deep Western Boundary Current (DWBC) flowing along the continental rise with an annual mean southeasterly speed of approximately 25 cm s^{-1}.

Water Mass Analysis Based on Historical Data.

Historical temperature and salinity data, along with recently acquired tracer information, have been collected, edited, and analyzed with focus on the deep western boundary water masses, their formation and transformation as the boundary flow progresses southward. The effort includes mapping water mass properties in the far northwestern Atlantic region where North Atlantic Deep Waters (NADW) are formed, their modification as they flow to the south along the western boundary, and their introduction into the basin interiors in the North and South Atlantic.

The first phase of the project, involving the initial historical data analysis has been nearly completed. Specific results are as follows:

- A modern meridional data section through the interior of the western Atlantic has been made and compared with one along the western boundary current. This has led to the identification of a number of recirculation cells in the deep thermohaline circulation and confirmation of earlier suggestions of such cells.

- Temporal variations in the NADW complex have been tracked. The result suggests at least two major swings in properties in the NADW since the early part of the 20th century. These swings are most pronounced in the far North Atlantic, but can be traced throughout the North Atlantic and into the northern reaches of the South Atlantic.

- A surprising finding is that variations in the NADW, which have been known for some time, are actually smaller than those seen in the bottom waters in the Argentine Basin. This raises concerns about the idea that the NADW variations dominate the thermohaline variations in the world ocean, and points toward possibly important questions for future thermohaline circulation research.

EPOCS- and TOGA-Related Studies

Current CIMAS studies on equatorial Pacific dynamics are conducted in two complementary problem areas: data assimilation technique development for numerical ocean models, and analysis of dispersal dynamics for satellite-tracked drifters.

Data Assimilation in Equatorial Pacific Models

This work is conducted at AOML with CIMAS staff participation and in the immediate context of NOAA's EPOCS program. The results should however be applicable in a much broader context. Work is concentrated on the development of an adjoint model code for the Geophysical Fluid Dynamics Laboratory (GFDL) numerical ocean model. Following are FY 90 accomplishments:

- The adjoint model code for the GFDL model was completed and was also installed and tested on the Cyber 205 supercomputer facility in Gaithersburg.

- An assimilation experiment based on Pacific equatorial data showed that the limited amount of data that is available on a weekly basis is under most circumstances insufficient to provide a unique analysis of a time-dependent state.

- Trials using data from longer time periods in different modes of mixing analysis and prediction were undertaken but the number of case iterations is as yet too small to allow firm conclusions about the methods.

Plans FY 91

CIMAS plans for research related to climate dynamics are based on consideration of the established objectives of NOAA's Climate and Global Change Program, with primary emphasis on the Atlantic Climate Change Program (ACCP). A central goal of the ACCP is to develop an understanding of the climatically significant meridional overturning of waters in the entire Atlantic basin, the so-called Atlantic Conveyor Belt. The ACCP plan recognizes the significance of maintaining observations of the meridional transport patterns in the Florida-Bahamas section of the Atlantic western boundary regime, and places high emphasis on studies of the basic processes and the variability associated with export of cold deep waters from the North Atlantic to the rest of the world ocean system and the associated warm water suction from the tropics into the northern temperate latitudes. The following plans have been developed in the CIMAS framework jointly between scientists at AOML and the University of Miami, with the benefit of discussions about possible national and international cooperation on studies in the Western Tropical Atlantic held at an international workshop in January 1990.

Circulation in the Subtropical and Tropical Western Atlantic

The long-term objectives of the planned work are the following:

- To improve precision in the transport estimates for the DWBC.

- To establish the relation between length of observation period and precision in DWBC transport estimates for several potential monitoring sites, based on the regional characteristics of the variability of currents.

- To determine the rates and analyze the mechanisms responsible for the observed diversion of boundary current waters into, or exchange with recirculation domains in the Atlantic interior.

- To establish causal connections between observed variability in the western Atlantic transport fluctuations and variations in meteorological forcing conditions.

- To compare observations and general circulation models, for improved understanding of the influence of Atlantic variability on climate.

- To develop monitoring strategies suitable for estimating the thermohaline circulation.

In pursuing these goals, every effort is made to enhance the NOAA-sponsored CIMAS activities on coordinated projects drawing on other U.S. agencies, and with international cooperation with countries concerned with Atlantic circulation variability and its climatic effects.

Specific activities proposed for FY 91 are the following:

Florida current

- A minimal effort to continue current profiler (Pegasus) based calibration control for indirect transport monitoring (based on tide gauge and electromagnetic induction data) will be maintained, but the main effort will be an extension of ongoing analysis of transient wind influences on the observed transport fluctuations, including critical comparisons with different model predictions.

Subtropical western Atlantic

- Moored current meter observations aimed at determining the DWBC structure off the northern Bahamas (Abaco) will continue, supported by several ship-based surveys including current profiling. Four moorings in the array are supported through FY 91 by the National Science Foundation (NSF); a fifth mooring and the shipboard work are supported by NOAA/ERL. The region is one of the primary sites chosen for possible long-term monitoring. Interpretation of the FY 90–91 observations in terms of circulation on larger scales than that of the current meter array will also benefit from a simultaneous regional deep-ocean-floats study supported by NSF.

- In addition to the standard current meter sampling, two moorings will be instrumented with temperature-pressure recorders at four depths and precision bottom pressure gauges. These are designated "dynamic height" moorings, since the measurements allow continuous monitoring of the absolute dynamic height profiles at these sites, from which the spatially integrated geostrophic flow can be determined. The moorings will be deployed for a period through January 1992.

- Current (Pegasus) and CTD profiling, as well as detailed sampling of CFC concentrations on NOAA ship surveys of the Abaco section will continue to complement the continuous current meter observations.

- Analysis of the characteristics of the Abaco section data sets with regard to time and space scales of the fluctuations and their dynamic character will be expanded on the basis of the increasing data base. This will provide a critically needed extension of the observed fluctuation time history as a basis for design of a long-term monitoring system, and will facilitate comparisons with numerical model results acquired from several research groups.

- The study of historical hydrographic data will be merged with the analysis of CFC distributions in order to establish locations of dominant recirculation domains for deep water, and the rates at which these domains interact with the DWBC system.

Tropical western Atlantic

The cross-equatorial warm water transport into the North Atlantic is subject to strong variations in the actual paths of transfer to the subtropical regions because of the complicated seasonal variability of the North Brazil Current (NBC). Although a broad agreement between model-produced and observed fluctuation characteristics has been demonstrated, the available oceanic observations are far from sufficient to quantitatively verify the adequacy of high-resolution ocean models in this respect. The remarkable steadiness in the observed southward flow of deep water observed off French Guiana commends this site for consideration in long-term monitoring plans. Extension of the present data source from a single mooring to an array capable of defining the total transport rate, and a follow-up of tracer (CFC concentration) observations to establish the degree of continuous water mass integrity along the path of the DWBC are therefore priority items in CIMAS research planning.

Currently deployed instruments (for the period September 1989 to September 1990) are involved in a coordinated study of the NBC retroflection region with German (three moorings along 44° 20′ W from the Equator to 3° 20′ N), French (moored array across the Demerara Rise), and other U.S. investigators (Pegasus measurements and CTD surveys). Our initial objective is to obtain a first-order description of the circulation and variability in this region and to explore the dynamical coupling between the various current systems. Following are plans for continuation of this work:

- Redeployment of a shallow-water mooring on the Amazon Cone on the R/V *Malcolm Baldrige* cruise in September 1990, and of three deep-water moorings on a January 1991 *Malcolm Baldrige* cruise (pending support through the ACCP). The shallow-water mooring will be recovered 1 year later and then will be redeployed for a second year (September 1991 to September 1992). The other moorings will be recovered in January 1992. These deployments will extend to 4 years the continuity of long-term current time series measurements across the NBC at the Amazon Cone section and they provide two moorings across the DWBC that will be used to compute transports.

- In addition to the moored arrays, the CTD and Pegasus surveys are also proposed to continue, consistent with the overall program strategy.

- Estimates of volume and heat transports across the Equator for both the NBC and the DWBC will be facilitated by a complementary effort by the University of Kiel, comprising a three-mooring array along 44° 20′ W that forms a triangle crossing the NBC at the Equator and at 4° 20′ N. The combined array also brackets the region where the NBC retroflection into equatorial countercurrents begins.

EPOCS and TOGA-Related Studies

Data assimilation research

Continued work on technical aspects of variational data assimilation in numerical models, based on the developed adjoint model code, is essential in order to optimize procedural efficiency. This task will be approached along two complementary lines:

- Data assimilation into a steady-state (stationary) model. Computationally, this is equivalent to varying the initial conditions so that change over a single time step is as small as possible. The resulting fields will then be compared with those used to initialize forecasts at the NOAA Climate Analysis Center. The advantage of this approach is that it is computationally inexpensive because only one time step is involved.

- Exploration of computational algorithms to speed up iteration convergence. This will be done within the framework of the stationary model assimilation since its computational efficiency allows a large set of experiments. CIMAS investigators (at AOML and the University of Miami) have been at the forefront of the TOGA–WOCE (World Ocean Circulation Experiment) Global Surface Velocity Program development. Diagnostic studies from drifter data will be based on the Global Drifter Data Center maintained at AOML.

Accomplishments included the following:

- Development of kinematic simulation model for tracking drifters in specified equatorial current and wave fields as a tool for diagnostic method development.

- Preliminary theory development for the probability distribution of drifters near the Equator.

- Exploratory mapping of currents in the northern Indian Ocean, using the joint NOAA–NSF drifter data set from the period 1985–1988.

FISHERIES ECOLOGY AND ECOSYSTEM DYNAMICS

Research under the theme of Fisheries Ecology and Ecosystem Dynamics is conducted in cooperation with the Miami Laboratory of the NMFS Southeast Fisheries Center (SEFC) and with support derived from NOAA's office of Oceanic and Atmospheric Research as well as from SEFC. The major activity in FY 90 was a multidisciplinary study of the regional ecosystem on the ocean side of the Florida Keys. SEFCAR (Southeast Florida and Caribbean Recruitment) aims to elucidate ties between the oceanic circulation processes in the boundary region between the Gulf Stream and the Florida Keys and the stock recruitment of spiny lobster and important reef fish species in the region. Cooperative efforts between University of Miami and SEFC scientists in Ecosystem Dynamics include larval ecology of bluefin tuna in the Gulf of Mexico and satellite remote-sensing technology applied to a range of problems in larval and adult stock distribution modeling.

The SEFCAR project combines field studies of physical processes, using current measurements from standard moored instrumentation plus bottom-mounted acoustic Doppler current profiler (ADCP) observations and shipboard hydrographic surveys, and biological sampling in the field to determine the distribution and abundance of target species larvae as well as of the zooplankton which serves as larval food. The larval distribution surveys are conducted using a Multiple Opening and Closing Net Environmental Sampling System (MOCNESS) which allows controlled depth distribution of samples along with temperature and salinity data acquisition. The field work is complemented in a shore laboratory by rearing of larvae for identification purposes, and by studies of larval feeding behavior and growth rate including time of settling from free-swimming to bottom-attached behavior. A complementary biochemical genetic analysis effort is aimed at elucidating the degree to which local recruitment of spiny lobsters and snappers relies on geographically disperse populations as sources for larvae. The approach combines conventional protein starch gel electrophoresis and mitochondrial DNA (mtDNA) restriction endonuclease analysis. The end result of this research is information useful to fisheries managers who must choose between different management practices.

Accomplishments FY 90

SEFCAR Field Studies

Field studies in SEFCAR were focused on an approximately 100-km-wide region off the central Florida Keys, identified as the Pourtales Terrace, but extended in part as far upstream as Key West. The principal findings were as follows:

Physical observations

- The physical basis for the project strategy is the existence of a cyclonic gyre over the Pourtales Terrace between Key West and Key Largo. The presence of this gyre has been confirmed, and its seasonal variability has been characterized. Approximately aligned with the Pourtales Terrace, the gyre extends typically about 40 km offshore of the shelf break between Looe and Sombrero Reefs, forming a significant potential capture and retention region for pelagic larvae being transported by the large-scale currents and local wind drift.

- Upwelling in the center of the gyre and along the continental slope lifts the thermocline into the euphotic zone where nutrients are available for planktonic uptake. Upwelling velocities in the cold core are roughly estimated from conservation of relative vorticity at about per 6.5 m per day.

- Prevailing easterly winds cause a convergence of boundary layer (Ekman) transport into the gyre from the surface layer of the Florida Current. This facilitates the transport of pelagic larvae from the Current to coastal waters.

- The combined effect of the circulation in the Pourtales gyre and local onshore surface Ekman transports can act to concentrate fish and lobster larvae for recruitment into the Florida Keys coral reefs in the northwest quadrant of the gyre and in a coastal strip along the continental slope.

- Retention times in recirculating gyres off the lower Florida Keys match the 1-month planktonic stage for grouper and snapper larvae, which should lead to significant recruitment from locally spawned sources.

- The long 6-month planktonic stage for Florida lobster larvae necessitates recruitment from remote upstream sources, or a recruitment pathway through Florida Bay, retention in the Bay lasting from 3 to 5 months.

Larvae and zooplankton distributions

- Abundance of larval fish and zooplankton is high in the physically defined Pourtales Gyre concentration region.

- Larvae of grouper family *Serranidae* are distributed in the mixed surface layer and therefore subject to transport by currents in the layer during this phase of larval life.

- Distributions of lobster larvae differ in a species-dependent fashion, some apparently being adapted for local retention and others for wide dispersal. This fact permits use of a comparative approach for generalizable results concerning oceanography and recruitment.

- Late-larval-stage spiny lobsters show depth and areal distributions consistent with a Pourtales Gyre or Tortugas Gyre concentration effect.

- Food (zooplankton) distributions show a strong seasonal and spatial variability. High plankton abundances occur in the region of fronts.

Shore-based studies

- Food preferences were assessed; most larvae were dependent on young stages of copepods.

- Larvae of six species were reared and their growth determined. Temperature and food abundance have a profound effect on the growth and time-to-settlement of these larvae.

- Observations of otoliths of preserved samples indicate that the otoliths of reared snappers contain easily identifiable daily rings, and no sub-daily rings. Otoliths will therefore be useful in determining settlement and transport time.

Video recording and image analysis systems were used to analyze larval behavior. Larvae of the the harlequin bass, *Serranus tigrinus*, are being used as the model fish, and the ontogeny of larval swimming speeds and swimming behavior has been determined.

Illustrations of preserved larvae of mangrove snapper, lane snapper, yellowtail snapper, and a yellowtail-lane snapper cross are being completed. A description of the lane-yellowtail hybrid was completed and may provide the basis to consolidate the genus *Ocyurus* and genus *Lutjanus*.

- Purification of mtDNA from local adult spiny lobster, local Spanish lobster, and snapper species was achieved as a critical first step in the biochemical genetic analysis approach.

- Purified mtDNA was "cut" into several size fragments with several restriction enzymes. Each cut in the mtDNA molecule generates a genetic characteristic that can be used to compare the relatedness of two individual lobsters. At present we have approximately 12 characters for comparisons.

- We successfully cloned the entire mtDNA molecules from both the spiny and Spanish lobsters. 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 that hybridizes with mtDNA from samples of other adult and larval lobsters, and identifies these molecules without need for further purification for each individual.

- In preliminary analyses of adult spiny lobster, there appears to be a large amount of variation in the mt DNA molecule.

- In conjunction with other CIMAS investigators, we carried out a sampling program for local and Caribbean spiny lobster and local post-larvae and larvae.

- We optimized the storage conditions for organisms used for mtDNA analysis. In addition to freezing of tissues, it appears that planktonic samples stored in 70% EtOH (normal conditions used by plankton biologists) will be sufficient for mtDNA samples.

Other Ecosystem Studies

In addition to the SEFCAR project, ecosystem dynamics research involves close cooperation with SEFC in studies of bluefin tuna larval ecology and fishery oceanography. Following are specific accomplishments:

- Publication of a new hypothesis for dynamic environmental control of bluefin tuna population dynamics through fluctuations in suitable larval habitat in the Gulf of Mexico.

- Definition of larval habitat in terms of sea surface salinity and temperature.

- Assessment of effects of transport from nursery area, using satellite and in-situ oceanographic observations.

Improved access to satellite data for SEFC via the University of Miami remote-sensing facility has been implemented.

Preliminary correlation analysis of Catch Per Unit Effort (CPUE) in the Caribbean swordfish with satellite-based thermal front analysis suggests only marginal dependence.

Plans FY 91

SEFCAR

Field work in SEFCAR will be continued to further define effects of physical processes on the recruitment of fish and lobster larvae in the Florida Keys. Two full years of field data are being used as a basis for a system model synthesis. The execution of field work plans for spring 1991 will depend on the actual available funding. The laboratory studies of larval growth and behavior, and the rearing for identification purposes, as well as the mitochondrial DNA work, are expected to reach a point where their effect on the overall set of questions raised in SEFCAR will be substantial. The SEFCAR field work will be coordinated with a recently

funded (for FY 91) Minerals Management Service (MMS) study of the physical oceanography of the Florida Straits region, thereby achieving greater area coverage of observations, and improving economy by coordinated vessel chartering.

Field Work Plans

- Survey temperature, salinity, and micro-zooplankton fields of the Florida Keys coastal and offshore waters seasonally, using expendable bathythermographs (XBTs) and a Sea Bird to measure conductivity, temperature, and depth (CTD) mounted on a Rosette with 30-liter bottles for biosampling on interdisciplinary cruises.

- Extend work with the moored current meters to provide two full annual cycles, complemented by physical and hydrographic observations carried out on cruises in support of the biological sampling efforts. Deploy three current meter moorings with three current meters per mooring, along the shelf break (30 m depth) of the Florida Keys off Carysfort Reef, Tennessee Reef, and Looe Reef, together with spiny lobster settling trap stations. ADCP deployment will be continued offshore of Looe Reef on the Pourtales Platform. Dual-beam acoustic sampling by AOML on the interdisciplinary sampling cruises will be used to calibrate the ADCP as well as the NOAA sonar system for plankton monitoring, on the basis of simultaneous MOCNESS plankton sampling.

- Acquire a 10 m^2 MOCNESS system and use it to enhance the sampling of the pre-settlement stage between the planktonic larvae and the settled juveniles.

- Implement monitoring of light traps and juvenile fish to increase emphasis on the survivors of the planktonic phase.

- Focus data synthesis on the relationships among plankton abundance and (1) diel vertical migration, (2) frontal effects, and(3) seasonality.

- Further elucidate the effect of temperature on time-to-settlement of planktonic larvae in laboratory studies. The results to date on temperature and food effects are intriguing, but we must continue these studies with a greater variety of species.

- Examine the food availability and its interaction with oceanographic conditions in more detail. Regions near spawning aggregations will be included in order that density-dependent effects may be studied.

- Test the hypothesis that conditions which favor short time-to-settlement also favor survival of larvae, by using validated ages from otoliths of reef species to assess growth, condition, and birth date distributions of larvae affected by different food abundances and temperatures. This can be determined from otoliths of juvenile fishes. Most studies that determine time-to-settlement do not have matching oceanographic data and have therefore been unable to explain variation in settlement time on this basis.

- Continue laboratory analysis of behavior of larvae.

- Continue rearing program for specific identifications.

- Finish the analysis of mtDNA variation in adult spiny lobster from the Caribbean. The results will enable us to determine if the spiny lobster is one large panmictic population or, alternatively, if there is genetic divergence between populations.

- Finish collecting samples of larvae and post-larvae that are recruited to South Florida, and begin analyses.

- Develop DNA-based methods to distinguish between larvae of spiny and Spanish lobsters.

- Apply protein electrophoresis and mtDNA methodology to species of snapper with two aims: (1) To develop biochemical methods to distinguish the larvae of different snapper species. These larvae are difficult, at best, to distinguish by traditional morphometric or morphological means. (2) To begin a Caribbean basin study of snappers that is analogous to our approach with the spiny lobster.

- Continue larval fish ecology work on bluefin as a target species of importance to fisheries.

- Utilizing existing SEFC data bases on larval fish community assemblages, supplemented with experiments at sea on a ship of opportunity, apply multivariate and comparative analysis to the problem of detecting global change effects on the reproductive output side of population dynamics of fishes on an ecosystem basis.

- Investigate associations between swordfish relative abundance and specific oceanic and topographic features (e.g., warm core rings, shelf water intrusions, submarine canyons) on the basis of NMFS data and remote-sensing data bases available at the University of Miami. We plan, in particular, to explore the reasons for the high variability in swordfish CPUE and investigate the related dynamics of fishing effort.

- Continue to support remote-sensing activities at SEFC. We are producing lower resolution (18 km) weekly satellite sea-surface temperature fields encompassing the whole northwestern Atlantic (including the tropical region) and the Gulf of Mexico. This series includes data from 1982 to the present.

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 NOAA and the University of Washington (UW). 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. Only the climate program has been block funded, and includes more than two-thirds of JISAO's work.

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 emphases have served to promote collaboration between the Pacific Marine Environmental Laboratory and university scientists involved in the Equatorial Pacific Ocean Climate Studies (EPOCS) program. JISAO has also been active in directing interdisciplinary research toward an 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 budget, organic carbon dynamics, and chemical processes involving the deposition of heavy metals. This work,

particularly the studies of heavy metals, is closely related to ongoing estuarine research efforts. Recently, JISAO's chemistry research has broadened in scope to include other biogeochemical cycles of interest for global climate studies. 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 90

JISAO scientists, in collaboration with NOAA scientists, were involved in a variety of climate research activities. They explored the sensitivity of interannual variability in a coupled ocean-atmosphere model to 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 tropical surface winds. Members of the Environmental Climate Forecast Center contributed to the definition of a TOGA program on seasonal to interannual predictions and to a document summarizing TOGA at its midlife.

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. Analyses 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 effect of stochastic forcing on the periodicity of such systems.

JISAO's Experimental Climate Forecast Center 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 factors that influence climate change on time scales of 100 years.

Research in environmental chemistry included participation in NOAA's Pacific Sulfur/Stratus Investigations (PSI) cruise off the Washington coast, measuring particle size distributions and cloud condensation nucleus spectra. This work has the long-term goal of relating gaseous sulfur emissions by the ocean to particle number or mass concentration of condensation nuclei.

Investigation into the chemistry of vent fluids and their entrainment into hydrothermal plumes continued at Axial Seamount and Juan de Fuca Ridge.

Interdisciplinary Initiative

JISAO coordinated and provided administrative support for submission of an interdisciplinary-initiative proposal to the Office of the UW Provost, "Program for UW Research on the Carbon Cycles and Climate Change," for which funding was granted. These funds are providing summer fellowships to seven competetively selected graduate research assistants, as well as equipment and supplies for related projects.

Plans FY 91

- Continue vigorous postdoctoral, visitor, and seminar programs.

- Continue to work with NOAA to expand programs 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 Pacific Sulfur/Stratus Investigations (PSI).
- Host the U.S.-Japan Bilateral Meeting at UW in September 1990.

JISAO will provide partial funding for a joint University of Washington-Princeton University course entitled Ocean Circulation: Dynamics and Geochemical Cycling. The seminar will be offered during summer 1991 at the University of Washington Laboratory Facilities at Friday Harbor, Washington. Graduate students from the United States, Japan, France, England, Switzerland, and Germany will participate. A number of scientists from the University of Washington and other institutions will visit and make informal contributions.

JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH
University of Hawaii
(808) 956–8084
Dennis W. Moore, Director

The Joint Institute for Marine and Atmospheric Research (JIMAR) was formed in 1977 by a Memorandum of Understanding between NOAA and the University of Hawaii. JIMAR is located at the University of Hawaii at Manoa and is part of the School of Ocean and Earth Sciences and Technology. The principal research interests of JIMAR are equatorial oceanography, climate and global change, tsunamis, and fisheries oceanography.

Accomplishments FY 90

Equatorial Oceanography and Climate Research

Western Equatorial Pacific Ocean Circulation Study (WEPOCS)

WEPOCS was a joint U.S.-Australian program to study water mass distributions and circulation in the near-equatorial region north of New Guinea. All WEPOCS III data have been finalized, and an overview paper has been completed on these observations. Analyses of WEPOCS I and II observations of water masses, currents in the Vitiaz Strait, and structure of the "warm pool" mixed layer were completed and documented.

Coupled Ocean-Atmosphere Response Experiment (COARE)

COARE is a program to understand the physical processes that maintain and perturb the warm pool in the western Pacific Ocean. Understanding the coupling between the ocean and atmosphere in this region is the major goal for the second half of the Tropical Ocean and Global Atmosphere (TOGA) program.

COARE planning continued and the COARE Science Plan was completed. A proposal for monitoring the thermohaline structure of the warm pool was submitted.

Hawaiian Ocean Time Series (HOT)

A deep-water station 100 km north of Oahu is occupied monthly to collect physical and biological data for the World Ocean Circulation Experiment (WOCE) and the Global Ocean Flux Study. JIMAR has been responsible for both hydrographic measurements and acoustic Doppler current profiling (ADCP) for this program. Data collection continued throughout the year.

Indo-Pacific Sea Level Network and TOGA Sea Level Center

Eighty-one Pacific stations (of 90 proposed for TOGA) and 18 (of 24) Indian Ocean stations are now operating. Hourly, daily, and monthly data are archived at the TOGA Sea Level Center. Data return from the Pacific is very good, much of it coming in near-real time via satellite. Data return from the newer Indian Ocean network is slow. Monthly maps of Pacific sea level are produced and distributed with about a 1-month lag. Sea level data are being compared with satellite altimeter data from GEOSAT, in anticipation of the TOPEX/POSEIDON altimeter data. Sea level data are being used in conjunction with other oceanic and atmospheric data sets to study both intraseasonal and interannual variability.

Modeling and analysis

The effect of nonlinear heating on moist atmospheric Kelvin waves was modeled. Empirical studies of the evolution and vertical structure of the El Niño–Southern Oscillation (ENSO) anomaly mode in the tropical atmosphere were done. Model studies in the β-drift baroclinic vortices were made. Analysis of deep equatorial currents is continuing. The 16-month Pacific Equatorial Ocean Dynamics (PEQUOD) data show vertical mean (barotropic) flows of about 2 cm^{-1}, on meridional scales characteristic of baroclinic disturbances.

Fisheries Oceanography

Seamount oceanography

Fieldwork involving Doppler Current Profiling and hydroacoustic scattering around Hancock Seamount has been completed. Analysis of the data is under way to relate circulation over seamounts to fisheries productivity.

Island-flow interactions and recruitment

Lobster larvae sampling has been conducted in the Hawaiian archipelago, along with ADCP and other oceanographic data collection. Analysis continued, to investigate the relationship between larval distributions, adult abundances, topography, and currents.

North Pacific transition zone

Both physical and biological measurements were obtained on transects in the North Pacific Transition Zone to help assess the effect of large-mesh fishing on pelagic fishes and marine turtles.

Tsunami Research

Inundation maps

The project to update tsunami inundation and evacuation maps for the State of Hawaii continued. Most of the work on the inundation maps is complete. Work continued on methods for run-up prediction and validation.

Tsunami modeling

Numerical simulations of tsunamis using a variety of source configurations were computed, and the results were compared with the open-ocean deep pressure observations from the Pacific Tsunami Observation Program (PacTOP). Shallow water equation codes have been used for this purpose. Calculation of inundation began, using both shallow water and fully three-dimensional Navier-Stokes codes.

Plans FY 91

Equatorial Oceanography and Climate Research

- Analysis of WEPOCS data will continue. A WEPOCS workshop is planned for spring 1991, to begin model-data intercomparison. COARE planning will emphasize final development of an experimental design for the field work.
- In collaboration with PMEL, conductivity sensors will be added to selected TOGA moorings so that space and time scales of the wind, temperature, and salinity of the western Pacific warm pool can be studied.
- Carbon dioxide measurements will be added to the ongoing HOT cruise program, as part of the Climate and Global Change Program.
- The Sea Level Network and TOGA Sea Level Center will continue to archive data, handle data requests, and use the data for research. The emphasis in FY 91 will be on refining altimeter corrections for water vapor and intense rainfall.
- Empirical studies of ENSO variability will be expanded from the equatorial wave guide to the global tropics and extended back to cover a 40-year period.
- A study to compare satellite-based rainfall estimates with ground-truth measurements from rain gauges and radar will be carried out for the Climate and Global Change Program, in preparation for analysis of the upcoming Tropical Rainfall Measuring Mission (TRMM) data.

Fisheries Oceanography

- Analysis of the Hancock Seamount data will be completed and written up for publication.
- A cruise will go to Palmyra Atoll to deploy drifting buoys, conduct Doppler profiling, and take biological samples.
- An oceanographic data base for the North Pacific Transition Zone data will be set up as a first step in establishing an oceanographic data "library" at the University of Hawaii. This JIMAR facility will be part of a NOAA–National Ocean Survey (NOS) network operating from the Center for Ocean Analysis and Prediction in Monterey.

Tsunami Research

- The State of Hawaii inundation maps will be completed. The corresponding evacuation zones will be determined in cooperation with civil defense officials on each island. New techniques for detecting tsunamigenic earthquakes by ionospheric and infrasonic techniques will be explored.
- Numerical modeling of the tsunami run-up using shallow water and Navier-Stokes codes will continue. The aim is to develop the capability for accurate inundation predictions. This is the beginning of JIMAR's effort in the Tsunami Inundation Program (TIP), designed to bring the tsunami warning process to the same state of sophistication as NOAA's storm surge program.

APPENDIX: Acronyms and Initialisms

AASE	Airborne Arctic Stratospheric Expedition
A&P	Analysis and Prediction [program] (FSL)
ACCP	Atlantic Climate Change Program
ACID MODES	Acid Model Evaluation Study
ADCP	acoustic Doppler current profiler
AEROCE	Atmosphere-Ocean Chemistry Experiment
AFOS	Automation of Field Operations and Services
AGASP	Arctic Gas and Aerosol Sampling Program
AI	artificial intelligence
AL	Aeronomy Laboratory (ERL)
AMS	American Meteorology Society
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
ARCS	Assessment and Remediation of Contaminated Sediments
ARL	Air Resources Laboratory (ERL)
ASCOT	Atmospheric Studies in Complex Terrain
ASHES	Axial Seamount Hydrothermal Emissions Study
ASOS	Automated Surface Observing System
ATLAS	Automated Temperature Line Acquisition System
AVHRR	Advanced Very-High-Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AWIPS–90	Advanced Weather Interactive Processing System for the 1990s
BAO	Boulder Atmospheric Observatory
BPR	bottom pressure recorder
CAPS	Center for Analysis and Prediction of Storms
CFC	chlorofluorocarbon
CFM	chlorofluoromethane
CG	cloud to ground
CGC	Climate and Global Change
CILER	Cooperative Institute for Limnology and Ecosystems Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIMRS	Cooperative Institute for Marine Resources Studies
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CLARET	Cloud Lidar and Radar Exploratory Test
CLASS	Cross-chain Loran Atmospheric Sounding System
CMDL	Climate Monitoring and Diagnostics Laboratory
CME	coronal mass ejection
CN	condensation nucleus
COADS	Comprehensive Ocean-Atmosphere Data Set
COARE	Coupled Ocean-Atmosphere Response Experiment
COAST	Combined Oceanic and Atmospheric Sensing Technique
COMET	Cooperative Program for Operational Meteorology Education and Training
COPS–89	Cooperative Oklahoma P–3 Studies—1989

COPS–91	Cooperative Oklahoma Profiler Studies–1991
CPUE	catch per unit [fish] effort
CSES	Center for the Study of Earth from Space
CSIRO	Commonwealth Scientific and Industrial Research Organisation [Australia]
CSU	Colorado State University
CTD	conductivity, temperature, depth
DARE–II	[PROFS meteorological workstation; not an acronym]
DIAL	Differential Absorption Lidar
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DOE	Department of Energy
DPID	Dual Port Interface Device
DWBC	Deep Western Boundary Current
ECC	electrochemical concentration cell
EC–GC	electron capture gas chromatograph
EFC	Experimental Forecast Center
ENSO	El Niño–Southern Oscillation
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
EPIC	Extensive PMEL Information Collection
EPOCS	Equatorial Pacific Ocean Climate Studies
ERICA	Energetics of Rapidly Intensifying Cyclones over the Atlantic
ERL	Environmental Research Laboratories (NOAA)
EUV	extreme ultraviolet
FAA	Federal Aviation Administration
FIDES	Forecaster's Intelligent Discussion Expert System
FIRS	Fourier transform Infrared Sounder
FOCI	Fisheries Oceanography Coordinated Investigations (NOAA)
FSL	Forecast Systems Laboratory (ERL)
GBSRN	Global Baseline Surface Radiation Network
GC	gas chromatograph
GCM	general circulation model
GCTM	global chemical transport model
GFDL	Geophysical Fluid Dynamics Laboratory (ERL)
GLERL	Great Lakes Environmental Research Laboratory (ERL)
GMCC	Geophysical Monitoring for Climatic Change (ARL)
GOES	Geostationary Operational Environmental Satellite
GPS	global positioning system
GUFMEX	Gulf of Mexico [project]
HARP	Hawaiian Rainband Project
HCFC	hydrochlorofluorocarbon
HEPAD	High Energy Proton and Alpha Detector
HIRIS	High-Resolution Imaging Spectrometer
HLMS	High Latitude Monitoring Station

HOT	Hawaii Ocean Time-series
IFR	Instrument Flight Rule
IFREMER	Institut Francais de Recherche pour l'Exploitation de la Mer
IGM	interplanetary global model
IMF	interplanetary magnetic field
INSAT	Indian Satellite
IR	infrared
ISCCP	International Satellite Cloud Climatology Project
ISEE	International Sun-Earth Explorer
ISPAN	Information Stream Project for AWIPS/NOAAPORT
JIC	Joint Ice Center
JIMAR	Joint Institute for Marine and Atmospheric Research
JISAO	Joint Institute for Study of the Atmosphere and Ocean
LAPS	Local-scale Analysis and Prediction System
loran	long-range aid to navigation
LOWS	Lake Ontario Winter Storms
MAPS	Mesoscale Analysis and Prediction System
MARA	Multimode Airborne Radar Altimeter
MARD	Modernization and Associated Restructuring Demonstration
MCLASS	Mobile CLASS
MCS	mesoscale convective system
MIT	Massachusetts Institute of Technology
MLOPEX	Mauna Loa Observatory Photochemistry Experiment
MMS	Minerals Management Service
MOCNESS	Multiple Opening and Closing Net Environmental Sampling System
MSA	methane sulfonic acid
MS&C	Marine Sulfur and Climate
MST	Mesosphere-Stratosphere-Troposphere
MWSR	Microwave Water Substance Radiometer
NADW	North Atlantic Deep Water
NAPAP	National Acid Precipitation Assessment Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NBC	North Brazil Current
NCAR	National Center for Atmospheric Research
NDBC	National Data Buoy Center
NDSC	Network for Detection of Stratospheric Change
NECOP	Nutrient-Enhanced Coastal Ocean Productivity
NESDIS	National Environmental Satellite, Data, and Information Service (NOAA)
NEXRAD	Next-Generation Weather Radar
NGDC	National Geophysical Data Center (NOAA)
NHC	National Hurricane Center (NWS)
NIMBUS-7	[NOAA satellite; not an acronym]
NIST	National Institute of Standards and Technology

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]
NODC	National Ocean Data Center
NOS	National Ocean Service (NOAA)
NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSL	National Severe Storms Laboratory (ERL)
NURP	NOAA Undersea Research Program
NWS	National Weather Service (NOAA)
NWSTG	NWS Telecommunications Gateway
OCEAN STORMS	[JISAO field experiment; not an acronym]
ODW	Omega dropwindsonde
OGCM	ocean general circulation model
OU	University of Oklahoma
PacTOP	Pacific Tsunami Observation Program
PAH	polycyclic aromatic hydrocarbon
PBL	planetary boundary layer
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]
PRE–STORM	Preliminary Regional Experiment for STORM
PROFS	Program for Regional Observing and Forecasting Services (FSL)
PROTEUS	Profile Telemetry of Upper Ocean Currents
PSI	Pacific Sulfur/Stratus Investigation
QVADIS	[code name for model; not an acronym]
RADM	Regional Acid Deposition Model
RAMM	Regional and Mesoscale Meteorology
RASS	Radio Acoustic Sounding System
RF	radio frequency
RITS	Radiatively Important Trace Species
ROSE	Rural Oxidants in the Southern Environment
RSMAS	Rosenstiel School of Marine and Atmospheric Sciences
SAFER	Spectral Application of Finite Element Representation
SAGA	Soviet-American Gas and Aerosol [experiment]
SBUV	solar backscatter ultraviolet
SEFC	Southeast Fisheries Center
SEFCAR	Southeast Florida and Caribbean Recruitment

SEL	Space Environment Laboratory (ERL)
SELDADS	SEL Data Acquisition and Display System
SEM	Space Environment Monitor
SERS	Storm Education and Research System
SESC	Space Environment Services Center (SEL)
SIO	Scripps Institution of Oceanography
SMMR	Scanning Multichannel Microwave Radiometer
SOLERS	Solar Electromagnetic Radiation Study
SRA	scanning radar altimeter
SSM/I	Special Sensor Microwave/Imager
SST	sea-surface temperature
STACS	Subtropical Atlantic Climate Studies
STORM	Stormscale Operational and Research Meteorology
SWAMP	Southwest Area Monsoon Project
SXI	Solar X-ray Imager
TAG	Trans-Atlantic Geotraverse
TAMEX	Taiwan Area Mesoscale Experiment
TAO	Tropical Atmosphere-Ocean
TDWR	Terminal Doppler Weather Radar
THEO	[system for predicting solar flare probabilities; named for Theophrastus; not an acronym]
TIROS	Television and Infrared Observation Satellite
TOGA	Tropical Ocean and Global Atmosphere
TOMS	Total Ozone Mapping Spectrophotometer
TOPEX	Topographic Experiment
TRACIR	Tracking Air with Circularly polarized Radar
TSC	Transportation Systems Center
UARS	Upper Atmospheric Research Satellite
UHF	ultrahigh frequency
USAF	U.S. Air Force
UTC	Coordinated Universal Time
UV	ultraviolet
VAS	VISSR Atmospheric Sounder
VENTS	[hydrothermal venting program; not an acronym]
VFR	Visual Flight Rule
VHF	very high frequency
VICBAR	[code name for barotropic hurricane track prediction model; not an acronym]
VISSR	Visible and Infrared Spin-Scan Radiometer
WATOX	Western Atlantic Ocean Experiment
WDC	World Data Center
WEPOCS	Western Equatorial Pacific Ocean Circulation Study
WHOI	Woods Hole Oceanographic Institution
WISE	Weather Information and Skill
WISP	Winter Icing and Storms Project
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

WOTAN	Weather Observation Through Ambient Noise
WPL	Wave Propagation Laboratory (ERL)
WSFO	Weather Service Forecast Office
XBT	expendable bathythermograph

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