Environmental Research Laboratories Programs and Plans

FY 1991 Programs and FY 1992 Plans

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

Environmental Research Laboratories Programs and Plans

FY 1991 Programs and FY 1992 Plans

December 1991

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Boulder, Colorado
Alan R. Thomas, Acting Director

NOTICE

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

Environmental Research Laboratories

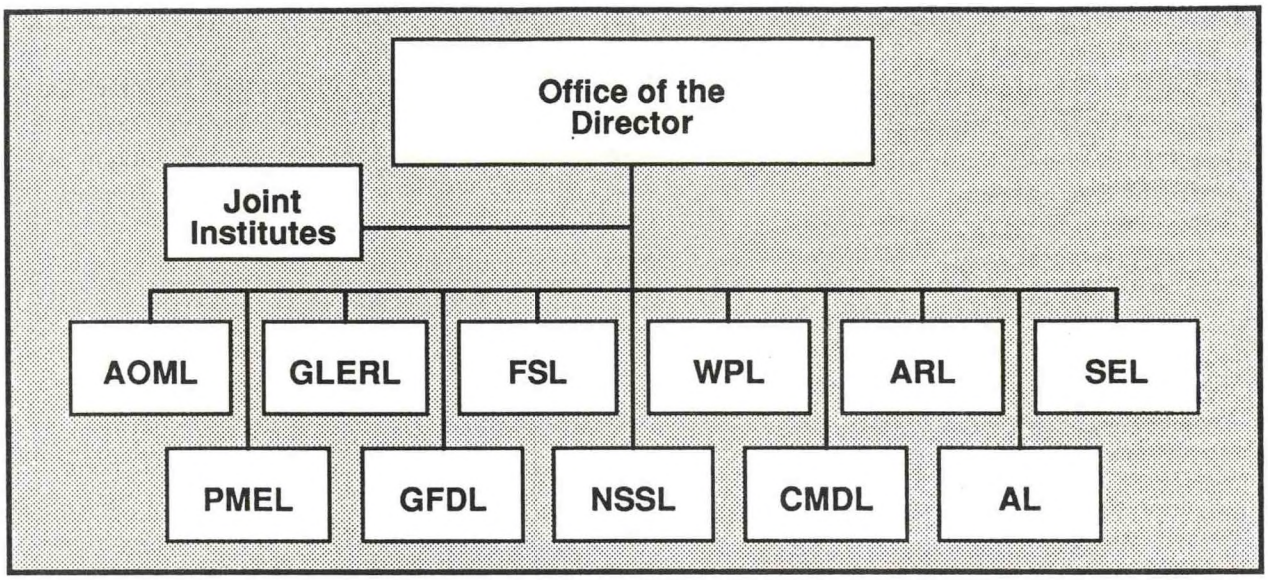
The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere,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

CONTENTS

Introduction and Summary of ERL Research 1
Office of the Director 11
Atlantic Oceanographic and Meteorological Laboratory 13
Pacific Marine Environmental Laboratory 27
Great Lakes Environmental Research Laboratory 39
Geophysical Fluid Dynamics Laboratory 53
Forecast Systems Laboratory 63
National Severe Storms Laboratory 77
Wave Propagation Laboratory 89
Climate Monitoring and Diagnostics Laboratory 101
Air Resources Laboratory 113
Aeronomy Laboratory 127
Space Environment Laboratory 141
Joint Institutes 153
- Cooperative Institute for Research in Environmental Sciences 154
- Cooperative Institute for Research in the Atmosphere 164
- Cooperative Institute for Mesoscale Meteorological Studies 168
- Cooperative Institute for Limnology and Ecosystems Research 173
- Cooperative Institute for Marine and Atmospheric Studies 177
- Joint Institute for Study of the Atmosphere and Ocean 185
- Joint Institute for Marine and Atmospheric Research. 187

Appendix: Acronyms and Initialisms. 193

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.*



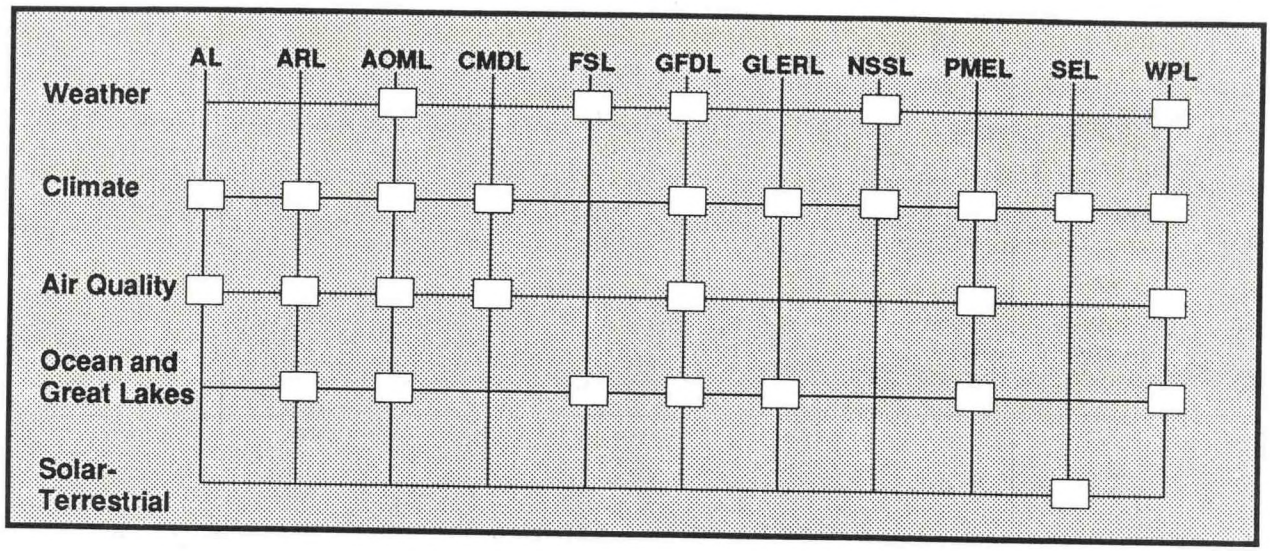
ENVIRONMENTAL RESEARCH LABORATORIES

The Environmental Research Laboratories (ERL) of NOAA's Office of Oceanic and Atmospheric Research are headquartered in Silver Spring, Maryland. 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 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 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 Stormscale Operational and Research Meteorology (STORM). 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: Weather, Climate, Air Quality, Ocean and Great Lakes, 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.

WEATHER

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 goal of ERL weather research is to provide the theoretical framework, scientific understanding, and technology to assure the 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. Major 1991 accomplishments and 1992 plans for weather research include the following:

- AOML omega dropwindsondes dropped from a NOAA WP-3D aircraft were used to obtain data to study the steering currents of mature hurricanes. Software for real-time processing of the data was tested on an airborne computer workstation during a flight in Tropical Storm Marco. The workstation allows the user to display, manipulate, and edit the sounding, and to encode mandatory and significant level wind and thermodynamic data that can then be relayed digitally to the National Hurricane Center (NHC) and the National Meteorological Center (NMC).

  In FY 92, a second computer workstation for the other WP-3D aircraft will be installed, and additional software improvements will be made to allow NHC to regularly receive two-dimensional analyses of the mesoscale precipitation and wind structure of tropical cyclone cores. The aircraft also will be

equipped with a C–band Scatterometer for measuring surface wind speed and direction, and with a sensor for measuring the horizontal component of the electric field in hurricanes.

- Using a spectral model, GFDL ran nine model integrations from nine different initial times for a 10-year (1979–89) period. All runs specified the same observed sea-surface temperature (SST). The study revealed that there are many occasions during the decade for which the stochastic forecast system exhibits a small spread, suggesting that the variables of concern are reproducible. These occasions represent stable, predictable atmospheric states, or "attractors," which must be the result of particular distributions of anomalous SST. The 1988 U.S. drought appears to correspond to one of these occasions.

  In FY 92, the 1988 U.S. drought will be studied to establish the statistical validity for the existence of attractors in the extratropics, and to explore the reasons for the reproducibility of these solutions.

- FSL installed 26 of the 31 profilers planned for the Wind Profiler Demonstration Network. Real-time hourly data from 22 profilers were sent to NWS for distribution to forecasters, and to Unidata for distribution to university and other researchers. Six-minute and hourly data on tape from 26 profilers were sent to the National Climatic Data Center (NCDC) for retrieval and permanent archiving.

  The Wind Profiler Demonstration Network will be completed before January 1992, and the Radio Acoustic Sounding System (RASS) with temperature capability will be installed at some network sites and tested during 1992. Network assessment using data from the completed network will begin.

- Improvements were made to the FSL Mesoscale Analysis and Prediction System (MAPS), such as parameterization of vertical transfers of heat, moisture, and momentum; increased horizontal resolution, from 80 km to 60 km, and increased numbers of vertical levels, from 18 to 25; and newly derived statistics to analyze incoming observations. The transfer of this new version of MAPS to NMC is under way.

  The transfer of MAPS will be completed and MAPS will begin running regularly on the NMC Cray Y–MP computer in 1992. Improvements in computational efficiency of the system by taking advantage of vector processors will be completed.

- In studies of mesoscale convective systems (MCSs), NSSL completed an analysis of airborne Doppler radar data from a WP–3D flight into an MCS during the Southwest Area Monsoon Project. The analysis indicated that the strong winds in the convective storm were initially generated by evaporative cooling, which produced locally intense downdrafts. Downward motion then was sustained by evaporative cooling of rain falling from the stratiform anvil.

  FY 92 plans include using data from the Preliminary Regional Experiment for STORM (PRE–STORM), Cooperative Oklahoma P–3 Studies–1989 (COPS–89), and Cooperative Oklahoma Profiler Studies–1991 (COPS–91) field programs to examine cooling rates of mid- and low-level air in the stratiform region as it flows across the band of heaviest rain to infer the importance of microphysics on MCS evolution.

- NSSL analyzed three splitting thunderstorms that occurred on 27 June 1989 during the North Dakota Thunderstorm Project. The airborne and ground-based dual-Doppler radar data taken from the first two storms revealed that a middle-altitude vorticity couplet formed on the lateral downwind flanks of each initial updraft, with cyclonic vorticity on the right and anticyclonic vorticity on the left when looking in the downwind direction. As new updrafts formed on the lateral flanks, the right-flank updraft acquired cyclonic rotation at middle altitudes and the left-flank updraft acquired anticyclonic rotation. A three-dimensional computer model of a rotating thunderstorm indicated why not all rotating thunderstorms develop tornadoes. For a storm to become tornadic, a balance between inflow from the environment into the storm and rain-cooled outflow is necessary.

  Planned studies include investigating the storm-environment interactions (pressure and buoyancy fields) that led to the splitting storms of 27 June, and completing a theoretical and numerical study

of the pressure field around a rotating thunderstorm updraft in strong environmental winds that veer with height.

- In FY 91, NSSL's multiparameter radar at Cimarron, OK, came back on line for the first time in several years. Cimarron provided real-time estimates of reflectivity, mean velocity, spectrum width, differential reflectivity, and differential phase for COPS–91. The radar was operated in a fully remote control status that included operation of the antenna, transmitter, signal processor, and back-up generators as well as remote display of the data in Norman, 40 km to the southeast.

  Plans for Cimarron include the enhancement of the multiparameter radar to produce additional dual polarization prarameters and to correct ground clutter filtering, and research support for the STORM Fronts Experiment Systems Test (STORM–FEST) field program scheduled for 1 February to 15 March 1992.

- WPL continues to push back the frontiers of atmospheric sensing with a new concept for profiling atmospheric winds and turbulence, a new lidar system for more accurate wind measurements, and an improved RASS. The new profiling system combines spatial filtering with speckle interferometry to provide better spatial resolution. The new lidar system is the world's first field-worthy, solid-state Doppler lidar at 2.1 μm that promises better velocity accuracy (5 cm s^{-1} for a 1-s average), spatial resolution (25 m), and pulse rate (200 Hz) than current lidars. The RASS combination with the wind profiler is now observing the structure of fronts in the middle and lower troposphere, and demonstrating the potential applications of the profiler-RASS network in mesoscale research and operational weather forecasting.

  FY 92 plans include proving the spatial filtering-speckle interferometry concept for profiling atmospheric winds and turbulence, field testing the new solid-state Doppler lidar, and installing RASS systems on the wind profilers to support the STORM program and research on severe weather events.

CLIMATE

Climate research is performed by most ERL Laboratories. The goals of this research are to recognize, diagnose, analyze, understand, and predict large-scale and regional changes in the oceans and atmosphere. Significant 1991 climate research accomplishments and 1992 plans include the following:

- AOML Tropical Ocean amd Global Atmopshere (TOGA) and Equatorial Pacific Ocean Climate Studies (EPOCS) field programs utilizing an array of more than 150 satellite-tracked drifting buoys across the tropical Pacific discovered and described novel and powerful solitary vortices that are formed near the Pacific coast of Central America. Satellite altimeter data were used to further investigate the genesis, evolution, and fate of these vortices in the context of the seasonal cycle in the eastern Pacific.

  AOML plans to continue operation of these drifting buoys to measure SST and currents with several other agencies. The Laboratory also will act as an operational data acquisition center for the international array of drifting buoys. These SST observations are of particular importance following the eruption of Mt. Pinatubo, for the prediction of an El Nino, and for observing effect of stratospheric particles on SST anomalies.

- PMEL utilized the GFDL ocean circulation model to study the seasonal cycle of the equatorial Pacific, the influence of westerly wind bursts on basin-wide circulation, and the disappearance of the Equatorial Undercurrent at 160° W during the 1982–83 El Niño–Southern Oscillation (ENSO). These analyses are critical for planning the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE) and for improving predictions of ENSO events.

PMEL plans to complete the description of the seasonal cycle in the eastern tropical Pacific, and to analyze a modeled seasonal cycle with idealized wind fields.

- GLERL analyzed sediment cores for gamma emitters; the cores were collected in 1988 from the central basin and eastern basin reference sites of Lake Erie. Box cores of very high quality had been obtained, subcored, and sectioned for radiometric analysis.

  In FY 92, 1991 collection cores will be analyzed for gamma emitters and lead-210. A historical sediment data base will be established for Lake Erie to determine historical nuclear contamination and historical climate variability.

- GFDL estimated the rise in sea level because of ocean warming using the coupled ocean-atmosphere model. The average rise is 15 cm for a doubling of greenhouse gases using the Intergovernmental Panel on Climate Change standard scenario, but considerable regional variation is predicted because of changes in ocean circulation.

  FY 92 plans include investigating changes in sea level associated with climate variability on a decadal scale using the GFDL climate model.

- WPL is developing a UV incoherent Differential Absorption Lidar (DIAL) laser system for measuring ozone in the lower 3 km of the atmosphere. The lidar is designed to measure ozone profiles with better range resolution (typically 100 m) and better accuracy in a shorter measurement period (seconds) than existing ozone lidars. Simulations showed that a new method combining polynomial fitting and nonstationary Wiener filtering would greatly improve retrievals of the mean ozone profile and small-scale perturbations of the profile in time and space. A simplified processing technique for correcting the effects of wavelength-dependent aerosol backscatter was also developed.

  Plans for FY 92 include completion of the ozone lidar, initial field tests, integration with data acquisition and other critical components, and field measurements and evaluations of ozone profiles.

- CMDL total ozone observations were continued at 15 stations. Measurements made since 1978 show no trend in ozone in equatorial regions, but a downward trend of 4–5% per decade over the contiguous United States. Ozone values at the South Pole during October, when ozone hole formulation occurs, have decreased by about 50% since 1978.

  FY 92 plans include studying the effects of the Mt. Pinatubo volcanic eruption on the ozone layer over Boulder and Hilo using digital ozonesondes, completing ozonesonde flights at the South Pole in the ongoing study of springtime stratospheric ozone depletion, and determining the compounding effects of volcanic aerosol on ozone depletion.

- CMDL satellite studies focused on two areas: global satellite-derived SST and atmospheric water content. Satellite-derived SST data and Coupled Ocean-Atmosphere Data Set (COADS) in situ data were compared for the period from 1982 to 1988. Temporal correlations between the two data sets were significant at the 95% confidence level for all basins and subregions examined, except the North Atlantic Ocean. Biases in the satellite products, caused by volcanic aerosols and by using the wrong satellite calibration tables, limit the utility of these data for climate monitoring. Data from the NOAA polar-orbiting satellites were used to assess the current capability of determining global atmospheric water vapor content. Thus far, observations of total atmospheric water vapor content do not provide sufficient accuracy over the oceans because of the low signal-to-noise ratio of the observations. The NOAA satellites have three channels that measure water vapor in the low, middle, and upper troposphere. However, the studies suggest that significant information can be obtained about upper-level water vapor variability.

  Work will continue on evaluations of satellite-derived SST observations, focusing on improved quality control of the satellite data and on the effects of volcanic aerosols. Efforts to develop a global climatology of atmospheric water vapor content will be expanded as part of the Global Energy and

Water Cycle Experiment (GEWEX) water vapor program. Multisatellite data sets will be used to examine regional air-sea interaction phenomena in the eastern equatorial Pacific Ocean.

- ARL updated the record of global tropospheric and low-stratospheric temperatures through the summer of 1991. In the troposphere, the global annual temperature was a maximum in 1990, 0.44°C above the 1958–88 mean and 0.02°C warmer than the previous maximum year of 1988. The 6 warmest years of this 33-year record all occurred after 1979. After adjustment for the influence of equatorial SST on global tropospheric temperature, 1990 becomes the warmest year of record.

  The temperature and ozone monitoring programs will continue, with particular attention to the influence of the Mt. Pinatubo eruption. Data from the global radiosonde network will be examined for record length, homogeneity, and completeness to select stations suitable for further analysis. The statistical characteristics of the resulting network will be established.

- AL continued wind observations at Christmas Island for the TOGA program. These observations are used operationally by the world meteorological centers, and monthly summaries of the winds are published in two climate bulletins. Based on an analysis of the first 4 years of wind observations, there is a pronounced annual variation in the tropospheric zonal winds over the central Pacific. The winds depend on the strength of the Walker Circulation, and their annual variation is related to the annual variation of that strength. The magnitude of the annual cycle is modulated interannually according to the phase of the Southern Oscillation.

  The Christmas Island operations will continue and 6-hourly data will be transmitted via satellite to the scientific community. The wind profiler at Biak, Indonesia, will be brought into operation during the year. An Integrated Sounding System (ISS) being developed as part of an AL and NCAR collaboration will be installed at Manus Island, Papua New Guinea, and a second system is planned for Kavieng, Papua New Guinea. Two shipboard ISS will also be constructed. All of these systems will be used to support TOGA COARE.

AIR QUALITY RESEARCH

ERL air quality research is led by GFDL, AL, ARL, 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 ozone and acid rain. Major 1991 accomplishments and 1992 plans include the following:

- A GFDL SKYHI model experiment allowed a first-time investigation of the chemical-transport-radiative-dynamical responses of the stratosphere to the Antarctic ozone hole. The model predicts that total column ozone reductions of 2–5% extend well into populated latitudes, and 0.5% reduction extends well into the Northern Hemisphere.

  In FY 92, a new series of stratospheric and tropospheric ozone chemistry/transport experiments will be initiated using both the Global Chemical Transport Model (GCTM) and the SKYHI model, and the effects of aerosol and ozone pertubations on lower stratosphere temperature change will be studied using the SKYHI model.

- ARL completed and released a four-volume users guide for the Regional Oxidant Model (ROM). ROM was used in several research investigations that indicated ozone was significantly influenced by biogenic emissions and the extent of the influence varied spatially.

  A multiyear effort to develop a third-generation air quality modeling system for gaseous, aqueous, and deposited pollutants over variable spatial scales from 100 to 1000 km will begin in 1992. Current second-generation regional models such as ROM will serve as a foundation for this model development.

- AL has developed techniques and instruments that can measure the trace species that shape air chemistry in rural environments. This rural air chemistry can form organic nitrates that lock up NOx, thereby inhibiting ozone production. Measurements were used to investigate the oxidation of the principal natural nonmethane hydrocarbons (NMHC), isoprene, methyl vinyl ketone (MVK), and the organic nitrate byproducts of the oxidation of MVK.

  These measurement techniques will be used during the second Rural Oxidants in the Southern Environment (ROSE II) field program scheduled for 1992. ROSE II will focus on the answers to three key questions: (1) What processes are responsible for exchange between the planetary boundary layer and the free troposphere? (2) Can current models adequately simulate these processes? (3) Are air concentrations of ozone precursors at a surface site representative of emission of those compounds within the surrounding region?

- WPL completed an analysis of the Grand Canyon studies conducted in 1990. The lidar studies revealed a down-canyon jet near the bottom that no other instrumentation system was able to detect. The jet may have a role in transport of visibility-reducing pollutants into the Grand Canyon from sources to the north, including the Lake Powell basin and a coal-fired power plant near Page, AZ.

  FY 92 plans include studies of the dynamics of complex terrain flow by analyzing lidar and other observations taken near Rocky Flats in Colorado. The New Mexico Flux Experiment to demonstrate the combined use of scintillometers and spectrometers for measuring the surface fluxes of trace gases also will be analyzed.

OCEAN AND GREAT LAKES RESEARCH

ERL studies of the oceans and Great Lakes are focused in three principal areas: prediction, ecosystem assessment, and resource assessment. Principal research is conducted by AOML, PMEL, GLERL, and GFDL. Significant accomplishments for 1991 and plans for 1992 include the following:

- AOML's Fisheries Oceanography Coordinated Investigations (FOCI) research confirmed a relationship between the Alaskan Coastal Current and a downwelling-induced concentration of plankton along a front between Surwik and Semich Islands. This relationship is critical to understanding and forecasting recruitment and out-year fish stocks.

  AOML plans include developing a multiple-frequency acoustic sampling system, testing the system under simulated ocean conditions, and developing software to derive real-time estimates of size-frequency histograms from the multiple-frequency acoustic backscatter data.

- PMEL supported the first U.S. FOCI research cruise into the Soviet sector of the western Bering Sea since 1974. Pollock samples, conductivity-temperature-depth data, shipboard Acoustic Doppler Current Profiler profiles, and nutrient samples were collected, and five ocean current moorings were placed in the southern inflow passes to the Bering Sea.

  Plans for FY 92 include evaluating otolith and genetic samples for evidence of walleye pollock stock separation between regions of the Bering Sea, and conducting a spring and summer experiment on coupling larval survival with turbulence.

- One of the most important accomplishments in PMEL's VENTS program in 1991 was achieving operational status for the T–phase event detection system. T phases are acoustic signals that can be generated by submarine earthquakes and shallow submarine volcanic eruptions. An important goal of the VENTS T–phase project is to detect events that may be or are associated with episodic hydrothermal events such as megaplumes. An unresolved question is whether either episodic hydrothermal events or deep volcanic eruptions generate distinctive acoustic signals.

Plans for 1992 include the continued development of software to refine automated detection and location of T–phase events, and the study of frequency and power spectra of T–phase signals in an attempt to classify events by specific source.

- GLERL zebra mussel research accomplishments included expanding the sampling program in Saginaw Bay to 26 sites, constructing and placing artificial substrates at 4 sites in the bay to document the rate and temporal variability of settling by free-swimming zebra mussel larvae, and documenting zebra mussel densities in the bay using divers.

  Plans for FY 92 include initiating experiments to determine filtering rates of zebra mussels on Saginaw Bay, determining if larvae can be raised from eggs to settling using selected algal species, and continuing to measure the toxicokinetics and develop a toxicokinetics data base.

- GLERL's Pollutant Effects research program completed an analysis of the effect of increased contact time between sediment and contaminants, and examined the relationship between respiration and contaminant accumulation from water. The studies concluded that increasing the contact time with sediments reduces the bioavailability of the contaminant. This reduction is rapid enough to affect the bioavailability of laboratory-dosed sediments. In the respiration studies, the accumulation of selected polycyclic aromatic hydrocarbons (PAH) was approximately four times the respiration rate for *Diporeia*, suggesting either a low efficiency for oxygen consumption or the accumulation of the PAH across more than just the respiratory membrane.

  FY 92 plans include performing studies to determine the appropriate approach for diluting sediments by examining the exposure to toxic contaminants before and after dilution, studying variations of sediment composition using laboratory-dosed sediments collected from various sites in Lake Michigan, and developing methods to determine the assimilation efficiency of sediment-associated toxins by *Diporeia*.

- GFDL modeled biological processes in the North Atlantic using a nitrogen-based ecosystem model that links ocean physics to biology. This model was incorporated into models of the equatorial Pacific Ocean and the Indian Ocean. The model predictions were used to help plan the sampling and cruise schedules of the Joint Global Ocean Flux Study campaigns in these oceans.

  FY 92 plans include developing a carbon-nitrogen ecosystem model to complement the existing nitrogen-based ecosystem model, and studying the effect of iron fertilization on N_2O and O_2 fields using the nutrient-depletion model.

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 are major accomplishments in 1991 and plans for 1992:

- On 1 December 1990, SEL's Space Environment Services Center (SESC) provided its 9130th daily forecast of solar activity and resultant terrestrial effects, marking 25 years of continuous services. SESC staff dealt with the prolonged period of intense solar activity that marked a second rise in the 22nd sunspot cycle. The cycle began in 1986 and reached a first peak in 1989.

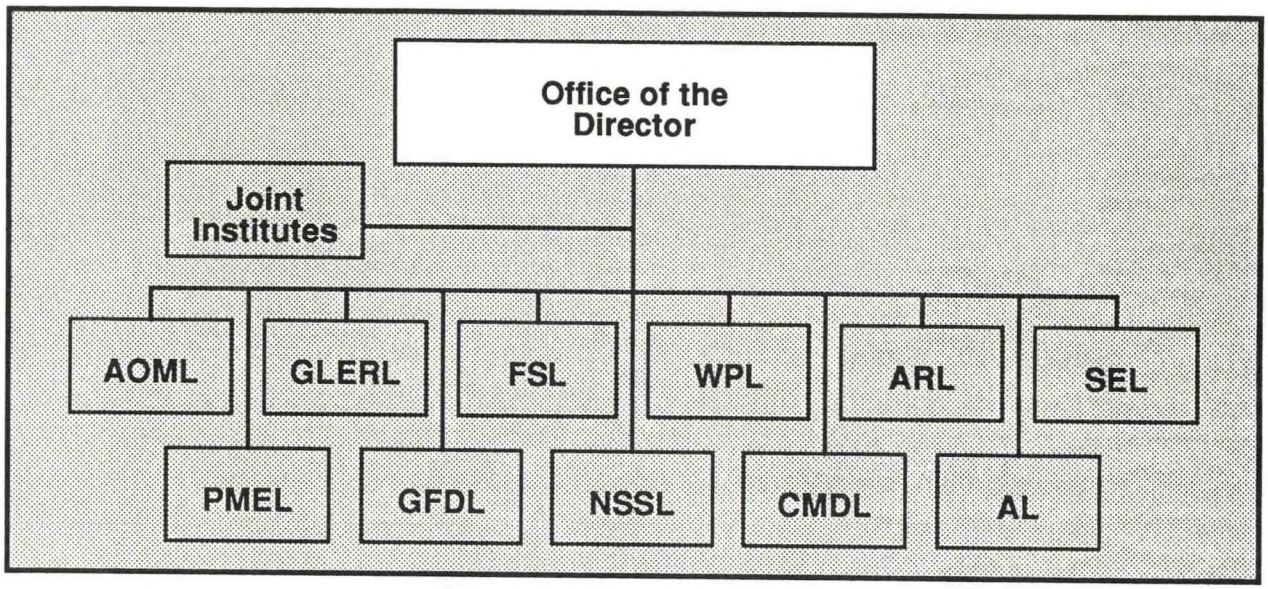
  During FY 92, a computer system will be installed to make and distribute geomagnetic forecasts, in probability format, to provide users with additional information on expected levels of geomagnetic storms. SESC will provide support for specialized research campaigns such as NASA's Gamma Ray Observatory observations and Max 91/FLARES 22.

- Preliminary analysis of the entire data set (1983 to present) from the GOES–6 High Energy Proton and Alpha Detector (HEPAD) was completed. The energy range (100–1000 MeV) covered by HEPAD fills a gap between typically low-energy satellite observations and extreme relativistic energy observations provided by ground-based neutron monitors. This energy range is important because it is the main ionization source for the lower atmosphere and determines the radiation environment at aircraft altitudes during solar energetic particle events.

  Plans for FY 92 include the reduction and evaluation of the HEPAD data base, and the establishment of a several-year archive of HEPAD data.

- SEL conducted two studies on the origin of magnetic fields on the sun. The first study revealed the gradual emergence in 1986–87 of a new, large-scale pattern of magnetic fields without significant contribution from active regions, which contradicts the prevailing theory of the origin of large- scale fields. The second study found that solar active regions that produce exceptionally hot x-ray flares occur only during the first 4 years of the solar cycle and possess a close relationship to specific, large-scale magnetic field patterns. This study also revealed a curious occurrence of hot flares in Solar Cycle 22 near the edge of a visible solar disk. This pattern was not observed in Solar Cycle 21.

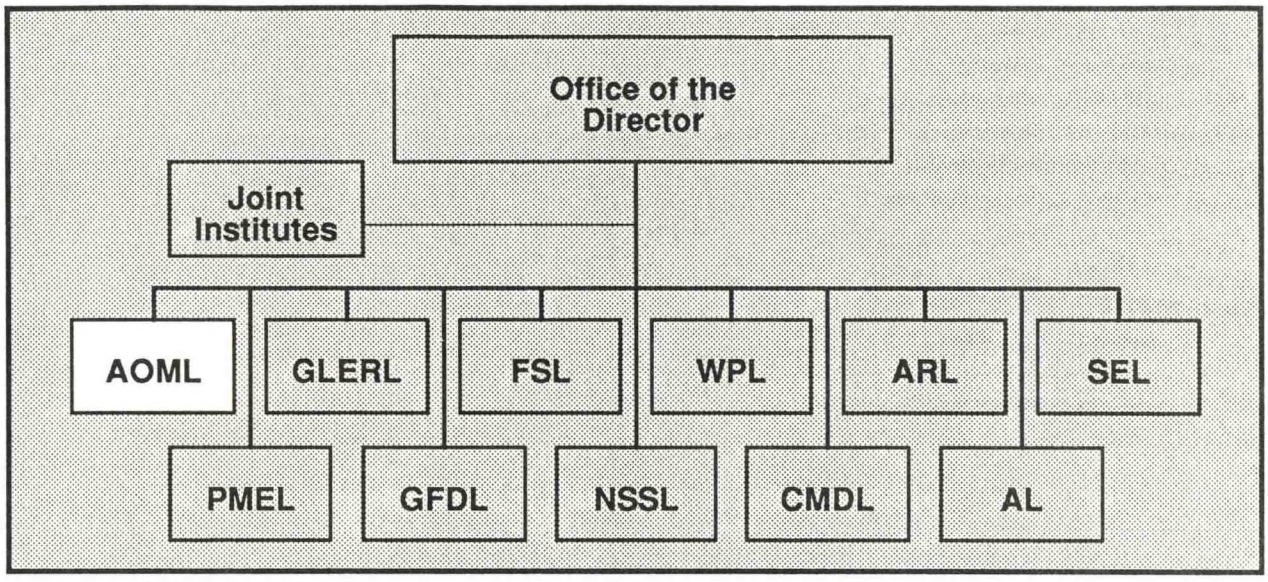
  A study to determine the feasibility of using multichannel, hard x-ray data to isolate a special class of solar flares, known as gradual hard x-ray flares, will be initiated in 1992 to evaluate their utility in geomagnetic forecasting. Efforts to include hardware related to this study on the next series of GOES satellites will be initiated with NESDIS.



OFFICE OF THE DIRECTOR

Silver Spring, Maryland
(301) 427-2458
Alan R. Thomas, Acting 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). This includes the NOAA–university cooperative research programs, the NOAA–National Research Council Resident Research Associateship Program, and editing services. The Budget Office provides budget analysis and execution, and financial and management information in support of the Laboratories. Program Development and Coordination (PDC) provides advice and support in areas of policy, program planning, budget formulation and analysis; program coordination and review; and implementation of management decisions.



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, ocean and 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. Meteorological research is carried out to improve the description, understanding, and prediction of hurricanes. The research program is enlarged by the Cooperative Institute for Marine and Atmospheric Studies (CIMAS), a joint enterprise with the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. CIMAS enables 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, research, 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 transfer of heat from low latitudes to high latitudes by the ocean circulation 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 is 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 participate extensively in its implementation.

Participation in these programs has led to close association with the international World Ocean Circulation Experiment (WOCE). Also, the appropriation of major new NOAA funding for climate research and applications has been associated with several new activity identifications with separate project managements. The simple TOGA/EPOCS identification is no longer appropriate for the expanded program. Beginning with FY 92, ocean research for climate at AOML will be categorized as Climate Change: Atlantic; Climate Change: Pacific; or Climate Change: Global Ocean for those activities that are not regionally focused.

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

The Heard Island Feasibility Test, conducted this year, was designed to measure the worldwide reception of low-frequency (57 Hz) coherent underwater acoustic transmissions from Heard Island in the southern Indian Ocean. Because acoustic time of flight is a measure of average ocean temperature over the acoustic path, such transmissions could be used to monitor ocean warming on basin and global scales.

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

Accomplishments FY 91

TOGA/EPOCS

AOML activities for the TOGA and EPOCS programs were focused primarily on oceanographic aspects of the eastern tropical Pacific. In cooperation with scientists from the Woods Hole Oceanographic Institution, the Scripps Institution of Oceanography, France, and Japan, AOML has maintained an array of 150 to 170 satellite-tracked drifting buoys across the tropical band of the Pacific. AOML operated a data acquisition center for this international array of buoys. Data from these buoys, combined with other kinds of data from research vessels and the GEOSAT altimeter, led to the discovery and description of novel and powerful solitary vortices that are formed near the Pacific coast of Central America. Satellite altimeter data were used to further investigate the genesis, evolution, and fate of these vortices in the context of the seasonal cycle in the eastern Pacific.

The Voluntary Observing Ship/Expendable Bathythermograph (VOS/XBT) observations program in the southeast Pacific had deteriorated significantly; that is, almost no observations were being made because of

lack of funding. During the year, new funding was obtained through the Surface and Upper Ocean Observations Project of the Climate and Global Change Program (CGCP), and observations are rapidly being improved and increased in this region.

Through a new level of cooperation with the National Ocean Service (NOS), several coastal sea level stations previously operated by AOML in Latin America are being replaced by "next generation" equipment operated by NOS for the Global Sea Level component of the CGCP.

To reduce the computer facilities requirement for four-dimensional data assimilation modeling, a new three-dimensional strategy was initiated. The feasibility of using steady-state logic for analysis of snapshots, like monthly means, is being evaluated for application to the tropical Pacific.

Atlantic Climate Change

The Florida Current monitoring activity suffered a substantial loss because of the failure of the abandoned telegraph cable used for measuring the electrical potential difference across the Straits of Florida. The monitoring was continued, albeit with reduced precision using sea level observations and electrical potential measurements from an active telegraph cable. The feasibility of laying a dedicated cable is being investigated.

The principal thrust of AOML work on Atlantic Climate Change continued to be investigation of the western boundary current structure in the tropical Atlantic, including the Deep Western Boundary Undercurrent that is believed to be a major factor in such climate-related phenomena as ocean heat transport and sequestration of greenhouse gases in the ocean. Three major research cruises were made to gather data in the region in cooperation with academic investigators from the United States, and scientists from the Federal Republic of Germany and France.

Funding from the Global Sea Level component of the CGCP was used to complete the GLOSS sea level station array for observing global sea level in the Gulf of Mexico/Caribbean region.

Under the auspices of the Surface and Upper Ocean Observations component of the CGCP, our evaluation of the WOCE/TOGA implementation plan for VOS/XBT observations in the Atlantic was completed, a regional science center for scientific quality control and analyses of VOS/XBT data was established at AOML, and the build-up of VOS/XBT observations was initiated.

Because of our experience as a drifting-buoy data acquisition center for the TOGA program in the tropical Pacific, AOML was funded from the Data Management component of the CGCP to serve also as a data acquisition center for the global requirements of the WOCE. The first drifting buoys for the WOCE were released in the North Atlantic, and we began receiving data from buoys released in the north Pacific Ocean by scientists of Taiwan, Korea, and Canada.

RITS/TPOME Pacific Cruise

A 2-month RITS/Tropical Pacific Ozone Minimum Experiment (RITS/TPOME) cruise was conducted in the Pacific to determine the extent of an equatorial ozone minimum observed during January and February. The data collected completed a picture of the annual cycle of the ozone minimum, as previously published data had been collected from April to November. Preliminary results from the cruise indicate that the equatorial ozone minimum had shifted eastward compared to previous measurements.

GCE/CASE/WATOX

For 2 months in the summer of 1988, 42 investigators conducted research for the Global Change Expedition/Coordinated Air-Sea Experiment/Western Atlantic Ocean Experiment (GCE/CASE/WATOX). By observing the interaction of components between marine air and the ocean, researchers investigated the transfer of significant atmospheric species from North America and Europe to the North Atlantic Ocean.

Twenty-three papers were published as a result of the GCE/CASE/WATOX program. These papers represent a unique and significant set of measurements and interpretations on this region during the summer season.

RITS/Carbon Dioxide South Atlantic Cruise

The FY 91 RITS CO_2 cruise was conducted in the South Atlantic Ocean from 5°N to 42° S during July and August 1991. Cruise participants investigated atmospheric transport, transformation, and deposition processes in both the trade winds and the westerlies of the South Atlantic. The hydrography of the equatorial and South Atlantic Ocean was studied, with emphasis on carbon cycling in the water column.

The first leg of the cruise focused on oceanic sources and sinks for CO_2 in the region during the austral winter. The second leg concentrated on the effect of biomass burning emissions from the surrounding continents on the distribution of ozone in the tropical South Atlantic atmospheric boundary layer.

Heard Island Experiment

All objectives of the Heard Island feasibility test were met. Sound from this particular source location insonified most of the world's oceans and was received on the east and west coasts of the United States, as well as in Africa, South America, South Asia, Australia, and Pacific Islands. The Ascension receiving station was set up by a team of NOAA researchers from AOML and the Wave Propagation Laboratory (WPL). The Heard Island signal received there was judged to be of the best quality of all the receiving stations. Many exciting features were noted of coherent acoustic signals propagating over distances never before observed. Seven nations and nine vessels participated in the experiment. Further understanding of the propagation over such long ranges, and its response to expected climate signals, is necessary for the design of a global monitoring network.

Rainfall Studies

Data from the 1988 Carysfort Reef deployment of a multiple frequency acoustic receiving system were partially analyzed. Using these data, it may be possible to characterize tropical rainfall events as having a two-portion acoustical signature: one portion corresponding to "convective" rain and one to "stratiform" rain. A series of local pond experiments were undertaken to evaluate different processing methodologies for extraction of rainfall-generated acoustical signatures.

Plans FY 92

Climate Change: Atlantic

A major emphasis in the Atlantic Climate Change Program will continue to be consideration of the poleward heat transport in the North Atlantic Ocean. An internationally coordinated two-ship survey will be conducted during the summer of 1992 to test indirect methods of estimating heat transport with direct measurements. If the indirect method is verified, relatively inexpensive approaches for monitoring heat flux can be developed. In support of this work, occasional local cruises will be conducted to maintain the calibration of the Florida Current monitoring system, and a new pilot program for observing the flow through the inter-island passages from the Atlantic to the Caribbean Sea will be initiated.

The VOS/XBT scientific analyses center will be operated to assure that all XBT data collected and archived for the Atlantic Basin are of the highest quality, and to generate regular data products to verify and demonstrate the effectiveness of the observations program.

An oceanographic/geodetic program for determining the true sea level change at Miami, FL, will be conducted in cooperation with the NOS and the U.S. Naval Observatory. True sea level requires adjustment of water level measurements for movement of the Earth's crust. Although this work is focused on Miami, it has potential for global application.

Work will continue on development of the methodology for four-dimensional data assimilation in support of the most effective use of dynamical models for interpretation of several kinds of data being collected.

Climate Change: Pacific

AOML will continue to operate satellite-tracked drifting buoys in the tropical Pacific for measurement of sea-surface temperature (SST) and currents in concert with several other agencies. These SST observations are of particular importance following the eruption of Mt. Pinatubo and prediction of an El Niño. Closer cooperation is planned with biological oceanographers involved with the Joint Global Ocean Flux Study (JGOFS) funded by the National Science Foundation (NSF).

Efforts will be continued to improve the VOS/XBT sampling in the southeast Pacific. Although some improvement has been effected, additional data are still needed from this historically undersampled region. This work will be done by maintaining close relations with several Latin American agencies. Many of the same agencies have cooperated with us in establishing and maintaining coastal sea level sites. With NOS taking a more active role for regional implementation of the Global Sea Level program, the emphasis at AOML is expected to shift from operations to scientific interpretation.

Altimeter data from the GEOSAT will be used to investigate in as much detail as possible the seasonal to interannual variability of the surface currents of the tropical Pacific and the energetic mesoscale features embedded therein.

Climate Change: Global Ocean

The only oceanographic variables for which the semblance of a regular, global program can be said to exist are SST and upper ocean temperature. Surface and upper ocean salinity are of comparable importance, but technology suitable for use in a global program is not available. AOML will initiate development of a prototype system for measuring salinity in cooperation with scientists of the Woods Hole Oceanographic Institution.

AOML also will operate a drifting buoy data acquisition center to encompass the global and multinational surface velocity program for the WOCE.

ASTEX Atlantic Cruise

Researchers will resume the Atlantic Stratocumulus Transition Experiment (ASTEX), temporarily stopped in the summer of 1988. Scientists will investigate the cause of significant chloride loss from certain ozone-initiated photochemical processes, and determine the contribution of these processes on the global distribution of tropospheric ozone.

RITS/Carbon Dioxide Equatorial Pacific Cruises

Seasonal changes in lateral export of nutrients, dissolved organic matter, and carbon from the equatorial Pacific will be studied in a series of cruises in the spring and fall. The cruises are timed such that they will coincide with JGOFS. The results of the cruise will be compared with the output from the equatorial Pacific nutrient model of the Geophysical Fluid Dynamics Laboratory (GFDL), which predicts that much of the nutrients and carbon is exported laterally in the form of dissolved organic material.

Heard Island Experiment

Efforts are under way to establish an ocean acoustic observatory at Ascension Island for long-term acoustic monitoring of the North and South Atlantic and for short-term basin and global-scale acoustic propagation experiments. It is expected the observatory will become a component of a global acoustic network. The choice of Ascension is based on the high quality of the data collected there by NOAA researchers as part of the Heard Island Feasibility Test and the availability of a data link by satellite between the island and Florida. The U.S. Air Force, WPL, the Applied Physics Laboratory/University of Washington (APL/UW), the University of Michigan, and the University of Miami are participants in the project.

Rainfall Studies

Additional local pond experiments are planned wherein acoustical data during rainfall events will be compared with rain gauge data, distrometer data, and other meteorological data to further understand the information obtainable acoustically on rainfall. An additional coastal ocean deployment is under consideration to obtain additional rainfall acoustical data relatively free from biological and ship interference.

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 NOAA WP–3D research aircraft are used to acquire unique data sets.

Accomplishments FY 91

Hurricane Modeling Research

The goal of this research is to understand and predict the motion, intensity, and structure of hurricanes. A general-purpose base model on nested horizontal domains, utilizing an accurate and flexible numerical method called Spectral Application of Finite Element Representation (SAFER), was developed and is being used by this and other HRD projects. A two-dimensional model in the vertical plane has been developed to test certain components that are needed for an eventual three-dimensional model. This new model involves a new approach to thermodynamics in which both pressure and temperature are thermodynamic state variables that are diagnostically determined. The predictive equations are formulated strictly in terms of conservative properties, such as mass, momentum, and entropy. It is anticipated that this will greatly simplify the modeling of moist processes.

Synoptic-Scale Aspects of Hurricanes

Omega dropwindsondes (ODWs) dropped from the NOAA WP–3D aircraft are being used to obtain data to study the steering currents of mature hurricanes. The ODWs measure temperature, relative humidity, pressure, and horizontal wind. During data gathering experiments, the ODW and flight-level data are transmitted from the aircraft to the NWS National Hurricane Center (NHC) and the NOAA National Meteorological Center (NMC) in real time. We wish to determine whether the ODW observations help to improve the official hurricane track forecasts issued by NHC, the effect of the ODW data on NMC's dynamical hurricane track model, and the effect of the ODW data on hurricane track models under development at HRD.

Software for real-time processing of ODW data was tested on an airborne computer workstation during a flight in Tropical Storm Marco in October 1990. The workstation allows the user to display, manipulate, and edit the sounding, and encodes mandatory and significant level wind and thermodynamic data that can then be relayed digitally to NHC and NMC.

The SAFER spectral nesting technique developed at HRD was used as the basis for a barotropic hurricane track prediction model. The spectral technique is used both for the analysis of observations and for the solution of the barotropic forecast equations. This analysis and prediction system (referred to as VICBAR) can produce operational hurricane track forecasts and can be used to study the impact of various types of data on the prediction of tropical cyclone motion.

An assessment of the impact of data from the ODW experiments on VICBAR hurricane track forecasts was completed. The ODWs were found to produce statistically significant reductions in 24–36 h mean forecast errors of 12–16%. This improvement is equivalent to the improvement in official NHC track forecasts over the past 20–25 years normalized by CLIPER (Climate and Persistence model).

Observational Studies of Hurricanes

Analyses of electric field data collected in Hurricane Gustav (1990) and in two oceanic cumuli experiments were completed. The initial detection of vertical electric field in maritime cumuli occurred nearly simultaneously with the initial observations of graupel and frozen drops. The strength of the vertical electric field increased with altitude. Large vertical fields were encountered only during cloud penetrations made at temperatures below 0°C. Clouds that failed to reach the melting level did not exhibit detectable vertical

electric fields. Hurricane Gustav contained moderate vertical electric fields at 3 km on its north and west sides. Only negative vertical electric fields were observed.

Analysis of data from a joint NOAA/Navy air-sea interaction experiment conducted in the Gulf of Mexico from NOAA hurricane research aircraft before, during, and after the passage of Hurricane Gilbert (1988) is in progress. Little change in SST was observed over the 29°C water of the western Caribbean during Gilbert's explosive deepening to a record 885 mb on 13–14 September. However, a dramatic decrease in SST accompanied the storm's traverse of the Gulf of Mexico on 15–16 September as it maintained its weakened state and dramatically altered wind structure following passage over the Yucatan Peninsula. A gradual basin-wide decrease in SST from 30°C to 28°C preceded the arrival of the storm. A further SST decrease to 25°C abruptly followed in the storm's wake over a 100–200 km wide area to the right of the storm, except for an area in the central Gulf dominated by the warm anticyclonic eddy. The small SST decreases in the Caribbean Sea and Gulf eddy water are attributed to the initial mixed layer depths in excess of 70 m. The large SST decreases across the undisturbed Gulf are attributed to the initial mixed layer depths of less than 30 m.

In cooperation with National Center for Atmospheric Research (NCAR) scientists, the role of hurricane rainbands in the modification of hurricane structure and intensity is being studied. The rate and degree of recovery of the hurricane planetary boundary layer (HPBL), that has been modified by rainband associated downdrafts, is being assessed and the impact of the modified HPBL on the eyewall convection is under study. A rainband/boundary layer experiment was flown on the southeast side of Hurricane Gilbert on 12 September 1988.

Aircraft and ODW soundings indicate that the boundary layer was disturbed on the outer side of the band beneath strong subsidence areas. This modified air was replenished with heat and moisture by the time it reached the rainband but surface fluxes alone could not explain the rapid increase of equivalent potential temperature along the low level air trajectory. Calculations with a mixed layer recovery model suggest that additional heat and moisture was provided by entrainment of outward moving air just above the HPBL, which had the thermodynamic characteristics of the rainband axis.

Atlantic Tropical Climate Studies

An investigation of the Atlantic hurricane cycles and the tropical wind variability associated with intraseasonal oscillations is nearing completion. Wind observations for the years 1980–1989 at 200 mb and at a near-surface level were used. The winds were filtered into three bands. The "monthly" band (50–85 days) includes variability on the month-to-month (60-day period) 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. Maps of energy and significant spectral peaks in the three bands at the lower and upper levels were made for both the summer (May–October) and winter (November–April) seasons. This work made use of a more rigorous statistical foundation than had been used before. Large regions of significant energy (over a red noise background) were found during the winter for both the 50–85 and 18–29 day bands. However, a significant peak was found only for a period of about 60 days.

The analysis was extended to include outgoing longwave radiation (OLR) to relate the wind fields to convective activity. A consistent relationship was found between the vorticity/divergence structure and the OLR. The vorticity anomalies tilt westward with height in the higher latitudes, but are barotropic near the equator. The divergence tends to be in quadrature with the vorticity, with convergence to the east of the low-level trough. Negative OLR anomalies, and upper-level divergence, tend to be in phase with the low-level convergence. Thus, convection tends to be associated with low-level convergence and upper-level divergence.

Plans FY 92

Hurricane Modeling Research

Development of the two-dimensional, vertical-plane model will continue and a series of tests that will include moist convection will be run. The success of these tests will depend critically on assumptions regarding irreversible processes, such as precipitation and nonlinear viscosity. Adequate parameterizations that can be extended to the three-dimensional model must be found.

Synoptic-Scale Aspects of Hurricanes

A new version of VICBAR that includes a background field and boundary conditions from the current Aviation model forecast will be run in the 1991 hurricane season. After the 1991 season, the VICBAR forecast errors from the 1989, 1990, and 1991 seasons will be analyzed.

Observational Studies of Hurricanes

Additional electric field data will be obtained in hurricanes. Only the vertical component of the electric field has been measured until now, and the component parallel to the wings will also be measured.

A second computer workstation for the other WP–3D will be installed, and additional software improvements will be made to allow NHC to regularly receive two-dimensional analyses of the mesoscale precipitation and wind structure of tropical cyclone cores.

The WP–3D will be equipped with a C–band Scatterometer (C–SCAT) for measuring surface wind speed and direction. Comparisons between C–SCAT winds and winds from the Stepped Frequency Microwave Radiometer (SFMR) will be made. Comparisons of flight-level winds adjusted to the surface and C–SCAT winds will also be made. A collaborative project with NESDIS will compare the SFMR and C–SCAT observations with Earth Resources Satellite (ERS)–1 scatterometer observations and radiometer observations.

Atlantic Tropical Climate Studies

A study to investigate the relationship of the Atlantic circulation to hurricane development, hurricane intensity, and hurricane track has been started. Atlantic tropical winds, heights, SST, and measurements of African rainfall and the ENSO will be used. Previous research has established a relationship between hurricane climatic fluctuations, the large-scale Atlantic circulation, and SST distribution. A strong relationship between intense Atlantic hurricane activity and African rainfall in both the simultaneous and previous season was recently reported in the published literature. The present study will attempt to isolate the physical mechanisms that are responsible for this relationship.

MARINE RESEARCH

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

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

The Fisheries Oceanography Coordinated Investigations (FOCI) program involves NOAA scientists at PMEL, AOML, and the NMFS Alaska Fisheries Center (AFC), as well as academic contractees. The program seeks to gain understanding of the controls on recruitment variability of walleye pollock in the Shelikof Straits of the western Gulf of Alaska. The major emphasis over FY 86–91 has been field study of the spawning event and its physical-biological context. This ecosystem 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 change in the spatial distribution of both eggs and larvae in relation to physical processes (e.g., advection and dispersion). Field studies conducted during cruises in FY 86–91 enabled us to examine the fine-scale (meters to tens of meters) distribution of pollock eggs, pollock larvae, and zooplankton prey using a towed submersible camera system, specialized net sampling systems, and, most recently, high-frequency acoustics.

The 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 on the global marine carbon cycle.

The Oceanic Plume Studies program seeks to study the interaction of water mass types and the processes that occur at their boundaries. Wastewater plumes are one category of water mass type that is released in turbulent flow into the receiving 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.

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

Accomplishments FY 91

VENTS

Gorda–Juan de Fuca Ridges and East Pacific Rise

- Developed a prototype sonar system that recorded the first whole three-dimensional images of hydrothermal plumes discharging from black smoker-type seafloor hot springs and rising into the overlying water column. these images were obtained by using the U.S. Navy Deep Submergence

Vehicle (DSV) *Turtle* on the East Pacific Rise off Baja California. AOML and the Naval Research Laboratory (NRL) are jointly developing the sonar system with support from NURP.

- Delineated a new area of seafloor hot springs on the Gorda Ridge, located off southern Oregon within the U.S. Exclusive Economic Zone. These hot springs are only the third such area identified on the 300-km-long Gorda Ridge.
- Defined fundamental differences in the characteristics and distribution of seafloor hot springs on the northern Gorda Ridge and the southern Juan de Fuca Ridge.
- Convened a symposium on global seafloor hydrothermal activity. The papers presented at this symposium are being prepared for publication.
- Updated an interactive, computerized bibliography of scientific publications on oceanic ridge processes prepared for use by VENTS program investigators.

Mid-Atlantic Ridge

- Discovered a new type of seafloor hot springs high in greenhouse gases (methane and carbon dioxide) and prepared four papers describing various aspects of the discovery with French collaborators in the French American Ridge Atlantic (FARA) program in support of NOAA's lead role in the U.S.–France Bilateral Agreement.
- Discovered what may possibly be the largest mound of polymetallic sulfides found in the oceans on a collaborative dive series with the Soviet MIR submersibles on the Mid-Atlantic Ridge in support of NOAA's role in the U.S./U.S.S.R. Bilateral Agreement.
- Combined NOAA–NSF–IFREMER support by preparing a research proposal for a joint U.S.–France effort to conduct collaborative dives with the DSV *Alvin*, planned for FY 93.
- Convened a symposium on Atlantic hydrothermal activity at the American Geophysical Union 1990 Annual Meeting. The symposium provided a forum for the U.S. and French work at the Mid-Atlantic Ridge, and related work by British, Canadian, Icelandic, and Soviet scientists. The symposium papers are being prepared for publication.

FOCI

- Delineated the fine-scale biological and physical structure at scales undetected by the coarser resolution of a previous FOCI survey.
- Confirmed the relationship between the Alaskan Coastal Current and a downwelling-induced concentration of plankton along a front between Sutwik and Semidi Islands and submitted these results as a manuscript.
- Analyzed data and prepared a manuscript describing the vertical distribution of pollock eggs and larvae as a function of local hydrography and developmental stage.

NECOP

- Conducted a series of process study cruises to document the development, extent, and dynamics of hypoxia on the western Louisiana Shelf.
- Conducted an examination of historical data for hypoxia in the Mississippi-Atchafalaya River area.
- Conducted a meeting of principal investigators that reviewed observations from initial field investigations and planned for future process study cruises.
- Developed the NECOP data servicing center at AOML.
- Completed arrangements for a NECOP Synthesis Workshop, which provides all NECOP principal investigators the opportunity to present the results of their research, and discuss the future of the project.

Ocean Plume Studies

- Began an extensive year-long study of anthropogenic wastewater plume behavior in the coastal ocean off south Florida. The data thus far gathered is being analyzed and is yielding valuable information on plume dynamics. A study was also carried out on a transient anthropogenic particulate matter discharge.

Plans FY 92

VENTS

Gorda–Juan de Fuca Ridges and East Pacific Rise

- Conduct sea trials on the second-stage development of the prototype hydrothermal plume imaging sonar system by installing an acoustic Doppler sonar system to measure fluid flow rate, and complete analysis of data on plume behavior recorded on initial sea trials in collaboration with the Naval Research Laboratory.
- Synthesize multidisciplinary data sets on the distribution, characteristics, and setting of seafloor hot springs known on the Gorda Ridge within the U.S. Exclusive Economic Zone off California and Oregon.
- Conduct a comparative study of seafloor hot springs on the southern Juan de Fuca Ridge and northern Gorda Ridge to determine how volcanism and tectonics control the nature and distribution of hydrothermal activity on these two ridge segments.

Mid-Atlantic Ridge

- Continue collaborative U.S.–France and U.S.–U.S.S.R. scientific studies of the Mid-Atlantic Ridge, including a joint IFREMER–NOAA series of dives with the French DSV *Nautile* as part of the FARA program.

FOCI

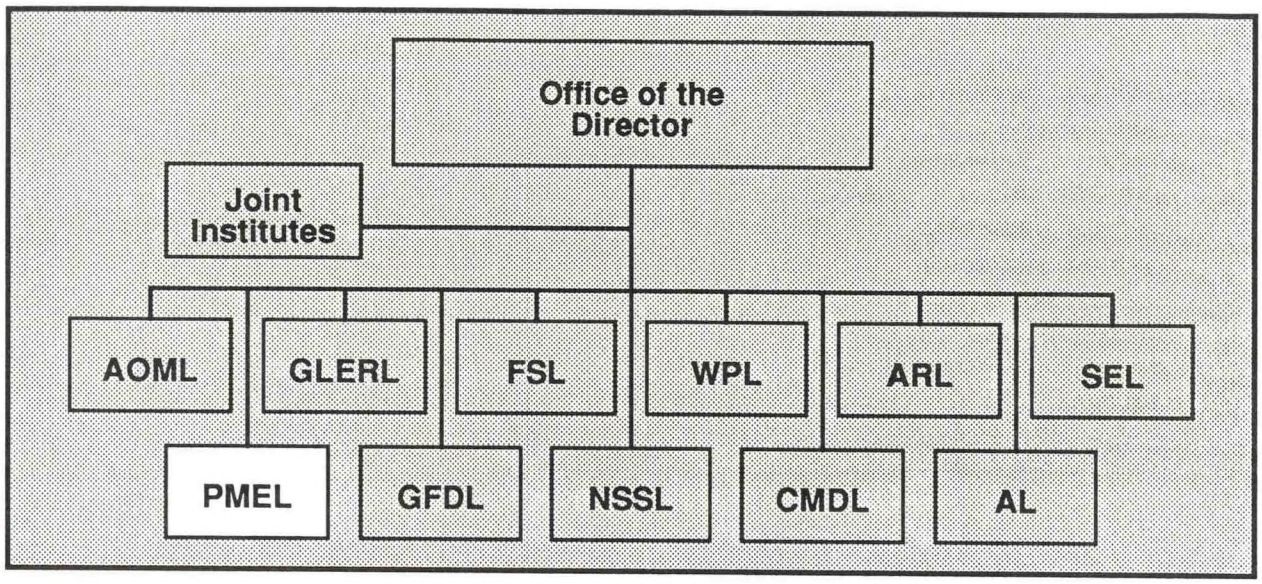
- Complete collaborative manuscripts describing the biological/physical relationships and interactions observed within a weak coastal eddy.
- Complete the development of a multiple frequency acoustic sampling system and conduct tests under simulated ocean conditions.
- Develop software to derive real-time estimation of size frequency histograms from the multiple-frequency acoustic backscatter data.
- Complete and submit a manuscript describing the vertical distribution of pollock eggs and larvae as a function of local hydrography and developmental stage.

NECOP

- Conduct the NECOP Synthesis Workshop.
- Conduct a major disciplinary cruise to the Mississippi-Atchafalaya River outflow area during the spring runoff, a season of high river discharge.
- Conduct analysis and synthesis of data from the 1991 process cruises.

Oceanic Plume Studies

- Continue the year-long study of plume behavior and potential exposure sites begun in FY 91. Extensive data sets of currents, density, dilution, nutrients, chemical constituents, and biological constituents will be gathered in the study. Data reduction will continue in parallel with the field efforts.



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, coastal and arctic observation, and prediction and research into the ocean environment. Studies are conducted to improve our understanding of the complex physical and geochemical processes operating in the world oceans, 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

The NOAA Ocean Climate Program was developed following 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 effects of technology and population growth on world climate. More recently, NOAA and other Federal agencies initiated the Climate and Global Change Program to study oceanic thermohaline circulation and its climatic impact. 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. The goal of this research is to determine 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 the El Niño–Southern Oscillation (ENSO).

Heat transport by major western boundary currents (the Gulf Stream and the Kuroshio in the Northern Hemisphere) is 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).

Oceanic chemistry is another aspect of climate change investigations. The 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 at the oceanic and atmospheric interface.

Accomplishments FY 91

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. Thirty-four moored stations measuring parameters such as the vertical distribution of temperature and current velocity in the upper ocean and surface wind velocity and air temperature are in place. These moorings transmit much of their data in real time via the Argos satellite. 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 Ocean.

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 ENSO time and space scales. During FY 91, analyses focused on the upper ocean heat budget for 1986 to 1988, which encompassed a moderate ENSO event. Results of the observational analysis indicate that seasonal and interannual variability of SST in the eastern Pacific cannot be accounted for solely by the observed surface heat flux; i.e., oceanic processes play an important role in the heating of surface water. Although no single process dominated the 1986–1988 SST change, the most important processes in the mean balance were the net incoming surface heat flux, the penetrative solar radiation, and the vertical turbulent flux out the bottom of the mixed layer. Mean vertical entrainment could not be estimated with the available data. On seasonal time scales, both vertical turbulent heat flux and vertical entrainment variations could be correlated with SST change. Zonal advection made a significant contribution to the heat flux variability, but its fluctuations were poorly correlated with mixed layer heating. In particular, it was found that zonal advective heat flux tended to be out of phase with the spring warming. At higher frequencies, little zonal advective heat was associated with the passage of a kelvin event in January 1987.

Surprisingly, meridional heat advection appeared to be more important than zonal heat advection in modifying the local SST as the event passed.

TOGA–TAO Project Office

In support of the Climate and Global Change Program, the TOGA–TAO (Tropical Atmosphere-Ocean) Project Office was established in FY 90 by the Oceanic and Atmospheric Research (OAR) and National Ocean Service (NOS) arms of NOAA. The project office is responsible for maintaining the TOGA–TAO array, which is planned to include 65 ATLAS moorings spanning the equatorial Pacific from 95°W to 130°E. By the end of FY 91, the array was 45% completed with 29 moorings in place. Expansion of the TOGA–TAO array is the highest priority for the global ocean observing system in the second half of the TOGA decade. Reports were prepared on wind sampling strategies for TAO, the response of the ocean to westerly forcing in the western Pacific, the meridional pressure gradient near the Equator, and the description of the thermal variability near 170°W.

PROTEUS Mooring System

In April 1990, the first PROTEUS (Profile Telemetry of Upper ocean currents) mooring was deployed at 0°, 140°W. A PROTEUS mooring consists of a downward-looking 153.6-kHz Acoustic Doppler Current Profiler (ADCP) interfaced to a buoy-mounted microprocessor and an Argos satellite transmitter. Hourly data are internally recorded; the microprocessor on the buoy forms daily averages of these hourly data and transmits them during two 4-hour periods every day. The profiles extend from 10 to 250 m below the surface with 8-m vertical resolution. The time series at 140°W has continued with two subsequent mooring deployments and is now more than 16 months long. PROTEUS systems have subsequently been deployed at 165°E, 110°W, and 155°E on the Equator, making a total of four in place at the end of FY 91. Also, the University of South Florida has acquired a PROTEUS system for deployment at 0°, 170°W as part of the TOGA observing array. Details of the PROTEUS system appeared in two recent publications. PROTEUS data have been used in a preliminary validation study of the NMC operational ocean general circulation model and were presented at the annual EPOCS meeting in Miami in January 1991. The data are now routinely acquired by NMC for its operational ocean model development efforts. The international satellite consortium, service Argos, is expected to make the PROTEUS data stream available on the Global Telecommunication System (GTS) as part of an agreement with the World Meteorological Organization.

Modeling of the Tropical Pacific

Scientific manuscripts were submitted for publication describing use of the Geophysical Fluid Dynamics Laboratory (GFDL) ocean circulation model to study (1) the seasonal cycle of the equatorial Pacific, (2) the influence of westerly wind bursts on basin-wide circulation, and (3) the disappearance of the Equatorial Undercurrent at 160°W during the 1982–83 ENSO. These analyses are critical for the planning of TOGA COARE (Coupled Ocean-Atmosphere Response Experiment) and improving predictions of ENSO events. Development continued on FERRET, an interactive display and analysis system for studying gridded data sets. FERRET was converted for use on UNIX workstations and is being tested by a number of other university and NOAA researchers.

Western Boundary Currents

Estimates of transport by the Florida Current are derived using electromagnetic cable techniques on active and inactive submarine cables. During FY 91, motional induction models were developed to provide guidance for evaluating whether a site is suitable for monitoring transport and for locating the cable-ocean contacts in order to minimize meandering effects. Model studies show that moving the Key West cable-ocean contact beyond the shelf region reduces current variability by more than 50%. Consequently, meandering effects can be greatly reduced by having electrodes beyond the shelf region. Use of such cable measurements is an integral part of the Atlantic Climate Change Program (ACCP).

Marine and Atmospheric Chemistry for Climate Change

PMEL conducts two important marine chemistry programs for NOAA under the National Climate Program. One project examines ways in which the ocean affects the atmospheric concentration of several radiatively important trace species (RITS), and 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

It has been proposed that the ocean plays a major role in mitigating global climate change by absorbing and retaining carbon dioxide and other greenhouse gases. Oceanic influx of these compounds depends on the detailed space- and time-dependent air-sea exchange of CO_2, the oceanic processes of thermocline ventilation, and the action of the marine biological "pump" by which carbon is fixed in particulate form in near-surface water, settles, and then decomposes at depth.

During FY 91, PMEL scientists compiled delta-PCO_2 data for the South Pacific Ocean based on measurements obtained on NOAA cruises between 1984 and 1989. The CO_2 data were obtained to constrain present and future models of the air-sea exchange of CO_2 in an area of the world oceans where no data were available before the present study. The delta-PCO_2 map for the South Pacific during austral autumn shows the expected source regions in the equatorial Pacific and a large sink in the midlatitudes of the western South Pacific. In addition, high source regions were documented in the eastern portion of the basin where upwelling and warming of surface water predominate. When the CO_2 data are integrated to obtain the total flux of CO_2 in the basin, the net result is that the range of estimated fluxes is from -0.03 to 0.09 GT C per year for austral autumn. These results indicate that the South Pacific Ocean is not as large a sink for CO_2 during austral autumn as previously believed, and are consistent with the atmospheric models that indicate smaller sinks for CO_2 in the South Pacific. PMEL researchers also contributed to development of a plan for long-range study of the atmosphere-ocean exchange of carbon in the oceans. Implementation of this plan will provide a world-wide data base of CO_2 measurements designed to constrain present and future models of the global carbon budget.

A 1-month cruise was conducted in the north Pacific along 150W to investigate the RITS gases in surface waters and the marine boundary layer. Analysis continued on data collected on previous RITS cruises and laboratory studies. Results from these analyses document the diurnal cycle of atmospheric ozone concentrations in wide regions of the marine boundary layer over the Pacific Ocean. The existence of a seasonal minimum of very low ozone concentrations in the equatorial mid-Pacific boundary layer was established by these data. Another major cruise was carried out off the Washington coast to continue the interdisciplinary, multi-institutional study (PSI–3) of the processes by which dimethylsulfide production in the ocean might

influence climate. This experiment documented the formation and growth of cloud nucleation particles in the atmosphere that will be used to qualitatively link marine sulfur emissions with atmospheric aerosol particle populations.

CFC Tracer Program

The PMEL Chlorofluorocarbon (CFC) Tracer Group played a lead role in planning and executing the first U.S. hydrographic section in the World Ocean Circulation Experiment (WOCE) along 150°W, from Hawaii to Kodiak. The full set of WOCE tracer and hydrographic measurements was obtained on this section by NOAA and university-based investigators. The analytical capability of the CFC group was approximately doubled during FY 91. A program was established at PMEL to prepare and distribute CFC gas standards to groups participating in WOCE (12 organizations from seven countries).

Plans FY 92

Equatorial Dynamics

- Continue implementation of the TOGA–TAO array.
- Complete analysis of North Equatorial Counter Current (NECC) data.
- Complete description of seasonal cycle in the eastern tropical Pacific.
- Conduct a high-frequency internal wave experiment at 0°, 140°W.
- Use moored data to examine the interaction of equatorial Rossby waves with mean zonal flows.
- Cooperate with U.S. Joint Global Ocean Flux Study (JGOFS) investigators during FY 92 equatorial experiment.
- Develop TOGA–TAO Analysis Center with the University of Washington.
- Complete analysis of model seasonal cycle with idealized wind fields.

Western Boundary Currents

- Continue Key West and West Palm Beach electromagnetic measurements.
- Upgrade West Palm Beach shore station.
- Examine feasibility of laying a new cable across the Florida Straits east of Jupiter Inlet.

Marine and Atmospheric Chemistry for Climate Change

- Participate in WOCE sections in the Southern Ocean on Australian and Soviet expeditions.
- Organize a NOAA-supported WOCE cruise in the western Pacific.
- Initiate a long-term tracer study in the Greenland/Norwegian Seas as part of NOAA's ACCP.
- Document and publish CFC data sets collected during the last decade.

- Participate in the first International Global Atmospheric Chemistry–Marine Aerosol and Gas E. change Program (IGAC–MAGE) field program with the JGOFS Program.
- Complete analysis of Soviet-American Gas and Aerosol (SAGA–3) Study and PSI–3 expeditions.

COASTAL AND ARCTIC RESEARCH

The Fisheries Oceanography Coordinated Investigations (FOCI) 5-year plan is to provide the scientific basis for understanding of recruitment variability of walleye pollock in Shelikof Strait. This study has been expanded to the Bering Sea as part of NOAA's Coastal Ocean Program–Coastal Fisheries Ecosystem Project. Walleye pollock is the most abundant fish in the Bering Sea ecosystem, and its harvest supports a major domestic fishing industry worth well over $1.0 billion per year. By volume, the catch is the largest single-species fishery in the United States and the world. By 1988, American fishermen fishing in the U.S. Exclusive Economic Zone (EEZ) caught approximately 1.2 million metric tons. Before 1980, however, most of the pollock resources in the North Pacific were taken by foreign fleets fishing in the U.S. and Soviet EEZ. Implementation of the Magnuson Fishery Conservation and Management Act eventually forced all foreign fishing out of U.S. waters by the mid-1980s. As a consequence, these fleets moved into the international waters of the central Aleutian Basin (the "doughnut hole"), and by 1988, the foreign-dominated catch exceeded 1 million metric tons in these waters. This high seas fishery is unregulated, and the effect of extensive harvest exploitation on U.S. EEZ fisheries is largely unknown.

The relationship between off-shelf (Aleutian Basin) and on-shelf components of the eastern and western Bering Sea pollock resource is not understood. Indirect evidence on the reproductive biology and growth of Bering Sea pollock, however, indicate possible stock mixing between all areas. Because of the international boundaries and the complex nature of the aggregations of pollock in the region, allocation of resources to the domestic fishery based solely on an understanding of population dynamics is a difficult management problem.

Phase 1 of the Bering Sea FOCI studies larval transport patterns in relation to oceanographic phenomena, biochemical genetic studies and tagging, concurrent biological and physical sampling in egg and larval aggregations, and numerical modeling. This research builds on experience acquired in successful FOCI studies on pollock conducted in the western Gulf of Alaska by NOAA/OAR and NMFS laboratories. A NOAA-wide partnership with regional academic institutions and foreign government laboratories is coordinated by the project managers.

The PMEL Tsunami Project, as part of the Coastal Hazards element of NOAA's Coastal Ocean Program, seeks to mitigate the effects of tsunami hazards to Hawaii, California, Oregon, Washington, and Alaska. To meet this objective, the Tsunami Project established the Pacific Tsunami Observation Program (PacTOP) to obtain high-quality tsunami measurements in the deep ocean and coastal regions, data that are essential to an improved understanding of tsunami generation, propagation, and inundation dynamics.

Accomplishments FY 91

Bering Sea FOCI

During August 1991, FOCI funds supported the first U.S. research cruise into the Soviet sector of the western Bering Sea since 1974. Pollock samples, conductivity-temperature-depth (CTD) data, shipboard ADCP profiles, and nutrient samples were collected, and five ocean current moorings were placed in the southern inflow passes to the Bering Sea.

A 0.025° ocean current model was implemented on NOAA's Cray supercomputer in Boulder, CO. Model results and analysis of drifting buoy data show a direct connection in the current field between the shelf and the deep Aleutian Basin, which controverts previous speculation.

Pollock samples were collected on four separate cruises from four Bering Sea subbasins for genetic and otolith studies.

A 1991 FOCI program implementation plan was completed and approved. A governing management council was established which includes the acting head of the newly ratified North Pacific Marine Science Organization (PICES); this relationship will provide a primary international forum for project coordination and scientific exchange.

Six joint FOCI projects have been established between NOAA scientists and external cooperators with FY 91 funds.

Shelikof Strait FOCI

During FY 91, efforts were focused on adaptation of a Semispectral Primitive Equation Model (SPEM) to be used for hydrodynamic and biophysical studies related to dispersion and transport of pollock eggs and larvae in the western Gulf of Alaska. Requirements on the model include an estuarine type flow field and the capability of generating eddies. High concentrations of larvae are often associated with the eddies observed in the region, and those larvae are in better condition than those found outside the eddy.

An experiment was designed to provide boundary conditions for SPEM "upstream" of the area where eggs and larvae are prevalent. In addition, moorings were deployed at two locations within the model field to provide current information to compare with model results. The three locations are all in the Alaska Coastal Current and will provide estimates of continuity along this current, which dominates transport of larvae.

Analysis of estimates of abundance of early life history stages of walleye pollock was conducted on the long-term FOCI time series. Results show that year-class strength was clearly set by the young-of-the-year stage in late summer. During some years, year-class strength was established during the larval stage in May. Data collected during the 1991 field season indicate differences from conditions observed during the last good year-class, 1988: water temperature was significantly colder, mixed-layer depth was significantly greater, and transport out of the sea valley appeared to be stronger. Ongoing analysis of wind mixing energy and hatch dates of successful larvae show that the survivors hatched during periods of relative calm. Therefore, the observation of a deeper mixed layer suggests that juvenile pollock survival during 1991 may be low.

Unlike previous years, in 1991, there were no patches containing large concentrations of larvae observed. This was most likely caused by anomalous physical conditions experienced during spring 1991. Because of the low larval abundances, planned process studies within a larval patch were not conducted. Instead, fine-scale physical and biological measurements were made. A section across the sea valley indicated spatial correlation between fluorescence (an index of zooplankton abundance) and water properties.

Arctic Research

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

A joint study of the ocean circulation from Bering Strait northward over the Chukchi Shelf and into the Arctic Basin was undertaken during 1990–91 by researchers from the Arctic and Antarctic Research Institute in St. Petersburg and from PMEL, using the Soviet research vessel *Professor Khromov* and the NOAA ship *Surveyor*. A total of 16 instrumented moorings were deployed and a thorough study of the hydrodynamic

properties of the shelf was undertaken to provide a detailed history of the currents, sea-surface elevation, temperature, salinity, nutrients, and dissolved oxygen. The program provides the first look at the circulation of the Chukchi Sea undertaken without the restrictions of national boundaries.

Additional observations were made by researchers from the University of Alaska and University of Texas, including a broad seabird census, mapping of stable isotope concentrations related to the feeding of bowhead whales, and measurements of trace chlorinated organics. This comprehensive observation program is expected to give an integrated view of a globally important conduit from the Pacific into the Arctic. Additional supporting work included a modeling study of the transport of ice and energy in winter from the Bering Strait region into the Arctic via the Chukchi Sea.

Atlantic Climate Change Program (ACCP)

A principal thrust of the ACCP is to examine the variability of vertical overturning of the global ocean, which appears to be strongly driven from the North Atlantic. Attention has been drawn to the upper high-latitude ocean, since the salinity structure there seems to control the convection. With this in mind, the decision was made to measure and monitor freshwater flux from the Arctic Ocean through Fram Strait between Greenland and Spitsbergen, the principal connection between the Arctic and the North Atlantic. During the summer of 1991, three moorings were deployed on the Greenland Slope at 79°N. Other moorings were deployed by Norwegian and German investigators. The moorings are all scheduled for recovery by a Norwegian research vessel during the summer of 1992, at which time a new set will be deployed.

Sea ice-troposphere interaction

A typical winter vertical temperature structure of a polar air mass is composed of a cold (-30°C) surface-based inversion or mechanically mixed surface layer and a broad temperature maximum layer, with a negative lapse rate aloft. Because the emissivity of the temperature maximum layer is less than the snow surface, radiative equilibrium maintains this inversion structure. Model calculations and analyses of CEAREX (Coordinated Eastern Arctic Experiment) atmospheric soundings from the fall of 1989 north of Svalbard were used to show that heat fluxes through the ice are insufficient to maintain Arctic air temperatures and that northward temperature advection by transient storms is required to maintain the balance. PMEL researchers were able to show that leads and thin ice contribute only 12% to the high Arctic winter tropospheric heat budget.

Tsunami

Field experiments

Three oceanographic cruises were carried out to recover and redeploy bottom pressure recorders (BPRs) of the PacTOP network. In collaboration with Scripps Institution of Oceanography, a high-frequency (1 Hz) BPR was also deployed in the Shumagin Seismic Gap on the Aleutian Trench slope to measure microseisms and, in the event of a tsunamigenic earthquake, provide additional information on the seismic source mechanism.

Alaskan Bight tsunamis

Existing analytic theory and an optimization approach to wave ray construction are being combined to develop a methodology for BPR data analysis. This technique was applied to the 6 March 1988 Alaskan Bight tsunami data. Observed waveforms agree well with theory, and the analysis may also provide estimates of the length scales characterizing seismic sources.

U.S.–Japan collaboration on Marianas Trench tsunami

On 5 April 1990, a small tsunami was measured by U.S. and Japanese tide gauges, by offshore BPRs of the Japanese Earthquake Phenomena Observation System (EPOS), and by PacTOP instrumentation located more than 8000 km distant from the source—a magnitude 7.6 earthquake in the Marianas Trench. An informal data exchange agreement was established, and a collaborative analysis of these data has begun.

Hilo Harbor inundation modeling

Tsunami inundation modeling of Hilo Harbor, HI, has begun. This activity is in direct support of the Coastal Ocean Program, which provided funding for the contract awarded to JIMAR at the University of Hawaii.

Plans FY 92

Bering Sea FOCI

- Evaluate otolith and genetic samples for evidence of walleye pollock stock separation between regions of the Bering Sea.
- Evaluate pollock stock structure from summer 1991 joint cruises.
- Combine ocean model results, wind statistics, and altimetry data to estimate variability of flow between the Soviet and U.S. continental shelves and the doughnut hole.
- Conduct a spring/summer experiment on coupling of larval survival and turbulence. Begin modeling this interaction.

Shelikof FOCI

- Use SPEM to investigate generation, translation, vertical velocities and fate of mesoscale eddies.
- Complete analysis of bottom pressure and coastal sea level data to provide information on the dominant patterns of sea level change.
- Complete analysis of comparison between observed winds and computed winds derived from a surface atmospheric pressure grid.
- Recover the 13 moorings deployed in spring 1991.

- Design and deploy an experimental system to examine upper mixed layer dynamics in light of th relationship between larval survival and wind mixing.

Arctic Research

- Complete the second set of cruises in the Chukchi Sea in support of the Joint U.S./U.S.S.R. Circulation Study, process the current meter and pressure gauge data from the first full year's moorings, and calibrate and process the hydrographic data set from the second set of cruises.
- Measure and monitor the fresh water flux from the Arctic Ocean through Fram Strait between Greenland and Spitsbergen as a part of the ACCP by recovering the first year's moorings, replacing the moorings, processing the sonar ice thickness and current meter data from the first year's moorings, and developing an analysis package for the upward-looking sonar ice thickness data.
- Continue analysis of circulation and mixing in the Greenland Sea, including the interactions between convective overturn and the distribution of sea ice.
- Complete a numerical study on the transport of ice and energy in winter over western arctic shelves, based on a decade of ice drift, current, and wind observations over the Bering and Chukchi continental shelves and funded by the Office of Naval Research.
- Deploy two sets of four Argos drifting ice stations during November 1991 and March 1992 to measure winds, currents, and ice drift in the Beaufort Sea, as a component of the LEADS Experiment funded by Office of Naval Research and as a furtherance of the sea ice-troposphere interaction observations.

Tsunami Project

- Maintain the PacTOP network by recovery and redeployment of deep-ocean BPRs.
- Continue development of methodology for BPR analysis.
- Acquire and digitize U.S. tide gauge data for the Marianas Trench tsunami; provide these data to collaborating Japanese scientists.
- Complete inundation modeling of Hilo Harbor.

OCEAN ENVIRONMENT RESEARCH

The VENTS Program is in its seventh year of research focused on determining the oceanic impacts and consequences of submarine hydrothermal venting. In pursuit of these objectives, the program directs most of its efforts toward achieving an understanding of the chemical and thermal effects of venting along northeast Pacific seafloor spreading centers on the North Pacific Ocean.

Accomplishments FY 91

Research results obtained during FY 91 continue to augment the case for hydrothermal venting at seafloor spreading centers having global significance in terms of the chemical and thermal state of the ocean. NOAA VENTS Program scientists, together with their non-NOAA research collaborators, are continuing to achieve major successes in quantitatively documenting these effects as they occur in the ocean over a very wide range

of temporal and spatial scales. During the year, VENTS research was concentrated in two general categories of activity:

- determining patterns and pathways for the regional transport of hydrothermal emissions as well as source strengths of the emissions and their relationships to the geology and tectonics of spreading centers; and
- establishing capabilities for monitoring hydrothermal activity at a wide range of temporal and spatial scales.

Transport and Source Strengths of Hydrothermal Emissions

One of the most interesting and potentially significant VENTS Program discoveries of past years has been that of large-scale, episodic hydrothermal bursts generally known as megaplumes. Several of these events have now been observed, and it is necessary to determine just how important such episodic processes are in terms of their contributions to ocean hydrothermal chemical and heat budgets. The amount of silica contained in the first megaplume event observed, for example, was equivalent to that produced in 1 year by the entire large, steady-state vent field located in the same area. It appears likely that megaplumes are a relatively common hydrothermal consequence of discrete volcanic and tectonic events signaling episodes of active seafloor spreading. This hypothesis is supported by the recent discovery by VENTS investigators of a series of volcanic mounds that erupted in the megaplume region sometime between 1981 and 1987, a period that includes the times when two large megaplume events were observed. This discovery is important because it provides the first opportunity to study hydrothermal (and biological) evolution processes that are a consequence of a documented seafloor spreading event.

This year, a study was completed that showed that hydrothermal activity along the Juan de Fuca Ridge is a significant factor affecting the concentration and distribution of silica in the northeast Pacific water column. Silica is an important nutrient in seawater, and hydrothermal venting increases the concentration of silica (H_4SiO_4) in the water column anomaly west of the Juan de Fuca Ridge by 17–27%. The distribution of silica in the water column is further affected by venting because biologically derived silica, which normally resides near the seafloor in northeast Pacific deep water, is entrained in buoyant hydrothermal plumes and is thereby transported into midwater depths.

Hydrothermal Monitoring

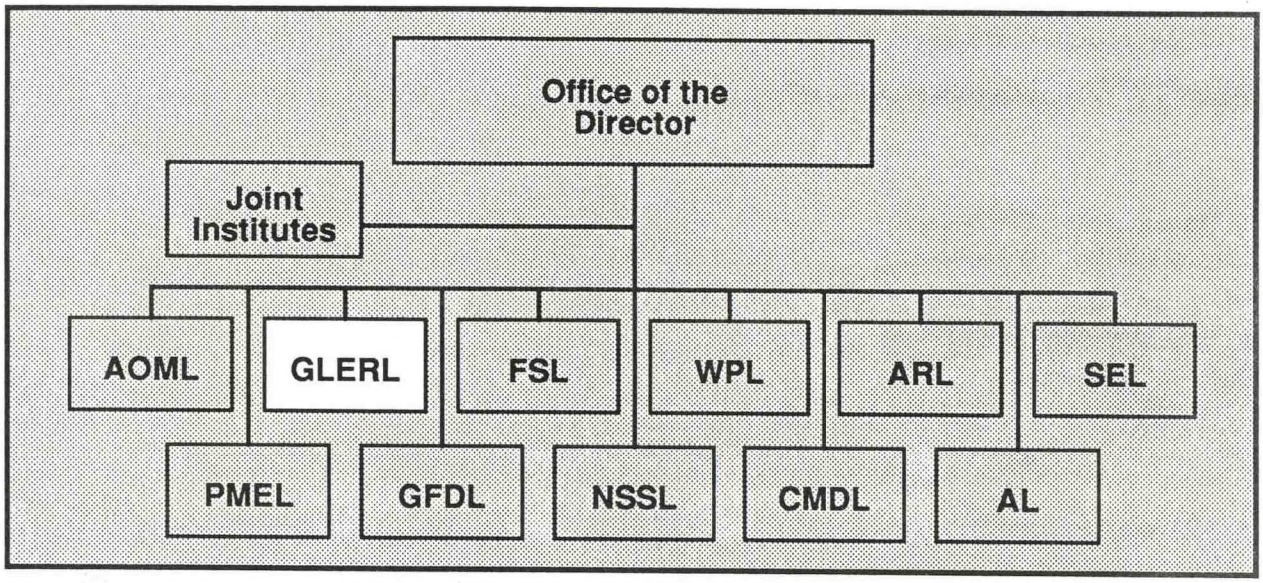
One of the most important accomplishments during FY 91 was achieving operational status for the VENTS T–phase event detection system. T–phases are acoustic signals that are generated by, among other things, submarine earthquakes and shallow submarine volcanic eruptions. One of the most important goals of the VENTS T–phase project is to detect events that either may be or are associated with episodic hydrothermal events such as megaplumes. From past research it is known that clusters of T–phases, i.e., earthquake swarms, can be traced to loci on northeast Pacific spreading centers. Earthquake swarms often accompany volcanic eruptions, so the ability to detect and locate such activity will be a major step toward giving us the ability to study episodic hydrothermal activity while it is active. An important unresolved question, however, is whether or not either episodic hydrothermal events or deep volcanic eruptions generate distinctive acoustic signals.

The VENTS T–phase event-detection project is the first of its kind in the United States and provides the VENTS Program with an important means to continuously monitor not only the northeast Pacific but virtually the entire Pacific basin. Moreover, since T–phase event detection both requires and provides very detailed information about water-column sound velocities, Ocean Environment Research Division scientists are also

considering using such data to help determine whether or not gradual, long-term changes in sound velocities are occurring in response to ocean warming.

Plans FY 92

- Reduce, analyze, and interpret physical, chemical, and geological oceanographic data obtained during the FY–91 VENTS *Discoverer* and *Atlantis II/Alvin* field season.
- Conduct the FY–92 VENTS *Discoverer* field season.
- Continue the decadal-scale monitoring of hydrothermal venting variability on the Cleft Segment of the Juan de Fuca Ridge, including ^{3}He-heat-silica relationships, through the use of existing instrumentation and techniques as well as through the development of new instrument systems. Examples of both include mooring arrays consisting of sediment traps, standard and ADCP current meters, and temperature sensors; a continuous chemical scanning system that detects and measures manganese, iron, and silica in hydrothermal plumes; an acoustic horizontal-strain measurement system; an enhanced BPR that will include a tilt meter and a vertical seismometer; tow-yo surveys with a CTD/transmissometer system; repeat Sea Beam swath sonar system bathymetric surveys; and seafloor gravity measurements.
- Continue development of software to refine automated detection and location of T–phase events.
- Study the frequency and power spectra of T–phase signals in an attempt to classify events as to specific sources.
- Continue numerical model of physical and chemical processes in buoyant hydrothermal plumes.
- Compare seafloor roughness statistics derived from Sea Beam backscatter information with those generated by spectral techniques and fractal measures.



GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Ann Arbor, MI
(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 Coordinated Research Programs considered critical to the NOAA mission and Great Lakes problems (Non-Indigenous Species, Coordinated Ecosystem Research, Climate Variability and Global Change in Large Lakes, Pollutant Effects, Marine Hazards and Water Management, Green Bay Coordinated Research) and, in addition, 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 the Non-Indigenous Species program is to expand knowledge of the biology and the ecological effects of non-indigenous species in the Great Lakes.

Two species recently introduced into the Great Lakes 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 as well as ecological implications to other species. *Bythotrephes* has become a dominant member of the plankton in all the Great Lakes. Our preliminary work suggests that *Bythotrephes* is a voracious selective predator. Recent shifts in Lake Michigan zooplankton community structure from Daphnia, the favorite food of *Bythotrephes*, to copepods have been hypothesized to be caused by *Bythotrephes*.

Accomplishments FY 91

The Zebra Mussel (Dreissena polymorpha)

Effects on lower food web of Saginaw Bay

- A meeting was hosted to plan agency coordination and resource pooling resulting in an agreement between GLERL, the Michigan Department of Natural Resources (DNR), the U.S. Environmental Protection Agency (EPA), and the U.S. Fish and Wildlife Service (FWS) to provide resources to enhance research efforts.
- A request for proposal was issued to address research gaps through academic institutions. Consultations with potential collaborators, reviews of proposals, and relevancy to planned GLERL activities in Saginaw Bay provided a basis for funding grants.
- An expanded sampling program was initiated in Saginaw Bay in April 1991. A total of 26 sites were sampled monthly until November.
- Artificial substrates were constructed and placed at four sites in the bay to document the rate and temporal variability of settling by zebra mussel veligers, the free-swimming zebra mussel larvae.
- Divers were employed to document zebra mussel densities in the bay.
- Mesocosms were constructed and preliminary experiments were conducted to determine small-scale changes in nutrients, bacteria, phytoplankton, and zooplankton as a result of the filtering activities of zebra mussels.

Metabolic physiology

- Analysis of data collected in Lake St. Clair in 1990 continued. Preliminary results show that lipid levels in zebra mussels are very site specific and possibly a function of abundance.
- A population survey of zebra mussels was conducted in Lake St. Clair in the fall of 1990 to determine abundances and biomass on a lake-wide basis. All mussels were counted and measured for length. In addition, the proportions of mussels attached to different types of substrate were determined.
- Excretion rates (phosphorus and nitrogen) of mussels collected from Lake St. Clair were measured monthly beginning in April 1991.

Toxicokinetics and bioaccumulation of organic contaminants

- Methods were developed to hold zebra mussels in the laboratory safely and in good health for toxicokinetic studies. An experimental design was developed that permitted the measurement of the toxicokinetics of organic contaminants in zebra mussles exposed only through the water. Calculations of the toxicokinetics required significant modification of existing kinetics models to calculate the uptake rate coefficient.
- Both uptake and elimination of benzo(a)pyrene; 2,4,5,2',4',5' hexachlorobiphenyl; DDT; 3,4,3',4'-tetrachlorobiphenyl; and pyrene were determined.

- Maintaining adult zebra mussels in the laboratory began and development of methods to induce spawning of the mussels to produce a supply of veligers was initiated.
- Growth kinetics of algae to be used as food for veligers were determined.

The Spiny Water Flea (Bythotrephes)

Ecology of an invader: The physiological ecology of Bythotrephes *and its direct effect on food web structure in the Great Lakes*

- The first year of nearly weekly collections of *Bythotrophes* at the offshore monitoring station and at an inshore station was finished.
- Analyses of a collection of tows made during day, dusk, and night of the same day over all depth strata showed highest abundances at night, second highest abundances at dusk, and extremely low abundances during the day. These results are consistent with net avoidance and suggest we may be grossly underestimating *Bythotrephes* abundance.

Plans FY 92

- Continue monthly sampling of the bay at the same 26 stations from April to November.
- Initiate experiments to determine filtering rates of zebra mussels on Saginaw Bay seston.
- Expand the mesocosm experiments.
- Build 10-liter CVS traps (in situ grazing chambers), refine equipment and experimental techniques, and perform experiments.
- Process first trap samples and evaluate further deployment plans.
- Analyze traps for organic carbon and nitrogen.
- Collect zebra mussels from Lake St. Clair and examine lipid levels. Lipid levels in individuals in Saginaw Bay will also be measured.
- Determine if larvae can be raised from eggs to settling using selected algal species.
- Determine feeding rate of veligers on algae.
- Continue to design appropriate experiments to measure particle filtration rates so that feeding studies can be designed.
- Continue to measure the toxicokinetics and develop a toxicokinetics data base.
- Design experiments to measure assimilation efficiency of particle-associated contaminants based on the experimental design to measure particle filtration rates.
- Develop analytical methods and pursue preliminary measures of organic contaminants from field-collected mussels.
- Continue coordination with Ohio State University on the toxicokinetics of organic contaminants in the zebra mussel and the contribution of the zebra mussel to the food chain transport of organic contaminants.
- Complete analyses of *Bythotrephes* population data collected during FY 90 and FY 91.

- Continue population study by increasing frequency of sampling.
- Assemble components of zoovideo system. The zoovideo system is an underwater videomicroscope, hardware, software, and positioning system that tracks zooplankton as they swim. The system was designed to improve the ability to observe free-swimming zooplankton in situ and in laboratory aquariums.

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 these components can be highly variable in time and space. Identifying the causes of this variability is 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. 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 quantify temporal and spatial trends and variability; identify first-order relationships among fish populations, lower food web, and physical factors; and provide estimates of biotic biomass for use in ecological simulation models.

Accomplishments FY 91

Pelagic-Benthic Energy Transfer and Bioenergetics Models of Macroinvertebrates

- Carbon transfer from 14C-labeled *Melosira* sp. to *Diporeia* sp. was quantified in laboratory microcosm experiments.
- Seasonal input rates of "new carbon" reaching the benthos were quantified using sediment trap collections.
- A carbon budget was developed to quantify the input, alteration, and burial rates of carbon from settling particles in Lake Michigan.

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

- Analysis of the whitefish recruitment model parameters for northern Green Bay and the north shore of Lake Michigan was completed.

Food Quality in Pelagic Food Webs

- Data analysis of lipid storage as it relates to life-cycle strategy of *Diaptomus sicilis*, a dominant suspension-feeding copepod in the Great Lakes, was completed.
- Feeding mechanisms of copepods (*Diaptomus* spp., *Limnocalanus*, *Senecella*, *Epischura*) were examined using high-speed microcinematography to correlate mouthpart usage and behavior as they relate to the creation of a scanning current (to sense prey), swimming behavior, and mode of perception (chemical and mechnical) of prey.

Plans FY 92

- Provide preliminary examination of the spatial and temporal abundance of microplankton in Lake Michigan.
- Continue exploring the use of flow cytometry to characterize phototrophic picoplankton communities.
- Map out three-dimensional reaction distances to various particles (plastic spheres, zebra mussel eggs and larvae, various microzooplankton, algae) of tethered calanoid copepods to gain insight into sensory mechanisms utilized to locate prey.
- Observe interactions of free-swimming predators and prey.
- Design and build Liposcan video system to allow simultaneous dorsal and side views of lipid droplets and sacs of zooplankton with shuttered video camera to quantify lipids in juvenile and adult copepods.

CLIMATE VARIABILITY AND GLOBAL CHANGE IN LARGE LAKES

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, and biogeochemical cycling. 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. GLERL's activities in this area include planning with NOAA's Land-Surface Processes and Ecological Systems and Dynamics Elements, the National Science Foundation (NSF) Long-Term Ecological Research Sites and Global Change Research, the Freshwater Initiative, the Global Exchange and Water Cycle Experiment, the 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 91

Effect of Climate Change on Large-Lake Ice Cycles

- Regression ice cover models of Lake Superior were developed using a lake evaporation model. The modeled ice cover data were then used to recalibrate the lake evaporation model.

Climate Variability Using Chaotic Dynamics

- Studies were initiated on measuring and characterizing chaotic processes from water level and temperature time series data.

Thermal Structure Studies

- The first year's data from the Vector Averaging Current Meter (VACM) mooring and the subsurface thermistor chain were recovered. Most of the VACM data appear to be useful.

- Fresh VACMs and thermistor strings were deployed. Analysis of the thermistor data began shortly after their retrieval.

Current Velocity Profile Measurements in the Straits of Mackinac Using Acoustic Doppler Current Profilers (ADCP)

- Two ADCP moorings were retrieved in October 1991. Preliminary analysis was completed, through the stratified season, and indicated the data are of high quality. The long-term mean profile clearly shows two layed flow.

Environmental Radiotracers

- Gamma emitter analysis of all sediment cores from the 1988 collection was completed. In July, cores from both the central basin reference site and the eastern basin reference site were collected. Box cores of very high quality were obtained, subcored, and sectioned for radiometric analysis.

Plans FY 92

- Continue to adapt and calibrate GLERL's runoff model to parts of the Caspian Sea basin. Begin to jointly formulate, develop, and calibrate evaporation models for the Caspian Sea.
- Collect GCM climate warming scenarios over the United States and the U.S.S.R. from the National Center for Atmospheric Research (NCAR), the Atmospheric Environment Service (AES), and other agencies.
- Continue to jointly assess GCM simulations for studying hydrological aspects of climatic change over the U.S.S.R.
- Continue to cooperatively estimate hydrologic responses of other agency climate scenarios.
- Complete development of conceptual-based, lumped-parameter ice cover models for Lakes Superior and Erie.
- Continue to analyze freeze-up/break-up climatic trends and continue to develop models of freeze-up/break-up for Grand Traverse Bay.
- Finish preliminary analyses of 1991 thermistor data.
- Deploy and retrieve a new METOCEAN drifter buoy with attached thermistor string in Lake Michigan.
- Maintain the primary thermistor monitoring site, i.e., retrieve, refurbish, and redeploy moorings.
- Continue analysis of the net flow through the Straits of Mackinac and speculate on the possible effects of global warming, i.e., longer periods of stratification, on Lakes Michigan and Huron.
- Initiate detailed analysis of the Great Lakes water level data, which will be used to characterize and quantify the long-term processes by using the concepts of deterministic chaos.
- Analyze 1991 collection for gamma emitters and lead-210.

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) Defining no-effect loads for both species and community, what is the assimilative capacity for toxic contaminants? (3) What kind of prediction can be applied to catastrophic events to ensure the best management decisions? (4) What are the effects of long-term, low-level contaminant exposures?

Accomplishments FY 91

Sediment-Associated Toxic Organics: Fate and Effects

- Data analysis and product generation were performed under this project. The relationship between the organic carbon content and toxicokinetics of sediment-associated contaminants was completed.
- Data analysis of the effect of increasing contact time between sediment and contaminant was completed. With increasing duration of contact, bioavailability is reduced. This reduction is rapid enough to affect the bioavailability of laboratory-dosed sediments.
- Data analysis examining the relationship between between respiration and contaminant accumulation from water was completed. The accumulation of selected polycylic aromatic hydrocarbons (PAH) was approximately four times the respiration rate for *Diporeia,* suggesting either a low efficiency for oxygen consumption or accumulation of the PAH across more than just the respiratory membrane.
- Data analysis and modeling were completed for examining field validation of the accumulation of PAH by *Diporeia* sp.
- Data from the initial bioturbation studies were analyzed and the reworking rate declines significantly with increasing concentration of DDT.

Physiological and Biochemical Measures of Contaminant Effects

- Two cruises were made to examine the relationship between respiration and excretion for *Diporeia* found under differing conditions in Lake Michigan. The oxygen consumption was the same for organisms taken from all depths, while nitrogen excretion increased for organisms collected from the deeper stations.

Long-Term Trends in Benthic Populations

- Progress was made on identifying and processing organisms collected in Saginaw Bay in 1987–88. Biomass estimates were obtained for all chironomids and sphaeriids in the samples.

Bioavailability of Sediment-Associated Toxic Organic Contaminants

- Quantitative structure activity models were employed to examine a set of data on the toxicity of organophosphorous and carbamate insecticides to *Chironomides*. The study incorporated exposures to water only and to sediment-associated contaminants.
- Assimilation efficiency studies of accumulation of sediment-associated contaminants by *Diporeia* are under way. Preliminary findings suggest that the assimilation efficiency for benzo(a)pyrene is similar to that for other nonpolar contaminants in other benthos.

Plans FY 92

- Assay sediments of opportunity using both the 28-d mortality bioassay and the avoidance/preference bioassay.
- Continue efforts to develop standard toxicants for solid-phase bioassays.
- Perform studies to determine the appropriate approach for diluting sediments by examining the exposure to toxic contaminants before and after dilution.
- Develop methods to determine the assimilation efficiency of sediment-associated toxins by *Diporeia* sp.
- Study variations of sediment composition using laboratory-dosed (with toxic contaminants) sediments collected from various sites in Lake Michigan.
- Develop methods to examine the bioaccumulation of polychlorinated biphenyl (PCB) congeners in *Diporeia* using field-collected sediments.
- Complete data analysis from initial experiments with freshwater oligochaetes and exposure to DDT.
- Test characteristics of an upgraded gamma scan system and perform initial experiments with marine organisms.
- Complete processing of all oligochaetes samples collected in Saginaw Bay in 1987–88.
- Continue processing benthic samples taken in Whitefish Bay and Lake Michigan.
- Process trap samples collected in September 1991: measure bulk parameters, and calculate fluxes and settling velocities.
- Collect boundary layer water samples and sediments.

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 significant 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 91

Lake Circulation and Thermal Structure Modeling

- A three-dimensional model code was adapted for use on the new Commerce Consolidated Scientific Computing System (CSCS) Cray Y–MP supercomputer.
- Implementation of an operational system for thermal and circulation structure forecasts for Lake Erie began in collaboration with Ohio State University.

Great Lakes Snow Characteristics

- The data base was searched for maximum snowfall occurrences at long-term stations. Relationships were found between maximum snowfalls and latitude, longitude, and elevation.
- New digital methods were established to delineate and quantify distributed parameter snowfall variability. Snowfall within the Great Lakes Drainage Basin was shown to have increased throughout this period because of increased lake effect and not continental snowfall.
- A preliminary analysis was made of upper air teleconnections with regional monthly average snowfall, air temperature, and ice cover on the Great Lakes.

Great Lakes Water Level Statistics for Decision Making

- The proceedings of the Great Lakes Water Level Forecasting and Statistics Symposium was published.
- An international network of researchers interested in improving Great Lakes water levels statistics was established under the auspices of Phase II of the International Joint Commission (IJC) Levels Study Reference.

Great Lakes Evaporation, Forecasting, and Simulation

- The evaporation model was refined with better heat storage models and was incorporated into the forecast package.
- Modification of the forecasting package algorithms to allow package use in simulation settings was finished.
- Development of a monthly runoff and net supply model package that incorporates approximations for over-lake evaporation was finished. This model is usable for simulations with early historical data where only monthly data are available.
- Great Lakes response simulations to extreme climate scenarios began for the IJC.

Objective Analysis of Great Lakes Marine Meteorological Observations

- A prototype operational program for objective analysis of Great Lakes winds was developed.

- Analyzed wind fields from Fleet Numerical Oceanography Center (FNOC) Field by Information Blending (FIB) procedure were collected and stored for comparison with wind fields developed in this project.

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

- The proper correlation and parameterization of wind waves led to advanced understanding and insights on the equilibrium range of the wave spectrum and its relation with wave dissipation and wave breaking.
- Continued collaborative efforts with scientists at the National Water Research Institute of Canada on the study of surface waves led to the development of simple algebraic formulation of realistic wave growth relations.
- Joint efforts with the Coastal Engineering Research Center showed that the accuracy of the wind field input is as important as differences in models in explaning differences between observed and hindcast waves.

Plans FY 92

- Test the three-dimensional circulation model with idealized topography against known analytic solutions for steady-state barotropic circulation, internal Kelvin wave dynamics, Ekman layer dynamics, and free surface normal modes.
- Attempt to simulate the three-dimensional development of stratification, including thermal bar dynamics and midlake vertical heat advection.
- Apply the three-dimensional circulation model with realistic atmospheric input to an annual simulation and comparison with observed features of lake circulation.
- Analyze the snowfall data base for temporal and spatial differences over the basin and within regions covering the period of record.
- Continue analysis of snowfall-upper air teleconnections using the gridded snowfall data base and upper air geopotential heights and ancillary data.
- Complete the final report on Great Lakes water level statistics for the IJC Water Levels Reference Study.
- Explore derived water level statistics, based on resampling approach: time-to-exceedance and duration probability distributions.
- Continue participation in the Office of Naval Research (ONR)/National Aeronautics and Space Administration (NASA) Surface Wave Dynamics Experiment (SWADE) program.
- Compare the FNOC FIB winds to objectively analyzed winds. Both types of wind fields will be evaluated for use with the Great Lakes Forecast System.
- Assess water balance groundwater fluxes and other water balance questions using the improved (and independent) evaporation models.
- Develop and refine evaporation models to relate meteorological point measurements with satellite images.
- Develop and refine spatial heat flux models, including evaporation.

- Develop a model to calculate incoming radiation on the basis of cloud cover and height from Geostationary Operational Environmental Satellite (GOES) and meteorological data.
- Assess and report on utility of the gamma snow survey data in runoff modeling and water supply forecasting.
- Compare GLERL and U.S. Army Corps of Engineers net supply forecasts.
- Integrate one-dimensional flow routing models for the St. Lawrence River.
- Apply GLERL hydrology models to St. Lawrence watersheds.
- Continue improving quality of hydrometeorological data base and finish building hydrometeorological station data base.
- Complete Great Lakes response simulations to extreme climate scenarios.

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. To address the problems in the bay, the EPA has undertaken the Green Bay Mass Balance Study, which has two major objectives: (1) provide information to aid and support regulatory activities in Green Bay, and (2) pilot the use of the mass balance approach to regulation of toxic substances in Green Bay. The EPA requested GLERL to take part in research aspects of this program. GLERL's portion of the accomplishments are listed below. This study is nearly completed. Future analysis of data will be integrated into other programs.

Accomplishments FY 91

Sediment Resuspension, Particle Settling Velocities, and Water Volume Transport Measurements

- Sediment traps were deployed and retrieved at five EPA stations in Green Bay. On retrieval, samples were dried, weighed, and stored frozen. Organic carbon analysis was completed.
- The horizontal sediment flux for both the summer and winter data was calculated. Preliminary analysis of resuspension data shows that at depths less than 15 m, wave action is the primary cause of resuspension, whereas at greater depths, tidal currents are the predominant agent.
- Water volume transports through key Green Bay cross sections were computed.

Plans FY 92

- Complete analysis of resuspension using the vertically averaged model.

NUTRIENT-ENHANCED COASTAL OCEAN PRODUCTIVITY (NECOP)

NECOP is one of a series of NOAA-wide programs dealing with major problems in the coastal ocean. The central hypothesis is that increased nutrient input from the Mississippi River has led to increased

productivity, with undesirable consequences. GLERL is involved in several studies that have been under way for a 1-year period.

Accomplishments FY 91

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

- Five separate incubation experiments were run. Calculated oxidation rates of the organic matter ranged from 0.002 to 0.012 in deep and plume waters, respectively.
- Analysis of the dissolved organic carbon (DOC) showed a strong relationship with salinity. We were able to show that a large fraction of the DOC that was transported offshore was carbohydrate, a fact not previously recognized.
- A new high-performance liquid chromatographic method, developed to directly determine nitrogen isotope ratios of ammonium in isotope dilution experiments, is being used to calculate nitrogen turnover rates.

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

- Transparency calibrations were completed for the 25-cm transmissometers on both NECOP cruises. Preliminary examination of the data shows that there may have been resuspension episodes during the winter cruise, but no such activity is evident from the summer data.

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

- Two sediment cores from NECOP cruise 1 were analyzed for C-13 and N-15; neither shows as large a signal as cores from Lakes Erie or Ontario. The implication is that anthropogenic effects are smaller. Three sets of cores were collected on NECOP cruise 2.
- A procedure for the analysis of trace amounts of lignin was implemented and applied to cores from the NECOP cruises.

Buoyancy and Nutrient Exchange in the Mississippi River Outflow Region

- Field work and analysis continued on both the historical data base and new data.

Primary Production and Vertical Flux of Organic Carbon

- Analysis of track autoradiographs from the first RV *Baldridge* cruise began.
- Modeling and mapping of primary production was initiated.

Plans FY 92

- Continue analyses of new field data and historical data sets.
- Continue analysis of sediments for lignin and alkane.
- Conduct bacterial and nitrogen dynamics studies for comparison with the RV *Baldridge* cruises. N-15 isotope dilution experiments will be conducted with ammonium in naturally lighted incubators to estimate nitrogen recycling rates.
- Continue analysis of primary production data.

GREAT LAKES COASTWATCH

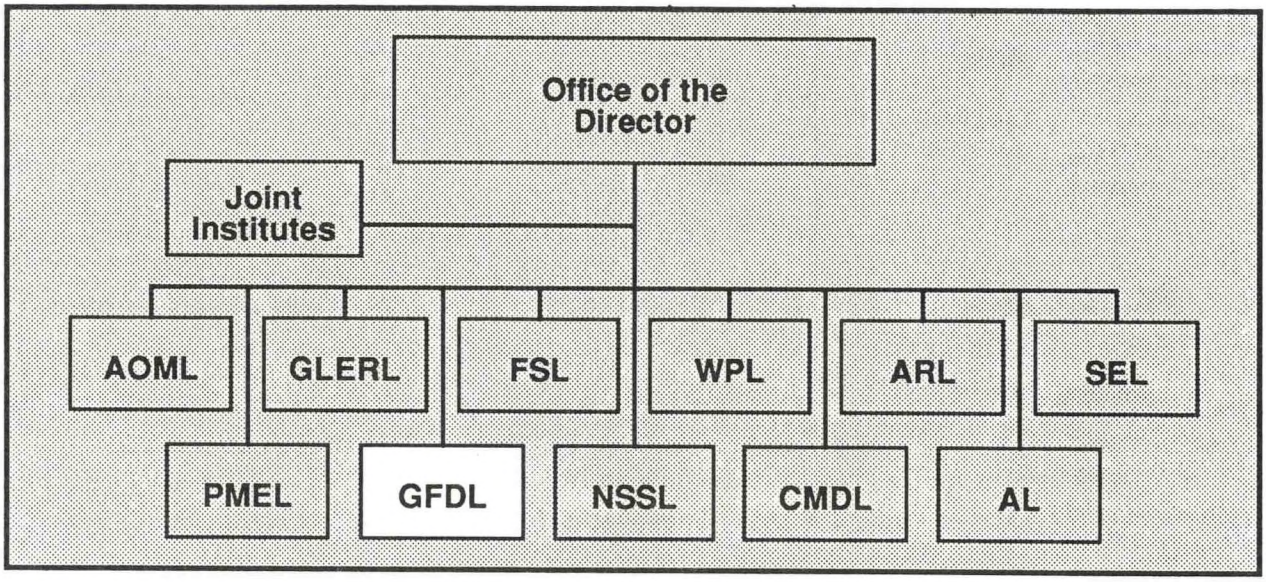
CoastWatch is a NOAA-wide program within the Coastal Ocean Program. As a CoastWatch Regional Site, GLERL is establishing operations of the Great Lakes Regional National Ocean Communications Network (NOCN) Node (RNN), identifying regional CoastWatch users and their NOAA data needs, and supplying useful products to participants in the Great Lakes CoastWatch Program.

Accomplishments FY 91

- Computer equipment for operation of Great Lakes RNN was installed.
- Center for Great Lakes Studies personnel were trained to operate the Interactive Digital Image Display and Analysis System workstation, and a prototype CoastWatch user site was established at Milwaukee, WI.
- The satellite-derived water surface temperature data were calibrated at GLERL against water temperature from NOAA weather buoys in the Great Lakes.

Plans FY 92

- Continue verification and analysis of Great Lakes sea-surface temperature algorithms.
- Continue to incorporate interested federal, state, and local agencies and institutions into the program as local CoastWatch sites and to identify regional product development and research needs.



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 can be 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 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.

WEATHER SERVICE

Synoptic-scale weather forecasts have improved considerably over the past two decades 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? 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 91

- Using a spectral model, nine model integrations from nine different initial times were run for 10 years (1979–89). All specified the same observed sea surface temperature. An investigation was conducted on the reproducibility of some variables among the nine model integrations. The study reveals that there are many occasions during the decade in which the stochastic forecast system exhibits a small spread, suggesting that the variables of concern are reproducible or consistent among the nine members. These occasions represent "attractors," in contrast to an overall chaotic background, and these attractors must be the results of particular distributions of anomalous sea surface temperature. Thus, seasonal forecasts might be feasible during these occasions, if accurate ocean temperatures are available. The 1988 U.S. drought appears to correspond to one of these occasions.

- A new initialization scheme for the Multiply nested Movable Mesh (MMM) hurricane model was formulated. It generates idealized vortices consisting of symmetric as well as asymmetric components. Because of the consistency of the idealized vortex structure with the prediction model, fictitious spin-up of the modeled vortex does not take place. The new technique leads to substantial improvement in the track prediction of hurricanes and enhances intensity forecasts as well. Efficient ways to transfer these techniques from GFDL to the National Meteorological Center (NMC) are being explored.

- The MMM hurricane model was improved by including vegetation data and more accurate treatments of radiation and land surface physics. Also, the MMM model can now be coupled with an ocean model to evaluate the effects of hurricane interaction with the sea surface.

- A study of the energetics of downstream-developing baroclinic waves for an idealized mean zonal flow indicates that waves tend to grow locally by baroclinic processes and by the convergence of ageostrophic geopotential fluxes from upstream eddies. They limit their growth by radiating energy through ageostrophic geopotential fluxes downstream. This behavior has also been detected in global observational data.

- The manner in which baroclinic waves determine their equilibrium amplitudes was investigated using a nondiffusive three-regime model without boundaries. The waves stop growing, not because of a change in zonal-mean potential vorticity as originally thought, but because of an alignment of the potential vorticity contours with the total flow.

Plans FY 92

- Numerical results from the prediction experiments using idealized vortices for the cases of Hurricanes Gilbert and Gloria will be analyzed. Experimental prediction studies using the Australian Monsoon Experiment (AMEX) data will continue.
- Analysis of tropical storm genesis processes will continue. Preliminary results indicate that the genesis mechanism of storms near Australia is strongly influenced by effects of radiation and land-surface processes, quite different from Atlantic cases.
- A case study of the 20 December 1990 cyclone and associated cold outbreak over the eastern Pacific and western United States will focus on determining the factors important in its development, including the role of ageostrophic geopotential fluxes.
- Analysis of the role of surface fluxes in the intensification of extratropical cyclones will continue. New case studies will be performed to assess the relative importance of these fluxes in cyclone evolution.
- An investigation into the causes for the systematic biases in the coupled air-sea forecast model will be the top priority. Seasonal forecasting experiments will continue using the current air-sea model.
- The 1988 United States drought will be studied to establish the statistical validity for the existence of stable, predictable atmospheric states (attractors) in the extratropics, and to explore the reasons for the reproducibility of these solutions.
- Cloud liquid water will be fully incorporated as a prognostic variable into the limited-area mesoscale version of the eta-coordinate model.

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 the following: large-scale wave disturbances and their role in the general circulation of the atmosphere; the seasonal cycle, which must be defined before departures from that cycle (interannual variability) can be understood; interannual variability associated with phenomena such as the El Niño–Southern Oscillation (ENSO); very long-term variability associated with the ice ages; and the meteorologies of various planets, the study of which enhances the scientific 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-land surface-cryosphere system, and various planetary atmospheres.

Accomplishments FY 91

- The seasonal dependence of the response of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2 was investigated. The increase of surface air temperature is a maximum over the Arctic Ocean and its surroundings in the late fall and winter and a minimum in summer, in agreement with the results from equilibrium response studies. The surface air temperature increase in the circumpolar ocean of the Southern Hemisphere is very small because of the vertical mixing

of heat over a deep water column. This result is very different from the results of equilibrium response experiments.

- Over the tropical Pacific region, ENSO-like interannual fluctuations in the coupled model's sea surface temperature did not change substantially with the gradual increase in CO_2. However, monthly mean precipitation, evaporation, and atmospheric water vapor in this region increase significantly with increasing CO_2.
- The wintertime stationary waves undergo a consistent modification as the climate warms, according to the predictions of a coupled atmosphere-ocean model, with the largest changes in the Western Hemisphere. The change in the stationary waves weakens the northerly flow at low levels over North America, thereby enhancing the warming.
- Baroclinic waves organize themselves spontaneously into coherent wave packets in a variety of nonlinear models, and observations clearly show that these packets are very prominent in the Southern Hemisphere.
- Simulations using an atmospheric general circulation model (GCM) with and without orography were used to examine the mechanisms by which the dryness of midlatitude arid regions is maintained in summer. The Tibetan Plateau, through its influence on the south Asian monsoon circulation, is an important contributor to the dryness of the Eurasian interior. Land surface-atmosphere interactions also contribute to dryness in the interiors of both Asia and North America.
- The atmosphere-mixed layer ocean model with prescribed cloudiness is incapable of initiating a Laurentide ice sheet over North America, so long as the orbital configuration and insolation are varied within realistic bounds.
- Experiments have shown that the sensitivity of climate and soil moisture to changes in land surface albedo is highly dependent on latitude. Other geographic factors, such as proximity to oceanic sources of water vapor, are also important.
- The incorporation of both a modified cloud prediction scheme and a finite-difference algorithm for computing moisture advection resulted in an improved simulation of certain aspects of climate by a higher resolution (R30) GCM. In particular, the model's seasonal variation of total cloud forcing (top of the atmosphere radiative flux) in high latitudes is now considerably closer to observation. In addition, highly localized spurious rainfall present in the previous simulation was reduced markedly.
- The accuracies of various solar cloud radiative parameterizations employed in GCMs were subjected to a series of rigorous tests against a set of reference line-by-line results. Noting the shortcomings in the previous treatments, primarily because of the complicated nature of the interactions associated with water vapor absorption and water drop extinction, a new parameterization was developed that improves the simulation of the solar fluxes and heating rates for a vast range of overcast sky conditions.
- A space-time spectral analysis of the high-resolution GCMs with and without the parameterization of orographical gravity-wave drag, as compared to the European Centre for Medium-Range Forecasting (ECMWF) data set, indicates that the parameterization improves not only the mean flow but also the amplitude and phase speed of extratropical transient disturbances.
- The rise in sea level because of ocean warming was estimated from the GFDL couple ocean-atmosphere model. The average rise is 15 cm for a doubling of greenhouse gases using the Intergovernmental Panel on Climate Change (IPCC) standard scenario, but considerable regional variation is predicted because of changes in ocean circulation.
- A 15-year control integration of the 3° latitude resolution GFDL troposphere-stratosphere-mesosphere GCM (SKYHI) was performed. The model displayed an impressively realistic degree of interannual variability in the Northern Hemisphere stratospheric circulation. In particular, several major stratospheric sudden warmings were simulated during the integration. This shows that the

SKYHI model can now be used as a tool to investigate stratosphere and upper troposphere climate and chemical change in the context of natural variability.

- A linear analog of the comprehensive SKYHI model was constructed. An integration was then performed in which the linear model was forced by the detailed time series of tropical convective heating from the full SKYHI model. The simulated field of vertically propagating gravity and equatorial waves was remarkably similar in the two models. This result strongly suggests that tropical convection is the dominant excitation mechanism for gravity waves throughout the middle atmosphere.
- Space-time spectral analysis of the 3° latitude resolution SKYHI GCM and the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE) data set indicates that this model adequately simulates Kelvin and mixed Rossby-gravity waves in the equatorial stratosphere. These waves occur over the range of wavenumbers 1–5, their dominant wavenumber and period shifting with altitude. This encouraging result leaves unresolved the question as to why the SKYHI model does not successfully simulate the Quasi-Biennial Oscillation.
- A first, detailed picture of the global entropy budget of the atmosphere was made based on real data. The outgoing flux of entropy at the top of the atmosphere associated with terrestrial radiation is about 22 times larger than the incoming flux through solar radiation. The entropy balance of the Earth is maintained through the high rate of production of entropy inside the atmosphere, mainly by the release of latent heat and the absorption of solar radiation. The rates of entropy production are highest in the equatorial region.
- Well-defined modes of variability were identified for monthly mean fields simulated in a 100-year GCM experiment subjected to climatological forcing. These recurrent monthly mean anomaly patterns are accompanied by systematic changes in the behavior of midlatitude, transient synoptic-scale disturbances. The dynamical interactions between the latter high-frequency features and the quasi-stationary flow field in the model atmosphere are similar to those deduced from observations.
- Cold air outbreaks over East Asia, North America, and Europe are associated with the passage of organized wave packets encompassing several pressure troughs and ridges. These wave packets typically grow spontaneously in amplitude as they traverse the North Pacific and North Atlantic. Periods of active cold surges are also characterized by prominent changes in the low-frequency, planetary-scale component of the atmospheric circulation.

Plans FY 92

- The time-dependent response of climate to gradual changes of atmospheric CO_2 will be evaluated using a coupled ocean-atmosphere model with higher computational resolution.
- For the study of climate variability, very long-term integrations of a coupled ocean-atmosphere model will continue.
- A series of calculations will be performed with a model of the radiative-convective equilibrium of a homogeneous atmosphere, using a two-dimensional cloud model to simulate the convection explicitly.
- The possible reasons why the atmosphere-mixed layer ocean climate model is incapable of initiating a Laurentide ice sheet over North America will be investigated.
- A series of midlatitude sea-surface temperature anomaly experiments with perpetual winter atmospheric GCMs will be run to study the linearity and frequency dependence of the response, in collaboration with a consortium of university scientists.

- Further analyses will be made of simulated and observed transient and stationary waves in both the Northern and Southern Hemispheres. The integration of the R30 model, with and without gravity-wave drag, will be extended to increase the statistical significance of the results.
- The task of preparing radiative parameterizations for non-CO_2 greenhouse gases, aerosols, and clouds for GFDL's GCMs will continue.
- The land-surface parameterization in the climate model will be improved, and global data sets for soils, vegetation, and topography will be incorporated. Preliminary analyses of the effects on climate of land-surface changes will be undertaken.
- Changes in sea level associated with climate variability on a decadal scale will be investigated using the GFDL climate model.
- To delineate the eddy forcing of the monthly averaged circulation simulated in the 100-year GCM experiment, the results from the steady-state solution approach will be contrasted with those from the tendency approach. The relative importance of the eddy heat fluxes and eddy vorticity fluxes in forcing atmospheric changes in the model will be compared with the corresponding findings based on observations.
- Correlation analyses will be performed to delineate the existence of temporal relationships, if any, between cold-air outbreaks at different geographical sites. The dynamical interactions between the synoptic-scale waves and the more slowly varying background flow during cold surge episodes will be investigated.
- Upgraded physical parameterizations will be considered for inclusion into the SKYHI model, especially the improved GFDL short-wave radiative transfer algorithms, and microphysical effects into cirrus and polar stratospheric cloud systems.
- A new SKYHI model series will be started on the predictability of stratospheric sudden warmings and on the stratospheric effects of major tropospheric anomalies, such as the Southern Oscillation.

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 following: 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 91

- The GFDL Global Chemical Transport Model (GCTM) was used to evaluate the behavior of chemically reactive nitrogen (NO_y) in the troposphere due to transport from the stratosphere. A recent study considered three classes of reactive compounds: soluble nitric acid and nitrate, insoluble nitrogen oxides, and insoluble organic nitrates represented by peroxyacetyl nitrate (PAN). The inclusion of PAN chemistry increases the simulated surface levels of NO_y by factors of 1.5–4. Although these are still a small fraction of the observed levels, this study suggests an important

long-range transport role for PAN. This could presumably be quite significant for the other upper tropospheric sources of NO_y, such as lightning.

- A new research activity has been initiated to study the atmospheric components of the CO_2 budget. An initial simulation is consistent with the Climate Modeling and Diagnostics Laboratory (CMDL) result that the observed CO_2 atmospheric meridional gradient is incompatible with the assertion that a large CO_2 sink is present in the Southern Hemisphere oceans. This suggests that GCTMs can add a powerful tool to the pursuit of the CO_2 budget mystery.
- A comparison of the high-resolution (1° latitude) SKYHI model data with those obtained from the Arctic Airborne Stratospheric Expedition (AASE) revealed a remarkably high level of agreement in the mesoscale (1000 km) tracer variance, both in terms of mean amplitude and rate of decrease of variance with increasing wavenumber. The observed data show that the 1° latitude model resolution does a reasonable job of reproducing the "wall" of tracer gradient at the polar vortex edge. These comparisons suggest that a new generation of model/data comparison can reveal heretofore unavailable insights about both models and observations.
- A GFDL SKYHI model experiment was completed that allowed a first-time investigation of the chemical-transport-radiative-dynamical responses of the stratosphere to the Antarctic "ozone hole." The model predicts that total column ozone reductions of 2–5% extend well into populated latitudes, whereas 0.5% reduction extends well into the Northern Hemisphere. These results show that model studies can help to identify how the impact of particular events (e.g., ozone hole or volcanos) can be diagnostically separated from the background effects of natural variability and systematic, long-term ozone decreases.

Plans FY 92

- Active chemistry simulations of reactive nitrogen will be completed and analysis will continue. The atmospheric part of the global CO_2 budget will be pursued in greater detail.
- A new series of stratospheric and tropospheric ozone chemistry/transport experiments will be initiated using both the GCTM and the SKYHI models.
- The analysis of stratospheric aircraft data and its relation to high-resolution SKYHI structure will be completed. More detailed studies on the detailed mechanisms of tracer transport will be initiated using the SKYHI model.
- The effects of aerosol and ozone perturbations on lower stratosphere temperature changes will be pursued and a variety of stratospheric climate change SKYHI experiments will be initiated.

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 91

- The potential oceanic uptake of anthropogenic CO_2 by iron fertilization of the Southern Ocean was examined with a model of perturbation CO_2. For the ideal case of total depletion of Southern Ocean nutrients, the results imply that atmospheric CO_2 would be lowered by 61–72 ppm after 100 years of ocean fertilization; however, fertilization would have to continue indefinitely.
- The biological processes in the North Atlantic were modeled using a nitrogen-based ecosystem model that links ocean physics to biology. This model was incorporated into models of the equatorial Pacific Ocean and the Indian Ocean. The model predictions were used to help plan the sampling and cruise schedules for the Joint Global Ocean Flux Study (JGOFS) campaigns into those oceans.
- Collection of radium isotope samples for the Atlantic was completed during a cruise that was the last for the South Atlantic Ventilation Experiment and the first for the World Ocean Circulation Experiment (WOCE). The radium data set collected by Princeton's Ocean Tracers Laboratory now spans 85°N to 65°S. Data interpretation continues and includes studies of oxygen and nutrient budgets, western boundary currents, deep water formation in the Arctic, thermocline ventilation, abyssal circulation, and combined tracer modeling.
- Particle interactions throughout the water column control the transport of particulate organic carbon in the ocean. Thorium isotopic data are one of the few sources of information about particle cycling rate constants. A least-squares analysis of thorium isotope data sets from Station P in the Pacific and the Nares Abyssal Plain in the Atlantic suggests that the time dependence and transport terms in the isotope conservation equations cannot be neglected when calculating particle cycling rate constants.

Plans FY 92

- The anthropogenic CO_2 budget will be re-examined in an attempt to reconcile ocean model uptake estimates of 2 Gt C yr^{-1} with recent estimates of air-sea fluxes of less than 1 Gt C yr^{-1}.
- A coupled air-sea simulation will be initiated to investigate the effect of changes in ocean circulation caused by global warming on the oceanic uptake of anthropogenic CO_2.
- The effect of iron fertilization on N_2O and O_2 fields will be examined with the nutrient-depletion model.
- A carbon-nitrogen ecosystem model will be developed to complement the existing nitrogen-based ecosystem model.
- Princeton's Ocean Tracers Laboratory will continue to participate in the WOCE Pacific sampling program, which will require about 450 days of sea time over the next 2 years. Analysis and interpretation of these samples will continue over at least the next 5 years. Planning is now under way to continue this program in the Indian Ocean.
- A simplified three-dimensional world ocean model of carbon cycling is being developed; it will parallel an existing model of the phosphate/oxygen cycle.

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 only the sea-surface temperature and heat content of the upper ocean. More complex three-dimensional models are being developed to study many phenomena: the

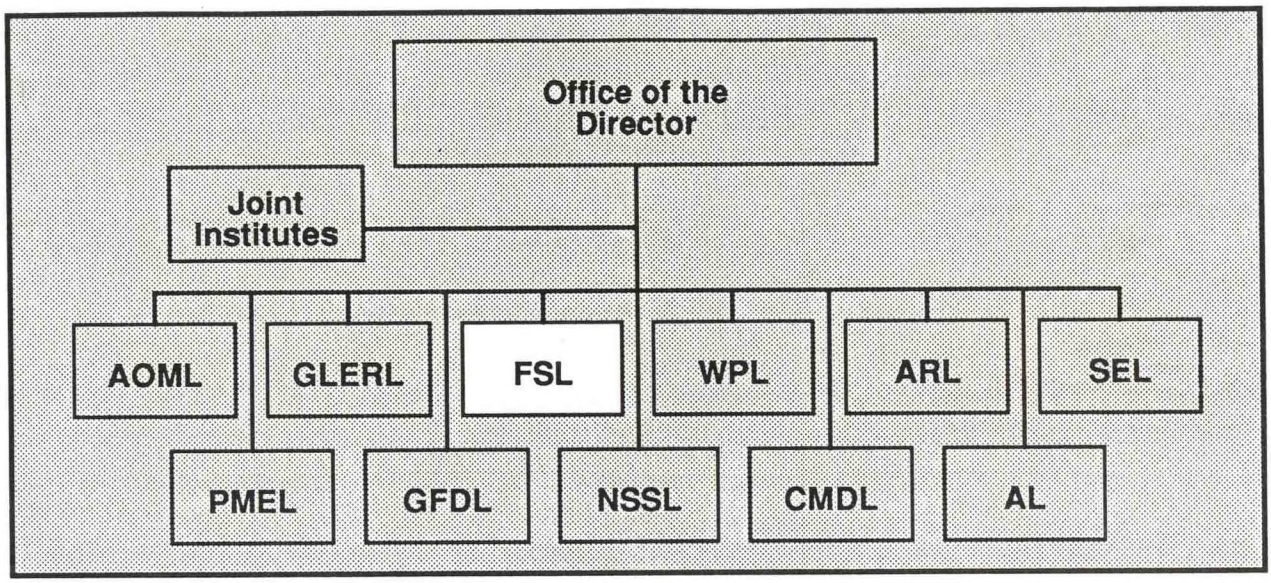
time-dependent development of Gulf Stream meanders and rings; the generation of the Somali Current after onset of the southwest monsoons; the response of coastal zones to atmospheric storms; and the development of sea-surface temperature anomalies, such as those observed in the tropical Pacific Ocean during ENSO phenomena.

Accomplishments FY 91

- A 200-year integration of a fully coupled ocean-atmosphere model was used to study the temporal variability of the thermohaline circulation in the North Atlantic. Substantial variability was found on decadal and longer time scales. Fluctuations in the intensity of the thermohaline circulation are related to large-scale changes in the density, salinity, and temperature fields.
- Calculations show that the seasonal response of the Equatorial Pacific is an equilibrium response to winds, and wave-like disturbances play only a minor role.
- Retrospective simulations for the tropical Atlantic indicate a response very different from that of the tropical Pacific. The main events have a much lower frequency, and the response is much less symmetric with respect to the equator.
- Model simulations of the depth penetration of CFCs compare favorably to Pacific Marine Environmental Laboratory (PMEL) measurements in the southern ocean. These comparisons provide a valuable test of the GFDL ocean-atmosphere model for the study of enhanced greenhouse warming.
- The predicted electromagnetic fields produced by the global ocean circulation were calculated from model output. The results provide valuable insights on possible ways to use electromagnetic measurements to monitor global change in the oceans.
- Based on model simulations, it is becoming clear that assimilation of satellite-derived altimetry and sea-surface temperature data can provide useful nowcasts and forecasts of the coastal ocean and Gulf Stream.

Plans FY 92

- Further studies of the seasonal response of the Equatorial Pacific will be made to evaluate the coupled atmosphere-ocean model performance.
- Retrospective calculations will be carried out for the Atlantic, over a greater span of latitude and for a longer period of time, to explore decadal climate variability and the effects of higher resolution.
- Work with PMEL will continue on the modeling and analysis of CFC penetration into the world ocean.
- The feasibility of different ocean monitoring techniques will be explored in collaboration with PMEL.



FORECAST SYSTEMS LABORATORY

Boulder, Colorado
(303) 497-6378
Alexander E. MacDonald, Director

The Forecast Systems Laboratory (FSL) is organized to transfer scientific and 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.

SCIENCE DIVISION

The Science Division surveys new developments in mesoscale meteorology and helps to broaden understanding of hazardous mesoscale weather events. Its principal goal, however, is to transfer research results into practical forecast techniques. These techniques range from decision trees and knowledge-based systems to data assimilation and short-range numerical predictions. All of them rely on rich and diverse sources of mesoscale data collected and processed by FSL. Gridded analyses and predictions help forecasters diagnose current atmospheric conditions and anticipate short-term changes on spatial scales ranging from

tens of kilometers to several hundred kilometers and time intervals of minutes to a few hours. They are the raw materials for the many products, developed by the division's meteorologists, that appear regularly on interactive workstations.

Accomplishments FY 91

Artificial Intelligence

The Artificial Intelligence (AI) Project develops, investigates, and tests AI applications in the environmental sciences. AI is a branch of computer science that focuses on using heuristic knowledge to solve problems. AI technology is complementary to gridded numerical models. For example, numerical models generate forecasts by solving equations at an array of grid points, whereas AI systems manipulate concepts such as "updraft," "cold front," and "supercell" to generate forecasts. Thus, much like humans, AI systems are designed to "think" about concepts.

- Shootout-91, a comparison of systems that forecast severe weather, was conducted. The experiment, built on a similar exercise held in 1989, was a joint venture of FSL, the National Severe Storms Laboratory (NSSL), the National Environmental Satellite, Data, and Information Services (NESDIS), and the National Weather Service (NWS). Canada's Atmospheric Environment Service and the U.S. Army Atmospheric Science Laboratory also participated. Three artificial intelligence systems, one system based on a numerical data assimilation model, and several teams of human forecasters made daily forecasts of severe and significant weather for Oklahoma and northeastern Colorado. Data from the experiment are unusually rich in severe and significant weather: in the total sample of 157 days for the Colorado and Oklahoma data sets, 60 days had severe weather and 46 had significant weather.
- An analysis of the Weather Information and Skill Experiment (WISE–I) was completed and preparations were made for WISE–II, which was held in October 1991. These experiments study the cognitive aspects of short-term weather forecasting. WISE–I tested the skill of weather forecasters under a variety of data loads, from very limited information (sketches of radar reflectivity) to full information (a computer workstation with full animation). Results indicate the following: (1) skill differences between individuals were substantial at each information level, (2) all forecasters showed the most skill when provided with full information, and (3) skill differences between individuals were larger than the skill differences due to increased information. Thus, a skilled forecaster working from limited information can do better than a less skilled forecaster working from full information. These results suggest that appropriate forecaster training is necessary if the full capability of new meteorological data sources is to be realized. WISE–II investigated the effects of training and information presentation on forecast skill. WISE is a cooperative effort with the State University of New York at Albany, the U.S. Air Force Phillips Laboratory, and the University Corporation for Atmospheric Research's (UCAR) Cooperative Program for Operational Meteorology, Education, and Training (COMET).
- The Metalog program, a system to maintain and manage scientists' comments about data, was applied to the Comprehensive Ocean-Atmosphere Data Set (COADS). Descriptive data, called metadata, were gathered from published sources, World Meteorological Organization (WMO) data tapes, and interviews with experts. The current version contains more than 270 items of cross-referenced information about COADS. To support the maintenance of these comments, Metalog was ported to the Macintosh operating system, and its user interface was entirely redesigned.

Forecast Research Group

The Forecast Research Group (FRG) is participating in the modernization of the Nation's weather services in four areas: quantitative data integration, modeling, visualization, and technology transfer.

The Local-scale Analysis and Prediction System (LAPS) is the object of research and development to assimilate all emerging observations technologies (e.g., profilers, Doppler radars, aircraft observations, and automated surface observations) in a high-resolution gridded framework. The eventual goal is to use LAPS analyses to initialize primitive equation models, and two independently developed models are being tailored to the LAPS grid. Within this high-resolution, three-dimensional grid, atmospheric processes are simulated in great detail, not all of which are physically realistic. Thus, development of techniques for applying the advanced graphics capabilities of mini-supercomputers to this problem is under way, in cooperation with the Systems Development Division (SDD). To ensure that these developments are optimally addressing weather forecasting problems, FRG meteorologists participate regularly in forecast shifts at the NWS Forecast Office (NWSFO) in Denver, CO.

- The LAPS suite of gridded analyses implemented on FSL's Denver Advanced Weather Interactive Processing System for the 1990s (AWIPS) Risk Reduction and Requirements Evaluation (DARE–II) workstation was improved, and some components were made available to the NWSFO in Denver. Feedback from Denver forecasters has been very positive.
- LAPS and the participation of FRG meteorologists were again important elements during the second year of the Winter Icing and Storms Project (WISP), conducted from January through March 1991. LAPS was used to produce gridded estimates of supercooled cloud water, an essential ingredient of aircraft icing.
- One of the products developed as a result of WISP was a program for using output from the Nested Grid Model (NGM), the model used for NWS forecast operations, to detect and forecast conditions conducive to aircraft icing. This technique was successfully ported to the National Aviation Weather Advisory Unit (NAWAU) in Kansas City, MO, which has sole responsibility for issuing civilian aircraft icing forecasts for the continental United States.
- FRG conducted a convection forecasting experiment called Zcast–91 to quantify the improvement in forecasts of radar reflectivity as a result of using LAPS for forecast guidance. New techniques for entering, manipulating, and verifying gridded probabilistic forecasts were tested, and preliminary results were weak but positive.
- Output from two numerical models, the Colorado State University Regional Atmospheric Modeling System (CSU–RAMS) and the Nickerson model, was used to develop and test three-dimensional visualization on recently acquired Stardent computers.

Mesoscale Analysis and Prediction System

The Mesoscale Analysis and Prediction System (MAPS) was developed to provide frequent detailed analyses of diverse surface and upper-air meteorological data over the contiguous United States and very short-term numerical forecasts (out to 12 h) in support of aviation and local nowcasting. Since August 1988, MAPS has been producing, in real time, surface analyses every hour and tropospheric and lower-stratospheric analyses every 3 h, connected in time by a numerical prediction. The unique aspects of this system are the high data assimilation frequency, heavy reliance on asynoptic data, and the choice of vertical coordinate—a combination of terrain-following coordinates close to the ground and isentropic (constant potential temperature) coordinates in the free atmosphere. Isentropic coordinates resolve features in the vicinity of fronts and

jet streams better than the more commonly used pressure coordinates. The matured system is ready for intensive, real-time testing at the National Meteorological Center (NMC).

- Several improvements were made in MAPS during the past year. Vertical transfers of heat, moisture, and momentum were parameterized in the model atmosphere. The horizontal resolution was increased from 80 km to 60 km and the number of vertical levels from 18 to 25. A new definition of the terrain-following coordinates has permitted a more detailed specification of the topography and should lead to a more accurate determination of wind close to the ground. Newly derived statistics (spatial correlations of 3-h forecast errors) have replaced the old statistics in the optimum interpolation module, which analyzes the incoming observations. These statistics are also being modeled in a new way. The old correlation model was based on the geostrophic approximation; the new one is more general and allows for divergent wind flows.
- New observational data were added to MAPS. The number of fully automated aircraft reports increased by 10% during the year. Reports from United Parcel Service (UPS) were recently added to the collection. The 20 UPS aircraft, flying mostly at night, add substantially to the relatively small number of reports normally available.
- The Wind Profiler Demonstration Network (WPDN) in the central United States was under construction all year. About half of the expected 30 stations are now supplying hourly wind profiles to MAPS. A wind profiler impact study has already showed a small but consistently positive effect of the new data on 3-h forecasts of wind, height, and temperature produced by MAPS. The study compared two versions of MAPS running in parallel, one with access to all incoming observations and the other without access to profiler data only.
- NMC has consented to run MAPS on its Cray Y–MP computer. The transfer of the new 60-km, 25-layer version of MAPS from FSL's VAX computer to NMC's Cray is under way. This work stems from a long-standing agreement between NMC and FSL to use MAPS as the basis for NMC's new Rapid Update Analysis and Prediction Cycle; it is also a major component of FSL's Aviation Project.

Weather Analysis and Prediction Program

The Weather Analysis and Prediction Program (WAPP) performs diagnostic studies of weather-related phenomena, including winter snowstorms, downslope windstorms, and mesoscale convective systems. These studies often result in products of value to forecasters, and WAPP assists in their transfer (and followup) to NWS. WAPP also assembles research-quality data sets to support its activities and makes these data sets available to NOAA laboratories and to research groups of the NWS.

- A climatological study that distilled observations made in 60 major Front Range snowstorms confirmed the ubiquity of two dynamic phenomena: middle- and upper-level jet streaks, and conditional symmetric instability (CSI) in midtroposphere. A snow-event climatology for the Front Range revealed two unexpected features: predominant northerly winds at Colorado Springs instead of southeasterlies, and many heavy snow events at Denver that occur in storms with shallow upslope.
- A PC-based, quasi-geostrophic diagnostic software package was modified to make it possible to analyze the thermally direct and indirect ageostrophic vertical motions associated with jet streak maxima. These circulations can cause the tropopause to fold downward, develop an upper front, and inject potential vorticity into midtroposphere where it becomes available for the development of extratropical cyclones. This diagnostic tool, when adapted for use on NWSFO workstations, will aid forecasters' understanding of the dynamic potential of midlatitude storm systems.

- A comprehensive statistical examination of all mesoscale convective complexes (MCCs) during a 10-year period (1978–1987) revealed significant differences between spring and summer MCCs. Specifically, spring MCCs were larger, produced more precipitation, and were less clearly modulated by the diurnal heating cycle. The characteristics of heavy rainfall in MCCs and in other rain-producing systems were described by WAPP staff in the flash-flood course taught at the NWS Training Center in Kansas City.
- Analyses of radiosonde data demonstrated that the geostrophic Richardson number computed on isentropic surfaces could be used to indicate regions of clear air turbulence (CAT).
- Collaboration continued with the Institute of Atmospheric Physics, Oberpfaffenhofen, Germany, on a study of turbulent transport and trace gas interactions of ozone in a boundary layer over very complex terrain (i.e., over Switzerland).
- An expert system to provide forecast guidance for the prediction of severe downslope winds was completed and installed at the Denver NWSFO. The system was used operationally at Denver during the 1990–1991 windstorm season.

Plans FY 92

Artificial Intelligence

- Analyze data from Shootout–91, distribute that data to interested parties, and publish results.
- Complete the Boulder phase of the WISE–II experiment and generate new materials for use in future phases of WISE–II to be held at Hanscom Air Force Base, MA, and other locations.
- Provide the Metalog system to climate researchers at the Climate Monitoring and Diagnostics Laboratory (CMDL), the National Climatic Data Center (NCDC), and other organizations. Monitor their use of the system to evaluate and improve Metalog and the metadata it contains. Port Metalog from the Macintosh to DOS-based and UNIX-based computers to expand usage. Apply the Metalog system to additional data bases.

Forecast Research Group

FRG is conducting a top-down redesign of the LAPS system to improve efficiency, add capabilities, and, above all, make the system portable to other forecasting installations. Toward that end, FRG will be a main participant in the Stormscale Operational and Research Meteorology Fronts Experiments Systems Test (STORM–FEST), a multiagency field project to be conducted during February and March 1991 in the vicinity of Kansas and

Oklahoma. A concurrent version of LAPS, separate from the Denver-area version, will provide services to the STORM–FEST area during the test. STORM–FEST has requested that FSL forecasters provide aircraft mission support forecasting.

Zcast–92 will run during the summer of 1992 to measure progress in the performance of LAPS convection-potential diagnostics against the baseline performance established during Zcast–91.

We will initialize at least one of the numerical models with LAPS analyses, and provide output diagnostics for critical examination during the FSL daily weather briefings.

Mesoscale Analysis and Prediction

The 60-km, 25-layer version of MAPS will begin running regularly on NMC's Cray Y–MP computer in January 1992. The output will be sent to the National Severe Storms Forecast Center and NAWAU in Kansas City; to NSSL and the NWSFO in Norman, OK; and to FSL and the NWSFO in Denver. In addition, the output will be made available to the Federal Aviation Administration (FAA) on disk at NMC.

In cooperation with the Meteorological Operations Division at NMC, FSL will evaluate the performance of the Rapid Update Analysis and Prediction Cycle and begin a quality-assurance program. Concurrently, FSL will work on several improvements to MAPS:

- Perform further tests with a 1-h assimilation cycle. Preliminary tests during FY 91 indicated that a 1-h cycle is feasible; the buildup of computational noise at this assimilation frequency does not seem to be a problem.
- Improve the computational efficiency of the entire system by taking advantage of vector processors. Vector processors can perform many similar calculations simultaneously. Most of the forecast model code is already vectorized, and the analysis code will be vectorized in a few months.
- Thoroughly test new code for a solar cycle, surface energy balance, and interactive clouds diagnosed from relative humidity.

Weather Analysis and Prediction Program

- As part of the proposed FAA Eta-model project, members of WAPP will assess the feasibility of forecasting the aviation impact variables (AIVs) (winds, temperature, visibility, ceilings, low-level wind shear, turbulence, etc.) using output from the Eta model run at 15-km horizontal resolution. CAT-related algorithms will be validated with diagnostic case studies and possibly profiler data. Forecast fields from the European Centre for Medium-Range Weather Forecasting model will be used to further investigate application of the geostrophic Richardson number to predict CAT over the Atlantic Ocean.
- WAPP will investigate new forecasting techniques for Front Range winds and snowfall by applying the results of the winter storms studies. WAPP will develop a flow chart to discriminate between heavy- and light-snow, shallow upslope snowstorms, and will statistically evaluate radiosonde observations of 60 heavy-snowfall storms to assess the utility of monitoring CSI-related environmental parameters (for instance, equivalent potential vorticity).
- Enhancements to the hourly precipitation data base will be introduced, including translation into Universal Time, visual display options, and revised and updated station histories.
- In collaboration with NCDC, WAPP will transfer its radiosonde archive to optical disk and make it widely available to the research community. Investigation of inaccuracies in existing radiosonde observations will continue, as will attempts to improve future upper-air observations.
- The Denver NWSFO expert system for predicting windstorms will be evaluated and revised.

FACILITY DIVISION

The Facility Division (FD) computer facility acquires, processes, stores, and makes available to FSL a wide variety of meteorological data for research and systems development. The computer facility provides

capabilities for testing and evaluating advanced weather observations and information delivery systems. FD staff maintains, modifies, and upgrades all FSL computers and networks.

Accomplishments FY 91

Computer Facility

- The central computing facility was upgraded with a DEC VAX 6000 Model 520 dual-processor vector machine that allowed significantly faster processing of MAPS and LAPS models. A 10-gigabyte mass storage array was installed to accommodate the increasing volume of meteorological data and products in FSL.
- To provide reliable, high-speed communications through NSFNET/Internet, two computer network gateways were installed for redundancy and the fsl.noaa.gov subdomain was established for FSL. Two terminal servers and two DECnet routers were replaced with more reliable, high-capacity systems.
- Four 8-mm, 5-gigabyte cartridge tape drive mass-storage systems were installed to facilitate access to archived Doppler radar data and increase the overall efficiency of FSL data storage.

Data Ingest

- The development of the new Mesonet data acquisition system was completed.
- An ocean buoy data decoder and storage system was completed and placed in operation.
- A highly efficient decoder for handling Edition–0 and Edition–1 Gridded Binary (GRIB) data was developed to facilitate the exchange of gridded analyses and model outputs with outside organizations in the WMO standard format.
- The Aeronautical Radio Incorporated (ARINC) Communications Addressing and Reporting System (ACARS) data-acquisition system was expanded to handle UPS and United Airlines automated pilot reports.

Research Support

- Real-time and retrospective meteorological data and products (including FSL Mesonet, Doppler radar, upper-air soundings, surface aviation observations, profiler, and satellite imagery) were provided to researchers at the National Center for Atmospheric Research (NCAR), CSU, and several ERL laboratories through dedicated or dial-up communications links.
- The AI Shootout experiment was supported with a wide variety of real-time meteorological data required to initialize the AI systems.
- The WISP and Cooperative Oklahoma Profiler Studies (COPS) experiments with data from the Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS) and Advanced Very High Resolution Radiometer (AVHRR) were also supported.

Project Support

- A central computing facility system was created for the Taiwan Central Weather Bureau (CWB). FD staff successfully demonstrated all functions of this system in Taipei.
- A high-speed Weather Surveillance Radar (WSR–88D) interface was developed and tested for use by the FSL-developed preprototype AWIPS Norman workstation.
- The preprototype AWIPS system was deployed at the NWSFO in Norman. We continued to provide the Denver NWSFO preprototype AWIPS system with real-time meteorological data and products.

Plans FY 92

The central facility and associated networks will be upgraded and expanded to support the increasing number of UNIX workstations and servers in FSL. Work will be initiated to place static tables associated with product generation (Product Table and Station Table) in a commercial data-base management system for increased efficiency and better maintainability. Efforts will continue to upgrade gridded data processing, formatting, and storage capabilities within FSL.

New data acquisition interface developments will include the Information Stream Project for AWIPS and NOAAPORT (ISPAN), national lightning data, national conventional radar data (NOWRAD), and upper-air data from Wave Propagation Laboratory (WPL) sensors.

DEMONSTRATION DIVISION

The Profiler Program Office of the Demonstration Division directs the procurement, installation, operation, maintenance, and assessment of a 31-site Wind Profiler Demonstration Network in the central United States. The goal is to demonstrate that such a network can support routine operations of the NWS and major scientific and meteorological field experiments, and can foster advances in atmospheric research and weather prediction.

Accomplishments FY 91

- Twenty-six of 31 profilers planned for the network were installed.
- Real-time hourly data from 22 profilers were sent to NWS for distribution to forecasters.
- Real-time hourly data from 22 profilers were sent to Unidata for distribution to university and other research users.
- Six-min and hourly data on tape were sent from 26 profilers to NCDC for retrieval and permanent archiving.
- The Radio Acoustic Sounding System (RASS) developed by Unisys was tested on the prototype profiler at the Unisys test site in Bloomfield, CT.
- A retrospective data management capability was designed jointly with NCDC.

Plans FY 92

- Complete the network installation before January 1992.
- Start the network assessment using data from the completed network.
- Install and test an experimental RASS temperature capability at some network sites.
- Send data electronically to NCDC.
- Support the STORM–FEST program with real-time network data.
- Initiate a program to enhance profiler availability by increasing lightning protection, redesigning the beam steering unit, and installing limiters to protect the receiver against excessive reflected power from the profiler transmitter.

SYSTEM DEVELOPMENT DIVISION

The System Development Division (SDD) is responsible for the design, development, and integration of new meteorological workstation systems. Historically, SDD has developed the workstation system executive functions, such as the menu interface, data management and display control. Collaboration continues with other FSL divisions on the testing and integration of meteorological applications. New display techniques and technology provide system documentation support, and the division provides technical guidance to FSL divisions and outside agencies.

Accomplishments FY 91

The functional prototype of the AWIPS–90 was installed in Norman, OK. The system receives a diverse set of advanced and conventional real-time data from both local and national sources and prepares it for display and manipulation at the workstation. The interface to the national data feed, known as ISPAN, was developed. ISPAN is being evaluated operationally at the Denver and Norman NWSFOs.

The PC workstation capabilities were extended to serve COMET in training NWS scientific operations officers. The system uses both real-time data and selected recorded data for training. The PC workstation is an integral part of a project with the Taiwan CWB. SDD is involved in the development of a Taiwan central facility, similar to the one at FSL, which acquires and processes a diverse set of meteorological data for use by operational forecasters. Two workstations were installed at CWB, and scientists there are acquiring and processing some real-time data. CWB technical employees were trained in the maintenance of the software.

Software modules were developed to display and manipulate model outputs from LAPS on a Stardent workstation. Several meteorological parameters can be displayed in three dimensions and overlayed on the local terrain. Among other functions, modules allow animation, cross section, transparency, and three-dimensional contouring.

SDD continues to provide technical support to the U.S. Air Force Mark IV–B program. This support includes evaluation of some of the Mark IV–B workstation functions, preparation of a user manual, technical guidance, and investigation of new meteorological products.

Plans FY 92

SDD will support the AWIPS–90 risk reduction activities at Norman and Denver. The workstation systems at these sites will be upgraded to receive additional functionality, and new data sources will be added as they become available. The ISPAN data feed will be evaluated for operational reliability and performance.

The PC workstation will be enhanced to include the hydrological data sources and applications. Additional display features will be added in support of COMET and the Taiwan CWB project. SDD will continue to provide technical assistance to CWB in the development of their central facility.

The PC workstation software and capabilities will be ported to a Reduced Instruction Set Computer (RISC) workstation, using the X–Window display software. This provides an opportunity for more users at universities and research laboratories to run the FSL workstation software and gain access to advanced meteorological data sets. Collaboration will continue between SDD and UCAR/Unidata to provide a high-resolution, real-time data feed of advanced and conventional data for researchers.

Additional data sources, specifically high-resolution radar data, will be displayed in three dimensions, and tools will be developed to assist forecasters in analyzing the data.

SDD will continue to provide technical guidance and assistance to internal and external projects with their meteorological systems developments.

AVIATION DIVISION

The Aviation Division, added in the past year, is the newest division in FSL. It works with FAA and NWS on two major activities: developing the Aviation Gridded Forecast System (AGFS) and developing aviation weather products for FAA's Advanced Traffic Management System (ATMS).

Accomplishments FY 91

Aviation Gridded Forecast System

AGFS is an interactive information-processing system that will generate high-resolution analyses and gridded forecasts of state-of-the-atmosphere variables (SAVs) and AIVs. SAVs specify the atmosphere's mass, momentum, and moisture. AIVs are variables such as turbulence and visibility. The variables that the AGFS generates will constitute the meteorological information required to support automation of the Air Traffic Control System at FAA and will enable the FAA to tailor decision-making products to users.

- An Interagency Agreement between NOAA and the FAA was signed that calls for FSL to develop methods of generating very high-resolution meteorological analyses and gridded forecasts for future use by NWS.
- A plan for developing the AGFS was prepared.
- We began development on the 15-km horizontal resolution analyses (for the national domain) and gridded forecasts using MAPS, the Eta model, and a mathematically "well-posed" model being developed by FSL. The well-posed model recognizes all terms in the system that correctly describe the motions of the atmosphere. This has the advantage of retaining all of the desirable mathematical properties of the original system.
- We began experiments with 2-km analyses, 10-km analyses, and gridded forecasts using FSL's LAPS, the CSU–RAMS, and the well-posed model for local area forecasting.

- We began to explore the utility of moderate- or massive-parallel processing to generate the analyses and gridded forecasts that the AGFS requires.
- We prepared requirements for the design of a functional prototype of the AGFS for testing in NWS operational facilities.
- We prepared a plan and gathered test data for conducting a forecast verification exercise to provide feedback to model developers about the ability of models to generate the analyses and gridded forecasts that the AGFS requires.

Advanced Traffic Management System

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

- A prototype ATMS aircraft situation display (ASD) was installed at FSL, providing ATMS researchers with real-time flight data of all aircraft within the NAS.
- A product generation and distribution system was implemented on FSL's VAX cluster to disseminate real-time weather information to the John Volpe National Transportation Systems Center (TSC), Department of Transportation, in Cambridge, MA.
- A satellite ground station and two-way communications link between FSL and TSC was installed to facilitate the exchange of data between the two facilities.

Enroute ATMS Development

- Real-time National Radar Summaries and Radar Legends products were integrated into the ATMS environment. These NWS Radar products were recomposed by FSL into a format that can be used by traffic managers and are being tested operationally on ASDs at the Central Flow Control Facility (CFCF) in Washington, D.C.
- Winds Aloft and Jet Stream products derived from MAPS were developed to enhance planning and management of enroute aircraft. The Winds Aloft product will be used in TSC's aircraft metering and spacing models; the Jet Stream product has gone through several iterations and is being tested operationally at CFCF.
- Acquisition of a high-resolution national radar reflectivity data base was completed. These high spatial and temporal resolution radar data are being used to develop new ATMS products.

Terminal Area Development

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

- A Profile Descent Cross-Sections product was developed and is being reviewed by researchers at TSC for future iteration. This product shows the vertical structure of weather phenomena along the approach path within the Stapleton Terminal Area.
- Three-dimensional terminal area weather products are being developed by FSL. These products will help FSL and TSC researchers assess the utility of using three-dimensional visualizations for operational traffic management.

Plans FY 92

- Construct a functional prototype of the AGFS and implement that prototype in NWS operational facilities to validate experimental meteorological products and test AGFS concepts.
- Continue to develop (for the national domain) 15-km horizontal resolution analyses and gridded forecasts using MAPS, the Eta model, and the mathematically well-posed model being developed by FSL.
- Continue experiments with 2-km analyses, 10-km analyses, and gridded forecasts using FSL's LAPS, the CSU–RAMS, and the well-posed model for local area forecasting.
- Acquire a moderate- or massive-parallel processor, and implement code on that processor to assess the processor's ability to generate the analyses and gridded forecasts that the AGFS requires.
- Conduct a forecast verification exercise and provide results to model developers to investigate improvements of models so that they can more efficiently generate the analyses and gridded forecasts that the AGFS requires.
- Integrate the NWS Radar Summaries, Radar Legends, and Jet Stream products into the operational traffic management system for validation.
- Upgrade FSL's data distribution system to TSC to provide higher reliability of experimental weather information to field sites for testing.
- Integrate an ATMS National Radar product derived from national conventional radar (NOWRAD) data into the ASD for testing.
- Develop a Convective Airspace Volumes product for integration into ATMS application programs.
- Integrate an Icing product developed for the WISP experiment into the ASD for testing.

MODERNIZATION DIVISION

The Modernization Division produces functional designs or working prototypes of techniques, workstations, and systems that may be implemented into NWS (or other agency) operations up to a decade later. The process includes selecting, tailoring, and implementing advanced techniques and devices produced by the research and development community, industry, or elsewhere. Developments are state of the art and continually evolving as knowledge expands.

The division includes three branches: Risk Reduction (Denver/Norman support and evaluation), Enhanced Forecaster Tools (AWIPS deferred capabilities), and Advanced Development Facility (AWIPS system evaluation and enhancement).

Accomplishments FY 91

Risk Reduction Branch

DARE–II continues to support all forecast and warning functions at the Denver NWSFO. The system was upgraded to provide a third workstation with animation and fast image loading capability. This was done in part to support an experimental aviation terminal forecast project conducted at the Denver NWSFO. This project is being evaluated. DARE–II evaluation reports were also prepared to assess training, product usage, and workstation usage.

The pre-AWIPS system was installed in Norman in January 1991. The staff at Norman was trained on the workstations and began using them in March to perform their forecast duties. During FY 91 data were received via high-speed links that were developed with the NWS Telecommunications Gateway (NWSTG) and NESDIS. An interface to the WSR–88D Doppler radar was also developed and tested. This interface emulates most functions of the WSR–88D principal user processor while integrating radar data and functions into the workstation.

Enhanced Forecaster Tools Branch

A development plan was written for the Gridded Representation of Analyses and Forecasts (GRAF) system. GRAF will be a graphical forecasting system for NWS that forecasters will use to visualize the weather over their area of responsibility.

Advanced Development Facility

A specification for a high performance, UNIX-based development computer system was prepared and submitted. Several vendor proposals have been evaluated. It is anticipated that this development system will be delivered early in 1992.

During FY 91, the Modernization Division also provided support to the NWS AWIPS Program Office by participating in the evaluation of AWIPS Development Phase proposals.

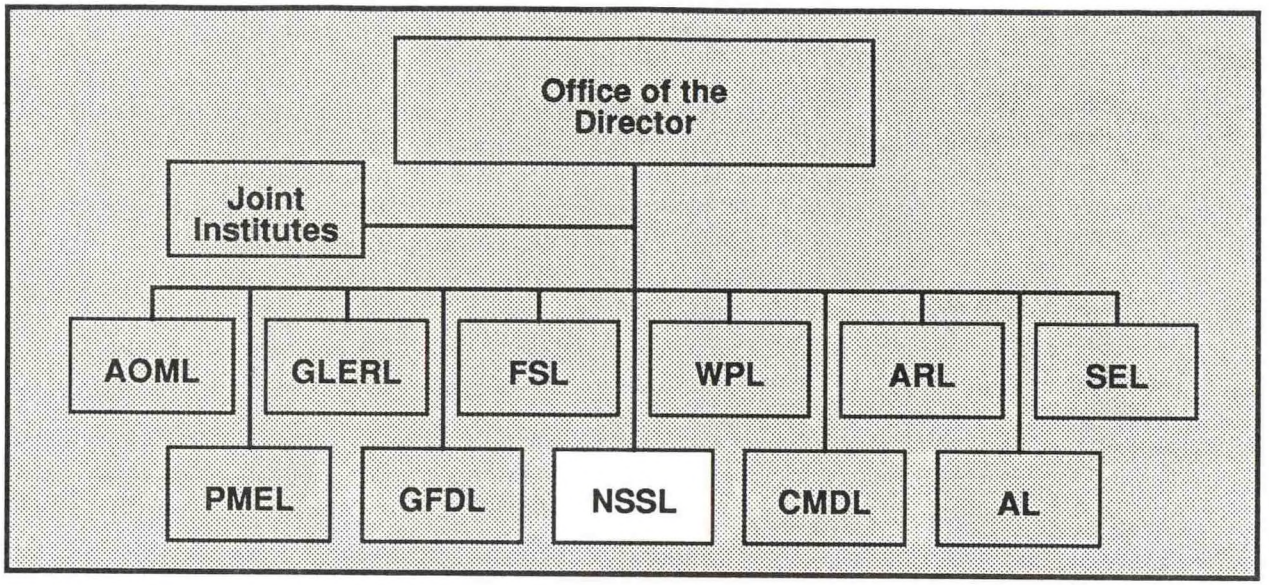
Plans FY 92

An interface linking an Automated Surface Observing System (ASOS) to pre-AWIPS will be developed. It will save data from a significant weather case for later review. Text workstation functions will be re-implemented using industry standard X Windows software. The WSR–88D interface at Norman will be enhanced to receive data from multiple radars simultaneously, and mosaicked products will be generated from these data. A link to the Tulsa Regional Forecast Center will also be developed for Norman. The national data stream feeding the DARE–II system in Denver will move from FSL to NWSTG and NESDIS as the primary sources.

During FY 92, the Modernization Division staff will be trained on the use of the new development system. This comprises 8 weeks of in-house training on the UNIX operating system and the C programming language. These are industry standards, and will bring the staff up to date.

Evaluation of AWIPS proposals will continue for much of the year; the AWIPS contract is to be awarded in late FY 92.

GRAF is to be deployed at the NWSFOs in the mid-1990s as part of the AWIPS. The AWIPS deferred capability will be developed jointly by FSL and the NWS Techniques Development Laboratory. The plan outlines several development stages, including investigation of visualization and data editing techniques, building a system within AWIPS, and testing of prototypes at NWSFOs. During GRAF's investigative stage, many new techniques will be developed, examined, and tested. Forecasters will be consulted during these investigations to ensure that the chosen techniques will fill NWS operational needs.



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

The National Severe Storms Laboratory (NSSL) develops scientific bases for improved weather forecasting through studies of mesoscale weather processes and numerical and conceptual modeling of storm phenomena. Technological developments, scientific advances, 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, lightning-mapping systems, wind profilers, and satellites.

MESOSCALE RESEARCH DIVISION

Accomplishments FY 91

Mesoscale Convective Systems Research

- Completed documentation of the Preliminary Regional Experiment for STORM–Central (PRE–STORM) 10–11 June 1985 squall line system. The analyses indicated that geostrophic balance in the stratiform region of the squall line developed when the convective region and the stratiform region separated late in the life of the system. In addition, the position, width, and intensity of the band of heaviest stratiform rain in the stratiform region can be explained by a maximum of ascending air at middle and upper levels just ahead of the rainband, which acted as a feeder zone for the stratiform precipitation.
- Analyzed the wake low region of the 3–4 June 1985 PRE–STORM mesoscale convective system (MCS), in which locally intense downdrafts developed along the trailing edge of an otherwise benign stratiform rain region. Perturbation pressure and buoyancy fields retrieved from dual-Doppler radar measurements indicate that these drafts contributed to the dramatic drop in surface pressure through

a combination of subsidence warming at midlevels and reduced depth of a stable cold pool adjacent to the Earth's surface.

- Completed an analysis of electric field meter data sets and Doppler radar data from the 3–4 June 1989 Cooperative Oklahoma P–3 Studies (COPS–89) mesoscale system. The electric charge structure of the bright band region, and its evolution over several hours, was described based on data obtained from several passes by the instrument through the region. The profiles reveal sharp transitions near the melting level, indicative of differing charge generation mechanisms.
- Completed an analysis of airborne Doppler radar data from a P–3 flight into an MCS during the Southwest Area Monsoon Project (SWAMP). The system, observed over southern Arizona, had strong surface winds. The strong winds were initially generated by evaporative cooling in convective storms, which produced locally intense downdrafts. Downward motion was sustained by evaporative cooling of rain falling from the stratiform anvil.
- Completed a study on the capabilities of a dynamic retrieval technique to determine optimal reference frame motion. We demonstrated the success of the technique on three Doppler radar data sets: a squall line, a tornadic storm, and a large hailstorm.
- Published a study of early electrification of a mountain thunderstorm. Research scientists from NSSL and the University of Oklahoma (OU) incorporated electrification mechanisms into dynamic cloud models and developed a simulation capability.
- Studied the 24 May 1989 dryline case during the COPS–89 experiment. Simulations were conducted with a nonhydrostatic mesoscale model, and observational and modeling results were prepared for conference presentation.

Cooperative Oklahoma Profiler Studies (COPS–91)

NSSL completed COPS–91, a field experiment held from 24 April to 10 June 1991 to assess the Wind Profiler Demonstration Network, including Radio Acoustic Sounding System (RASS) technology, in the High Plains. COPS–91 used the NOAA P–3 aircraft (110 flight hours); both NSSL mobile laboratories with Cross-chain Loran Atmospheric Sounding Systems (CLASS) and electrical field meter balloon launches; 15 National Center for Atmospheric Research (NCAR) portable automated meteorological (PAM) stations; the National Science Foundation (NSF) T–28 research aircraft (30 flight hours), capable of storm penetration; and NSSL's Norman Doppler and newly upgraded Cimarron polarization diversity radars. The Wave Propagation Laboratory (WPL) provided a 405 RASS profiler, a RASS boundary layer profiler, and a dual-channel microwave radiometer. Accomplishments included gathering data for 17 case studies, including aircraft penetrations into five storms.

Western U.S. Studies

- Obtained the Bureau of Land Management cloud-to-ground lightning archive from 1985–1990 and have begun converting this archive into a research data base. This data base will be the cornerstone of a lightning climatology of the southwest monsoon and the western United States, emphasizing the meteorological aspects of daily, seasonal, interannual, and spatial lightning variability.

Plans FY 92

Mesoscale Convective Systems Research

- Use PRE–STORM, COPS–89, and COPS–91 data to examine cooling rates of mid- and low-level air in the stratiform region as it flows across the band of heaviest rain to infer the importance of microphysics on MCS evolution.
- Document the relationships between electrical structure and the precipitation and kinematic features of four COPS–91 MCS cases.
- Investigate the dynamics of "bow echo" systems that were documented by airborne and ground-based Doppler radar during COPS–91.
- Carry out preliminary experiments as part of OU's Center for Analysis and Prediction of Storms (CAPS) program to investigate initialization of cloud models using observations.
- Investigate storm electrification and Doppler data insertion techniques with a three-dimensional dynamic cloud model enhanced to simulate charge separation mechanisms and to accept data by nudging.

Research Using Profiler and RASS

- Document the performance of the RASS on the Purcell, OK, profiler during passages of MCSs during COPS–91.
- Investigate the relationships between supercell structure, as seen by the airborne Doppler radar during COPS–91, and the local environment documented by nearby network wind profilers.

Dryline Research

- Document dryline structure and its evolution for the four COPS–91 dryline data sets collected by the P–3.
- Conduct experiments with the Colorado State University Regional Atmosphere Modeling System (CSU–RAMS) three-dimensional mesoscale model for COPS–91 cases.

Studies at the Kennedy Space Center

- Complete a multiyear central Florida lightning climatology.
- Explore the relationships of convective clouds and lightning using data collected during the Convection and Precipitation Electrification (CaPE) experiment conducted in central Florida in 1991.

GUFMEX AND DATA ASSIMILATION PROJECT

Accomplishments FY 91

GUFMEX

Ten research scientists from universities, NOAA, and cooperative institutes presented results of the 1988 Gulf of Mexico project (GUFMEX I) at the Symposium on Air/Sea Interaction and Air Mass Modification, Galveston, TX, January 1991. The results will be published in early 1992. The work covers a wide range of topics including data analysis, climatology, synoptic studies, research modeling of the boundary layer, and regional weather prediction.

We developed a proposal to the Partners' Program of COMET (Cooperative Program for Operational Meteorology, Education, and Training) to study the operational aspects of return flow forecasting in the Gulf during February and March. The proposal was approved and includes National Weather Service (NWS) Southern Region forecasters.

A case study was completed comparing moisture fields estimated from Special Sensor Microwave/Imager (SSM/I) satellite sounding images and rawinsondes collected in and near the Gulf of Mexico. Moisture fields were used to develop an integrated picture of moisture evolution and were compared to that simulated by predictive forecast and diagnostic models.

We explored the accuracy of satellite soundings' precipitable water estimates in two layers compared to rawinsonde observations.

We used microwave data from the SSM/I aboard the Defense Meteorological Satellite Program (DMSP) satellite to retrieve total precipitable water over the Gulf of Mexico during a 12-day period (24 December 1989 to 4 January 1990) following an intense cold air outbreak. The goal is to estimate the atmospheric water budget and to determine the relative importance of evaporation and advective processes leading to observed air mass modification.

In March 1991, the GUFMEX II field program took place in the Gulf of Mexico. This was a limited experiment designed to explore the feasibility of CLASS upper-air observations from an oil platform. Mobil Oil Company provided space on a platform for four NSSL scientists. More than 50 launches were made over a 2-week period, and many logistical problems associated with signal transmission and receipt were solved. Because of our success, the U.S. Department of Interior–Minerals Management Service will support CLASS soundings from two platforms in the Gulf for 1 year starting in April 1992.

Data Assimilation

Simulations of mesoscale flows such as dry lines were studied using sophisticated methods to assimilate wind and temperature data in nonhydrostatic models to determine the relative value of high temporal resolution wind data and temperature data to initializing these models. Results were presented at the Numerical Weather Prediction Conference in Denver, CO, October 1991, and have been submitted for publication. The work was accomplished in association with Pennsylvania State University.

Plans FY 92

GUFMEX

- As part of the COMET proposal, NWS forecasters will visit NSSL and NSSL scientists will visit the Southern Region for approximately 1 week each. These visits should lead to the definition of projects that combine the talents of the research and operational communities.
- NSSL scientists will collaborate with scientists in the National Environmental Satellite, Data, and Information Service (NESDIS), the Cooperative Institute for Meteorological Satellite Studies (CIMSS), and elsewhere to simulate atmospheric conditions using GUFMEX data. Moisture fields obtained from satellite will be used to develop an integrated picture of moisture evolution and will be compared to that simulated from predictive forecast and diagnostic models.

Data Assimilation

- Collaborative work between NSSL, Pennsylvania State University, and University of Wisconsin-Madison using adjoint method to estimate parameters in mixed layer modeling.
- Work with professors at OU using parallel processing machinery to make the adjoint method more efficient.
- Collaborative work with scientists at University of California-Davis to better understand cloud processes associated with Gulf of Mexico return flow phenomena. A cloud model with water and ice microphysics will be used at Davis, with data from the GUFMEX field programs as input.

FORECAST APPLICATIONS RESEARCH GROUP

Accomplishments FY 91

NEXRAD

We enhanced the experimental WSR–88D storm tracking, velocity dealiasing, hail, mesocyclone, and tornado detection algorithms. The enhanced storm tracking algorithm correctly located and tracked more than 98% of the storm cells in a data base of more than 1200 storms. A real-time Doppler radar algorithm system was developed and experimental versions of the WSR-88D algorithms were run in real time during the COPS–91 field program.

Training

Support to the WSR–88D training unit and COMET continued. Assistance was given to develop training modules on how to understand and interpret Doppler velocity aliasing and range folding of Doppler radar data. Major input to a COMET computer-based learning (CBL) module on Doppler radar interpretation was completed. Seminars and workshops on mesoscale and radar meteorology were presented at several NWS offices and at other locations. Nine hours of Doppler radar interpretation training videotapes were prepared for the Air Force.

Experimental Forecast Exercises

We conducted fall and spring experimental forecast exercises with the Norman NWS Forecast Office. These exercises tested concepts for forecasts in the future modernized NWS and documented present mesoscale forecasting skill. Forecast skill for severe thunderstorms, mesocyclones, tornadoes, flash floods, and lightning was documented and errors were investigated. Short-term (6- and 12-h) mesoscale quantitative precipitation forecasts were also made and evaluated.

Thunderstorm Initiation

A study was completed to examine the utility of WSR–88D, surface network, and rawinsonde data to determine the location and timing of the initiation of thunderstorms in the vicinity of Kennedy Space Center. We found that short-term forecasts of thunderstorm initiation can be made with high-resolution WSR–88D Doppler radar data. The Doppler radar data can be used to detect convergent boundaries and the first echoes aloft near them that are associated with incipient storms. The combination of these two signatures can give a lead time of 8–45 minutes before the first cloud-to-ground lightning strike associated with a thunderstorm.

Microburst Studies

Examination of wind and reflectivity fields from dual-Doppler radar data revealed that convergent shears of the ring gust front may be as large as the divergence maximum associated with the microburst center. In several events, when a preferred propagation direction was observed, strongest convergent shear was along those radials.

Short-term forecasting of severe downbursts using convergence in the midlevels of a storm as a precursor signature was examined for four severe downbursts in Oklahoma. A severe downburst is one that produces damaging winds at the surface. For these four downbursts, strong convergence aloft was evident 5–10 minutes before the strongest winds occurred at the surface.

Plans FY 92

- Further improve and test (both in real time and off line) WSR–88D and Terminal Doppler Weather Radar (TDWR) algorithms for detecting tornadoes, mesocyclones, hail, and gust fronts.
- Prepare additional training material for COMET and the WSR–88D training unit.
- Complete a study to determine the Doppler radar signatures of tornadoes from different regions of the United States and how the signatures differ for different types of tornadoes.
- Complete dual-Doppler analysis of near-surface kinematic fields associated with microburst ring vortex phenomena on a large data base.
- Explore the utility of lightning data for improving mesoscale forecasts and defining hazardous regions to aircraft.
- Examine the use of the profiler network to locate and determine the translation of short waves important to forecasting severe thunderstorms.
- Develop forecasting techniques using WSR–88D, surface, and lightning detection networks, and rawinsonde data to determine the location and timing of thunderstorm initiation and the first cloud-to-ground lightning strike.

DOPPLER RADAR AND REMOTE SENSING RESEARCH GROUP

Accomplishments FY 91

Storm Studies

At least three splitting thunderstorms occurred on 27 June 1989 during the North Dakota Thunderstorm Project. Analyses of airborne and ground-based dual-Doppler radar data from the first two storms revealed that a middle-altitude vorticity couplet formed on the lateral downwind flanks of each initial updraft, with cyclonic vorticity on the right and anticyclonic vorticity on the left, when looking in the downwind direction. As new updrafts formed on the lateral flanks, the right-flank updraft acquired cyclonic rotation at middle altitudes and the left-flank updraft acquired anticyclonic rotation.

Output from a three-dimensional computer model of a rotating thunderstorm was diagnosed to determine how cyclonic rotation develops very close to the ground. Our findings shed light on why not all rotating thunderstorms develop tornadoes. For a storm to become tornadic, a balance between inflow from the environment into the storm and rain-cooled outflow is necessary. The quantitative nature of this balance is being explored.

Polarization Studies

We analyzed four polarimetric measurements collected in the stratiform region of an MCS: the reflectivity factor, the differential reflectivity, the correlation coefficient between orthogonal copolar echoes, and the differential propagation constant. Most striking is a signature of large aggregates (about 10 mm) in the differential phase through the melting layer. Another significant feature is an abrupt notch in the correlation coefficient toward the bottom of the bright band. A one-dimensional model and aircraft observations were used to explain some polarimetric measurements; they also infer the presence of graupel and the growth of large aggregates in the melting layer.

Forecasting Research

An experiment was designed and conducted during the spring of 1991: the Storm Type Operational Research Model Test Including Predictability Evaluation (STORMTIPE). During this experiment, in collaboration with forecasters at the Norman NWS Forecast Office, tropospheric temperature, moisture, and wind profiles were forecast. These forecasts were input to an experimental cloud model run at the National Center for Supercomputing Applications (NCSA). The experiment had two primary objectives: to see how well thermodynamic and wind profiles could be forecast (subjectively), and to see if a state-of-the-art cloud model could employ subjective forecasts to make timely, operationally useful predictions of convective evolution. Mobile sounding observations were collected as verification, and storm type data were collected as part of normal NWS forecast and warning operations.

We tested a new tornado forecasting parameter, storm-relative helicity. Wind profiler data are crucial because only they can provide hourly hodographs from which helicity is computed. Preliminary evaluations reveal at least one example where the experimental forecast was very useful, the Woodward, OK, area tornado of 26 May 1991.

COPS–91

Some data from the boundary layer RASS and profiler were collected to determine if temperature fluxes and momentum fluxes can be measured.

Plans FY 92

- Investigate the storm-environment interactions (pressure and buoyancy fields) that led to the splitting storms of 27 June 1989.
- Complete a theoretical and numerical study of the pressure field around a rotating thunderstorm updraft in strong environmental winds that veer with height.
- Begin analysis of STORMTIPE data in collaboration with NWS forecasters and NCSA scientists. Detailed quantitative verification of the thermodynamic and wind profile forecasts will be done, and attempts to validate the model as well as subjective forecasts with observations will be made to separate model capabilities from those of the forecasters.
- Analyze profiler and RASS data in the planetary boundary layer.
- Begin comparative studies of polarization and aircraft data collected during COPS–91 experiments.
- Participate in the STORM Fronts Experiment Systems Test (STORM–FEST) program.

STORM ELECTRICITY AND CLOUD PHYSICS GROUP

Accomplishments FY 91

The following results have direct relevance to operational use of new observing systems in the modernized NWS.

- In collaboration with meteorologists at the Norman NWS Forecast Office, we investigated the limitations inherent in using current guidance products and routine observations in forecasting significant weather. This included experimental mesoscale forecasts of severe convective weather, precipitation amounts, and lightning.
- We completed an initial study of 25 MCSs using infrared (IR) satellite images and lightning ground strikes to look for possible patterns in the ground flash data. The composite of ground strike and IR data indicated thunderstorms better than the satellite imagery alone. Negative ground flashes usually clustered near the coldest cloud tops.
- An up-to-date review of lightning in tornadic storms was completed. The following hypotheses were developed for testing: (1) strong updrafts and the suppression of ground flashes are related; (2) intracloud lightning is enhanced in classic supercells because of large, strong updrafts; and (3) positive ground flashes are an indicator of mesocyclones.
- We completed independent research paralleling other NSSL–NWS forecast applications research on using positive ground flashes to enhance identification of low precipitation severe storms. Our results indicate that these storms, which often are difficult to identify by radar alone, produce predominantly positive ground flashes.
- We found the highest percentage of positive ground flashes in MCSs always occurred in the stratiform region during the lengthy dissipating stage. Furthermore, the positive flashes that occurred in the early stage of MCSs were related to convection, not stratiform regions.

- In several MCSs, we obtained the first ever multiple, synchronized, and spatially separated profiles of electric field, precipitation charge, and size with an electro-optical instrument we developed and tested last year. These data were collected in a coordinated way with other elements of COPS–91, including P–3 flights and NSSL's new multiparameter Cimarron Doppler radar.

Plans FY 92

- Analyze data from COPS–91 to determine the electric field, charge structure, and precipitation charge in MCSs.
- Continue collaborative development of sophisticated, high speed models incorporating electrification and its effects in storms. Begin incorporating results from COPS–91 as constraints in these models.
- Participate in joint U.S.-Japan seminar on lightning as part of NSSL's commitment to develop lightning data applications.
- Participate in STORM–FEST by making observations with NSSL's polarization diversity Doppler radar at Cimarron.
- Work with the Office of the Federal Coordinator for Meteorology, the Federal Aviation Administration (FAA), and other components in NOAA to develop operational uses for cloud electrification and lightning data.
- Begin testing hypotheses developed this year using COPS–91 data. From those tests of hypotheses will come additional information to include in our models and forecast applications research.

REGIONAL WEATHER PROCESSES (RWP)

Accomplishments FY 91

Following the successful completion of the first field phase of the SWAMP, a meteorologist position was established at the NWS Forecast Office in Phoenix, AZ, to emphasize collaborative research and transfer of results into operational weather forecasts.

The RWP group coordinated and supported a SWAMP forecasting symposium during June in Phoenix. This meeting was attended by more than 50 NWS Western Region forecasters and university scientists. The group also helped organize and participated in a week-long synoptic workshop in Obregon, Mexico.

Studies and analyses under way using SWAMP data sets include the following:

- Satellite regional rain estimations for extended periods.
- Four-dimensional structure of the Phoenix heat island.
- Severe thunderstorm environments in the Southwest.
- Long-term monsoon climatology and associated large-scale forcing.
- Documentation of the broad character of the "Mexican Monsoon."
- Definition and documentation of the horizontal and vertical scales of moisture surges, episodic low-level jets over the Gulf of California and the lower Colorado River Basin.

Other projects relate to regional climate and radiative forcing, moisture variability, mesoscale processes, and regional convective environments. Several draw heavily on numerical modeling, satellite-sensed data, and data sets from the GUFMEX project. Specific results include the following:

- Studied the possible effects of a sublimation-initiated mesoscale downdraft on the wind field evolution below a precipitating anvil.
- Compared low-level wind profiles from CLASS, Doppler radar velocity azimuth display (VAD), and NWS rawinsondes during several low-level jet events. We found that the NWS data processing and archival techniques degrade the data substantially, raising questions as to the appropriateness of these highly smoothed wind profiles for input into sophisticated numerical models.
- Expanded and refined previous analyses of the effect of deep convective clouds on the radiation budget. We used more recently available Earth Radiation Budget Experiment (ERBE) data and combined these with hourly statistics from geostationary satellite data. Diurnal variation of deep convective clouds (52° C cloud-top temperature) deduced from ERBE data (after normalization for uneven data sampling) taken in July 1985 and 1986 is similar to that obtained from Geostationary Operational Environment Satellite (GOES) data. We assessed the sensitivity of the regional energy budget to differences in monthly mean albedo and diurnal coverage of deep convective clouds.
- Developed a research project with Utah State University and NESDIS to help validate surface wetness detection from SSM/I, from the impact on outgoing longwave radiation measured from ERBE and GOES. We provided input to the science plan for the Global Energy and Water Cycle Experiment (GEWEX) Continental-scale International Project (GCIP).

Plans FY 92

In addition to continuing work on many of the projects described above, the RWP group plans include the following:

- Organize and conduct data gathering in Sonora, Mexico, and in Arizona in July 1992. This work will be done in close coordination with Centro de Investigacion Cientifica y de Educacion Superior de Ensenada, Instituto Tecnologico de Sonora, NWS, and the Salt River Project. The goal is to gather additional data required to answer questions raised by the SWAMP data set.
- Collaborate with NASA on an extended documentation of the convective climate and diurnal character over subtropical regions of North America from Florida to Baja.
- Study the long-term forcing conditions that lead to nighttime rainfalls in the central United States.
- Extend ERBE analyses to assess feedback of deep convective clouds on global warming.
- Develop comparative analyses of ERBE, GOES, vegetation, and surface wetness data over the central United States and Brazil for wet and dry growing seasons to complete a study for the Atmospheric and Land Surface Processes core project of the NOAA Global and Climate Change Program.
- Determine the feasibility of estimating upper tropospheric moisture response to changes in temperature and convective activity from satellite sounding data. The response of upper level moisture to global warming and associated changes in convection is now recognized as a critical factor in determining the effect of increasing CO_2 on the atmosphere.
- Compare variational and nudging assimilation techniques using the Lorenz model of Rayleigh-Benard convection.
- Investigate the importance of including mesoscale convective outflows in mesoscale model initial conditions. We will develop methods to incorporate outflows into the initial conditions based on only a few observations.

- Examine the importance of elevated residual layers to the evolution of the planetary boundary layer in regions of complex terrain.
- Complete studies of Mediterranean convective systems that have produced floods along the southeast coast of Spain.

SCIENTIFIC SUPPORT DIVISION (SSD)

Accomplishments FY 91

Computing and Data Management

Computing capabilities remain near state of the art. Through interactions with Forecast Systems Laboratory, a pre-Advanced Weather Interactive Processing System (AWIPS) station was made operational, allowing us to stop using the McIDAS system. A VAX 3100 was added to the cluster increasing the computing power. A new multiport router was installed for improved management of our local ethernet networks. An advanced Doppler display and editing system (NDREX) was used by the Forecast Applications Research (FAR) group to display Doppler products in real time during COPS–91. An ethernet network was added to support real-time algorithm evaluation for COPS–91. New 8-mm tape drives were added to systems in Boulder and Norman to increase storage capacity at a reduced cost. Additional disk storage was also added to the Boulder system to increase user capabilities for processing satellite images. GEMPAK software was added to the Norman system and various software systems were made current. A new internet link was implemented to increase access speeds between OU and NSSL by a factor of 10. SSD improved the laboratory budget tracking system, provided an improved computer system for scientific note taking on the P–3, provided a new problem tracking system, and provided engineering, technical, and computer support to scientists.

Cimarron Doppler Radar

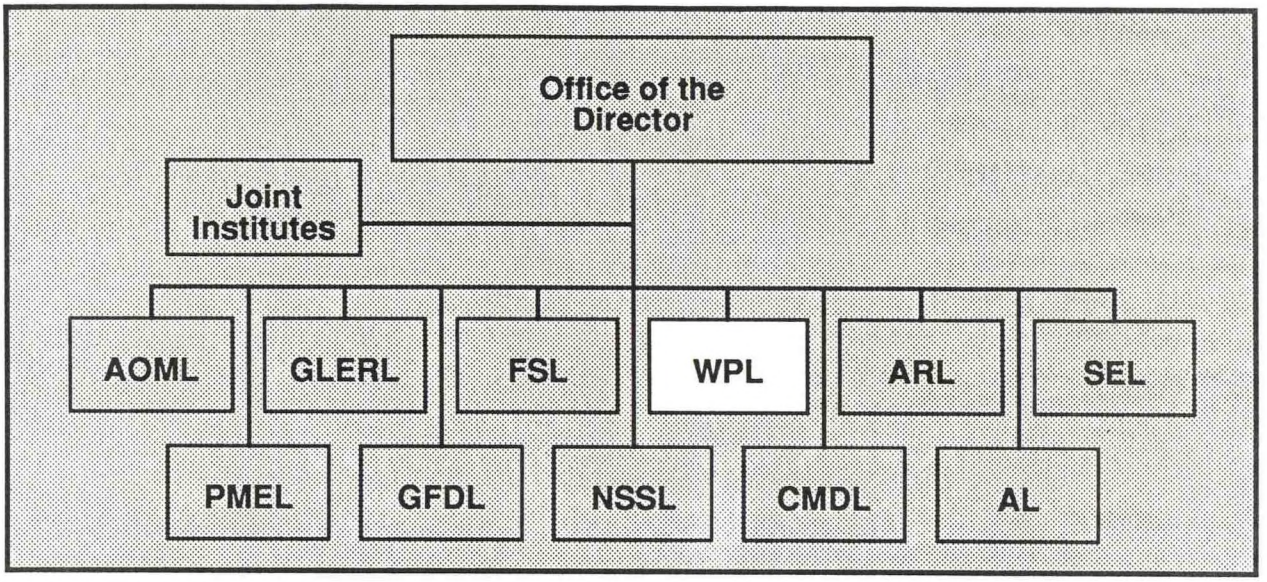
The Cimarron multiparameter radar came back on line for the first time in several years. Cimarron provided real-time estimates of reflectivity, mean velocity, spectrum width, differential reflectivity, and differential phase for the COPS–91 program. The radar was operated in a fully remote control status that included operation of the antenna, transmitter, signal processor, and back-up generators as well as remote display of the data in Norman, 40 km to the southeast

Mobile Laboratories

NSSL continued to improve its mobile laboratories by adding both satellite and 800 MHZ communication systems. In addition, the fourth CLASS system was installed on the P–3 aircraft for dropsonde operations during the COPS–91 field program. The third CLASS system will be housed in a trailer to support field programs. The mobile laboratories used in the COPS–91 field program gathered upper-air data during 150 flights. The mobile CLASS (M–CLASS) systems were also used in two other field projects. One was during March on a Mobil Oil Company platform in the Gulf of Mexico 125 miles south of Cameroon, LA, for GUFMEX II. The other was a systems test to compare upper air winds from CLASS systems, profilers, theodolites, and Doppler radars.

Plans FY 92

- Continue to upgrade mobile laboratory capabilities by building a transportable laboratory to house the M–CLASS and surface station in a trailer.
- Enhance the Cimarron multiparameter radar to produce additional dual-polarization parameters and to correct ground clutter filtering.
- Provide three M–CLASS systems and operate the Cimarron Doppler radar for STORM–FEST (1 February to 15 March 1992).
- Add high-speed workstations to complement the current computing capabilities.
- Improve data management of lighting, radar, and mobile laboratory data.



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 by developing, demonstrating, and transferring cost-effective remote measurement systems. To achieve this goal, WPL 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.
- 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 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.

WEATHER RESEARCH

MICROMETEOROLOGY

Accomplishments FY 91

Sensor Development

We carried out the New Mexico Flux Experiment and confirmed certain aspects of the theory of optical, infrared, and millimeter-wave flux measurements. Path-averaged horizontal fluxes of temperature, humidity, trace gases, and momentum were measured with scintillation and in situ techniques.

Although the current eyesafe CO_2 Doppler lidar has performed well for almost 10 years, its drawbacks are large size, labor-intensive operation, frequency instabilities, and coarse range resolution. Two new transportable coherent lidar systems, also eyesafe, with improved capabilities are under development.The new CO_2 lidar with a high pulse-repetition rate (5 kHz) is distinguished by its small size, robust construction, and excellent stability. It will initially operate from the surface, but later use on an aircraft is intended. This lidar promises to be very useful for velocity and turbulence observations and for both Differential Absorption Lidar (DIAL) measurements of trace gases (including water vapor and ozone) in the planetary boundary layer and automated observations of clouds at all heights. Performance tests of the master and local oscillator components, designed and constructed at WPL, were done. The instruments met expectations for frequency stability (10 kHz long-term), adjustable pulse length (25–500 m resolution), and energy (100 μ J). Simulations showed that proper averaging of many low-energy pulses should provide better Doppler estimates than originally believed; maximum range in the aerosol-laden boundary layer is expected to exceed 5 km.

One limitation of typical UHF radar systems is the long dwell time (20–30 s) required to obtain a Doppler spectral estimate along a particular radial beam. Because six such estimates are usually obtained in succession (to cover three directions and high and low pulse resolutions), rapidly changing winds associated with convective motions could be undersampled and result in inaccurate measurements of the mean wind. This effect was studied and quantified with Boulder Atmospheric Observatory (BAO) wind data from eight levels to a height of 300 m. We are using these test data as we design optimum UHF radar sampling strategies to accurately represent boundary layer winds.

Research

Theory and experience show that coherent lidars operating at 1.06 and 2.1 μm wavelengths undergo different propagation effects (in particular, degradation by optical turbulence and molecular absorption) than does our 10.6 μm system. To better understand these effects, we undertook an experimental study that provided the first quantitative measurement comparison of wavelength-dependent lidar performance in a turbulent boundary layer.

Numerical simulation of the scavenging rates of aerosols by ice crystals was improved by considering processes involving electric multipoles. Low concentrations of ionic salts were shown in laboratory experiments to strongly affect the morphology of ice crystals that grow from vapor in the presence of supercooled cloud droplets.

Plans FY 92

We will participate in a proposed regional mesoscale weather system study, Stormscale Operational and Research Meteorology Fronts Experiment Systems Test (STORM–FEST).

We will evaluate quantitatively the impact of changes in precipitation on water resources, and evaluate the effectiveness of cloud seeding for increasing water supplies and suppressing hail.

Our recently completed Mobile Atmospheric Sounding System (MASS) will be evaluated at the BAO. In anticipation of such instrument development and evaluation needs, the BAO was recently refurbished and a new data system was developed for routine archiving of mean wind, temperature, and humidity data.

In the spring of 1992 we will use new remote and in situ sensors to study the meteorological effect of leads that develop in the Arctic sea ice. Using these sensors to measure the boundary layer response to large fluxes of heat and momentum and to measure the background state of the Arctic atmosphere will be essential for improving and evaluating models being developed under the Leads Experiment (LEADEX) program sponsored by the U.S. Office of Naval Research (ONR).

Using suites of remote and in situ sensors and new modeling and analysis techniques, we will study a broad range of shallow tropospheric circulations that develop over complex land and ocean surfaces.

MESO-BETA AND MESO-GAMMA SCALES

Accomplishments FY 91

Sensor Development

A new concept for profiling atmospheric winds and turbulence was advanced. It combines spatial filtering with speckle interferometry to provide better spatial resolution.

A WPL coherent lidar will be the world's first field-worthy, solid-state Doppler lidar at a new wavelength (2.1 μm). It promises better velocity accuracy (5 cm s^{-1} for a 1-s average), spatial resolution (25 m), and pulse rate (200 Hz) than the current CO_2 lidar, but equivalent maximum range (15–30 km) in the boundary layer. A broad design was completed and major transmitter components were ordered under funding from the U.S. Army Research Office.

The remarkable ability of a combined wind profiler and Radio Acoustic Sounding System (RASS) to observe the structure of fronts in the middle and lower troposphere was documented through synoptic analysis. The results from these studies demonstrated the potential applications of forthcoming profiler-RASS networks in mesoscale research and operational weather forecasting.

A single expression was derived for the expected signal power of a RASS that uses a monostatic pulsed Doppler radar and a continuous-wave acoustic source, the usual RASS technique with wind profilers. The effects of horizontal winds, atmospheric turbulence, vertical temperature gradients, and acoustic absorption are included. Broadening the focus of the scattered electromagnetic waves caused by turbulence and temperature gradients mitigates the effects of displacement of the acoustic wavefronts by horizontal winds. The expression can be used to predict the altitude coverage of RASS with wind profilers, the benefits of having multiple acoustic sources, and where these sources should be located.

A technique was developed for using UHF wind profiler radar data to monitor the drop size spectra of number density, liquid water density, and liquid flux in time and height. These observations reveal the height-time location of rapid growth zones and the drop size growth rate in an important part of the number density spectrum. A model was developed that reproduces major features of the observations.

Knowledge of the location and amount of supercooled liquid water (SLW) in clouds would be extremely valuable for helping aircraft avoid regions of hazardous icing and for cloud seeding operations. A new radar method for obtaining such information has been tested in the field using simultaneous observations with two different wavelengths that are subject to greatly different levels of attenuation by liquid water.

Comprehensive field demonstrations of the technique for Tracking Air with Circularly-polarized Radar (TRACIR) were completed. This radar depolarization technique provides dramatic three-dimensional visualizations of the movement of chaff-tagged air parcels inside clouds and precipitation, similar to earlier observations in clear air.

WPL provided the scientific direction and coordination for Lake Ontario Winter Storms (LOWS), a multi-agency project whose primary sponsor was the Niagara Mohawk Power Corporation. The goal was to apply new remote sensing techniques to mitigate the impact of winter storms on utility operations near the shores of the Great Lakes. The performance and usefulness of the remote sensors in this setting were evaluated on the basis of field project experience. Specific recommendations for establishing a privately operated advanced weather monitoring system were presented to the utility company in a final report.

The area-time-integral (ATI) technique to estimate convective rainfall proved very successful with radar data that are comparable within the High Plains climate regime. The technique also appears promising with satellite infrared data.

Research

Analysis of NOAA research aircraft observations taken during the Ocean Storm Program described the mesoscale environment for polar low formation in the Gulf of Alaska and the microscale (~1 km) structure of a Pacific cold front. The front was less than 2 km in width at the sea surface and contained stratospheric ozone that had been injected into its upper portion and transported downward to the sea surface.

Data collected with a dual-wavelength radar system during the Winter Icing and Storms Project (WISP) is being analyzed to test a method for mapping and measuring liquid water in clouds. Potential applications of the method include cloud seeding and aircraft icing research.

The quantities of ice particles in clouds commonly exceed those explicable by heterogeneous nucleation theory. For convective clouds in the Midwest, we measured a strong and highly significant correlation between large cloud drops and concentration of ice particles. The results support theories that large-drop freezing generates large concentrations of ice, and offer an explanation for observed ice crystal concentrations.

Airborne tracking of sulfur hexafluoride and silver iodide in winter mountain storms showed conclusively that plumes of seeding material released from ground-based generators can be entrained into seedable regions of clouds, thus resolving some aspects of a long-standing ambiguity.

Plans FY 92

We will direct and participate in the 1992 Eastern Pacific medium-range prediction experiment, a collaboration between WPL, the NOAA National Meteorological Center, the European Centre for Medium-Range Weather Forecasting (ECMWF), and the U.S. Air Force Air Weather Service.

We will assess the realism of numerical weather prediction model simulations of mesoscale structure and physical processes by comparing the simulations with in situ and remote sensor observations of mesoscale and microscale weather systems.

By analyzing WISP data, we will determine the feasibility of differential attenuation to detect SLW in mixed-phase clouds, a serious hazard to aircraft. The results of this analysis will determine the development of a two-wavelength radar designed for SLW detection.

We will deploy a network of 915-MHz wind profilers and surface flux stations as part of the STORM–FEST program. Four profilers will be equipped with RASS temperature systems and will provide detailed information on boundary layer phenomena during the passage of wintertime fronts across the midwestern United States.

SYNOPTIC AND MESO-ALPHA SCALES

Accomplishments FY 91

Sensor Development

In two ocean-monitoring experiments we used the U.S. Air Force's over-the-horizon (OTH) defense radars on the east and west coasts. Surface wind direction was mapped for 12 days over the 15 million km^2 radar coverage areas in the North Atlantic and North Pacific Oceans. Assimilation of radar data into a National Aeronautics and Space Administration (NASA) general circulation model (GCM) enhanced the resolution of mesoscale forecasts.

Active support of NASA's Laser Atmospheric Wind Sounder (LAWS) development continued. Two WPL scientists on the LAWS science team investigated key issues of signal processing, calibration, backscatter strength, and cloud measurements.

WPL's research wind profilers (50, 405, and 915 MHz) were equipped with new PC-based radar control and data processing. These new systems, developed by the Aeronomy Laboratory, are particularly important for RASS research because they allow simultaneous measurement of the speed of sound and vertical wind. This allows measurement of RASS temperature profiles in a wider variety of meteorological conditions. With the data systems used since 1983, the vertical wind had to be ignored.

Monthly averaged backscattered power profiles were computed for a 5-year period with data from a 50-MHz profiler operating in northeastern Colorado. Backscattered power is a measure of the radar refractive index structure parameter, C_n^2. Below the tropopause, a long-term variation was found in addition to the expected seasonal cycle. Above the tropopause, the seasonal cycle nearly disappeared but the long-term trend persisted. Similar results were obtained using data from other radars in the Colorado network. Such long-term trends could have very serious consequences for the height coverage of wind profilers.

We continued to explore techniques that combine data from different remote sensors to derive meteorological products. We obtained preliminary results using the international TIROS Operational Vertical Sounder (TOVS) processing package to profile temperature and humidity by combining ground-based RASS and space-based TOVS measurements; the profiles were compared with nearly simultaneous radiosonde data. We made progress toward the simultaneous retrieval of pressure, temperature, humidity, and cloud liquid water profiles from an integrated system composed of a microwave radiometer, a lidar ceilometer, and a wind-profiling radar equipped with RASS.

Research

We did further mesoscale analysis of the ERICA (Energetics of Rapidly Intensifying Cyclones over the Atlantic) extratropical marine cyclone of 4–5 January 1989, using multiple-view airborne Doppler radar observations of internal mesoscale vortices and frontal circulations. Additional numerical simulations of this

cyclone were made with the Penn State/National Center for Atmospheric Research (NCAR) mesoscale prediction model and with a high-resolution (20-km) version of the ECMWF operational prediction model. The emphasis was on diagnosing frontogenetical processes, the potential vorticity perspective of cyclogenesis, and the role of latent heating in the formation of secondary upper-level jet streams, associated tropopause folding, and stratospheric tropospheric exchange.

Plans FY 92

The basic components of a ground-based upper air sounding system will be installed at Platteville, CO, as a TELESONDE test facility. The initial instruments will include a wind profiler with RASS, dual-channel radiometer, surface station and ceilometer, and radiosondes for verification. Satellite data will also be part of the test facility data base.

The RASS technique for temperature profiling will be developed for NOAA's Wind Profiler Demonstration Network and for TELESONDE. The goal is to measure temperature profiles in nearly all weather conditions from the surface to 3–5 km altitude.

The processes that govern the performance of wind profilers will be studied. Our goal is to optimize radar systems for the next generation of wind profilers for operational meteorology.

New UHF and VHF radar techniques such as radar interferometry will be developed. Our goal is to determine if the next generation of wind profilers should continue to use multibeam Doppler techniques or whether the new methods are superior.

We will continue to develop and improve instruments and techniques for measuring tropospheric meteorological variables from both ground-based and aircraft-based platforms. We will develop real-time ingest and display capabilities of TOVS, combine the TOVS soundings with ground-based soundings from the microwave radiometric profiler and RASS, and use physical retrieval techniques to derive profiles of temperature, water vapor, and cloud liquid.

AIR QUALITY

Accomplishments FY 91

Sensor Development

One of our long-term goals is to maximize the amount of information available from active remote sensors, particularly in the derivation of wind, temperature, and turbulence fields. Recent analyses of 915-MHz wind profiler data showed exceptional promise for the extraction of vertical profiles of the dissipation rate of turbulent kinetic energy. Such parameters will prove useful in determining mixed layer depth, determining the location of clouds within the radar beam, and providing linkages to other boundary layer turbulence variables, such as the eddy diffusion coefficient, which determine the concentrations and diffusion of pollutants. In another investigation, we found that the effect of beam wander and turbulence inhomogeneity could degrade the calculation of velocity variances and covariances using multibeam Doppler acoustic sounders. These results suggest that these mechanisms could account for discrepancies found in past comparison experiments.

In the past, stand-alone instrument systems served well in short-term intensive field studies. However, reliable and complete lower-tropospheric soundings of wind, temperature, and turbulent fluxes awaited more sophisticated integrated sounding systems. The Atmospheric Studies Program Area recently developed and

fielded a prototype of such a system that uses a high-power workstation and diskless computer nodes to allow integration of a 915-MHz wind profiler with a unique acoustic source, a multifrequency combined Doppler sodar and RASS that is digitally controlled. With additional fast-response surface layer turbulence instrumentation and real-time spectral analysis routines, this facility constitutes a MASS. This integrated platform will allow addition of further remote sounding and in situ instruments as well as provide truly integrated data processing. Because of overlapping height coverage, data quality assurance can be built directly into the system.

Research

We continued analysis of the Grand Canyon studies of January 1990. The lidar observations revealed a down-canyon jet near the bottom that no other instrumentation system was able to detect. The jet may have a role in transport of visibility-reducing pollutants into the Grand Canyon from sources to the north, including the Lake Powell basin and a coal-fired power plant near Page, AZ.

Building on our experience in the 1990 San Joaquin Valley Study, we began a major multiyear joint research effort with the California Air Resources Board to study atmospheric transport corridors and processes throughout California. This effort focuses on analyses of boundary layer depth observations and parameterizations, development of the 915-MHz wind and temperature profiler as a major tool in understanding mesoscale pollutant transport, evaluation of lower-tropospheric profiler data in diagnostic and primitive equation models, examination of the thermally and dynamically driven mesoscale eddy phenomena, and studies of marine air intrusions of pollutant transport.

The coupling of the free atmosphere to surface sources of biogenic precursors is critical to understanding the formation of ozone in rural areas. With the Aeronomy Laboratory, we used radar reflectivity data from the Rural Ozone in the Southern Environment (ROSE I) experiment to derive time series of boundary layer depth, which help explain rapid daytime fluctuations in ozone precursors.

A cooperative research and development agreement with industry was completed, and the first commercial clones of NOAA's 915-MHz wind profiler were deployed in the Lake Michigan Ozone Study during the summer of 1991.

Plans FY 92

We will analyze the data from the New Mexico Flux Experiment to demonstrate the combined use of scintillometers and spectrometers to measure the surface fluxes of trace gases.

We will study the dynamics of complex terrain flow by analyzing lidar and other observations taken near Rocky Flats in Colorado. With the Doppler lidar, we also plan to examine the potential hazard to aircraft from rotors generated by downslope windstorms.

In two studies, the Measurement of Haze and Visual Effects (MOHAVE) study and our ongoing study of transport of pollutants from the South Coast Air Basin of California, we will deploy eleven 915-MHz wind profilers throughout the southwestern United States. These will provide an opportunity to study long-range transport of pollutants that are major contributors to visibility reduction in the West.

We will continue our analysis of lower-tropospheric turbulence structure and parameterizations using a unique data set gathered during our California Transport Study. It includes data from a 915-MHz wind profiler with RASS, routine radiosonde soundings, a monostatic sodar, a laser ceilometer to provide aerosol layer depth, and extensive surface turbulent flux measurements.

CLIMATE

Accomplishments FY 91

For the first time, a long-term (7-year), global, satellite data base of ocean surface solar irradiance was used to assess the realism of the ocean surface solar irradiance simulated by atmospheric GCMs. It is important to simulate accurately the flux of solar radiation absorbed into the ocean because it is a dominant term in the ocean surface heat budget and because deficiencies in the simulations of this field indicate deficiencies in the GCM cloud-radiation interaction parameterizations. Results were obtained for cases involving the nine-layer Goddard Laboratory for Atmospheres' GCM with the simple biosphere and the Geophysical Fluid Dynamics Laboratory's GCM.

A third lidar under development is a UV incoherent DIAL system for measuring ozone in the lower 3 km of the atmosphere. It will be used for air quality studies and climate research. Because of its hardware design and improved data processing techniques, this lidar is expected to measure ozone profiles with better range resolution (typically 100 m) and better accuracy in a shorter measurement period (seconds) than existing ozone lidars. Parts for the transmitter were purchased and tests to optimize the Raman frequency-shifting configuration began. Simulations showed that a new method combining polynomial fitting and nonstationary Wiener filtering would greatly improve retrievals of the mean ozone profile and small-scale perturbations of the profile in time and space. A simplified processing technique for correcting the effects of wavelength-dependent aerosol backscatter, a critical problem, was also developed.

Much is yet to be learned about the effects of the bulk and microphysical structure of clouds on radiative transfer and climate. The Cloud Lidar and Radar Exploratory Test (CLARET) continued with an additional field phase and successfully demonstrated new techniques. Simultaneous lidar and radar measurements provide a much better description of bulk structure than either sensor alone. CLARET showed that the simultaneous measurements also give profiles of the effective particle radius of cirrus clouds. The wavelength-dependent depolarization of lidar backscatter at visible and infrared wavelengths was investigated experimentally and observed differences verified through scattering calculations. A new technique for measuring the mean particle radius of water clouds with the CO_2 (10.6-m wavelength) lidar was also demonstrated.

The study of the aerosol backscatter climatology over Boulder continued into its ninth year. The arrival of debris from the Mt. Pinatubo volcano was detected 27 July 1991. Research programs to study its structure and possible ozone depletion (with the Climate Monitoring and Diagnostics Laboratory) were organized. Arrangements were also made to use the stratospheric aerosol to study stratospheric/tropospheric exchange and cirrus optical properties.

A Fourier transform Infrared Sounder (FIRS) was assembled and tested in the laboratory. This instrument will be a component of an integrated sounding system and will provide cloud and radiation measurements.

We participated in several major field experiments on climate research during 1991. The first was WISP, an aircraft icing experiment sponsored by the Federal Aviation Administration (FAA). Data from three Microwave Water Substance Radiometers (MWSRs), RASS, and National Weather Service ceilometers were combined to make aircraft icing nowcasts. We supplied dual- and three-channel radiometer data for an experiment at Platteville sponsored by the U.S. Department of Energy. We operated a dual-channel radiometer near Norman, OK, as part of the Cooperative Oklahoma Profiler Studies–1991 (COPS–91). We also supplied cloud liquid, meteorological, and satellite data to CLARET–II.

We renovated and documented the radiative transfer mode that simulates microwave radiometer measurements from radiosonde data. We advised DOE on procuring dual-channel microwave radiometers for their Cloud and Radiation Testbed (CART) field sites.

Radar observations of nonprecipitating clouds were coordinated with lidar, radiometer, and other sensor data to infer the microphysical structure and radiative features of the clouds. These studies address the role of clouds in climate change.

Spectral analysis of 5 years of data from wind profiling radars in Colorado revealed characteristic periodicities of wind velocity in the middle troposphere. These periodicities have implications for long-term weather forecasting and climate prediction.

Data from the Tropical Oceans and Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment (TOGA/COARE) pilot cruise were analyzed. This cruise was the first extensive study of air-sea fluxes under strong convective winds and under light winds in the marine surface layer and the first use of infrared hygrometers to obtain latent heat fluxes over the ocean. Cloud cover and precipitation were found to play a major role in variations of the tropical ocean surface energy balance. These analyses show that knowledge of convective activity is paramount in understanding the ocean surface energy balance, and they reveal the importance of proper parameterization of air-sea fluxes in climate models.

Plans FY 92

By analyzing the correlated variability of earth radiation budget parameters (such as planetary albedo and ocean surface solar irradiance) and meteorological and oceanographic parameters (such as sea surface temperature), we will investigate possible cloud radiation feedback mechanisms. We will also use observational data sets to validate and improve algorithms in a variety of climate models.

We will examine the feasibility of a basin-scale sonar for monitoring ocean climate using the acoustic backscatter from natural undersea targets, such as islands, seamounts, and continents.

A unified theory for how low-frequency sound travels global distances is needed to interpret "acoustic thermometer" measurements of ocean warming over basin-scale paths, and to measure transverse currents using scintillations. Present theories for shorter ranges leave out scattering and diffraction by land forms, internal waves, and mesoscale eddies; strong scattering by turbulence; horizontal refraction by climatological temperature gradients; and corrections for a nonspherical earth. We will work to develop a unified theory using ocean models that have both deterministic and stochastic components.

We will participate in the design, deployment, and operation of a global network of underwater acoustic thermometers for monitoring the temperature of the deep ocean on basin scales.

We will complete development of the ozone and the fast-pulse coherent CO_2 lidars and perform initial field tests with them, and renovate older lidars with modern computer data acquisition and other critical components.

We will move toward deployment of compact, robust, unattended lidar systems for studying and monitoring atmospheric and oceanic processes, and toward use of lidar techniques for measuring fluxes of atmospheric turbulence and trace species.

By combining satellite and surface-based remote sensing methods, we will provide calibrated and validated global observations of clouds, winds, and other parameters, as well as improved information that describes small-scale processes.

In the Atlantic Stratocumulus Transition Experiment (ASTEX) during June 1992, WPL microwave and infrared radiometers will be deployed on Porto Santo Island, Madeira. We are negotiating to deploy a dual-channel radiometer on the Soviet ship *A. Kurchatov.*

An experimental program that employs island- and ship-based microwave radiometers will provide data to validate satellite measurements of precipitable water vapor and cloud liquid. The resulting radiometric data will be useful in our research on the effect of cloud liquid on solar radiation.

We will continue to apply measurements of cloud liquid water and water vapor by MWSRs and infrared radiometers to research in climate, satellite product validation, meteorology, geophysics, aviation, and communications.

The new antenna will be installed on our cloud-sensing radar, which will be used for studies of cirrus clouds in the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE) project and studies of marine stratus clouds in the ASTEX project. Both cloud types are pervasive and have important effects on global climate. The cloud sensing radar will be operated continuously for an extended period with other components of an integrated sounding system test facility. In addition to reflectivity and vertical motion measurements, the radar will provide detailed height and thickness information for single and multiple cloud layers that is not adequately measured by other instruments.

In a cooperative program with NCAR and the Aeronomy Laboratory, we are developing a seagoing 915-MHz wind profiler. This system will be tested during an equatorial cruise in late 1991. It will aid studies of marine cloud dynamics in the summer of 1992 during ASTEX.

OCEANS AND GREAT LAKES

Accomplishments FY 91

Sensor Development

A way was found to compute travel times and pulse spreading for global underwater sound propagation. The method was used to simulate the acoustic arrivals observed at Ascension Island during the Heard Island Feasibility Experiment. Nonlinearities due to mode coupling in simulations with moderately strong warm eddies indicate the need for nonlinear inversion methods.

A patent was awarded for the concept of using a single radar station to measure the two-dimensional ocean surface current using spaced antenna or interferometric techniques.

The Scanning Radar Altimeter (SRA) mode of the Multimode Airborne Radar Altimeter (MARA) became fully operational in fall 1990. The instrument measured the directional wave spectra and electromagnetic (EM) bias during the Surface Wave Dynamics Experiment (SWADE) off the U.S. mid-Atlantic coast from November 1990 through March 1991.

The theory for a stepped-frequency radar method to measure ocean surface currents has been examined and expanded. Hardware modifications to an existing Doppler radar are in progress to implement this technique.

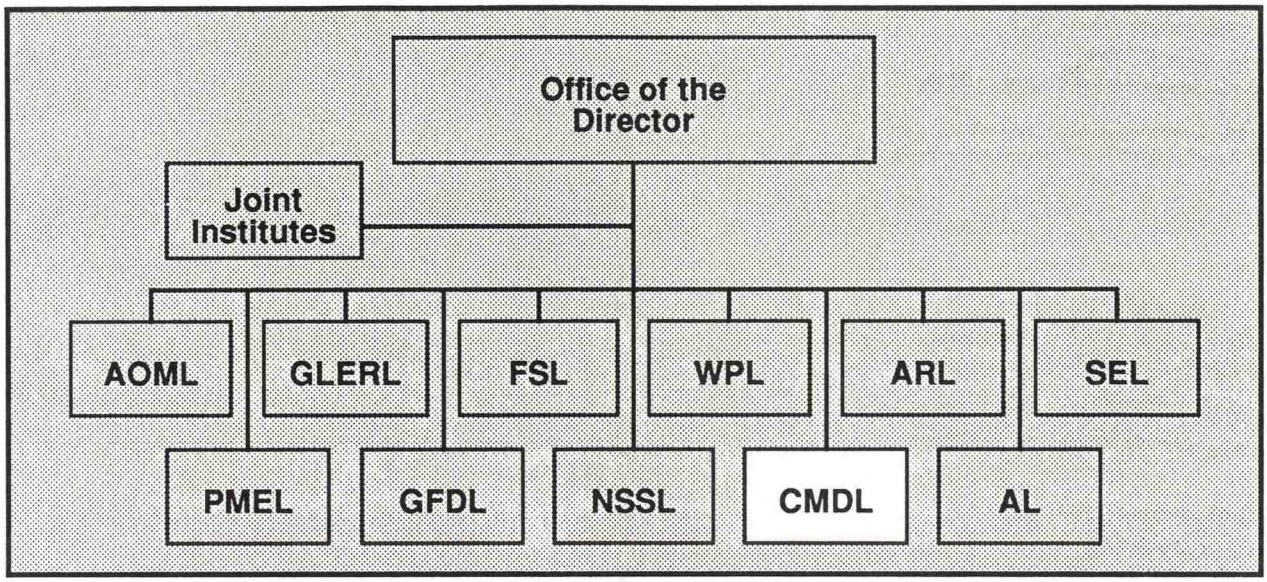
Research

We operated an underwater acoustic receiving station at Ascension Island in the South Atlantic in concert with the Heard Island Feasibility Experiment in January 1991. For the first time, coherent 57-Hz transmissions were recorded from almost one- quarter of the way around the Earth. Their strength and stability indicate the feasibility of a global network of acoustic thermometers to monitor the signatures of climate change in the world's oceans.

Plans FY 92

Data from a commercial, two-station, ocean current mapping system will be used to test the concept of single-station ocean current mapping by spaced antenna and interferometer techniques. Data from a single station will be used to derive two-dimensional ocean currents and the results will be compared with two-station measurements.

The stepped-frequency radar system will be implemented in a Combined Oceanic and Atmospheric Sensing Technique (COAST) to obtain simultaneous measurements of ocean surface currents and the boundary layer airflow that drives the currents.



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.

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, AK; Mauna Loa, HI; Cape Matatula, American Samoa; and the 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 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 (ENSO) effects on larger space-scale weather and climate.

CARBON CYCLE

Accomplishments FY 91

In situ monitoring of CO_2 at the four CMDL baseline observatories continued, as did monitoring of CH_4 at Point Barrow and Mauna Loa. In situ monitoring of CO commenced at Point Barrow. CO_2 and CH_4 were measured in flask samples from the global cooperative flask sampling network, and CO and the stable isotopes of CO_2 were measured in samples from a subset of the network. The isotopic measurements were done in collaboration with the University of Colorado at Boulder.

Newly designed flask pumping units were tested and distributed to most field sites. Further improvements were developed, in particular a thermoelectric cooling stage to dry the air stream, and greaseless tapered joint connectors were added to the flasks. Drying the air stream is expected to improve the measurement of the $^{18}O/^{16}O$ ratio of CO_2 in the samples.

New flask sampling sites were added: Mace Head on the west coast of Ireland; Tae-ahn Peninsula on the west coast of South Korea, in collaboration with the Korean National University of Education; Mt. Waliguan in western China, in collaboration with the State Meteorological Administration; and a regular shipping transect between Singapore and Hong Kong, in collaboration with Chevron Shipping Company.

Most design and testing was completed for a fully automated system to take air samples in flasks aboard nonresearch aircraft. Such aircraft sampling will economically obtain vertical profiles of CO_2, CH_4, and CO in the same place at weekly or biweekly intervals. The data will be used to define limits for numerical global modeling of the sources and sinks of these gases.

A study was completed of the high temporal frequency variations of CH_4 in background air at Mauna Loa. The variations were shown to be correlated with air mass origin, e.g., higher values with air from the East-Asian mainland and lower values with air from the tropical Pacific Ocean.

An expert system was developed to select in-situ CH_4 gas chromatographic data for instrument evaluation. Since air samples are alternated with reference gas, the algorithm checks for stability of the analytical system by checking the baseline code, retention time, peak width, variability of the reference peak heights, and variability of the analysis time.

Correlations between variations of CO_2, CH_4, and CO were analyzed for aircraft samples in the Arctic and the Persian Gulf, the latter in connection with the oil well fires. Relative source strengths for these gas emissions were estimated from the data.

Plans FY 92

- Continue monitoring of CO_2, CH_4, and CO through in situ measurements and the current flask network. Expand the flask program to additional sites and to regular sampling aboard aircraft to better define sources and sinks over the continents, and to better constrain the parameterization of vertical transport in three-dimensional atmospheric transport models.
- Continue measurements of stable isotopes of CO_2 in samples from the flask network, in collaboration with the University of Colorado at Boulder, to distinguish between uptake of CO_2 by the terrestrial biosphere and by the ocean.
- Start monitoring CO_2 on a very tall tower inside the continental United States to develop methods to define boundary layer concentrations of CO_2 in vegetative regions.
- Install an in situ gas chromatograph for CO monitoring at Mauna Loa.
- Complete the design and assembly of a system to perform absolute calibrations of the CO_2 mixing ratio in reference gas cylinders. The calibration will be based on first principles, temperature, and pressure in well-defined volumes. Compare the calibrations to those performed at the Scripps Institution of Oceanography and at the National Institute of Standards and Technology (NIST).
- Develop an independent calibration scale for CH_4, based on the gravimetric method.

NITROUS OXIDE AND HALOCARBONS

Accomplishments FY 91

The new automated gas chromatograph (GC) system for measuring N_2O, CFC (chlorofluorocarbon)-12, CFC-11, CFC-113, CH_3CCl_3, and CCl_4 was completed and is now in operation. Weekly flask samples from the four CMDL observatories, from Niwot Ridge, CO, and from Alert, Canada, are analyzed on this GC as well as on the old GC for intercalibration of N_2O, CFC-12, and CFC-11. Intercalibration of the instruments is expected to continue for at least 6 months. Monthly measurements of flask samples for H-1301, H-1211, HCFC (hydrochlorofluorocarbon)-22, and CFC-113 also continued with flasks collected from the same six locations. At mid-year, Cape Grim, Australia, was added to the flask program.

In situ hourly measurements of N_2O, CFC-12, CFC-11, CFC-113, CH_3CCl_3, and CCl_4 continued at the four CMDL observatories and at Niwot Ridge. Records from these systems are now revealing seasonal cycles as well as long-term trends in the trace gases.

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. In conjunction with the Carbon Cycle Group of CMDL, an independent calibration scale for gravimetrically prepared standards was completed for CO and published.

A compact, automated, airborne GC was designed, built, and tested to measure halocarbons from an ER-2 aircraft at altitudes of more than 20 km. The system, which must operate under a wide range of pressures and temperatures, has obtained the first in situ measurements of stratospheric halocarbons. The work was done in association with the Aeronomy Laboratory and the National Aeronautical Space Administration (NASA). These relatively high-frequency measurements of halocarbons will be useful in determining the relative effects of physical and chemical processes in stratospheric ozone depletion.

A program to measure HCFCs and HFCs was begun. A GC–MS (mass spectrometer) was purchased, installed, and tested to measure several trace gases, including HCFCs and HFCs. Preconcentrating air samples on adsorbents began with a series of tests of adsorbent capacities for a variety of CFCs, HCFCs, and HFCs. The MS will allow identification of interfering peaks not only in HCFC and HFC measurements, but also for the analysis of all the gases now monitored by gas chromatography.

Plans FY 92

- Continue routine monitoring by in situ analysis and by flask collection at seven sites for N_2O, CFC-12, CFC-11, CFC-113, CH_3CCl_3, CCl_4, HCFC-22, and halons H-1211 and H-1301.
- Add new flask sampling stations at Bermuda and at Harvard Forest (Harvard University), MA, 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.
- Continue development of calibration scales for N_2O, CH_4, and halocarbons. Begin use of GC–MS for testing purity of purchased gases.
- Add additional detectors to the airborne GC system for measuring vertical and stratospheric profiles of long-lived gases.
- Participate in Arctic ER–2 missions through the boreal winter and spring of 1991–1992 to conduct in situ measurements of stratospheric halocarbons along with measurements of N_2O, NO_y, CLO_x, and O_3 by other laboratories.

- Continue to develop mass spectroscopy and enhanced electron capture (EC–GC) technology to measure the new substitute CFCs, HCFCs, and HFCs in the atmosphere. Obtain first measurements of background air for these gases.
- Evaluate approaches to improve raw data analysis, reduce instrumental noise, and improve accuracy and precision of all measurements. Integrate station meteorological and other pertinent data into the halocarbon data base.

ATMOSPHERIC RADIATION

Accomplishments FY 91

We participated in the Winter Icing and Storms Project (WISP) and obtained 30-second average measurements of downwelling total- and direct-solar irradiance, thermal irradiance, zenith-sky radiance, and precipitable water. During the 1-month measurement period, the Wave Propagation Laboratory (WPL) CO_2 lidar was operated occasionally to obtain measurements of cirrus for several Cloud Lidar and Radar Exploratory Test (CLARET) II experiment episodes. CMDL archived its radiation data, and other data are archived by WPL.

The Boulder Atmospheric Observatory radiation measurement array was upgraded to include the capability of measuring downwelling solar and infrared (IR) irradiances at the base and upwelling irradiances at two additional levels on the tower. The additional levels will provide data to improve our understanding of the effects of altitude on radiation emitted and reflected from an inhomogeneous surface.

Fifteen Robertson-Berger ultraviolet (UV) meters operating in NOAA's network were characterized in the laboratory for their spectral response to radiation in the 300–330 nm band. The spectral response functions of these instruments had not been characterized previously and, therefore, their changes with time could not be determined. Nevertheless, these spectral response functions were compared with a spectral response function published in 1976 and agreed remarkably well, suggesting little to no change. The network was established in 1974 and has operated continuously. This result implies only that the spectral characteristics of the instruments remained stable and that the calibration (i.e., the magnitude of the instrument's response) must be determined. All network instruments were cleaned, repaired, and calibrated, and then returned to their respective station.

We established a new Baseline Surface Radiation Network (BSRN) ocean site in northern Bermuda, and have collected approximately 1 year's worth of data.

Umkehr ozone profiles for stratospheric aerosol error were corrected through 1990 for four latitudes where Dobson instruments are located. The data indicate no upturn in ozone concentration since it reached a low point in 1985.

Plans FY 92

- Organize and host an international intercomparison of broad-band infrared radiometers at the First International Satellite Cloud Climatology Program (ISCCP) Regional Experiment II (FIRE), Coffeyville, KS, 13 November to 7 December 1991. The objective of FIRE II is to measure and model the properties of cirrus clouds for an improved understanding of their effect on the Earth's radiation balance and to determine the field performance accuracy of available broadband infrared radiation instrumentation. With the University of Maryland, the Atmospheric Radiation Monitoring (ARM) group will measure total ozone, ozone profile, and the trace gases CO_2, fluorocarbons, NO_2, and CH_4. The chemistry and ozone groups in CMDL assist the ARM group with apparatus and analyses. The

ARM group will also measure the surface radiation budget, aerosol optical depth, and precipitable water.

- Continue upgrading the U.S. component of the BSRN in cooperation with the U.S. Department of Energy (DOE) and NASA. Upgrades will be done at sites in Kwajalein, at Bermuda, and at the main site at Boulder. New sites in planning are the Agricultural College at Iowa State and the University of Georgia. A site in the southwestern United States is also being considered. The establishment of these sites is also seen as future support for the Global Energy and Water Cycle Experiment (GEWEX).
- Assist the DOE Atmospheric Radiation Measurements Program with selection, operational procedures, and placement of radiation instrumentation (similar to the BSRN instrumentation) at its first continental atmospheric radiation testbed site to be located in the middle southern region of the United States.
- Analyze radiation measurements for volcanic aerosol effects on the radiation balance. The eruption of Pinatubo injected a tremendous amount of aerosol material into the stratosphere. Aerosol information will be acquired from lidar, SAGE II satellite, and aircraft in situ measurements to be used to correct Umkehr measurements of the vertical profile of ozone. In cooperation with the National Environmental Satellite, Data, and Information Service (NESDIS), we will routinely provide such corrections for validation of the operational NESDIS Solar Backscatter Ultraviolet (SBUV) satellite ozone sensor. In cooperation with the World Meteorological Organization (WMO) World Ozone Commission, these corrections are also supplied to users of Umkehr ozone profile data archived by the World Ozone Data Center (WODC) at Toronto, Canada.
- Continue to operate the NOAA ultraviolet monitoring network of 15 instruments. Plans for the coming year involve an evaluation of the archived UV data for discrepancies in calibration and of mishandled operational procedures. In addition, work will begin on the establishment of an appropriate laboratory calibration procedure that will assure long-term stability of the field measurements.
- Analyze long-term radiation measurements for effects of the Pinatubo volcanic cloud on the Earth's surface radiation budget. The results will be compared to those of El Chichon for the same time interval to learn of their similarities and differences.
- Using the additional measurements at the tower, studies of radiative effects will be conducted for changes in solar zenith angle, season, and altitude relationships.

AEROSOLS, OZONE, AND WATER VAPOR

Accomplishments FY 91

Aerosols

Aerosol measurements were continued at the four CMDL baseline stations. Continuous condensation nucleus (CN) concentration and aerosol scattering extinction (σ_{sp}) measurements have been made at Point Barrow since 1976, at Mauna Loa since 1974, at Samoa since 1977, and at the South Pole since 1974 (σ_{sp} since 1979). The aerosol data show an annual cycle at Point Barrow and a spring maximum due to the Arctic haze phenomenon, an annual cycle at Mauna Loa and a late spring maximum due to long-range transport of Gobi Desert dust, no annual cycle at Samoa, and an annual cycle at the South Pole and a late austral winter maximum due to the long-range transport of sea salt. No statistically significant long-term trend was detected.

A 3-month experiment was conducted at Mauna Loa Observatory (MLO) to compare a new high-sensitivity, three-wavelength nephelometer with the existing four-wavelength instrument that has been at

MLO since 1974. The conclusion was that the existing instrument does not have the necessary sensitivity to measure aerosol light scattering during the cleanest times at MLO.

A CN counter, based on the TSI 3760 alcohol-based instrument, was constructed for aircraft measurements. This instrument has a sensitivity of 1 particle cm^{-3} at a time resolution of 1 second and will be used in aircraft measurement programs such as the Arctic Gas and Aerosol Sampling Program (AGASP) and Front Range Lidar and Balloon (FRLAB) experiment. We participated in an aerosol study at the DYE–III site in Greenland in cooperation with the University of New Hampshire. We supplied an automatic CN counter for a 3-month springtime project in 1991. Aerosol studies in Greenland are important because this location is very clean and appears to be in the return path of the Arctic haze circulation.

An International Symposium on the Tropospheric Chemistry of the Antarctic Region was hosted by CMDL 3–6 June 1991 in Boulder. Approximately 100 Antarctic specialists from around the world attended this meeting to present research results and recommend topics for future research. Proceedings of the symposium will be published as a collection of papers.

Site surveys were conducted at Bermuda and at Sable Island, Nova Scotia, in preparation for a comprehensive study of anthropogenic sulfate in the perturbed troposphere. The study at Bermuda will be conducted in cooperation with the University of Miami and the University of Rhode Island. The study at Sable Island will be conducted in cooperation with the Atmospheric Environment Service of Canada.

Ozone

World Standard Dobson spectrophotometer no. 83 was again operated at MLO during the summer of 1991 to check its calibration and to obtain total ozone data for comparison with ozone data obtained by the Total Ozone Mapping Spectrometer (TOMS) and SBUV satellite spectrometers. Similar comparison observations made at MLO since 1978 have proven highly valuable in assessing the long-term calibration drift of the satellite instruments, and have lent credence to recently published global ozone trends derived from the TOMS data.

Total ozone observations were continued during 1991 at 15 Dobson instrument stations operated by CMDL, four of which are foreign cooperative stations. At six of these stations, ozone vertical distribution measurements are made by the Umkehr method. The data are being incorporated into a WMO/UNEP (United Nations Environment Program) assessment report on measured trends in ozone and temperature. Measurements made since 1978 show no trend in ozone in equatorial regions, but a downward trend of 4–5% per decade over the contiguous United States. Ozone values at the South Pole during October, when ozone hole formulation occurs, have decreased by about 50% since 1978.

In an ongoing program to calibrate the instruments in the global Dobson spectrophotometer station network, eight domestic instruments were calibrated relative to World Standard instrument no. 83 during 1991 and 18 foreign instruments were calibrated in 1990.

The focus in past Dobson and satellite instrument calibrations was on long-term instrument stability, and research is now beginning on instrument ozone measurement biases. To this end, Dobson instrument and satellite instrument (TOMS, SBUV, and SBUV–2) comparison observations were made at a high-latitude station (Point Barrow) in March and April 1991, under conditions of low sun and high ozone. Final results were obtained for comparison of Dobson instrument no. 83 and ground-based SBUV–2 satellite instrument observations conducted in Boulder in 1990. As part of this effort, Dobson instrument no. 86 was established as a tertiary standard, and an investigation was conducted on new Dobson instrument ozone absorption coefficients to be used throughout the world beginning 1 January 1991.

A final report was prepared in 1991 on the Stratospheric Ozone Intercomparison Campaign (STOIC) project, conducted at Table Mountain, CA, in 1989 to assess the performance of lidar and microwave ozone instruments destined for the Network for Detection of Stratospheric Change (NDSC). During STOIC,

valuable information was obtained on the performance of electrochemical concentration cell (ECC) ozonesondes, balloon-borne chemical instruments that are widely used by scientists throughout the world to measure atmospheric ozone vertical distributions.

The conversion to a digital ozonesonde system at the South Pole was accomplished in November 1990. Weekly soundings were carried out during the austral summer and winter, and the schedule was intensified to every 3 days during the spring stratospheric ozone hole formation. During 1990 the ozone hole persisted into early December over South Pole, giving the lowest ozone amounts seen so late in the year. In July 1991, weekly ozone profile measurements using balloon-borne digital ozonesondes were reestablished at Hilo, HI, and at Boulder in response to the eruption of Mt. Pinatubo in the Philippines. The digital ozonesonde was also flown as part of an international ozonesonde intercomparison program at Saskatoon, Canada, in May 1991.

Surface ozone data were obtained at the four CMDL observatory sites and at four locations in the North Atlantic that are part of the Atmosphere-Ocean Chemistry Experiment (AEROCE) network. A new site was established at Niwot Ridge in the mountains west of Boulder. The dramatic decline in summer ozone values at the surface at the South Pole was linked to the severe depletion of the stratospheric ozone layer over Antarctica and changes in the transport in the troposphere of ozone-poor air from the periphery of Antarctica.

Water Vapor

A 10-year record of stratospheric water-vapor profiles was obtained at Boulder through the continuing monthly sounding program. An intercomparison of the CMDL balloon-borne frost-point hygrometer with the Aeronomy Laboratory Lyman hygrometer flown on the NASA ER–2 high-altitude airplane was carried out at Edwards Air Force Base, CA. Stratospheric water vapor measurements were made in joint research programs with scientists from the University of Wyoming at the South Pole and McMurdo in the Antarctic and at Alert, Canada, and Kiruna, Sweden, in the Arctic. These measurements led to a better understanding of the formation of polar stratospheric clouds.

Plans FY 92

Aerosols

- Install instruments to measure aerosol chemistry and size at MLO and at the South Pole. Install a butanol-based CN counter and an aethalometer at Samoa. Install a new, more sensitive aethalometer at the South Pole.
- Establish supplementary aerosol monitoring stations in clean and polluted marine locations and at a clean continental site. The clean marine site will be operated in cooperation with the University of Washington. Instrumentation will include integrating nephelometers, CN counters, and sunphotometers.
- Develop (in cooperation with the University of Washington) and deploy new sample inlets for size selection and volatilization of aerosols to link the physical measurements with the chemical composition of the particles. These studies will be done in cooperation with the Pacific Marine Environmental Laboratory (PMEL).
- Develop a cloud CN measurement program for installation at the supplementary monitoring stations. Cloud CN are an important subset of the total aerosol material because these are the particles that act as condensation centers at the very low supersaturations found in clouds.

Ozone

Comparison of Dobson instrument no. 83 and satellite total ozone observations will again be made at MLO during the summer of 1992. Ozone observations will continue at 15 domestic and foreign cooperative stations. The Tallahassee, FL, station, where operations were temporarily discontinued in 1989, will be resurrected. We will apply final corrections and archive total ozone data obtained in the past.

- Study the effects of the Mt. Pinatubo volcanic eruption on the ozone layer over Boulder and Hilo using the digital ozonesonde.
- Make digital ozonesonde flights at the South Pole in the ongoing study of springtime stratospheric ozone depletion. The expected compounding effects of volcanic aerosol on ozone depletion will also be investigated.
- Begin a surface ozone monitoring program in Iceland as part of the NOAA Climate and Global Change activities during the North Atlantic Regional Experiment (NARE).

Water Vapor

- Correlative water vapor measurements with the Upper Atmospheric Research Satellite (UARS) using the frost-point hygrometer will begin in January. Balloon soundings will be carried out in New Zealand, Sweden, Hawaii, and California. Ongoing balloon soundings will continue in Boulder, the Arctic, and the Antarctic.

CLIMATE RESEARCH

Accomplishments FY 91

Data Management and Data Set Development

The Climate Research Data Center, a new project in the Climate Research Division, has the mission of assimilating new technologies to better serve the data access and analysis needs of the climate and global change research community. This goal is being approached along two avenues: development of a software data extraction, visualization, and preliminary-analysis package; and development of an archive of commonly used data sets for climate research.

During FY 91, CRDtools, software developed over the past several years, was converted to a nonproprietary windowing system and displayed on a Sun SPARCstation, DEC DECstation, Apple Macintosh IIcx, and various PC clones. New features were added to CRDtools, including the ability to display multiple fields simultaneously for easy comparisons and a new analysis tool that automatically calculates and displays the power spectra, coherency, and phase for any pair of variables.

In a continuing cooperative project with NCAR and the National Climatic Data Center (NCDC), significant progress was made in acquiring and preparing a variety of data for future releases of the Comprehensive Ocean-Atmosphere Data Set (COADS). Recent acquisitions include Soviet ship data and a quality-controlled version of the global drifting-buoy archive prepared in cooperation with Canada's Marine Environmental Data Service. A preliminary comparison of COADS with the U.K. Meteorological Office Marine Data Bank was completed in support of the scientific assessment by the WMO/UNEP Intergovernmental Panel on Climate Change; results from this work support a planned merger of COADS and U.K. data. COADS software development focused on converting individual observations into a revised uniform format.

Strategies were developed to evaluate biases in the COADS data. Preliminary analyses indicate that different COADS input sources may require different levels of correction to such variables as sea-surface temperature (SST), air temperature, and surface winds. A set of homogeneous ocean regions was defined based on similarities in the annual cycle of SST and on similarities in the interannual variability of these ocean areas. Using these regions for climate monitoring will help researchers focus on the different forcing mechanisms operating in different ocean regions and will help improve climate change detection techniques.

A high-quality precipitation data set for global land areas was developed in cooperation with the University of Massachusetts and the University of East Anglia. This data set should prove valuable for studying climatic change and variability, as well as for verifying the accuracy of precipitation climatologies produced by general circulation models.

Climate Diagnostic Research

Studies using global satellite data are required for monitoring global change on time and space scales ranging from seasonal and regional to interdecadal and global. In the past year, investigations were carried out in two major focus areas: global satellite-derived SST and atmospheric water vapor content. Satellite-derived SST data and COADS in situ data were compared for the period 1982–1988. Statistical methods were used to assess the quality of the satellite SST data. Temporal correlations between the two data sets were significant at the 95% confidence level for all basins and subregions examined, except for the North Atlantic Ocean. Biases in the satellite product, caused by volcanic aerosols and by use of the wrong satellite calibration tables, limit the utility of these data for climate monitoring. Accurate monitoring of SST variability in the southern oceans is not possible without satellite data, but because of the stringent accuracy requirements of SST data for climate monitoring, satellite data alone for this purpose is only marginal without further improvements.

Data from the NOAA polar-orbiting satellites were used to assess the current capability of determining global atmospheric water vapor content. Thus far, observations of total atmospheric water vapor content do not provide sufficient accuracy over the oceans because of the low signal-to-noise ratio of observations in the infrared portion of the spectrum (i.e., the high emissivity of the ocean masks the low-level water vapor signal). The NOAA satellites, however, have three channels that measure water vapor in the low, middle, and upper troposphere. Studies suggest that significant information can be obtained about upper level water vapor variability from the NOAA satellite data.

Time series analysis and cross-correlation techniques were used to assess the degree of coherence between tropical convection and the tropical and extratropical circulation during northern winter for three time scales: 30–70 days, 14–30 days, and 6–14 days. On the 30–70 day time scale, variance in tropical convection is dominated by the Madden-Julian Oscillation (MJO). The MJO was studied throughout its life cycle. Significant downstream propagation of Rossby waves is found when the tropical convection moves toward the dateline. Tropical forcing of the extratropical circulation is much weaker on the 14–30 day time scale than on the 30–70 day time scale, although convective heating over Africa, the eastern Indian Ocean, and Australia appears effective at generating anticyclones, which appear to act as Rossby wave sources, giving rise to extratropical wave trains and modulation of the east Asian jet. The same is true for the 6–14 day band, where strong signals of extratropical forcing of the intertropical convergence zone (ITCZ) convection are also found over the Atlantic. In this band, tropical forcing of the extratropical circulation is only weakly evident over most regions, and fluctuations in the east Asian jet are linked more to local transient eddy developments rather than to tropical convection.

A general circulation model study of the period 1985–1987 was completed. Global SSTs were specified for the model boundary condition and were allowed to evolve as they were observed. For the winter of 1985–1986, the model simulation was poor because the model's physical parameterizations could not produce

precipitation in the correct geographical regions. For the winter of 1986–1987, the model simulation was much better, although still flawed in details. An analysis of the source of the remaining discrepancies showed that the flaws are attributable to errors in the mean winds simulated by the model over the equatorial Pacific Ocean.

Plans FY 92

Data Management and Data Set Development

- CRDtools software will be enhanced and the data archive will be expanded. Analysis tools to be added include empirical orthogonal function (EOF) analyses, Hovmöller diagrams, histograms, and simple movie looping. Many refinements will be added in response to user feedback. New data sets will include DOE's gridded land station temperature and precipitation data sets, the Climate Analysis Center's Climate Diagnostics Data Base, and some satellite-derived data sets such as the Special Sensor Microwave/Imager (SSM/I) geophysical products.
- A revised update strategy is planned for COADS to avoid introducing new inhomogeneities into the record becaue of changes in COADS processing methods. First, a 1980s update consistent with data products available from COADS Release 1 (1854–1979) is planned in FY 92. Data for the entire period of record, 1854 to the present, will be reprocessed using improved techniques and additional data. This new set of products will be designated Release 2. In preparation for Release 2, an international users workshop will convene in Boulder in January 1992. A major goal of the workshop will be to produce recommendations for the revised data set, such as whether to increase the temporal or the spatial resolution of summary statistics. Another goal will be to explore possible collaboration with outside investigators to study methods of adjusting early records for measurement and observational biases.
- Different adjustment techniques for SST will be developed and the results will be compared with published results. The influence of different algorithms for gridding station temperature and precipitation data will also be assessed. Assessments are planned of the effect that changing spatial coverage of data over time has on estimates of interannual precipitation changes on regional to hemispheric scales. Indices of atmospheric circulation changes, such as variation in cyclone tracks, will be developed to improve our knowledge of natural climate variability.

Climate Diagnostic Research

- Work will continue on evaluations of satellite-derived SST observations, focusing on improved quality control of the satellite data and on the effects of volcanic aerosols. Efforts to develop a global climatology of atmospheric water vapor content will be expanded as part of the GEWEX water vapor program. Multisatellite data sets will be used to examine regional air-sea interaction phenomena in the eastern equatorial Pacific Ocean.
- A major effort will involve an investigation of global climate variations during 1985–1991, a 6-year period that includes a well-defined ENSO cycle, a major climate transition during early 1988, and systematic poleward propagation of anomalies. Initially, the interannual variations of the zonally averaged circulation will be the focus of study. The "chi-problem" will be used to obtain dynamically consistent fields of sensitive quantities such as divergence. Understanding the role of eddy transports during the period will lead to further investigations of interaseasonal variations, including the MJO, Rossby wave dispersion, and storm track fluctuations. The study of tropical-extratropical interaction on intraseasonal time scales will be expanded to include seasons other than northern winter.

- A new set of general circulation model experiments will begin to simulate the period 1985–1990. Global SSTs will be specified and will evolve as observed. An improved model will be used to determine the mechanisms by which SST affects the atmosphere and to assess the ability of a modern general circulation model to simulate these effects.

SPECIAL PROJECTS AND OBSERVATORY PROGRAMS

Accomplishments FY 91

The scientific highlight of the year for the Special Projects Group was the identification of a decreasing trend in surface ozone concentrations over the past decade at the South Pole. This trend is attributed to enhanced classical tropospheric ozone destruction due to increased amounts of UV radiation reaching the surface, a consequence of the Antarctic ozone hole. These findings were published in June 1991.

Analysis of the 1989 AGASP III data was completed, and 15 papers were submitted for publication.

In June, two members of the Special Projects Group mounted equipment on the National Center for Atmospheric Research (NCAR) Electra and flew on the Kuwait Oil Fire Project in the Persian Gulf. On these flights they operated the NOAA airborne 3–λ nephelometer and aethalometer (to measure soot carbon), exposed gas sample flasks, and collected a wide range of aerosol samples for NOAA, university, and other institution scientists. These activities have produced the only single-particle chemical analyses of the smoke aerosol from the airborne program. Soot aerosol particles (attributed to the Kuwait oil fires) have also been collected with balloon-borne impactors over Laramie, WY.

These balloon-borne impactors have also been successful in capturing stratospheric aerosols from the Pinatubo volcanic plume as it passed over the western United States.

Members of the Special Projects Group were instrumental in arranging funding for and organizing the First International Symposium on the Tropospheric Chemistry of the Antarctic Region, held in Boulder, 3–6 June 1991. The group also presented three papers at the conference.

Analysis of the historical Arctic radiosonde data set (now at 1.8 million sondes collected and prepared with support from the NOAA Climate and Global Change Program) shows that parts of the Arctic troposphere have warmed over the past 30 years, whereas other portions have cooled (up to 2°C). The entire radiosonde archive is being transcribed onto optical disks for distribution to the general scientific community beginning in October 1991.

The analysis of meteorological and aerosol conditions during the Arctic haze flights by the NOAA WP–3D aircraft in March 1989 in the Scandinavian Arctic (AGASP–III) was completed. On three flights, significant haze layers were detected and determined to be of either Northern European or Soviet Arctic origin. In the Scandinavian Arctic, the haze layers are thicker than in the Alaskan Arctic and generally contain a smaller ratio of large to small particles.

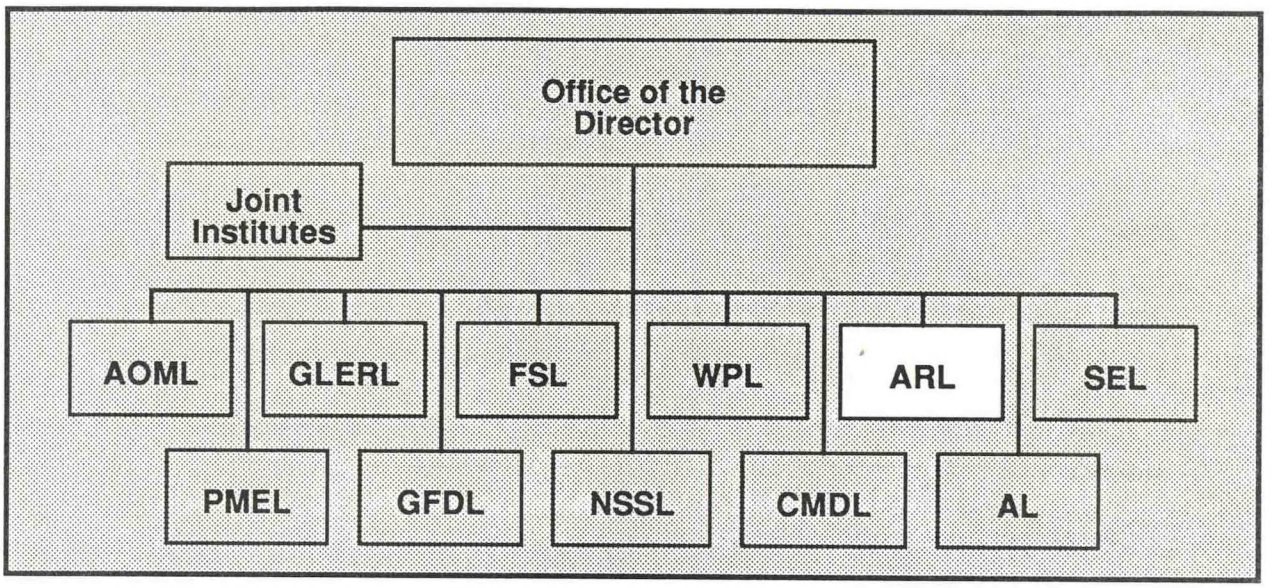
As part of an ongoing study of Arctic climatology, monthly mean surface temperatures were used to convert sea-level pressures to 1000 mb heights. Monthly mean thickness temperatures were calculated for the 1000–850 mb layer (1961–1990) and 1000-500 mb layer (1946–1990). Interannual variability in the 1000–850 mb thickness temperatures for the polar region (60°–90°N) shows the same pattern seen in the 850–700 mb layer temperatures reported earlier.

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 and cover such projects as aerosols, greenhouse gases, isotopes, precipitation chemistry, and solar and terrestrial radiation. Specific examples include detection and characterization of polar stratospheric clouds (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 Commonwealth Scientific and Industrial Research Organization); 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 DOE Environmental Measurements Laboratory); and detection and characterization of tropospheric chemical processes (University of Rhode Island and NCAR).

Plans FY 92

- Conduct the month-long (10 March–10 April 1992) AGASP–IV operations north of the Point Barrow baseline station using the NOAA WP–3D and the Office of Naval Research (ONR) ice station, which will be located 300 miles north of Prudhoe Bay. One hundred scientists will be involved in this program staged out of Anchorage, AK.
- Calibrate the Point Barrow baseline station in terms of the representativeness of the surface measurements related to vertical profiles of the same aerosol and gas species measured from the NOAA WP–3D. This research activity will be a component of the overall AGASP–IV program.
- Continue collecting and analyzing balloon-borne, single-particle, aerosol impactor samples of the Kuwait oil fire plume and Mount Pinatubo volcanic ash cloud as they flow past the Colorado-Wyoming region.
- Conduct a series of NOAA King Air research flights to calibrate the NOAA airborne aethalometer under rapid ascent/descent rates as a component of an aerosol characterization program supported by White Sands Missile Range.
- Continue to analyze Arctic radiosonde data sets and prepare three to five publications on the past 30–40 year temperature trends in the Arctic.
- Conduct a detailed study of the barrier winds along the North Slope of the Brooks Range, south of the Point Barrow Observatory, to describe the mesoscale flow influencing local transport in the region as part of the AGASP–IV Leads Experiment (LEADEX) Arctic leads program in March 1992.
- Install wind and temperature sensors at six levels on the 40-m tower at MLO to study the transition periods between upslope and downslope flows and the separation in the nocturnal boundary layer flow.
- Continue the analysis of layer temperatures in the Northern Hemisphere polar and temperate regions to explain interannual variability in the measured concentrations of trace constituents at high latitudes.
- Begin preparations to conduct an airborne calibration of the MLO baseline station along the lines of the March–April 1992 Point Barrow baseline station calibration.
- Complete collection and analysis of all the available Antarctic surface ozone records. This includes digitizing 6 years of continuous strip-chart ozone data from McMurdo Station.
- Continue the program of cooperation with universities, research institutions, and other government agencies at the baseline observatories. Detailed planning will continue for construction of a new building at MLO for the NDSC, which will involve several institutions in continuous, high-altitude monitoring of those species related to stratospheric ozone depletion.



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 (NRC), the Federal Aviation Administration (FAA), and the Environmental Protection Agency (EPA). The general areas of study relate to air quality and climate, and research focuses 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 also the official government source for information on atmospheric dispersion to guide emergency responses.

ARL consists of a Headquarters group in Silver Spring, MD; the Field Research Division (FRD) 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, atmospheric aerosols, and emergency response and preparedness, and an evolving theme on global climate change.

AIR QUALITY AND DISPERSION

FIELD STUDIES

Accomplishments FY 91

During FY 91, ARL teams were involved in field studies across the United States and reaching into the Pacific, and Mexico.

- In October 1990, ATDD participated in the First Look by ASTER at Turbulence (FLAT) experiment near Carpenter, WY. ASTER is the Atmospheric Surface Turbulent Exchange Research facility developed by the National Center for Atmospheric Research (NCAR). Eight microbarographs were installed and optically tracked airsondes were launched; data obtained will be used to study gravity wave activity and wave-turbulence interactions.
- In February 1991, ATDD participated in the DOE-sponsored Atmospheric Studies in Complex Terrain (ASCOT) field study near the Rocky Flats plant in Colorado. An extensive body of trajectory data was generated, for use in assessing the dispersion of emissions from the plant and for developing corresponding numerical models.
- Early in 1991, ARS participated in the NOAA Utah Atmospheric Modification Program (NUAMP). The NOAA King Air flew 77 research hours to help identify the mechanisms responsible for natural snowfall in Utah's Wasatch Mountains and to discern whether purposeful modification of the clouds might increase snowfall.
- In January 1991, ASMD and FRD participated in the Stagnation Model Analysis Program (STAGMAP) diffusion study in Medford, OR. The purpose of the field study was to develop and evaluate numerical dispersion models applicable to stagnation conditions. Preliminary analysis indicated the presence of terrain-driven flows.
- The airplane-mounted ATDD Mobile Flux Platform (MFP) was used in the DOE Atmospheric Radiation Measurement (ARM) Program at Boardman, OR, during June 1991. This platform combines the latest miniaturized atmospheric sensing and positioning technology with newly developed computer programs to derive accurate eddy flux information, even when the instrument package is not fixed in space. Almost 100 hours of airborne MFP data were obtained.
- During June 1991, studies on indoor air pollution were initiated by ASMD for the EPA. A home being studied in Roxboro, NC, was found to have wellwater contaminated with benzene, toluene, xylene, and other organics. Several experiments were conducted to assess the dispersion of air contaminated by the release of benzene from this water, such as via shower activity.
- ARL operates the only global network addressing the causes of pollution in rain in remote regions. In 1991, similar activity, MAP3S (Multistate Atmospheric Power Production Pollution Study), previously sponsored by DOE in the United States was terminated. Because of the urgent need for such measurements to quantify the consequences of emissions reductions, ARL joined with EPA to ensure the continuation of this network. The only precipitation chemistry network operating in the United States with the potential for early detection of the benefits of emission reductions is now largely an ARL program.
- ARS participated in the Lake Michigan Ozone Study (LMOS–2), from 9 June through 9 August 1991; the NOAA King Air flew 22 research flights. The purpose of LMOS–2 is to recommend the best ways to reduce ozone concentrations in the region.

- The ATDD MFP was flown during the EPA-sponsored preliminary Great Lakes Toxics Deposition study over Lake Michigan during July 1991 to conduct an initial test of instrument systems.
- Aerosol and rain samples continued to be collected on research cruises in the Pacific Ocean. Data obtained demonstrate that atmospheric transport of continental particles is an important pathway for nutrient deposits on the ocean surface, which in turn can affect ocean ecology.
- Only one major international field study involved a large ARL commitment during FY 91, although several cooperative projects continued their normal operation. This was the first Mexico City Air Quality Research Initiative (MCAQRI–I) field experiment, which started at the end of FY 90. Meteorological station and tethered balloon data were gathered by ATDD during the study. In February 1991, ATDD equipment was provided to Los Alamos National Laboratory for use during the second phase of the Mexico City study.

Plans FY 92

- Analyses of data obtained in the 1990 ASCOT/WATEX (Waves and Turbulence Experiment) will be completed. ATDD plans to repeat the experiment, using the newly improved position-locating capability of the MFP.
- A desert dust experiment is being planned by ARS to measure dust emission, transport, and deposition factors above the arid Owens Lake, CA, in cooperation with a group of Soviet scientists.
- ATDD will design and participate in a field study of cold air drainage and pooling near the DOE's proposed Yucca Mountain high-level radioactive waste repository in Nevada, in collaboration with DOE and National Weather Service (NWS) scientists.
- An expanded focus on ozone in the Southeast will be evident in the field work of two ARL divisions. ASMD will continue planning for the Southern Oxidant Study (SOS), a 5-year research program to examine oxidant problems in the southern United States. ATDD will collaborate in the 1992 experiment on Rural Oxidants in the Southern Environment (ROSE–92), with the Aeronomy Laboratory. As before, ATDD will provide airborne MFP technology and tower-based eddy correlation systems to measure fluxes.
- ARS will continue its studies of marine aerosols and precipitation to examine the linkages between aerosols, cloud condensation nuclei (CCN), cloud microphysics, and precipitation chemistry. Emphasis will be placed on the coastal areas of the western Atlantic and Pacific Oceans, as well as the Gulf of Mexico.
- Both ASMD and FRD will conduct field and modeling studies in the Measurement of Haze and Visual Effects (MOHAVE) Project. The project is mandated by Congress to determine the contributions of the Navajo Generating Station to visibility impairment at the Grand Canyon National Park.
- ASMD, in cooperation with the University of North Dakota, will conduct a field study measuring cloud and aerosol properties in the vicinity of Lake Michigan. Tentative experiments include characterization of aerosol distribution entering and leaving clouds, characterization of aerosols in an urban plume, and venting of the mixed layer by cumulus clouds.
- The research aircraft operated by ARS will be involved in several field campaigns during FY 92. The LMOS project over Lake Michigan appears likely to require a third field campaign, during the summer of 1992. The NUAMP program will extend through FY 92, leading to a second field campaign during the winter of 1992–1993.
- The Clean Air Act Amendments of 1990 affect several ARL divisions. ASMD is participating in the EPA Clean Air Status and Trends Network (CASTNET) program to implement a national monitoring network to assess changes in air quality and acidic/toxic deposition resulting from emission changes.

Several ARL groups, together with the Aeronomy and Wave Propagation Laboratories, are joining to measure the consequences of emissions changes more rapidly than is possible using standard monitoring procedures.

MODELING STUDIES

All ARL divisions are involved in air quality modeling. At ARL Headquarters, the focus is on regional and larger scales, using Lagrangian methods. At ATDD, the emphasis is on local to regional scales, using both Lagrangian and Eulerian methods. At ASMD, most activity relates to the need for improved assessment models, which are developed using both Lagrangian and Eulerian methods applied over continental scales. ARS and FRD are involved through testing models and refining specific modules.

Accomplishments FY 91

- A four-volume users' guide for the Regional Oxidant Model (ROM) was completed and released for public dissemination. ROM was used for several research investigations. For example, ozone was found to be significantly influenced by biogenic emissions, with the extent of the influence varying spatially. Also, ROM was employed to assess the relative benefits of more than two dozen regional control strategies for ozone.

- The Regional Acid Deposition Model (RADM), version 2.6, was developed, incorporating improved treatment of nonprecipitating clouds, improved vertical mixing, and improved boundary conditions. A project to determine deposition to sensitive areas corresponding to different emission reduction scenarios was initiated using the RADM. RADM was also used to examine the effect of oxidant limitation (a nonlinearity) on emission changes. The spatial extent of oxidant limitation covers most of eastern North America, where the absolute deposition reductions for sulfur are 10% smaller than if the conversion of sulfur to acidic deposition were linear.

- A nested-grid version of RADM was developed with a horizontal grid interval three times smaller than that of the 80-km grid in the current version of RADM. Using measurements from the Oxidizing and Scavenging Characteristics of April Rains (OSCAR) IV experiment, the nesting procedure was shown to yield improved estimates of sulfate and nitrate deposition than the coarser version of RADM.

- A Tagged Species Engineering Model (TSEM) was developed to estimate contributions of specific sources to total concentration in deposition. TSEM compared favorably to RADM in calculating the reduction in sulfate deposition due to a 50% reduction in sulfur emissions from electric utilities.

- Work started on improving computer-generated graphical outputs, a critical element of the operation of the Mesoscale Meteorological Model–Version 4 (MM4) using four-dimensional data assimilation (4DDA). The 4DDA technique requires expert review of thousands of meteorological observations before they are used for model guidance. A pilot effort using the Advanced Visualization System (AVS) program has allowed generation of three-dimensional color visualizations of observed scalar variables and horizontal wind vectors superimposed on the primary gridded model guidance for MM4–4DDA operation.

- ASMD is involved in several "Great Waters" environmental studies, including Chesapeake Bay and the Great Lakes. These studies involve both NOAA and EPA. Ten source-receptor matrices were developed using the ASMD Regional Lagrangian Model of Air Pollution (RELMAP) to determine annual amounts of wet and dry deposition, and annual air concentrations of sulfur compounds and toxic pollutants across the Chesapeake Bay Basin.

- Preliminary estimates of the deposition of airborne toxins to the Lake Michigan basin were prepared, using RELMAP, for emissions from sources 21 counties around the lake. For many substances, dry deposition appeared to dominate over wet. The model indicated that at least 70% of the diazinon contained in air entering the basin is deposited across the basin; for other chemical species the proportion deposited ranged from 15% to 40%.
- ASMD developed the Asymmetrical Convective Model (ACM) to improve treatment of vertical mixing in convective boundary layers (CBL). This model assumes that vertical transport within the CBL is inherently asymmetrical.
- At ARL Headquarters, the Hybrid Single Particle Lagrangian Integrated Trajectories (HY–SPLIT) long-range transport model was evaluated with a new nonlinear chemistry module that includes gas- and aqueous-phase oxidation of sulfur dioxide, and dry and wet removal of sulfur dioxide and sulfate particles in a Lagrangian framework. Ratios between sulfate deposition measured in the United States and modeled deposition estimates were between 0.5 and 1.6, with the best results occurring in the high deposition regions of the northeastern United States.
- ATDD researchers continued to concentrate on modeling flow and dispersion in complex terrain. Wind data from the 1990 ASCOT experiment near Oak Ridge, TN, were analyzed using wind roses, power spectra, cross spectra, and variograms. ATDD's puff model, VALPUFF, designed for modeling dispersion in the nocturnal drainage flow in a deep valley, was evaluated using ASCOT data.
- FRD completed work on the EPA's Stagnation Model Analysis Program. The work involved field measurements, data base development, and model evaluation.

Plans FY 92

In addition to continued work on existing regional models (RADM, ROM, and the Regional Particulate Model, RPM), ASMD has embarked on a multiyear effort to develop a third-generation air quality modeling system (MODELS–3) for gaseous, aqueous, and depositing pollutants over spatial scales from ~100 to ~1000 km. The MODELS–3 system will employ variable spatial resolution. Current second-generation regional models will serve as foundations for model development.

ASMD is heavily involved in a 5-year program on High Performance Computing and Communications (HPCC) for EPA, involving studies of software and modeling, technology transfer, and infrastructure.

ASMD, in a cooperative effort with the EPA, National Park Service, and U.S. Forest Service, will develop, evaluate, and apply air quality dispersion models for situations such as the effect of a proposed source on a class I area involving long-range transport over complex terrain. ASMD will also continue to participate in the environmental studies of the Chesapeake Bay Area and the Great Lakes.

Title IX of the Clean Air Act Amendments of 1990 requires the EPA Administrator to develop an experimental and analytical research effort to be conducted at the DOE Liquefied Gaseous Fuels Spill Test Facility. ASMD will be coordinating this activity.

ATDD will continue the analysis of detailed wind data from the 1990 ASCOT experiment in Tennessee, and will use the data set to test flow and dispersion models. Work will be initiated on Lagrangian particle modeling of pollutant dispersion in the nocturnal boundary layer in complex terrain. To represent pollutant transport in coastal areas and over complex terrain, available techniques to incorporate wind shear and terrain effects in puff trajectory models will be reviewed, and an effort will be made to incorporate the best techniques into TRIAD (a computer dispersion model involving initialization, dispersion, and transport) or VALPUFF.

ATDD will continue to study the interactions between gravity waves and turbulence using data from Oak Ridge and eastern Wyoming. Some of this work will be sponsored by the U.S. Army Research Office. The main goal of the work will be to correlate nocturnal episodes of turbulence with the presence of gravity waves.

Model performance evaluation will include at least five air quality dispersion models and they will be evaluated and compared.

AIRCRAFT VORTICES

The FAA has a high-priority Vortex Wake Program to minimize the effects of the aircraft trailing vortex hazard to air traffic in terminal area flight operations and to safely increase airport capacity. To support this objective, the FAA requires investigation of the vortex wake characteristics of the newer-generation, relatively heavy twin engine jets.

Because of the FAA's previous high success with using the tower fly-by techniques at the FRD vortex wake flight test facility and their personnel, the FAA selected the facility to investigate vortex wake characteristics, starting in the fall of 1990. The flight test program was to characterize the vortex wakes as a function of various ambient atmosphere indices.

Accomplishments FY 91

Three test aircraft were leased by NOAA from United Airlines and tested in take-off, landing, holding, and cruise configurations. In addition, the FAA B–727 was used for a small number of tower fly-bys. For landing configuration tests more representative of real airport operations, a Precision Approach Path Indicator (PAPI) system was installed at the test site. The flight test operations were very successful. Of the 205 tower fly-bys that were flown, 136 runs had one or both vortices intercept the data acquisition tower.

Plans FY 92

The results of the wake vortex analyses will be submitted to FAA to assist the update, as necessary, of air traffic control operation criteria and procedures at airports throughout the United States. FRD will process and analyze the data acquired and prepare a report.

BACKGROUND MONITORING

Accomplishments FY 91

As a result of the recommendations from a small group of international experts regarding the status of the World Meteorological Organization's (WMO) Background Air Pollution Monitoring (BAPMoN) program, a summary document was completed and submitted to the WMO. The report recommends revamping the BAPMoN program and incorporating it into the Global Atmosphere Watch (GAW). A monitoring guide giving concise summaries of the important measurements in the GAW is being written. More than 22 program summaries, including those for greenhouse gases, solar radiation, and precipitation chemistry, were completed, giving an outline of the measurement program's importance, siting requirements, methods of measurement and sampling frequency, and data reduction and archiving procedures.

Plans FY 92

A summary of the status of the routine turbidity measurement program conducted under the auspices of the WMO will be completed. The GAW summary guide will also be completed and submitted to the WMO for publication.

FLUID MODELING

ARL operates two fluid modeling facilities, the larger (ASMD) concentrating on studies of the physical processes underlying transport and dispersion as they are affected by large obstacles, and the smaller (ATDD) concentrating on studies of processes involved with deposition and dispersion around smaller objects.

Accomplishments FY 91

- At ASMD, investigation of flow structure and dispersion of dense gas jets released in flat terrain and in the vicinity of buildings. This was in cooperation with a visiting scientist from the University of Hamburg, Germany.
- At ASMD, examination of the flow structure and dispersion of pollutants through an array of cubical blocks simulating an urban or industrial complex; this was in cooperation with a visiting scientist from the University of Cambridge, England.
- At ASMD, study of the concentrations of pollutants resulting from steady point-source above-roof exhaust releases above each of four rectangular building models.
- At ATDD, studies of turbulent mass transfer of pollutants to the surfaces of selected architectural components (e.g., equestrian statues, columns) using naphthalene as a surrogate material, in collaboration with National Park Service personnel. Results were reported at international meetings on dry deposition processes in Montreal, Canada, and Glasgow, Scotland.

Plans FY 92

The ASMD Fluid Modeling Facility will continue to be used to study flow in complex terrain, flow around buildings and other obstacles, basic characteristics of boundary layer flow, and dispersion of gas plumes in air and water.

FLUXES AND AIR-SURFACE EXCHANGE

DEPOSITION

Accomplishments FY 91

The ATDD dry deposition CORE/satellite network continued to monitor any changes in dry deposition that may result from implementation of new emission controls. During FY 91, more process-level modeling was incorporated into the air/surface exchange parameterizations for the major pollutants of interest.

Several years of chemical concentration records were analyzed to assess the use of weekly average concentrations in the ATDD-developed inferential approach to estimating dry deposition of sulfur dioxide. Summertime correlations between measured concentrations and inferred deposition velocities for SO_2 in Oak Ridge indicate about a 14% underestimate of inferred annual SO_2 deposition.

At ARL Headquarters, a comparison of precipitation depths from MAP3S station locations was made with data from collocated National Atmospheric Deposition Program (NADP) instruments. Results indicate that agreement is excellent at many of the stations and that it may be possible to extract event precipitation chemistry data from several of the weekly precipitation chemistry records. Weekly precipitation monitoring is generally not perceived to be adequate to meet the long-term needs of deposition trend modelers.

Precipitation quality measurements were also compared. Except for minor, but statistically significant, biases in sulfate concentration and deposition, the other analyses were found to be generally comparable between the two data sets and with the measurement precision as estimated from about 1 year of duplicate sampling under the MAP3S protocol.

Work continues on several studies in the Global Precipitation Chemistry Project. The role of chlorine in the marine atmosphere is being studied in conjunction with the National Science Foundation (NSF). Work to establish a Soviet precipitation chemistry station at Bolshoi Perog has also continued.

Under NOAA's Coastal Ocean Program, the Atmospheric Nutrient Input to Coastal Areas (ANICA) project began. Workshops on deposition to coastal and estuarine areas, with emphasis on the Chesapeake Bay, were sponsored. A data archive was set up to evaluate wet deposition to the Bay and to begin monitoring dry deposition.

Plans FY 92

A new dry deposition CORE/satellite station will be installed near Chesapeake Bay, in collaboration with the Smithsonian Institution and EPA, as part of the ANICA effort to characterize airborne deposition to coastal waters. Research will continue to focus on improving the parameterization of the deposition process. Comparative analyses among the three CORE sites will be performed to determine whether the weekly sampling protocol results in error limits that are acceptable to the dry deposition program.

Many of ARL Headquarters programs conducted during FY 91 will be continued. An intercomparison of precipitation chemistry from a variety of North American programs will be conducted. The role of chlorine as an active chemical constituent of precipitation collected at sea will be explored aboard a NOAA research ship near the Azores during a summer field study.

ATMOSPHERE-SURFACE EXCHANGE

Accomplishments FY 91

ATDD conducted experiments to evaluate newly developed instrument systems for measuring air-surface exchange of mass, momentum, and energy. Important developments include the infrared water/carbon dioxide (H_2O/CO_2) concentration fluctuation sensor and the MFP. Such instrumentation will become essential in future climate change studies. One significant test, carried out during late 1990 over the sea near the Florida Keys, demonstrated the relative ease with which such measurements can be made with the newly developed instrumentation.

A leaf-to-canopy photosynthesis and evaporation model was developed at ATDD and tested against data from a soybean field and a deciduous forest canopy. The model computes foliar source and sink strengths

based on biochemistry, physiology, micrometeorology, and radiative transfer algorithms. Computations agree very well with measurements of CO_2 and water vapor flux densities. The model shows promise for examining the two-dimensional transport of gases over incomplete canopies and for trace gases that exhibit bidirectional exchange characteristics between the air and the surface.

The ATDD Lagrangian random-walk canopy model was also modified for estimating nitric acid (HNO_3) deposition over soybeans and a deciduous forest. Model computations of deposition fluxes and concentration profiles agree well with data measured over the Walker Branch, TN, forest. The influences of mutual leaf sheltering and the errors that are induced by applying flat-plate theory to compute mass transfer to leaves cancel each other.

Wavelet theory, a method for detecting local events in temporal or spatial records of environmental variables, is being developed and tested at ATDD. The method is being used to characterize the size, shape, duration, and frequency of occurrence of sunflecks under a deciduous forest, and the coherent turbulent structures that transport heat, vapor, and momentum within and above corn and pine canopies. Information obtained from wavelet detection methods will affect modeling of chemical reactions inside plant canopies; this information can be used in a time-dependent model to link turbulent mixing and air chemistry.

An analysis of sensing techniques for estimating the leaf area indices (LAI) of forest canopies was completed. The ATDD canopy traversing system was used to measure the probability of solar beam penetration and to estimate LAI. ATDD also collaborated with University of Alberta scientists to test energy exchange and soil moisture budget modules of an agroecosystem model.

Plans FY 92

- A further step will soon be taken in the development of a chemical flux measurement system for the NOAA King Air: the implementation of a system for measuring the fluctuating component of the wind. This will be an adaptation of the ATDD technique. Fabrication and testing of this system should be completed during FY 92.
- A study on the transfer of mass and energy at several levels in a deciduous forest will examine the role of coherent eddy structures on turbulent transfer. Further investigation will focus on the role of pressure fluctuations and large-scale coherent structures on trace gas exchange at the soil surface beneath a forest canopy.
- An overview of sulfur deposition to plant canopies will be prepared for a workshop on Sulfur Nutrition and Sulfur Assimilation in Higher Plants: Physiology Functions and Environmental Significance, to be held in Garmisch-Partenkirchen, Germany, during April 1992.
- The ATDD canopy photosynthesis model will be adapted to study the exchange of isoprene and carbonyl sulfide (COS) from and to a deciduous forest canopy. These trace gases are of interest because isoprene emission is linked to photosynthetic electron transport, and COS is taken up through stomata and is released from the soil. ATDD's models already deal with these exchange pathways. The canopy photosynthesis and evaporation models and eddy correlation flux measurement systems will also contribute to the planned Atmosphere-Ecosystem Gas Interchange Study (AEGIS) and Boreal Ecosystem-Atmosphere Study (BOREAS) over boreal forest environments, and to the continuing DOE ARM Program over crops and desert.

EMERGENCY RESPONSE AND PREPAREDNESS

Accomplishments FY 91

At ARL Headquarters, a Volcanic Ash Forecast Transport and Dispersion (VAFTAD) model was developed to replace the forecast trajectory model designated in the Volcanic Hazards Alert Memorandum of Understanding between NOAA and the FAA. VAFTAD is presently applicable for volcanic eruptions anywhere in the Northern Hemisphere and can be run, upon notification of an eruption, on a personal computer in about five minutes. The model improvements incorporate ash settling and dispersion.

ARL Headquarters provided trajectory forecast guidance for the eruptions of Mt. Pinatubo in the Philippines. ARL responded to each of 15 eruptions with a forecast run and at least one update run when new meteorological data were available. Altogether, 39 model runs were made. The National Meteorological Center (NMC) has subsequently taken over the operational responsibility for providing trajectory forecast guidance to the National Environmental Satellite, Data, and Information Service (NESDIS). ARL will provide backup support to NMC and will continue model development.

Part of ARL's emergency assistance program is to supply trajectory forecasts for special events, such as long-distance manned balloon flights. ARL participated in two of these events recently: a record-breaking cross-Pacific hot air balloon flight from Japan to northwest Canada in January 1991, and a test flight in the northwest United States in preparation for an around-the-world flight planned for November 1991. The former flight required preparation and active participation by an ARL emergency assistance team for 2 months, much of which was due to delays in launch because of trajectory forecasts of unacceptable flight paths.

A high-resolution dynamic wind field model was set up to run on the ARL Headquarters Reduced Instruction Set Computer (RISC) workstation. High-resolution terrain and land-water coverage data were incorporated. The first application of this new technology was in response to demands for improved dispersion information for the Arabian Gulf region. The model has the attraction that it can simulate the seabreeze front, known to be a factor influencing the spread of smoke from the Kuwait oil fires.

FRD provided the first U.S. meteorological and dispersion adviser to the Arabian Gulf countries. Two FRD employees have been stationed in the Gulf region for nearly 3 months.

A system of meteorological towers developed by ATDD for DOE was set up in Kuwait to provide information on wind fields in the area of the oil fires. A health-alert system was generated for the area. Many ATDD personnel have been personally involved in studies and advisory roles in Saudi Arabia, Kuwait, and other Arabian Gulf locations. An ATDD representative has been stationed in Kuwait since March. ATDD has provided scientific expertise and briefings for the U.S. Embassy in Kuwait and visiting U.S. officials.

Trajectory and dispersion forecasts generated by ARL Headquarters for the Arabian Gulf region were set up to run automatically, including facsimile transmission of results to interested governments in the region. The ARL-modified dynamic wind-field model was set up at King Faud University of Minerals and Petroleum, Saudi Arabia, so as to provide a local capability to model sea breeze effects.

The WMO expert conference on the Kuwait oil fire plume and its atmospheric effects was chaired by an ARL representative. The current operational assessment of potential future exposure regimes is an ARL product. FRD has provided emergency assistance to DOE at the Idaho National Engineering Laboratory (INEL) for more than 40 years. In the late 1960s, the first network of mesonet stations was established over the upper Snake River plain, in and around the INEL, to provide meteorological support to DOE and its INEL contractors. Through the 1970s and 1980s, FRD provided such services continuously. The first phase of an upgrade of the mesonet system began in FY 90 and was completed late in FY 91.

ATDD provides somewhat similar services for the Oak Ridge Operations Office of DOE. A year-long meteorological site survey of the Oak Ridge area was completed in December 1990. Preliminary analysis

of the site survey data was completed in March 1991, and ATDD recommended that DOE install 10 supplemental meteorological towers in the Oak Ridge area over roughly 40 km by 15 km. Support of the DOE emergency management office in Oak Ridge also included improvement of HARM–II (the Hazardous Atmospheric Release Model) in use at several DOE and state facilities, and development of detailed documentation and training materials for model operators.

ARL Headquarters is now responsible for providing meteorological support to the Operations Center of the NRC in Bethesda, MD. This includes providing ARL personnel to the Operations Center during an emergency for meteorology and dispersion training for NRC personnel, and evaluating current and future modeling efforts at the NRC.

Plans FY 92

Collaboration with Kuwaiti environmental specialists is expected to continue until the oil fires are extinguished. Installation of an improved modeling capability in Kuwait is anticipated.

Further development of VAFTAD will include incorporating precipitation and ash deposition in the model, running sensitivity studies on the particle size/activity distribution with height within the initial ash cloud, and verifying the model using data from past eruptions.

Support of DOE at both Oak Ridge and Idaho Falls will continue. At Idaho Falls, Phase 2 of the upgrade began in late FY 91 and will continue. The revised system will feature a quick response capability and on-line dispersion modeling for predefined emission scenarios developed for INEL facilities. Data archiving, expanded quality assurance, communications, and video displays of data and calculations will be featured.

The high-resolution dynamic wind field model now in place at ARL Headquarters will be modified to use NMC forecast and initialization fields as boundary conditions to permit the model to be run in real time for any location.

GLOBAL CLIMATE CHANGE

CLIMATE DIAGNOSTICS

Accomplishments FY 91

The record of global tropospheric and low-stratospheric temperatures, maintained at ARL Headquarters since 1958, was updated through the summer of 1991. In the troposphere the global annual temperature was a maximum in 1990, 0.44°C above the 1958-88 mean and 0.02°C warmer than the previous maximum year of 1988. The 6 warmest years of this 33-year record all occurred after 1979. After adjustment for the influence of equatorial sea-surface temperature (SST) (El Niño) on global tropospheric temperature, 1990 becomes by far the warmest year of record.

The global surface temperature at the radiosonde sites was also indicated to be a maximum in 1990 (0.10°C warmer than the previous maximum year of 1987), and the global temperature in the 100–50 mb layer of the low stratosphere a minimum (0.07°C cooler than the previous minimum year of 1988). Global tropospheric and surface temperatures for the first three seasons of 1991 are essentially the same as for the first three seasons of 1990.

There is evidence of considerable stratospheric warming following the Pinatubo eruption in June 1991. The 30 mb (24 km) temperatures at Balboa (Canal Zone), Singapore, and Ascension Island increased by 4.0°C, 5.0°C, and 3.7°C, respectively, between June and August relative to their average values.

The record of 300-mb north-polar vortex size, beginning in 1963, was updated through the spring of 1991. The size was a minimum in 1989 and 1990, 6% below average. The contracted vortex of 1990 is consistent with the tropospheric warmth of that year.

The rocketsonde record, extending from 1972 through 1989, indicates a temperature decrease of 0.9°C per decade in the middle stratosphere, 1.6°C per decade in the high stratosphere, and 2.0°C per decade in the stratopause layer.

The record of U.S. cloudiness and sunshine, beginning in 1950, was updated through the spring of 1991. In both 1989 and 1990 the quantities were near their long-term average.

Global total ozone and ozone profiles were updated through 1990 using ground-based data. Global total ozone decreased by 3.6% between 1979 and 1990. A value of 4.1% is obtained from the total ozone mapping spectrometer (TOMS) satellite and a value of 3.2% from the Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS). The ground-based data indicated essentially no ozone depletion between 1958 and 1979, however. The total ozone decrease in the last 12 years mostly reflects an ozone decrease in the low stratosphere.

A preliminary examination of global radiosonde data suggested that absolute humidity in the western Pacific region has increased since 1973. This finding was supported by an analysis that also detected an El Niño–Southern Oscillation (ENSO) signal in global water vapor. A preliminary analysis of 15-day periods in January and July 1989 showed little day-to-day change in global average total water vapor in a column extending from the surface to 700 mb, giving confidence in the data analysis techniques.

A study of the changes in instruments and reporting practices of U.S. radiosondes shows the effects of changes on the climate record. The acquisition of information (under WMO auspices) on the history of other nations' instrumentation and practices continued; some changes were substantial enough to affect the analysis of climate change.

ASMD obtained climatological data and completed the processing for the Environmental Monitoring of Air Pollution Forest Pilot Project in New England. Summaries of drought, temperature, precipitation, and disturbance events were produced for the most recent 30 years, the most recent decade, and 1990. The information was prepared in map, graph, and narrative form. This is a cooperative project with the U.S. Forest Service.

Plans FY 92

At ARL Headquarters, the temperature, cloudiness, sunshine, and ozone monitoring programs will continue, with particular attention to the influence of the Mt. Pinatubo eruption. The examination of relationships between humidity and temperature on a monthly time scale will also continue. Relationships between anomalies of mean monthly precipitation and mean monthly precipitable water will be investigated, in cooperation with Climate Analysis Center scientists.

Data from the global radiosonde network will be examined for record length, homogeneity, and completeness to select stations suitable for further analysis. The statistical characteristics of the resulting network will be established.

ASMD, working with the U.S. Forest Service Southern Global Change Program, will provide guidance regarding future climate conditions in the southern United States. Future activities will include studies of relationships between the global general circulation and regional climate and air quality, including the development of exposure and climate scenarios for use in assessing the effects of climate changes on climate and ecosystems.

AEROSOLS AND RADIATION BALANCE

Accomplishments FY 91

Several ATDD scientists participated in a major multilaboratory field campaign in Oregon for the DOE ARM Program. Turbulent fluxes of sensible and latent heat, CO_2, and ozone were measured directly using the eddy-correlation technique from tower and aircraft systems. In addition to examining these fluxes and how they might affect cloud development, ATDD scientists are analyzing the spatial variance of these fluxes using the data collected from the aircraft MFP.

At ASMD, a method for describing aerosol dynamics was incorporated into the RPM. Airborne aerosols are characterized as an assemblage of distinct populations of particles, distinguished by size and chemical composition. The model will be used for the prediction of gaseous and particulate pollutants over regional scales for assessments of acid aerosol, visibility, radiative transfer, and airborne toxins.

ARS took the first step in developing a flux measurement system for the NOAA King Air research aircraft. During FY 91, an inertial navigation system was designed, fabricated, and tested. This system allows the precise computation of aircraft attitude, position, speed, and acceleration as a function of time. This information is required for accurate momentum flux calculations.

ARS continued the analysis of the U.S./U.S.S.R. Working Group 8 "Dune" experiment. Data were obtained related to a dust storm on 16 and 20 September 1989 in the Kafirnigan Valley, Tadzhik, S.S.R. (Tadzhikistan). The experiment provided data for six problem areas: (1) specifications of dust-producing mechanisms at the source, (2) specification of dust movement, (3) description of physical and radiative properties of the desert dust, (4) description of chemical transformations and composition of the desert dust, (5) specification of the large-scale structure of dust storms through satellite remote sensing, and (6) modeling of the Kafirnigan Valley dust system.

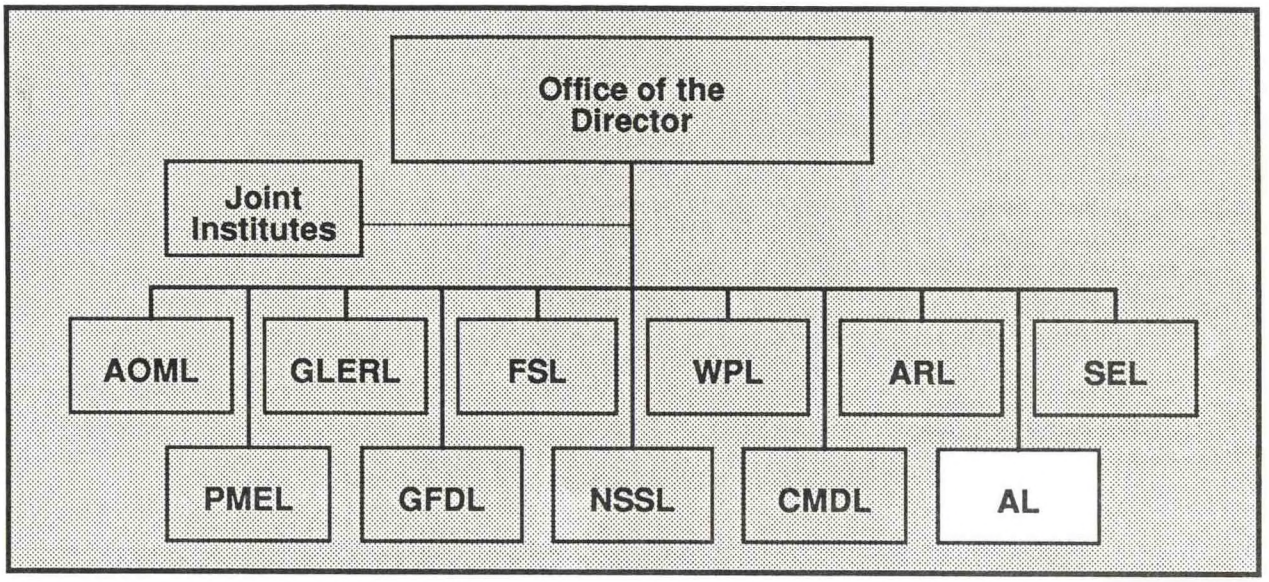
For application in the context of resuspension of particles, ARS finished initial experimental work on wind stress partitioning. Data were obtained in collaboration with the University of New Mexico from desert locations in New Mexico, Arizona, and Soviet Central Asia. The data were compared with previous results on the partitioning of momentum by nonerodible spheres, with good agreement for the southwestern United States.

Plans FY 92

ATDD's work within the DOE ARM Program will continue; a second field study in Oregon is expected. ATDD will assist ARM management in designing the permanent field sites to be used during the later portions of the ARM Program.

ATDD will collaborate in field experiments to measure sources and sinks of CO_2 and methane (CH_4) over northern peatlands in the multi-agency (NSF, NOAA, and several universities) AEGIS program in northern Minnesota. Fluxes will be determined using micrometeorological methods on towers and aircraft, and attempts will be made to assess the controlling processes.

At ARS, development of remote sensing techniques for the detection and study of large-scale dust storms will continue, in cooperation with the U.S. Geological Survey. ARS is cooperating with the National Geophysical Data Center Paleoclimate project in examining visibility records and National Park Service aerosol monitoring data. The intent is to define relationships between dust and other climatic variables that can be used for paleoclimate research.



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 protect the quality of the atmosphere. The research concentrates on the stratosphere and troposphere, but also involves the mesosphere and thermosphere.

The research methods involve 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. The Laboratory plays a major role in providing scientific advice in these areas to policymakers.

ATMOSPHERIC WAVES AND TURBULENCE THEORY

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

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

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

Accomplishments FY 91

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:

- Applied our turbulence theory to derive the first formula for the kinetic energy of wind shear turbulence. This formula is critical for planetary boundary layer models.
- Completed calculation of pressure fluctuations in the atmosphere.
- Initiated a theory for viscous dissipation, a principal sink of atmospheric fluctuations.

Atmospheric Gravity Waves

- Developed a method for determining the source of gravity waves in the atmosphere.
- Completed a developing theory that explains the ubiquitous minus 3 power law of saturated gravity waves in the middle atmosphere.
- Determined a relation between Stokes drift (a recently discovered nonlinearity of gravity waves) and diffusive transport of mass and momentum.

Plans FY 92

Turbulence Modeling

- Derive equations that determine the turbulence spectrum of any shear flow. This equation is needed to make turbulence models reliable.
- Continue to develop a theory for viscous dissipation of atmospheric fluctuations.
- Initiate a theory to predict all atmospheric spectra at small wavelengths.

Atmospheric Gravity Waves

- Determine the spectrum of unsaturated gravity waves, which provide information about wave sources.
- Initiate a theory for the spectrum of atmospheric temperature variations.

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. 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. These data are used to understand the effects of natural and anthropogenic chemicals on the environment.

Accomplishments FY 91

- The kinetics and mechanisms of the reactions of metastable atomic oxygen with chlorofluorocarbon (CFC) replacements were studied. These data help define the stratospheric lifetimes, altitude of loss, and products of degradation of the replacements.
- The photochemistry of ozone at 193 and 222 nm was investigated. This provides information needed to fully understand ozone chemistry in the upper atmosphere.
- The ultraviolet (UV) absorption cross sections and hydroxyl (OH) reaction rate coefficients of four common halons, which are used as fire extinguishers, and of one proposed halon substitute were measured. These data provide a basis for assessing their environmental effects and for regulating these compounds, which destroy stratospheric ozone.
- The mass accommodation coefficients for $ClONO_2$ and N_2O_5 over sulfuric acid surfaces were measured. Model calculations using these results suggest that the loss of N_2O_5 on stratospheric aerosols could cause a significant ozone loss at high latitudes in the lower stratosphere.
- The photochemistry of HNO_3 and H_2O_2 at 193, 222, and 248 nm was investigated. The data obtained help us to understand the chemistry of these molecules in the atmosphere as well as in laboratory studies.
- The UV absorption spectrum and cross sections and the ν_2 infrared band intensity band of HOCl were determined. The UV spectrum defines the atmospheric lifetime of HOCl, and the infrared data will be used to interpret field measurements.
- High-resolution infrared absorption measurements for several bands of OClO were made and analyzed to develop improved spectroscopic parameters for this stratospheric trace gas.
- About 1200 infrared absorption lines of the HO_2 radical were measured, assigned, and analyzed. The spectroscopic parameters obtained are useful to identify and detect this important radical in the atmosphere and in the laboratory.

Plans FY 92

- The mechanisms for the reaction of $ClONO_2$ with HCl on ice surfaces of the types found in polar stratospheric clouds will be investigated.
- The reactions of OH with several organic compounds will be investigated at atmospheric temperatures.
- The reactions of Cl atoms with CFC replacements will be studied.

- Methods will be developed to detect the key intermediates in the atmospheric oxidation of the CFC substitutes and some reactions of these species will be studied.
- The photochemical processes that destroy fully fluorinated gases in the atmosphere will be studied.
- The kinetics and UV absorption spectrum of Cl_2O_3 and some other chlorine oxides will be studied.
- Infrared absorption measurements, suitable for greenhouse gas model calculations, of CFCs and the proposed CFC replacements will be made.

ATMOSPHERIC DYNAMICS

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

Much of our research is based on data obtained using wind-profiler radars, which are also called stratosphere-troposphere (ST) radars. Such radars can measure wind profiles about 1,000 times faster than routine balloon soundings and can also directly measure vertical velocity.

Accomplishments FY 91

We continued our systematic studies of the properties of the atmospheric gravity wave field in the troposphere and lower stratosphere. We further developed our model for the frequency spectrum of Doppler-shifted gravity waves and compared the model with spectra of wind fluctuations observed by the Flatland radar near Champaign-Urbana, IL. Measurements of the vertical flux of horizontal momentum show that, over the very flat terrain in central Illinois, the momentum flux is usually very small but increases dramatically when meteorological fronts pass over. Further measurements will permit assessment of the relative contributions to the global momentum flux over mountainous and very flat terrain (which, including the oceans, occupies at least 80% of the surface of the Earth). Divergence of the momentum flux leads to accelerations of wind, which are very important to numerical weather prediction.

Six sensitive air pressure sensors were installed in an array around the Flatland radar to detect the passage of fronts and to measure the wavelength and velocity of the gravity waves being observed by the Flatland radar.

Simultaneous observations with the Urbana wind-profiler radar, 23 km to the northeast, show that both radars measure the same variations of the vertical wind as a function of altitude, averaged over periods as long as 1 day. This shows that wind-profiler radars are capable of precise measurements of the vertical wind, which is a critical, but very difficult to measure, meteorological parameter.

Plans FY 92

The radar antenna will be modified to point vertically to improve its capability for measuring the vertical wind. An interferometric radar will be installed at the Flatland site for several months to compare the capabilities of two different kinds of radars and to study the radar echoing process. Then the interferometric radar will be moved to a station about 25 km to the east, to form a triangle with the Flatland and Urbana

radars. Data can then be used to compute atmospheric vorticity, which is an important parameter for weather forecasting.

A 915 MHz lower-tropospheric radar and an associated Radio Acoustic Sounding System (RASS) will be installed at the Flatland site to provide wind and temperature profiles from near the ground up to a few kilometers' altitude.

About 20 more air pressure sensors will be installed at the widespread field stations of the Illinois State Water Survey to study waves with longer wavelengths.

The Flatland radar and its associated instruments will be operated in campaign mode to support the STORM Fronts Experiment System Test (STORM–FEST) program and other special observing programs.

TROPICAL DYNAMICS AND CLIMATE

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

Accomplishments FY 91

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.

Based on an analysis of the first 4 years of wind observations from Christmas Island, we have found a pronounced annual variation in the tropospheric zonal winds over the central Pacific. The winds observed at Christmas Island depend on the strength of the Walker Circulation, and their annual variation is related to the annual variation in the strength of the Walker Circulation. The magnitude of the annual cycle is modulated interannually according to the phase of the Southern Oscillation. Direct measurements of long-term vertical motions over the central Pacific Ocean have been made for the first time using the Christmas Island wind profiler. Monthly mean profiles of vertical motion show subsidence through much of the free troposphere. Above 14 km, vertical motions are upward, and maximum velocities are recorded near the tropopause. The magnitudes of observed vertical motion at tropopause heights suggest an important influence of optically thin cirrus clouds. The phase of the diurnal cycle of vertical motions observed in the tropopause region supports this interpretation.

Substantial progress was made in the construction of a trans-Pacific network of wind-profiling Doppler radars. The Piura, Peru, wind profiler has been upgraded and now observes horizontal as well as vertical motion. The Darwin, Australia, wind profiler has been upgraded with the construction of an expanded antenna array. During the past year it has been operated in collaboration with the Australian Bureau of Meteorology Research Centre. The Saipan wind profiler has been used by the Joint Typhoon Warning Center in Guam. Site preparations have continued for the wind profiler to be constructed at Biak, Indonesia.

Observations taken with the UHF wind profiler used in support of the Hawaiian Rainband Project (HARP) have been analyzed in conjunction with scientists at McGill University. A pronounced capping inversion is clearly evident in signal strength records. Velocity observations show evidence of nighttime drainage flows, which play an important role in the evolution of heavy rain episodes experienced at Hilo.

We operated a UHF wind profiler equipped with RASS in conjunction with the Wave Propagation Laboratory (WPL) and the National Center for Atmospheric Research (NCAR) to measure winds and

temperature during several intensive field campaigns in support of the Department of Energy's Atmospheric Radiation Measurement (DOE/ARM) Program. The results are being evaluated to advise DOE of the best combination of instruments to be utilized at DOE/ARM Cloud and Radiation Testbed (CART) sites.

AL scientists have worked with colleagues in WPL to establish a Cooperative Research Development Agreement that serves as a vehicle for transfer of lower wind profiling technology to the private sector. The private sector companies have already successfully used lower tropospheric wind profilers equipped with RASS in support of a major air quality field program, the Lake Michigan Study.

In June, AL scientists worked with NCAR scientists to install and operate a lower tropospheric wind profiler on a ship for the first time. The test was made aboard the *Malcolm Baldrige*, and NCAR Cross-chain Loran Atmospheric Sounding System (CLASS) balloons were utilized for wind comparison purposes. A gyro-stabilized platform was used to isolate the profiler from ship pitch and roll. The profiler winds were corrected for ship motion using a global positioning system (GPS) receiver. Root mean square (RMS) wind speed differences between profiler and balloon measurements were typically less than 1 m s^{-1}. This development effort is part of an ongoing collaboration between AL and NCAR to develop Integrated Sounding Systems (ISS) for use in TOGA and the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE).

Plans FY 92

Our operations at Christmas Island will continue with TOGA funding, 6-hourly data will be transmitted via satellite to the scientific community, and high-resolution optical disks 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 during the year.

We plan to install with NCAR an ISS at Manus Island, Papua New Guinea. A second land-based ISS is planned for Kavieng, Papua New Guinea. Two shipboard ISS will also be constructed. All of these systems will be used to support TOGA COARE.

Several UHF lower tropospheric wind profilers will be constructed for deployment on islands in the tropical Pacific in support of TOGA. We plan to develop the capability of unattended operation of profilers on uninhabited islands.

Collaborative research with the University of Colorado and the Australian Bureau of Meteorology Research Centre will continue, utilizing the observations of the Trans-Pacific Wind Profiler Network.

We will continue to use the available tropical Pacific rawinsonde data base to study 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 El Niño warming at extratropical 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 by collaborative experiments. In recent years the principal research activities focused on 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 a sufficient understanding of the composition and energy budgets of the atmosphere so that trends can be accurately predicted.

Accomplishments FY 91

In a collaborative study with the AL Tropospheric Chemistry Program, WPL, the Air Resources Laboratory (ARL), NCAR, and several universities, we analyzed the measurements made in Alabama during the Rural Oxidants in the Southern Environment (ROSE) campaign and made three-dimensional model simulations of the photochemistry and budget of OH and ozone for the eastern United States. In the model, average surface layer (0–80 m) concentrations of OH increase by about a factor of 3 from preindustrial times to the present. In some areas, the increase is greater than a factor of 10. In the planetary boundary layer or the mixed layer, average OH concentration increases by about a factor of 2. The increase is mostly due to the reaction of NO with HO_2 and the increase of ozone.

Above the boundary layer, our model results indicate a decrease of OH by 10% to 20%, mostly because of the increase of CO and CH_4, which are the major sinks of OH. The boundary layer OH concentrations over remote areas are also estimated to have decreased by similar amounts. Globally, we estimate that the average OH concentration may have decreased by about 10% because of anthropogenic activities. This estimate has about a factor of 2 uncertainty at upper and lower sides.

Aerosols from anthropogenic sources contribute significantly to the scattering of solar radiation in the atmosphere over most populated areas. Using observed values of visual range, we estimate that in nonurban areas of the industrialized countries, the amount of biologically active solar radiation (UVB, 290–320 nm) reaching the surface has decreased by 6 to 18% since the industrial revolution, primarily because of aerosols formed from emissions of sulfur dioxide (SO_2). The UVB reduction in the industrialized countries may have offset partly or fully the UVB increases associated with current stratospheric ozone depletion at continental midlatitudes in the Northern Hemisphere. However, this offset is not expected to continue because the SO_2 emissions are leveling off in the industrialized countries.

Plans FY 92

The Aeronomy Laboratory three-dimensional mesoscale model will be modified to make diagnostic and prognostic studies in collaboration with two international field experiments, the East Asian–North Pacific Regional Experiment (APARE) and the Northern Atlantic Regional Experiment (NARE). The major objectives of the two regional experiments are similar: (1) to investigate the natural budgets of and anthropogenic impact on the tropospheric ozone and ozone precursors, including NO_x, methane, and nonmethane hydrocarbons; (2) to investigate several aspects of the sulfur and aerosol cycles; and (3) to study the photochemistry of OH.

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 91

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 double reticon array detector is now operational. OH abundance determinations were made in the spring and summer of 1991. A detailed intercomparison campaign with the Georgia Institute of Technology was planned and successfully completed.

Tropospheric Trace Species Long Path Experiment

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 Observatory and is producing very high quality data.

Stratospheric OH Radical

The ground-based absorption measurements of stratospheric OH continued in FY 91 at Fritz Peak. The average level of OH increased significantly in FY 91 over previous years, and the seasonal behavior of OH was observed to covary with solar activity over the past 10 years. An interferometer similar to the one at Fritz Peak was deployed in New Zealand and is producing new, high-quality Southern Hemisphere data. New theoretical analysis indicates an effect of lower stratospheric OH on total column OH.

International Network for Detection of Stratospheric Change

A program started in 1989 to develop a new observing system to measure stratospheric trace gases using spectroscopic absorption of light in the UV and visible portions of the spectrum is nearing fruition. The instruments developed as part of this program will be installed at several global locations. The prototype instrument, including a new spectrograph and telescope system, is now being tested at Fritz Peak. This instrument is working very well, and has demonstrated significant advances over our older instrumentation.

Plans FY 92

Routine measurements of tropospheric OH are anticipated in FY 92. 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 another full year of data for the Southern Hemisphere. Prototype testing of the new trace gas measurement system will continue, and an international intercomparison campaign is planned for May 1992 in New Zealand. 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. Installation of the first operational

instrument is expected at the NOAA Mauna Loa Observatory in Hawaii. A new IR Fourier transform instrument will begin development for determination of tropospheric OH sink species.

METEOROLOGICAL CHEMISTRY

The program's central focus is the composition and meteorology of the upper troposphere and lower stratosphere. This atmospheric region is of major importance to global change both scientifically and in terms of policy-making. The program has great interest in two areas: (1) the meteorological and chemical state of the lower stratospheric vortex through autumn, winter, and spring, and its relationship to midlatitudes in both hemispheres; and (2) the content of water vapor and ice throughout the global upper troposphere.

Accomplishments FY 91

Instrument Development

A new airborne instrument for simultaneous measurement of NO and NO_y was built and successfully operated on test flights for the Airborne Arctic Stratospheric Expedition (AASE)–II mission. It has four channels, one of which is currently hosting a fast-response gas chromatograph for measurements of CFC-11 and CFC-113. This chromatograph, built by CMDL, was also successful on the AASE–II test flights. These instruments, together with the existing ER–2 water vapor and ozone instruments, all used the new data system and associated software constructed by the program's engineers. The laboratory prototype version of the laser ionization mass spectrometer was built, and initial experiments are being conducted. Laboratory experiments in cooperation with NIST were conducted to investigate the feasibility of a far infrared laser magnetic resonance instrument for detection of $O(^3P)$, OH, and HO_2.

Airborne Missions

A short series of flights was conducted at Edwards Air Force Base, CA, to intercompare the program's ER–2 Lyman-α resonance fluorescence hygrometer, the Climate Monitoring and Diagnostics Laboratory (CMDL) balloon-borne frost point hygrometer, and the NASA Langley SAGE II water vapor channel. The results show a ~17% discrepancy between the two in situ hygrometers, with the frost point hygrometer recording the lower values. A qualitatively similar effect was shown by the UK Meteorological Research Flight, where independently constructed Lyman-α and frost point hygrometers were operated in parallel on the same aircraft. Laboratory experiments using quantitative conversion of methane to water vapor are being undertaken to pinpoint the source of the discrepancy.

Data Analysis and Publication

During the year, articles were submitted and published in the scientific literature on the polar ozone missions, the Stratosphere-Troposphere Exchange Project (STEP) tropical mission from Darwin, and the serendipitous discovery of a large wintertime asymmetry in the upper tropospheric water content between the hemispheres.

Plans FY 92

Instrument Development

Work will continue on the laser ionization aerosol mass spectrometer to define the design parameters for an airborne instrument. Experiments to establish the sensitivity of far infrared laser magnetic resonance as a function of pressure will be performed, and should permit realistic assessment of attainable signal-to-noise ratios for an airborne instrument.

Airborne Missions

The major effort of the program during FY 92 will be the operation of the ER-2 NO&NO_y, H_2O, and O_3 instruments on the AASE–II mission. AASE II consists of six 2–3 week sub-missions, one from Fairbanks, AK, and the remainder from Bangor, ME, between October 1991 and March 1992. A second H_2O instrument will be operated on the NASA DC–8 aircraft during the period.

Data Analysis and Publication

Publication of papers from the STEP tropical mission is expected during the year. The analysis of data from the AASE–II mission will be a major activity in the second half of the fiscal year. Planning for the leadership of and instrumental participation in the Airborne Southern Hemisphere Ozone Mission (ASHOM) will also begin during this period.

TROPOSPHERIC CHEMISTRY

Accomplishments FY 91

Global Ozone Production

Ozone production over the North American continent and transport to the Atlantic Ocean are being measured in response to the growing concern that long-range ozone transport may influence air quality on an interhemispheric scale. Ozone is formed by reactions involving carbon monoxide (CO), nonmethane hydrocarbons (NMHCs), and nitrogen oxides (NO_x). The prevailing winds can carry these compounds and the ozone they form from the United States across the North Atlantic to Europe. It is believed that NO_x and NMHC will be rapidly depleted, and longer-lived O_3 and CO will persist and be transported over greater distances.

The initial study involves a survey of the concentrations and transport patterns of tropospheric ozone and its precursors over the North Atlantic region. Major aspects of the study are measurements of O_3, CO, and meteorological parameters at Seal Island, approximately 10 miles off the southeast tip of Nova Scotia; at Sable Island, approximately 150 miles southeast of Nova Scotia; and at Cape Race, on the southern tip of Newfoundland. The measurements show strong correlations between O_3 and CO, suggesting photochemical production of O_3 from anthropogenic precursors.

Regional Ozone Production

High levels of ozone are observed over large regions of the United States during the summer. These elevated ozone concentrations are detrimental to human health and cause crop and vegetation damage. Our research has focused on determining the chemical processes whereby the ozone is formed.

Ozone is the byproduct of the oxidation of hydrocarbons and CO by OH in the presence of NO_x. However, OH has not been measured. The Tropospheric Chemistry group collaborated in experiments designed to evaluate two promising new techniques to measure OH, a long-path optical technique developed in the Aeronomy Laboratory and an in-situ chemical-ionization OH-measurement technique being developed by colleagues at the Georgia Institute of Technology. Since OH concentration is determined by the levels of NO, NO_2, and O_3, a systematic evaluation of these techniques requires determination of those compounds. Long-path measurements of NO_2 and O_3 were made in coincidence with the long-path measurements of OH, while in-situ measurements of NO, NO_2, NO_y, and O_3 were made at the location of the in-situ measurement of OH.

A major research emphasis of the Laboratory has been the understanding of the chemical processes involving natural NMHC that influence rural ozone. The contribution of the Tropospheric Chemistry Group has been to develop techniques and instruments that can measure the trace species that shape the chemistry in rural environments, and to use these techniques to measure the species in rural areas. This chemistry can form organic nitrates that lock up NO_x, thereby inhibiting the ozone production. Measurements were concentrated on the investigation of the oxidation of the principal natural NMHC, isoprene, methyl vinyl ketone (MVK), and the organic nitrate byproducts of the oxidation of MVK.

Biosphere-Atmosphere Exchange

Measurements of NO_x emissions from soils in the United States have been used to develop the first inventory of these emissions for the United States. The inventory indicates that during the summer in the midwestern United States, the emissions of NO_x from the soils may contribute substantially to the NO_x background in that region.

Plans FY 92

Regional Ozone Production

During ROSE I in the summer of 1990, the first detailed altitude profiling of ozone and its precursors indicated that the levels of ozone and ozone precursors are much larger than predicted. We will develop a follow-on study, ROSE II, to answer three key questions: (1) What processes are responsible for exchange between the planetary boundary layer and the free troposphere? (2) Can current models adequately simulate these processes? (3) Are air concentrations of ozone precursors at a surface site representative of emissions of those compounds within the surrounding region?

This research program will combine chemical measurements at the ROSE ground station, airborne measurements of key compounds using fast-response instruments, and height profiles of the dynamical properties of the free troposphere. The measurements will be obtained for a variety of meteorological conditions to provide the most robust data base. Comparisons will identify processes that play major roles in regional distributions and chemistry and will assess the degree to which the models simulate them. Avenues for model improvement will be identified.

Development of Measurement Capability

The study of atmospheric photochemistry requires unequivocal measurements of NMHCs. Great headway has been made in ground-based measurements of these compounds, but their distribution as a function of altitude is very uncertain. To this end, an airborne system for the measurement of NMHCs will be developed.

Nitric acid plays a critical role in the transport of reactive nitrogen and in the balance of the reactive nitrogen budget in the atmosphere. There are lingering concerns regarding potential systematic errors that may be involved in the filter measurements of HNO_3. As an alternative method for this measurement, a continuous-flow denuder system using on-line ion chromatographic detection will be developed.

Global Ozone Production

A second mission to Mauna Loa is under way to study the production of ozone in the remote free troposphere. Three important constituents of this budget are being measured: nitric acid, nitrate particulate, and total reactive nitrogen. These data will give a seasonal representation of the photochemical processes that control ozone production in the remote free troposphere.

MIDDLE ATMOSPHERE STUDIES

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

Accomplishments FY 91

Field Measurements

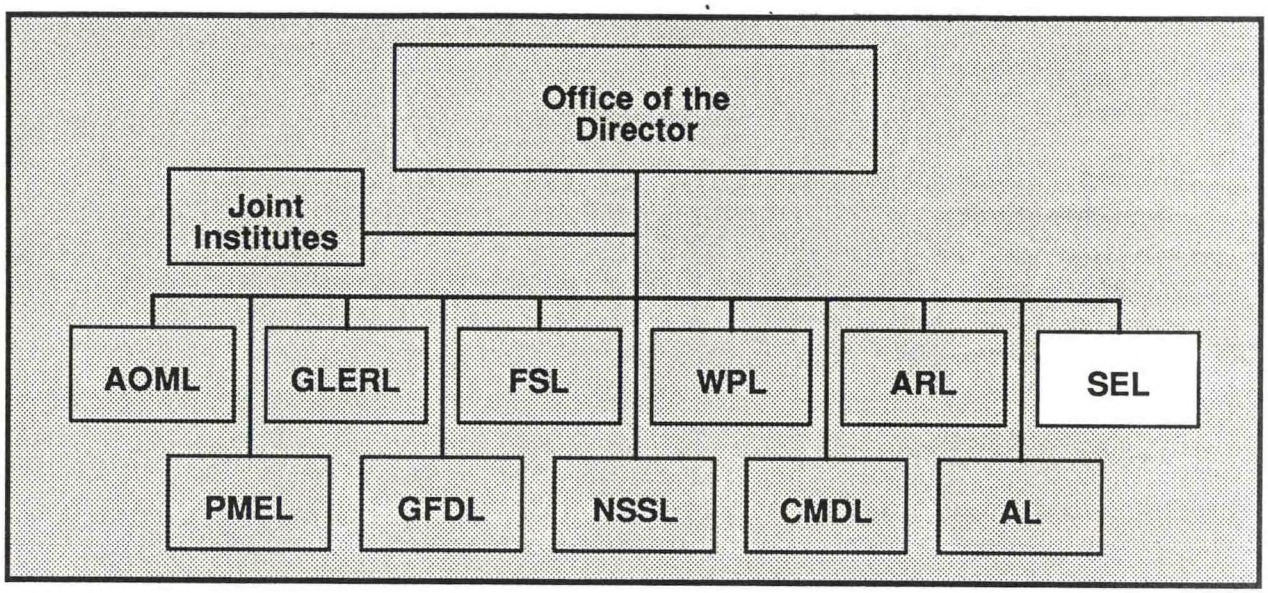
Measurements of the column abundances of stratospheric nitrogen dioxide have been carried out by the Aeronomy Laboratory for more than a decade. These observations have played a role in current theories of springtime Antarctic ozone depletion, in which a key role is played by heterogeneous reactions occurring on the polar stratospheric clouds that exist under cold conditions. In collaboration with scientists from the Department of Scientific and Industrial Research in New Zealand, we have used observations of nitrogen dioxide to study the composition of the stratosphere not just in the Antarctic spring but also in the much warmer fall season. The measurements suggest that chemical perturbations begin at temperatures much too warm for polar stratospheric clouds to be present, suggesting a significant role for heterogeneous chemistry on the background stratospheric aerosol layer. Such measurements are critical for attempts to understand the annual cycle of polar ozone depletion and mechanisms for producing ozone losses at midlatitudes. In addition, a field measurement program was carried out in Antarctica beginning in February 1991, to obtain observations of chlorine dioxide together with nitrogen dioxide and ozone, allowing for further study of these key questions.

Stratospheric and Mesospheric Modeling

A broad range of modeling studies has addressed issues in stratospheric and mesospheric processes. Among these is a study of models together with measurements to better quantify ozone depletion potentials, which are the basis for international regulations of substances that deplete the ozone layer. It has been shown that the ozone depletion potentials derived from gas-phase chemistry models are in error because of their neglect of lower stratospheric ozone losses. For several key species, including HCFC-22, an empirical analysis reveals ozone depletion potentials that can be as large as twice the values predicted by gas-phase models. The study provides a new and more realistic framework for evaluating the extent of ozone damage expected from compounds suggested as CFC substitutes.

Plans FY 92

Both observational and theoretical studies will continue. Near-term observational studies will focus on analysis and interpretation of measurements of ozone, NO_2, and OClO obtained in the Antarctic during February–November 1991, allowing a more detailed view of the annual cycle of stratospheric ozone and its depletion to be obtained. Several theoretical projects are also in progress. A focus is the use of semi-empirical approaches to evaluate the ozone depletion potentials of compounds containing bromine, and the development of a coupled wave/mean flow model for studying stratospheric chemistry.



SPACE ENVIRONMENT LABORATORY

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

In FY 91, the Space Environment Laboratory (SEL) continued to provide uninterrupted space environment services to its civilian and military customers. SEL conducted research on the solar-terrestrial environment, developed new techniques to carry research results into improved services, and found new ways to improve the delivery of those services. During the past fiscal year, SEL celebrated 25 years of continuous daily forecasts.

An especially noteworthy activity in FY 91 was the completion of the upgrade to the SEL Data Acquisition and Display System (SELDADS). Important improvements in service were extended to SEL's customers, including a multiline, dial-up, PC- based bulletin board system as well as real-time displays on workstations at customer sites.

SEL's pursuit of new and useful data streams included the evaluation of new interplanetary scintillation data for potential use in geomagnetic forecasting; the results were mixed. It had been anticipated that a vendor would be under contract in FY 91 to build the U.S. Air Force-funded Solar X-ray Imager (SXI), to fly on the Geostationary Operational Environmental Satellites (GOES). A contract was not let, but cost and feasibility studies were completed. In addition, SEL is seeking real-time solar wind data to allow more timely alerts of imminent geomagnetic storms. An arrangement was made with the National Aeronautics and Space Administration (NASA) whereby real-time data from that agency's WIND spacecraft will be available to SEL. Unfortunately, SEL's plans for research in solar influences on climate and global change were not accomplished in FY 91.

In FY 92, SEL plans to continue to improve the delivery of its products, pursue new data sources, conduct new research, and develop new techniques for all of these areas. SEL will expand the number of customers to whom it provides software, and will develop new data for display on customers' workstations.

Data streams to be developed in FY 92 involve real-time solar wind data, preferably obtained at the Lagrange (L1) point, and interplanetary scintillation data.

Also important to SEL's future is the planning and design of the next version of SELDADS, the completion of which is scheduled to coincide with SEL's move to its new building. Planning and oversight of progress

on the building will also be a major activity in FY 92, as will the continued effort to establish SEL's role in NOAA's Climate and Global Change Program.

SPACE ENVIRONMENT SERVICES

Accomplishments FY 91

Space Environment Services Operations

On 1 December 1990, the Space Environment Services Center (SESC) provided its 9130th daily forecast of solar activity and resultant terrestrial effects, marking 25 years of continuous services. SESC staff dealt with the prolonged period of intense solar activity that marked a second rise in the 22nd sunspot cycle; this cycle began in 1986 and reached a first peak in 1989.

The services operation has grown from one that used a few solar observations and geomagnetic activity indices, gathered mostly by telephone and teletype from cooperating agencies, to a national focal point that receives, in real time, more than 1000 continuous data streams. Federal agencies and other organizations have increasingly relied on a synergistic program of sharing their observations in real time through the SESC because of this organization's ability to synthesize a picture of the space environment as a whole. For example, the U.S. Department of Defense, through the U.S. Air Force Air Weather Service, provides continuous images and reports from their solar patrol telescopes; NASA provides solar wind measurements from interplanetary space, and the U.S. Geological Survey sends its terrestrial geomagnetic field measurements to the SESC in real time.

NOAA, though SEL, continued to operate the SESC jointly with the Air Weather Service. Space scientists, forecasters, and technicians collect and analyze the data, make forecasts, and distribute alerts and warnings. SESC's Boulder, CO, headquarters is operational 24 hours a day, 7 days a week.

In addition to providing daily scheduled services, the staff provide information and forecasts to users with special needs. In FY 91 these customers included the FLARES 22 (Flare Research in Solar Cycle 22) and Max 91 (coordinated solar research around the maximum of Solar Cycle 22, originally projected for 1991), the space shuttle program, and rocket launches from Alaska (to study space-weather connections) and New Mexico (to study the Sun). The staff assisted other agencies in analyzing the effects of the space environment on their systems, including problems in command and control systems on the Hubble space telescope. A study was published, describing the national capability for forecasting hazardous solar particle events and the improvements necessary for undertaking extended exploration missions to the Moon and Mars.

Additional major activities of SESC staff included publishing user newsletters, distributing weekly and monthly summaries of activity, and taking queries from customers who encountered adverse effects traceable to the space environment. To increase the breadth of the SESC's information flow, the staff participated in user conferences and gave papers describing variations in solar-terrestrial activity. A two-volume set of proceedings from the October 1989 Solar-Terrestrial Predictions Workshop held at Leura, Australia, was published. The first operational implementation requirements for an SXI were developed.

Space Environment Data Systems

Changes in the computer and communications technology necessary to operate the SESC have been rapid and continuous: data systems become obsolete, data volumes grow, and the world communications network expands.

An interim upgrade to the SELDADS system continued in the past year to replace aging computers. Most of SESC's service products are now available on files in SEL's VAX mainframe computer, and users can obtain them electronically over the NASA Science Internet. A new computer system and a new auroral radar, funded by the U.S. Air Force, were installed at the High Latitude Monitoring Station in Anchorage, AK. Data from additional USGS magnetometers were added to SEL's data base. Computer connections between SELDADS and the new Space Forecast Center (SFC) at Falcon Air Force Base in Colorado Springs, CO, were installed and tested. This new system will allow the SFC to remotely issue its products through SELDADS in the event that its own computer system fails.

Plans FY 91

SESC Operations

- Install a computer system to make and distribute geomagnetic forecasts, in probability format, to provide users with additional information on expected levels of geomagnetic storms.
- Continue to stimulate user involvement with SESC, by increased use of the media and by participation in user symposia.
- Continue to plan for incorporating solar wind data from the NASA WIND satellite into the SEL database, to make optimum use of the limited amount of real-time data to be available in FY 92.
- Convert SEL software to standard file image transfer (FITS) formats, to provide access to additional solar image data.
- Support specialized research campaigns such as NASA's Gamma Ray Observatory observations and Max 91/FLARES 22.
- Assist the Air Force SFC in training their new staff.

Space Environment Data Systems

- Plan for the next major version of SELDADS (SELDADS 3), to be completed in concert with SEL's move to its new building.
- Convert international data exchange from old teletype systems to modern computer networks, beginning with links to Australia, Japan, France, and possibly the Soviet Union.
- Convert SEL's High Latitude Monitoring Station at Anchorage to completely automatic operation.
- Procure and install replacements for the 20-year-old instruments currently receiving satellite data at Table Mountain Observatory.

RESEARCH

Accomplishments FY 91

Ionosphere and Upper Atmosphere Studies

The total electron content of the ionosphere continues to be measured by SEL researchers. Hourly total-content values from April 1990 through June 1991 were archived at the National Geophysical Data Center (NGDC) in Boulder.

A three-dimensional (3–D), time-dependent, global model of the thermosphere and ionosphere was installed on the new NOAA Cray Y–MP computer at Gaithersburg, MD. A graphics package is also being developed to aid in analyzing and interpreting the model's numerical simulations. Work has begun on coupling a plasmasphere code to the thermosphere/ionosphere model, in collaboration with the University of Sheffield, England.

Magnetospheric Physics

Development of computer-animated particle flux maps at 850 km has continued. The color animation program provides a 3-day running average of the trapped and precipitating energetic particles as monitored by the Television and Infrared Radiation Observation Satellite (TIROS) NOAA satellites. SEL is developing a new system to display a more complex data base.

Preliminary analysis of the entire data set (1983–present) from the GOES–6 High Energy Proton and Alpha Detector (HEPAD) has been completed; the data appear to be of good quality. The energy range (100–1000 MeV) covered by the HEPAD fills a gap between typically low-energy satellite observations and extreme relativistic energy observations provided by ground-based neutron monitors. This energy range is important because it is the main ionization source for the lower atmosphere and determines the radiation environment at aircraft altitudes during solar energetic particle (SEP) events. The radiation dose-equivalent rate for travelers on supersonic transport aircraft during such events is being evaluated at SEL.

Theoretical studies of the dynamics of the geomagnetic tail continued. These studies predict certain properties of particle distributions in the tail; the predictions agree well with satellite observations. A steady-state simulation code was developed to examine the equilibrium state of the magnetotail current sheet, providing new insight into its plasma properties.

Interplanetary Physics

The study of energetic particle propagation using the 2 1/2–D Interplanetary Global Model (IGM) continued in collaboration with European colleagues. An empirical algorithm was developed to predict the total flux and anisotropies of particles up to about 1 MeV. The 2 1/2–D IGM was used in a parametric study to compare its shock time of arrival at 1 astronomical unit (1 AU) and peak solar wind momentum flux increases, also at 1 AU, with the results from a full 3–D IGM. It was found (in agreement with theory) that the more-realistic 3–D shocks travel more slowly than the axially symmetric 2 1/2–D shocks; however, the peak momentum flux increases are similar.

A parametric study of shock time-of-arrival at Earth was conducted with the 2 1/2–D IGM. The shock arrival times at Earth are signaled by the sudden commencement of geomagnetic storms. Data for associated solar and geophysical events include measurements of type–II radio bursts, which provide the initial shock velocities in the low corona. These radio bursts are measured routinely at SESC; their association with solar

flares aids in locating their solar sources. A method of resolving problems pertaining to the magnetic-field helmet-streamer configuration in IGMs was developed with Israeli colleagues. A newly developed analytical foundation will greatly simplify and improve accuracy in numerical modeling procedures by helping to evaluate the self-consistency of immediate results. These new procedures will be used in the study of isothermal, polytropic, and thermally conductive solar winds.

During FY 91, SEL began receiving all-sky interplanetary scintillation (IPS) data at 3-hour intervals from the Mullard Radio Astronomy Observatory in Cambridge, England. A corrected version of the data is now routinely converted to all-sky scintillation maps, which are undergoing detailed study at SEL to assess their utility in forecasting geomagnetic activity.

Construction of a catalog of synthetic IPS all-sky maps has begun, using the 3–D IGM. IPS observations are matched to these maps, and the likelihood of geomagnetic storms is assessed. A Cray Y–MP computer became available in FY 91, and will increase the 3–D IGM's computational capability.

SEL continues to collaborate with the IPS group at the Physical Research Laboratory (PRL) in India. Progress was assessed via a small workshop, attended by scientists from both SEL and PRL. The all-sky maps from India and England were compared with the synthetic maps, and their usefulness in forecasting geomagnetic storms was evaluated.

The international Solar Connection to Transient Interplanetary Processes (SOLTIP) program was initiated. SOLTIP held an SEL-led symposium in Czechoslovakia in late September 1991. This meeting promoted collaborative solar and interplanetary observations by both remote (such as IPS) and in situ methods.

Collaboration continued with the University of Alabama in Huntsville, focusing on the relationship between coronal mass ejection (CME) mechanisms and the shearing of photospheric neutral lines in helmet streamers. The magnetic field lines appear to have a slow initial rise, in agreement with theory, but a catastrophic ejection occurs when the plasma velocities achieve specific values.

Solar Physics

The Solar Influences theme of the NOAA Climate and Global Change Program emphasizes the need for a long-term data base containing measurements of energetic particles and solar ultraviolet (UV) radiation. A system design was developed to provide SEL-wide access, analysis, and display of such data.

Nitric oxide (NO) is an important, chemically active atmospheric component. The response of thermospheric NO in the upper mesosphere and lower thermosphere to changes in EUV flux over a solar cycle has been modeled; the predicted variation is in good agreement with observations from NASA's Solar Mesosphere Explorer satellite.

Solar UV measurements from the Solar Backscatter Ultraviolet monitors (SBUV–2) aboard the NOAA 9 and NOAA 11 satellites were used to derive the Mg II (once-ionized magnesium) core-to-wing ratio (RMgII), an index of solar UV temporal variations. RMgII values for 1986-1988 were submitted for publication to NGDC and the World Data Center A for Solar-Terrestrial Physics; thus, 11 years of solar UV data are now available for research of the stratospheric effects of UV temporal variations, and construction of the solar UV data base has begun.

The very successful SOLERS22 Workshop was held 3–7 June 1991 in Boulder, CO, and was led by SEL staff. SOLERS22 is an acronym for the Solar Electromagnetic Radiation Study for Solar Cycle 22. It is an international collaborative program, spanning 1986 through 1997, for research of the long-term changes in solar total and spectral irradiance. The workshop's proceedings are under review.

A special session of the workshop was devoted to solutions for computer analysis of solar data; this successful session showed how 12 major vendors would create images of the same solar data set.

A study of solar-variability indices was completed, and results indicate that indices measuring solar variability are closely linked to active-region lifetimes. Indeed, the well-known 155-day periodicity in

solar indices was found to be only a temporary result of active-region evolution; e.g., if 1980 and 1982 are removed from the data sets, this period is absent from the indices related to strong, emerging magnetic fields. The apparent solar rotation rate depends strongly on the height of radiation emissions at the solar source.

The fluid flow within a jet was found to be successful in reproducing the extended blue wings observed on soft x-ray line profiles during the rise phase of solar flares; this is in contrast to the behavior of a flow with rigid walls (such as within a pipe), which could not reproduce the observations.

Study of the evolution of solar active regions continued. There were multiple indications that the region classifications may contain excessive noise because the slight differences between some classes were not resolved.

A study was made of Martens-Kuin models of normal and inverse polarity filament eruptions and CMEs. Inverse polarity models were found to be inconsistent with observations of CME structure.

An atlas of large-scale solar magnetic fields and coronal holes for two solar cycles (1966–1987) was published. This study reveals long-lived patterns with variable motions, giving important clues to the nature of solar global circulation. The atlas was produced in collaboration with Australian colleagues.

The program to produce hydrogen-alpha synoptic charts with each complete solar rotation continued. Preliminary charts for March–June 1991 were assembled, providing data for predicting the geometry of the solar corona during the total solar eclipse of 11 July 1991. Actual photographs of the eclipse were compared with this prediction, and the results appear valuable in improving future predictions.

Also studied was the origin of solar magnetic fields at the beginning of an 11-year sunspot cycle, which provided a "clean slate" on which to view the emergence of the first active regions and their associated large-scale magnetic field patterns. This study revealed the gradual emergence in 1986–1987 of a new, large-scale pattern of magnetic fields without significant contribution from active regions, which contradicts the prevailing theory of the origin of large-scale fields.

Solar active regions that produce exceptionally hot x–ray flares were found to occur only during the first 4 years of the solar cycle and to possess a close relationship to specific, large-scale magnetic-field patterns. This study also revealed a curious occurrence of hot flares in Solar Cycle 22 near the edge of the visible solar disk. This pattern was not observed in Solar Cycle 21.

A special class of high-temperature solar flares was found to have several properties of potential interest to solar physicists, and of particular interest to solar forecasters. It was shown that the distribution of maximum flare temperature with respect to maximum x-ray flux can be divided into two "families" of flares: a minority group, associated with SEPs, and the majority, which lack this association. The distributions converge at high temperature and high x-ray flux; however, at low values (of maximum x-ray flux) the families are clearly separate and can be used to identify SEPs on the basis of temperature.

Comparison of temperatures derived from broadband soft x-rays with those derived from soft x-ray spectroscopy indicates that the super-hot component is not usually evident in the broadband data, but temperatures of the bulk flare plasma in a rare class of events can reach at least 50 million degrees.

A comparison of x-ray flares observed simultaneously by GOES and the Soviet geophysical satellite PROGNOZ has demonstrated that an evolving high-temperature kernel may be detectable in flare plasma during a flare's rise to maximum. This research also appears to confirm that flare plasmas, believed to be highly nonhomogeneous during the rise phase, thermalize at or very near maximum and remain isothermal during the entire decay process.

The SEL-supported Max 91 program of coordinated solar observations continued. Two worldwide flare observing campaigns were conducted, and support was provided for four solar rocket flights. Participation in this international program continues to increase; 20 new organizations were added to the Max 91 mailing list over the last fiscal year.

Plans FY 92

Ionosphere and Upper Atmosphere Studies

- Continue analysis of total ionospheric electron content.
- Assess the effects of high-velocity ion convection channels on the thermosphere and ionosphere.
- Quantify the magnetospheric input driving the storm-time ionospheric changes observed at middle latitudes.
- Compare current theoretical models of the midlatitude ionosphere at high solar activity with observations.
- Continue work on coupling a plasmasphere code to the global ionosphere/thermosphere model.

Magnetospheric Physics

- Complete development of TIROS/NOAA data computer animation.
- Establish a several-year archive of HEPAD data.
- Begin empirical study of cosmic ray cutoff variation by comparing GOES and TIROS/NOAA data.
- Continue evaluating and reducing the HEPAD data base.
- Continue theoretical studies by investigating the role of chaos in magnetotail dynamics, further developing and studying simulation codes, and comparing resulting models with satellite observations.

Interplanetary Physics

- Begin consideration (with the 2 1/2–D IGM) of an operational energetic particle prediction model.
- Complete the comparison of magnetohydrodynamic (MHD) IGM results with data.
- Close the 2 1/2–D helmet-streamer model, to make the assumed electrical currents self-consistent, via iteration, with the solar wind plasma flows along the helmet-streamer and interplanetary magnetic field lines.
- Investigate using the 2 1/2–D helmet streamer model to provide a self-consistent, steady-state heliospheric current configuration for the 3–D IGM.
- Continue processing the maps of IPS data from Cambridge, England, with emphasis on differentiating between IPS and ionospheric scintillations, identifying true IPS events, and relating IPS events to solar and geomagnetic activity.
- Continue constructing the catalog of synthetic all-sky maps; compare with IPS observations.
- Continue monitoring the Indian IPS program, and explore the possible integration of Indian facilities into a multistation network; also, continue to consider other possible IPS sites (Soviet Union, China, United States, Japan) in addition to the one in England.
- Participate in the SOLTIP campaigns now under consideration.
- Participate in CME simulation studies.

- Initiate a study, using the 3–D IGM computer code, on the effects of the interplanetary magnetic field on the propagation of interplanetary shocks within 1 AU.

Solar Physics

- Extend the data base of solar UV MgII radio bursts back to 1947.
- Publish the proceedings of the SOLERS22 Workshop.
- Continue to emphasize the need for building a data base for energetic particles and solar UV radiation.
- Develop a prototype system to compress and transfer and archived data from magnetic tape to the new SEL Retrieval and Analysis of Scientific (SELRAS) data system.
- Continue to study the variability of NO in the upper mesosphere and lower thermosphere.
- Continue collaboration, with the SOLERS22 EUV working group, to develop a working model of solar x-ray, EUV, and UV emission.
- Continue to investigate the evolution of solar active regions, concentrating on sources of possible errors in classification and the proper ordering of classes to reflect increasing magnetic complexity and flare potential.
- Examine the role of instabilities in the jet model used to reproduce the soft x-ray line profiles observed during the rise phase of solar flares.
- Develop initial algorithms for automatic detection of solar features.
- Continue to develop models of normal and inverse polarity filament eruptions and CMEs.
- Continue research on the structure and evolution of large-scale solar patterns.
- Continue production of H-alpha synoptic charts and the development of methods for their analysis.
- Study properties of solar active regions that produce exceptional activity.
- Initiate a study of the feasibility of using multichannel, hard x-ray data to isolate a special class of solar flares, known as gradual hard x-ray flares, to evaluate their utility in geomagnetic forecasting; arrange with the National Environmental Satellite, Data, and Information Service (NESDIS) to include hardware related to this study on the next series of GOES satellites.
- Continue to support the Max 91 international program of solar observations.

SYSTEMS SUPPORT

Accomplishments FY 91

Operational Satellite Instrumentation

SEL continued to supervise the contract for the Space Environment Monitor (SEM) systems for the TIROS/NOAA–K, –L, and –M spacecraft scheduled to fly in the mid-1990s. The design of the SEM systems is complete, and a satisfactory Critical Design Review was held. Flight hardware fabrication has begun; the delivery of the instruments for the spacecraft is on schedule, despite delays due to funding constraints. SEL supported the procurement process for the SEM systems to fly on NOAA N–P series of satellites.

SEL continued to supervise contractors for the SEM systems to fly on the GOES I–M satellites. All flight hardware for the SEM is now delivered except for the magnetometers, which are being reworked to eliminate instabilities. Preparations continued for the SXI, which has been funded by the Air Force and will fly on one of the later GOES I–M satellites. A new accommodation study was completed by the main spacecraft contractor; a separate study, funded by NOAA, is under way at NASA to define instrument requirements and costs.

SEL Scientific Workstation System

The initial design and installation of a new, workstation-based computer system for the Research Division was completed. This new system significantly upgrades that division's computer capabilities, providing state-of-the-art graphics for scientific data visualization, data analysis, integrated computer networking, and office automation.

Three new general-purpose UNIX workstations were purchased in addition to several PC and Macintosh systems, increasingly preferred by SEL's scientific and operational staff for general-purpose data visualization and analysis. This enabled the retirement of the remaining earlier-generation systems. Various commercial and custom software options for image processing were surveyed; software was purchased to enable interactive matrix analysis and automatic feature recognition.

Poker Flat Upgrade Project

Funding was received from the Air Force and NASA to provide a space environment launch decision support display system at the Poker Flat Rocket Range near Fairbanks, AL. The existing client-server and display software were leveraged to provide an X–window display system, drawing its data directly over Internet from the SEL operational data base. Three new workstation-class systems were acquired to form the basis of a networked operational file-server system to benefit all SEL users with access to Internet and the Solar Physics Analysis Network (SPAN).

Artificial Intelligence Technique Development

SEL continued to study the relative merit of various schemes in predicting M–class flares. This study has used a variety of observational data, and it is clear that there is considerable redundancy in these data. It is difficult to show significant differences in performance between the predictive (machine) mechanisms investigated. Human data on the same task show more variability than the machine data, but none exceed the performance limit seen in the machine data. Human forecasters also tend to over-predict flares, while the machine techniques tend to neither over- or under-predict them.

Wide-Area Networking

Computer networking is a vital means of disseminating SEL data and acquiring data from other institutions. The internal SEL TCP/IP and DECNET network was expanded to support the many new desktop systems acquired during the year. The SEL MicroVax now hosts SEL's SPAN connection, replacing the third-party VAX.

Interplanetary Scintillation Observations

The IPS antenna array at Cambridge, England, continued to function on an automatic, quasi-operational basis.

The Indian IPS site was revisited; an engineering review was performed, and a data aquisition system was installed.

Discussions were held with the Florida Institute of Technology on the installation of a third IPS site in Florida, the Caribbean, or Mexico. Multiple IPS sites are required for reliable forewarning of interplanetary disturbances.

Scientific Data Base System

Studies began to define the objectives and implentation of a general-purpose, on-line data base system to provide SEL staff with immediate and convenient access to historical data on the space environment.

Plans FY 92

Operational Satellite Instrumentation

- Continue contractor and subcontractor reviews of the programs to develop SEM systems to fly on the GOES and NOAA satellites.

SEL Scientific Work Station System

- Continue to develop general-purpose software tools to implement a prototype forecaster workstation and operational solar-mapping tools.
- Add software to the new network file-server system, to provide general-purpose access to SEL operational data products.
- Continue upgrading computer systems to meet the rapidly growing requirements of SEL researchers.
- Expand the new computer system in the Research Division to a laboratory-wide scientific data base.
- Develop a scientific data system prototype that uses a laboratory-wide data base and an interactive graphics user interface.

Poker Flat Upgrade Project

- Complete the operational data base server software; finish testing and installing the launch decision support system.

Artificial Intelligence Technique Development

- Complete the study of neural net and other experience-based computer reasoning systems and methods for making solar-terrestrial predictions; compare predictions with observations.

Wide-Area Networking

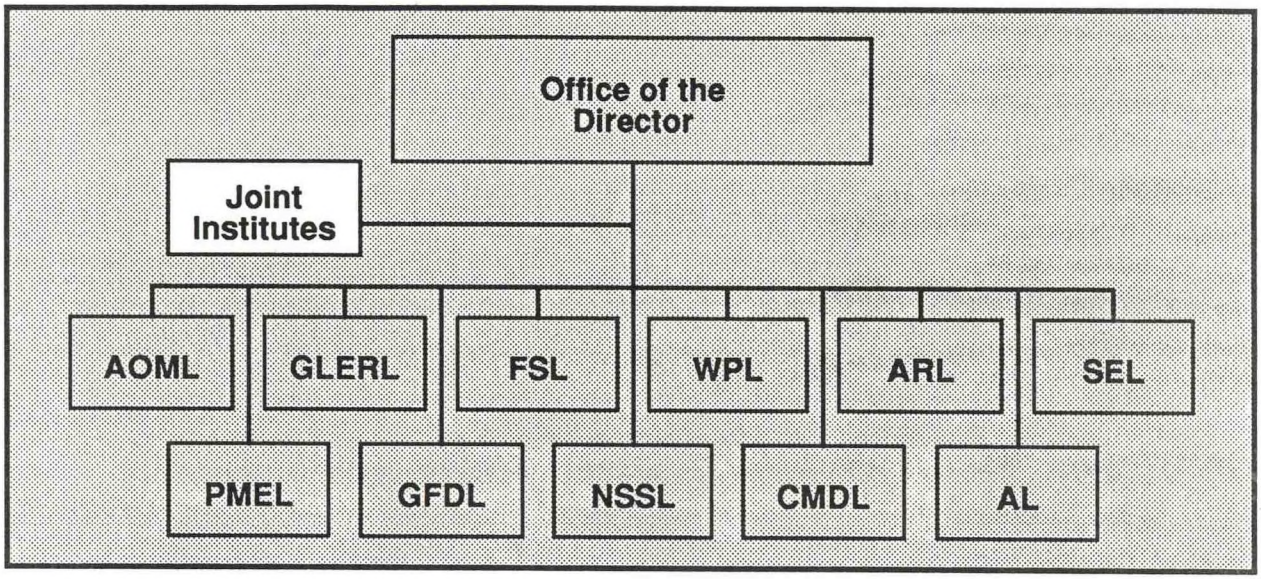
- Convert the SEL LAN to a separate, self-contained entity.

IPS Project

- Continue the joint operation of the Cambridge system to support operational evaluation; encourage the Indian program and continue to participate in planning for a third site.

Scientific Data Base System

- Commence prototype implementation using the new network file server system as a host.



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 atmospheric, oceanic, limnology, solar environment, and near-space research while also serving as a focal point for multidisciplinary collaboration of research from local areas, the Nation, and the world.

ERL's seven Joint Institutes and associated universities are

- CIRES (University of Colorado)
- CIRA (Colorado State University)
- CIMMS (University of Oklahoma)
- CILER (University of Michigan)
- CIMAS (University of Miami)
- JISAO (University of Washington)
- JIMAR (University of Hawaii)

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

Boulder, Colorado
(303) 492-7943
Robert E. Sievers, Director

The Cooperative Institute for Research in Environmental Sciences (CIRES) is a joint endeavor of the University of Colorado and the NOAA Environmental Research Laboratories (ERL) founded in 1967. CIRES' primary function is to act as a research interface between scientists at ERL and at the University to provide training of students and postdoctoral scientists in the environmental sciences and to facilitate collaborative research. The CIRES Council of Fellows represents seven University departments and two NOAA Line Offices. This report concerns research at CIRES that is directly relevant to NOAA missions but is funded by other agencies; NOAA funding of CIRES is leveraged approximately two fold by the research reported here. Additional research that is relevant to NOAA missions takes place in the CIRES Division of Solid Earth Sciences, including geodesic monitoring of sea-level rise and Earth remote sensing of desertification processes in the High Plains of North America. This is described in the CIRES Annual Report.

ATMOSPHERIC AND CLIMATE DYNAMICS

Atmospheric and climate dynamics research at CIRES is a collaborative effort with scientists at the NOAA/ERL Aeronomy Laboratory (AL), Air Resources Laboratory (ARL), Climate Monitoring and Diagnostics Laboratory (CMDL), Forecast Systems Laboratory (FSL), National Severe Storms Laboratory (NSSL), Space Environment Laboratory (SEL), and Wave Propagation Laboratory (WPL). Additional sources of support include the Department of Defense (DOD) [through the Army Research Office (ARO) and the Office of Naval Research (ONR)], the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF).

Highlights of NOAA-funded research at CIRES during FY 91 include the following:

- Experiments designed to improve aerosols instrumentation and to learn more about sources and fates of atmospheric aerosol pollutants.
- Development and refinement of new and innovative analytic and predictive techniques to study interactions among different climatic regimes and circulation systems.
- Collaboration in field programs in a major effort to improve understanding of the monsoon of southwestern North America.
- Sponsorship of a workshop for the Solar Electromagnetic Radiation for Solar Cycle 22 Working Group I.
- Theoretical and field studies aimed at improving lidar systems for measuring atmospheric aerosols, turbulence, and fluxes.
- Development of new analytic techniques and improvements in instrumental sensitivity of NOAA profiler systems and radar systems.
- Analysis of ocean acoustic data from the Heard Island Experiment using modal decomposition techniques, which provides an independent check on ray-path techniques.

Additional research in the CIRES Atmospheric and Climate Dynamics Program during FY 91 both complemented and built on this NOAA-sponsored work.

Accomplishments FY 91

Global and Regional Climate Variability

The data base of ground-based cloud observations, produced from the surface weather observation archive, was updated to include all of the 1980s to allow comparisons with results from the International Satellite Cloud Climatology Project (ISCCP). Studies using the cloud data base involved the performance of climate models in predicting cloud cover, the performance of cloud-retrieval techniques for satellite observations, the role of clouds in the radiation budgets of the atmosphere and the Earth's surface, and the climatological significance of chemical reactions in clouds.

The development of large data sets requires addressing the problem of distribution and access. Geographic Information Systems (GIS) techniques offer one solution to this problem, and the application of GIS to climatological and other data bases was investigated.

Regional proxy data sets were used to investigate trends in climate. Observations of the departure of ice in the spring from the U.S. Great Lakes were used to study global warming. The average date was found to have been increasingly earlier at most locations over the past 35 years, and the trends in the data are statistically significant.

Proxy data sets were also used to study the history of El Niño–Southern Oscillation (ENSO) variability. Dendrochronological records from the north coast of Peru were studied using image-analysis techniques and ^{14}C dating.

The behavior of the atmosphere and the ocean in the context of climate change was studied using numerical models. Because Earth's atmosphere is strongly affected by orography, general circulation models were used to evaluate the role of continental configurations in determining Earth's paleoclimate. One significant finding is the absence of polar ice caps on the early Earth because of the different positions of the continents.

The role of the oceans in global warming was explored using a new ocean circulation model. The feedback associated with air-sea interaction processes subjected to perturbations expected to be associated with global warming was explored. Additional studies concerned the changes in the strength of the thermohaline circulation, which carries trace chemicals injected from the atmosphere throughout the global ocean.

Small-Scale Processes and Turbulence

A comparison of the variability of sea-surface temperature (SST) and cloud cover using the Comprehensive Ocean-Atmosphere Data Set (COADS) revealed a statistically significant, negative correlation in the marine stratocumulus regimes over the cool, upwelled waters of the subtropical oceans off the west coasts of North and South America and northwest and southwest Africa. Because less cloud cover implies stronger solar heating of the ocean below, and vice versa, a positive cloud-climate feedback is implied.

Analysis of research aircraft data obtained in 1987 during the First ISCCP Regional Experiment (FIRE) showed that changes in atmospheric humidity above these cloud decks can have a strong influence on the character of the cloud. Since the origin of the air above the cloud deck can be thousands of kilometers away, in remote parts of the subtropical high pressure cells, this result shows that the problem of understanding the behavior of marine stratocumulus cloud systems is not limited to local processes.

Additional analysis of FIRE data sets obtained with fast-response instruments capable of resolving space scales down to less than 10 m revealed details of the entrainment process. The origin of air parcels within

the cloud was traced by subjecting data to conditional sampling to develop composite pictures of the structure and make-up of the turbulent motions in the boundary layer. Results from the FIRE missions provided the first direct observational documentation of the process of cloud-top entrainment instability. However, the hypothesis that this instability causes a solid cloud deck to break apart was not borne out in the FIRE data.

The transport of atmospheric pollutants was studied using statistical modeling techniques. Studies were conducted on the effects of transport on the mean concentration field due to a variety of sources. In addition to the mean concentration, the model was used to determine the vertical flux distribution ("footprint") due to a surface source in the boundary layer. Results showed that the horizontal profile of the flux at different heights collapses to a nearly universal curve in the lower half of the layer.

An alternative method to expensive, range-limited aircraft for probing the boundary layer using a high-altitude kite system was investigated. Analysis of data obtained during a "truth-of-concept" experiment that took place on Christmas Island in the equatorial Pacific showed marked success. This is a significant advancement in atmospheric research technology, since, for the first time, it provides the ability for long-term, continuous monitoring of atmospheric variability at all levels in the atmosphere, including the high troposphere and the low stratosphere.

Remote Sensing Research and Development

The Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) provides spectral data in the visible and near-infrared in 224 channels with 10-nm spectral resolution and 20-m spatial resolution on the ground. AVIRIS data sets were used to improve discrimination of clouds using spectral signatures, improving the ability to determine fractional cloud coverage, a crucial parameter for climate studies. Satellite measurements of atmospheric water vapor were also improved based on techniques developed from the AVIRIS data. In addition, atmospheric correction techniques, vital for satellite-based studies of Earth's surface, were improved.

Work on the Pacific wind profiler network included data analysis from all stations and acquisition of computer hardware and development of software necessary for more sophisticated analyses of convective variability. Work also began on installation of a wind profiler in Antarctica, on King George Island on the Palmer Peninsula.

The leading order effects of refractive turbulence on coherent laser radars were determined and found to be important for lidar systems operating in the atmospheric surface layer for ranges of a few kilometers. Atmospheric scintillation data were analyzed to determine the properties of the atmospheric turbulence spectrum; it was shown that this approach yields results that agree with traditional turbulence measurements.

Plans FY 92

- The global data base of surface-based cloud observations will be compared to results from satellite observations of global cloudiness.
- The GIS data-base analysis methods will be implemented on both Macintosh and Sun environments.
- The dendrochronological research will be used to identify the temporal occurrence of major El Niño events during the past few hundred years with an accuracy of about 10 years.
- The studies of the sensitivity of the circulation of the North Atlantic Ocean will use a more realistic model that includes both bottom topography and coastline geography.

- The second phase of FIRE will begin, with extensive CIRES participation in the Atlantic Stratocumulus Transition Experiment, designed to observe and model the morphology and development of cloud cover in the eastern subtropical North Atlantic.
- Results from the statistical dispersion model will be used to determine the surface flux distribution of trace species from aircraft measurements at some height in the boundary layer.
- A full-scale effort to "fly" kite platforms in and well above the boundary layer (higher than 18 km) and to measure continuously critical atmospheric quantities (e.g., ozone, water vapor, electric fields, radiation) will be undertaken.
- Work on AVIRIS data will continue and will be scaled up to the properties of the High Resolution Imaging Spectrometer planned for the Earth Observing System (EOS) of the late 1990s.
- The Pacific profiler network will be integrated with the Tropical Ocean and Global Atmosphere (TOGA) experiment on ocean-atmosphere interaction. The Antarctic profiler system will be used to study wind patterns in the vicinity of the polar vortex, near the ozone depletion region.

CRYOSPHERIC AND POLAR PROCESSES

Cryospheric and polar processes research at CIRES focuses on the role of the cryosphere and the polar regions in the global and climate system. Activities involve basic and applied research and the related projects of the World Data Center–A for Glaciology (WDC–A) and the National Snow and Ice Data Center (NSIDC). In addition to NOAA National Geophysical Data Center (NGDC) support for these data centers, support for research is provided by ONR, NASA, the NOAA Global and Climate Change Program, NSF's Division of Polar Programs, and the Electric Power Research Institute.

Accomplishments FY 91

Data Center Activities

The Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) is a high-resolution microwave imager that provides near real-time microwave data on sea ice, atmospheric moisture and precipitation, soil moisture, snow cover over land, and ocean parameters. NSIDC converts compact antenna temperature to brightness temperature values using an antenna pattern correction algorithm and grids orbital swath data into brightness temperature grids for the polar regions. During FY 91 a new geolocation correction algorithm was implemented in the software that maps the SSM/I brightness temperature grids to correct large location errors in the SSM/I data. These errors are thought to be caused by orbit prediction errors coincident with increases in solar activity and errors in the location software at the Fleet Numerical Oceanography Center. New software was added to correct a residual 0.5 yaw-angle error.

In January 1990, NSIDC began distributing SSM/I brightness temperature grids for the polar regions on CD–ROM. Ten CD–ROM volumes of daily polar grids, covering the period July 1987 through December 1989, were distributed to more than 200 users.

NSIDC worked to develop a capability for the production of daily snow parameter products from the DMSP SSM/I. The data system being developed produces, archives, and distributes Northern Hemisphere snow extent products. The potential of the SSM/I for mapping other snow cover properties such as snow water equivalent, snow depth, and dry/wet snow boundary was also explored.

Within this project, NSIDC coordinates the activities of the SSM/I Products Working Team (SPWT), a multiagency and multidisciplinary working group focusing on extracting land surface (primarily vegetation,

soil, and snow cover) information from SSM/I. Snow cover algorithm comparison was undertaken in a cooperative effort with scientists at the University of Innsbruck, Austria, using regional test areas in the western United States and central Europe.

NSIDC began analysis of the DMSP imagery for the occurrence of lightning. Lightning signatures appear as horizontal streaks on the nighttime visible-band images. DMSP data provide unique information about lightning since no other satellite system operates a visible-band sensor at night. A data base of the location and time of nighttime lightning signatures was created for the entire global coverage imagery collection, which dates from 1973.

NSIDC developed a new snow-depth model to replace the current model used by the U.S. Air Force Global Weather Central (AFGWC). It provides state-of-the-art integration of all snow-cover data available at AFGWC, providing a global snow-cover product at a 40-km grid resolution. An improved interpolation technique was developed based on distance and elevation weighting criteria as well as spatial variance as defined by snow cover climatology. In addition, a method to extrapolate from high-confidence grid points into data-void mountainous regions based on generalized orographic precipitation gradients was developed.

NSIDC was funded by the NASA Polar Oceans Program to develop and operate a computer-based Cryospheric Data Management System (CDMS) to provide a single focal point for snow and ice data sets. The CDMS is an enhanced version of the Jet Propulsion Laboratory's NASA Ocean Data System customized for the archival of satellite data and the production of cryospheric data sets.

NSIDC provided data management services for the international, interdisciplinary Coordinated Eastern Arctic Experiment (CEAREX), which took place in the East Greenland Sea west of Svalbard, between 70° and 85°N, August 1988 through May 1989. A CD–ROM containing some of the key data sets collected during CEAREX was created in August 1991; data sets include meteorology; hydrography (conductivity, temperature, depth); ship- and ice floe-borne surveys of bathymetry; location of observations; biophysics; sea ice; and ambient noise and acoustic spectra samples.

Polar Climate Processes

A physical process model was developed to test the sensitivity of surface energy flux in the ice pack to variations in wind speed, air temperature, ice thickness, and dimensions of open water area, critical to understanding the transfer of heat to the polar atmosphere and the resulting ice growth and modification of the salinity structure of the ocean.

To study the response of the polar system to climate forcings, two-dimensional thermodynamic-dynamic models of the Arctic sea ice were modified to accept different treatments of surface albedo and surface energy fluxes, including radiative processes. Comparisons of model results point out the importance of dynamic processes in the ice pack, and set the groundwork for more detailed analyses of the effects of possible shifts in cloud cover and changes in surface albedo that might result with an increase in polar air temperatures.

Analysis of the existing time series of remotely sensed and field-collected observations for high latitudes has continued. This includes intercomparisons of meteorological measurements from drifting buoys and Soviet ice stations, statistical correlations of pressure patterns and ice outflow in the East Greenland Sea, and calculation of basic meteorological and ice statistics for the entire Arctic, as well as subregions. Results show a good consistency between ice station data and buoy data, which increases confidence levels in the multiyear buoy-data record for climate studies. Also, a strong and significant correlation was detected between high pressure systems in the Canadian Archipelago and ice outflow in the East Greenland Sea, which suggests a strong atmospheric connection to "Great Salinity Anomaly" events in the North Atlantic. The basic statistics for the Arctic show no significant trends in wind speed, but a noticeable upward trend in minimum air temperatures during winter.

Over the last year, all historical Arctic sounding data north of 65°N including land stations, drifting ice stations, and ships were compiled into a single-format, quality-controlled archive. The data base contains over 1.3 million soundings, which were analyzed to examine long-term variability and possible trends in Arctic tropospheric temperatures. Climatological characteristics of atmospheric pressure and upper-air height analyses were also examined in conjunction with a synoptic typing scheme to address relationships between temperature fluctuations and regional atmospheric variability.

Artificial intelligence (AI) techniques (expert systems and neural networks) were applied to satellite imagery and field observations to improve classification algorithms and assimilation of remotely sensed data, surface observations, and physical models. Image analysis techniques for extracting pattern information from different satellite image types were refined to relate the accuracy of these methods to the data requirements defined by the physical modeling work.

To improve understanding of sea-ice formation and deformation processes, under-ice shape was studied. Compilation of a data base on Arctic Ocean sea-ice draft continued. These data are based on analysis of under-ice thickness distribution data recorded during voyages of 12 nuclear submarines that traversed all regions of the Arctic Ocean during all seasons.

Analysis of under-ice thickness distribution data from transects in the Arctic Basin was aimed at using the fractal dimension of the roughness spectrum of the underside of the ice pack as a descriptor of ice roughness. It was found that sea ice on the large scale is smooth.

The degree of error expected in the measurement of widths of sea-ice leads along a single transect was also a focus of research. Methods were developed for estimating the distribution of actual widths (measured perpendicular to the local lead orientation) knowing the apparent width distribution (measured along the transect), and vice versa. The problem was applied to Landsat imagery along a submarine sonar transect. Results, determined for a range of geometries, indicate the importance of orientation information if data sampled along a transect are to be used for the description of lead geometries.

Satellite data were used to address the problem of estimating radiative and turbulent heat fluxes. Surface temperature, which is needed to estimate the fluxes, is best estimated by relating satellite observations to surface-temperature observations with a regression model. Lacking sufficient observations, however, satellite radiances or brightness temperatures can be modeled by application of the radiative transfer equation. A method to correct for atmospheric attenuation of satellite-measured thermal radiances was developed for use in retrieving ice surface temperature from the thermal channels of the Advanced Very High Resolution Radiometer (AVHRR) sensors. These corrections are specified for three Arctic "seasons" and as a function of satellite viewing angle.

Work progressed on analysis of variability in large-scale patterns of snow melt and parameterized surface albedo over Arctic sea ice, based on a 10-year data set compiled from manual analysis of DMSP visible-band satellite imagery. Variations in the timing of snow melt were examined in relation to synoptic-scale forcings of winds, surface pressure, temperature, and cloud cover.

The sea iceatmosphere interaction project is testing the feasibility of applying multispectral satellite data to polar surface-energy-flux estimates. In the past 6 months, the work concentrated on energy-flux sensitivity studies, ice-surface-temperature retrievals, corrections to AVHRR thermal infrared data, modeling of cloud-fraction retrievals, and radiation climatologies. A first conclusion is that the passive microwave satellite data may not provide accurate enough estimates of ice concentration and type to improve short-term energy-flux estimates. Derived parameters may still be applicable in longer term climatological flux characterization. Further, considerable variation in modeled energy-flux estimates was found when bulk transfer coefficients are modulated by lead fetch. Data sets for ice surface temperature retrieval were assembled and preliminary data analysis began. More atmospheric data were collected over Greenland during the summer of 1991.

Validation of the NASA-team algorithm to determine sea-ice concentrations from the DMSP SSM/I was completed using 28 cloud-free Landsat scenes. Mean absolute differences between SSM/I and Landsat ice concentrations are within 1% during fall using local and global tie points; in spring, the overall difference of

the NASA-team algorithm is higher. The algorithm tends to underestimate ice concentration in areas of close pack ice, and to overestimate ice concentrations in areas of open pack ice. In summer, larger differences are attributable to surface melt and comparison problems arising from a time lag of up to 8 hours between DMSP and Landsat overpasses.

Field Work

The Greenland Expedition is a major part of the longer term Greenland Ice Sheet Climate Programme, a collaborative project with the Swiss Federal Institute of Technology, Zürich; NASA Headquarters; and the Ohio State University, Byrd Polar Research Center. The program studies the atmospheric boundary layer above the ice sheet, the physical processes of the energy and mass fluxes in the snow layer and at the surface, the climatology of the entire Greenland ice sheet, and the use of satellite and aircraft data for the interpretation of the ice surface.

During the spring 1991 field campaign, the albedo in 875 spectral bands between 300 and 2500 nm was measured throughout the aging of snow at the expedition camp northeast of Jakobshaven. Further, the bidirectional reflectance distribution of several different surface types, such as dry snow, wet snow, refrozen snow, glacier ice, and glacier ice flooded with water, was measured with a portable spectrometer in the wavelengths 300 to 2500 nm at 1.5-nm resolution. From these measurements, correction functions were obtained for each surface type to derive high-resolution albedo maps based on AVHRR and DMSP–Optical Line Scanner (OLS) satellite data for the entire Greenland ice sheet.

The monitoring of the net radiative flux at the ice/snow surface was completed for May and June 1991, in conjunction with daily radiosonde profile measurements of the atmospheric temperature and water vapor distribution up to 25 km altitude. These measurements were analyzed and used as input variables in the LOWTRAN–7 radiative transfer model to calculate correction coefficients for NOAA AVHRR and DMSP–OLS visible and thermal infrared satellite measurements.

A NASA DC–8 flight mission was carried out successfully on June 14 over the Greenland ice sheet and the field camp area. The synthetic aperture radar (SAR) images in the L–, C–, and P–bands were correlated to ground-based observations, and to AVHRR visible satellite imagery. Best results were obtained with the P–band SAR imagery, because areas of slush, crevasses, and subglacial channels could be identified in great detail.

Analysis of gas and aerosol samples taken in March–April 1989 during the third Arctic Gas and Aerosol Sampling Program (AGASP–III) was completed. Significant boundary-layer ozone destruction was found to occur in the vicinity of large leads, particularly when excess aerosol bromine was very high.

The Antarctic ozone hole was studied from the perspective of its relationships to climatological variability. Research linked a downward trend in surface ozone concentrations at the South Pole (a decrease of 17% during austral summer since the mid-1970s) to enhanced photochemical destruction of ozone in the lower troposphere as a consequence of increases in UV radiation. During the same period, there was a decrease in the amount of total solar radiation reaching the surface at the South Pole as a result of a 25% increase in cloudiness. Additional work began on relating these phenomena to dynamical processes associated with possible changes in large-scale circulation patterns.

An analysis of International Geophysical Year (IGY) radiosonde observations from stations at different elevations on the Antarctic ice sheet confirmed a useful single linear dependence of the mean temperature of the layer between the surface and 500 mb on the surface temperature. Glaciologically implausible surface pressures, deduced from total gas contents in the lower reaches of the Vostok core with currently accepted isotope-surface temperature relationships, suggest the possibility that the latter (though not the isotope-cloud temperature relationship) may have been different in other phases of the glacial cycle. This hypothesis and its implications were formulated for ongoing discussions with prominent ice-core analysis specialists.

Plans FY 92

- NSIDC is proceeding with plans to develop an archive capability for the digital data being generated from the DMSP system. This effort will address a major data access problem faced by the science community since the production of analog images ceased about 1 year ago.
- In the final stage of the 3-year SSM/I/SPWT project, the combined research potential of the SSM/I-derived snow-cover and sea-ice products for studies of climate dynamics and global/regional hydrology will be explored.
- The ice-pack energy flux model will be incorporated into more comprehensive ice models. Planned work includes driving the models with radiative forcing calculated from satellite-derived cloud cover and surface albedos.
- Work will begin on a comparison of the sounding archive with satellite-derived thermodynamic soundings provided by data from the Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder.
- Further work on data set development will include refinement of the AI methods and broader application to larger data sets, and comparison of AI-based filtering methods to methods such as Kalman filtering.
- Ozone studies will attempt to explain recent discoveries through a better understanding of the relationships between dynamical, radiative, and photochemical processes in that region.
- Results from analysis of the IGY observations will be used to refine the Australian operational 500 mb analyses for 1987. The Antarctic Weather Station data for that year, together with radiosonde observations, will be used to study the link between katabatic flow fluctuations and changes in the upper circumpolar vortex.

ENVIRONMENTAL CHEMISTRY AND BIOLOGY

CIRES collaborates with NOAA's Aeronomy and Climate Monitoring and Diagnostics Laboratories in Environmental Chemistry and Biology (ECB) 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.

Additional CIRE—ECB research complements NOAA research goals and promotes the development of new NOAA research initiatives.

Accomplishments FY 91

Global Change

Over the last 12 months, methane fluxes were measured in Colorado montane environments. Methane release rates were surprisingly high; they overlapped at some times measurements taken in Florida and in the

Amazon flood plain. However, the seasonality of active release is relatively short because it coincides with above-freezing temperatures. The data show substantial accumulation of methane under ice in lakes during the winter, with sudden release at the time of thaw. This may produce the strong seasonality in the concentration variations of methane in the Rocky Mountain region.

Studies were initiated on an ambitious data collection program for methane flux from the Orinoco flood plain in Venezuela. Methane fluxes from tropical flood plains are a potentially significant component in the global methane budget because these flood plains are highly active metabolically, contain extensive anaerobic organic deposits, and cover large areas adjacent to the large tropical rivers. Preliminary results show relatively low release rates over open water but very high release rates over vegetation mats. These mats, which account for as much as 50% of the area of inundated flood plain, can enhance methane release because they create pockets of anaerobic conditions, and because the aquatic plants conduct methane at the surface quickly, thus preventing it from being oxidized near the surface before leaving the water column. This 2-year project was supported by the NOAA Global Climate Change Grants Program.

CIRES scientists are investigating the use of high spectral resolution optical and infrared spectra for estimating plant-canopy chemistry and biophysical properties that control biogeochemical cycling. Plant material and reflectance spectra were collected at the Konza Prairie, KS, and in Colorado grasslands. Preliminary results indicate that foliar chemistry affects the leaf reflectance spectrum in detectable and quantifiable ways.

Vegetation response to climate occurs through changing species composition and altered physiology. CIRES scientists are working in collaboration with colleagues at other institutions on an interdisciplinary project, "Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Arid and Semiarid Lands." The goal is to couple a simple ecosystem model to spectral data from EOS sensors to monitor changing patterns of ecosystem physiology and function in response to climate variation and change. Field and aircraft spectrometer data in the Konza Prairie, a grassland steppe, were collected along with canopy profile measurements of gas exchange, light interception, and foliar chemistry. This airborne spectral information is used to track the nitrogen disposition and cycling in the ecosystem. During the summer of 1991, a similar pilot study was made at a test site (La Copita, TX). This site, a savanna parkland, is representative of the vast semi-arid shrublands, which are major global terrestrial ecosystems.

A team of CIRES scientists, in cooperation with colleagues from Venezuela, combined a comprehensive assessment of Orinoco River studies with existing information from other rivers of northern South America to produce the first comprehensive overview of the mass transport of nitrogen, phosphorus, and carbon to the sea from northern South America. These studies are important additions to global biogeochemical cycling research that attempts to determine the relative transport rates of chemical elements by aquatic and atmospheric media.

A detailed series of studies on the Orinoco flood plain, using isotope identification, demonstrated that the aquatic food chain depends almost exclusively on carbon derived from algae rather than from vascular plants. It is believed that algal biomass is more easily obtained and more easily digested than biomass of vascular plants. The emerging view is that any perturbation of the algal food base may be extremely important to the aquatic communities of flood plains.

Isotope geochemistry was used to investigate variations in the isotopic compositions of elements with radiogenic isotopes. In these projects, radiogenic isotopic data are used as "tracers" to investigate processes occurring both within, and at the surface of, the Earth. This work included studies of the isotopic compositions of strontium (Sr) dissolved in both groundwaters and hydrothermal fluids to track fluid flow pathways and studies of the Sr isotopic composition of marine carbonates to analyze the chemical evolution of the Arctic Ocean.

Regional Environmental Problems

A new technique to measure carbonyl compounds, ozone precursors, in the atmosphere was developed and field tested. The technique is based on the simultaneous collection and derivatization of these aldehydes and ketones on microcartridges containing porous glass beads impregnated with dansyl hydrazone (DNSH). Measurements of sub-ppbv levels of formaldehyde, acetaldehyde, and some higher carbonyl compounds were made at Niwot Ridge during the summer of 1991. The high sensitivity of the technique suggests the possibility of future measurements of formaldehyde in the free troposphere.

The principal sources for nonmethane hydrocarbons (NMHC) in rural areas are thought to be emissions from vegetation. Regional NMHC emission inventories have been based on empirical algorithms derived from relatively few emission rate estimates. CIRES scientists are working to develop a more mechanistically based algorithm for leaf isoprene emission, and to test this algorithm with field measurements. Isoprene emission rates from individual trees were investigated with a laboratory gas exchange system and an environmentally controlled leaf cuvette. Isoprene emissions were slightly dependent on humidity and CO_2 concentration, but strongly dependent on light intensity and leaf temperature, which forms the basis for an improved empirical isoprene emission rate model. Field data collected during the 1990 Rural Oxidants in the Southern Environment (ROSE) study in Jachin, AL, indicated that this emissions model provides a superior framework for isoprene emissions inventory development.

A comprehensive modeling effort based on the South Platte River below Denver was initiated to explain the reasons for the observed oxygen deprivation there. The factors that determine oxygen concentrations in western rivers are poorly understood, but are thought to involve a complex pattern of daytime photosynthesis counterbalanced by high rates of nighttime oxygen respiration. The model combines diurnal cycling of photosynthesis with oxygen-suppressing nitrification and respiration. The model results will be used by the EPA in determining the course of regulatory action on the South Platte River.

Remediation

Widely used separation processes such as distillation, extraction, and precipitation suffer from poor selectivity or inefficient use of energy. New separation technologies are important because remediation of polluted sites often requires removal of the pollutants from the site and concentrating them prior to final treatment or storage. Also, if industrial separation processes can be improved, they will be more energy efficient and will produce less waste. Because most available separation technologies are not energy efficient, remediation activities often end up cleaning up one site while polluting another that is associated with the production of the energy required for the initial removal.

Research at CIRES is aimed at developing new or improved separation processes. Work conducted during FY 91 included the following:

- Studies of facilities transport in liquid and polymer membranes; this promising separation technique is based on a chemical carrier that is confined to a supported liquid membrane and selectively binds the solute to be separated.
- Investigations of electrochemically modulated complexation; this is combination of electrochemistry and solvent extraction that selectively removes pollutants from a contaminated liquid phase.
- Studies of photoelectrochemistry at particulate semiconductors; this is a photoinduced catalysis that uses illuminated TiO_2 particles for the remediation of waste streams that contain both organics and metal ions (e.g., plating bath solutions).

Halogenated aromatic compounds are widely used as pesticides and herbicides, and are also a byproduct of certain industrial processes. These compounds tend to accumulate in the environment because biodegra-

dation of halogenated aromatic molecules is slow. CIRES research focused on the mechanisms of critical enzymes required for the metabolism of chlorinated aromatic compounds by soil microorganisms. These organisms use metabolism strategies involving either oxidation and rearrangement of the compound to form an easily degradable chlorinated intermediate or removal of the chlorine in the initial step leading directly to destruction of the compounds. Research at CIRES addressed several questions concerning these strategies:

1) What modification in the structure or reaction mechanism expedites destruction of chlorinated molecules?

2) Can the enzymes that catalyze the chlorine removal be isolated?

3) Can the chemical reason for these processes be identified?

4) Can a more efficient enzyme be evolved in the laboratory?

5) If a more efficient enzyme can be evolved, can the mechanistic changes leading to an improvement in catalytic activity be understood?

Plans FY 92

- Measurement of methane fluxes in the Orinoco River basin will be completed. Data should provide a sound basis for estimating the total methane release for the Orinoco flood plain.
- Temporal studies of light interception and reflectance, gas exchange, and nitrogen allocation will be conducted using acquisition of imagery from the AVIRIS spectral and spatial analyses of the landscapes of the grassland and shrubland study sites.
- Based on present results, new methods that can achieve a tenfold improvement in sensitivity of the carbonyl detector will be implemented.
- Development of selective detectors will proceed using redox (NO) chemiluminescence to detect compounds that containing sulfur and nitrogen, which are vitally important in atmospheric chemistry but are difficult to detect and measure.
- Selective detection of sulfur compounds using a thermionic emission converter that generates SO from sulfur-containing species followed by SO-chemiluminescence will be developed.
- Development of a new process will continue for the transport of reagents by a supercritical fluid, followed by chemical deposition of a film, to use these films as chemical sensors in monitoring devices.

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, Colorado, and the Nation. CIRA operates under the auspices of the CSU Graduate School and its Office of Vice President for Research. Its 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. Participation by NOAA is primarily through the Environmental Research Laboratories (ERL), the National Environmental Satellite, Data, and Information Service (NESDIS), and the National Weather Service (NWS). At CSU, the Departments of Atmospheric Science, Civil Engineering, Computer Science, Earth Resources, Economics, Electrical Engineering, Physics, Psychology, Recreation Resources and Landscape Architecture, and Statistics have been or are involved in CIRA activities. CIRA research concentrates on air quality, cloud physics, mesoscale studies and forecasting, satellite applications, climate studies, agricultural meteorology, model evaluation, and the economic and societal aspects of weather and climate.

Accomplishments FY 91

Each year CIRA hosts at least two workshops, one of which is for all CIRA research personnel. This year's research workshop was held 26–28 June 1991 and was well attended by many CIRA researchers, which includes employees of CIRA, CSU, and the Regional and Mesoscale Meteorology (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.

An invitational workshop sponsored jointly by CIRA and its Center for Geosciences was held on 21–24 May 1991. The topic was four-dimensional data assimilation. The workshop included participants from CSU, several outside universities, NOAA, the U.S. Army, and the National Center for Atmospheric Research (NCAR).

A very successful Fellowship Program supported scientists from Canada, Denmark, and Italy. Many prominent scientists also visited CIRA and gave seminars.

Plans FY 92

In addition to ongoing regular research, CIRA will continue to cooperate with the U.S. Army Research Office through the Center for Geosciences. CIRA will also hold a general research workshop and an invitational workshop.

CIRA will continue its Fellowship Program with the scientists from Italy and Canada, host visiting scientists, and support the seminar program.

SATELLITE CLOUD CLIMATOLOGY PROJECT

Accomplishments FY 91

CIRA participates in the International Satellite Cloud Climatology Project (ISCCP) (part of the World Climate Research Programme) as a Sector Processing Center. Major accomplishments included the following:

- Prepared histograms to support the World Climate Research Programme rainfall estimation project.
- Investigated problems of global cloud analysis using high-resolution geosynchronous satellite data.
- Coded advanced software to handle GOES-Next data.

Plans FY 92

- Prepare high-resolution cloud estimates from Indian Satellite (INSAT) data.
- Examine cloud forcing of vertical cloud distribution.
- Complete the INSAT review and reformatting.
- Compare ISCCP C1 products and sea-surface temperatures.
- Collect and archive ISCCP B1 and B2 data from GOES West with the 4.5 years of ISCCP data (March 1983–December 1987).
- Collect METEOSAT–50 data.

SEVERE WEATHER RESEARCH

Accomplishments FY 91

Studies supported NOAA's severe weather prediction mission in mesoscale analysis and forecast product development.

- Developed major hardware and software upgrades for the CIRA ground station in preparation for GOES Variable Format (GVAR) ingest.
- Investigated convective initiation and tornado genesis, and analyzed in detail the rapid-scan GOES imagery and five channel TIROS–AVHRR imagery for the devastating 28 August 1990 Plainfield, IL, tornadoes.
- Developed mesoscale cloud climatologies and explored their uses by synoptic flow stratification.
- Continued to interact with NOAA elements on TIROS data uses, mesoscale soundings with VAS data, and expert system forecasting regions.
- Utilized expert system forecast (nowcast) applications in continued interactions with the Cheyenne, WY, NWS Forecast Office.
- Developed methods for using VAS and TIROS radiances for mesoscale sounding derivation and mesoscale product development.
- Evaluated several Oklahoma-Kansas Preliminary Regional Experiment for STORM (OK–PRE–STORM) data sets.
- Transferred information through publications, seminars, training programs, and CIRA research retreats.
- Developed and transferred software to the NWS National Severe Storms Forecast Center in Kansas City, MO, to aid in analyzing rapid-scan imagery through storm-relative animation.

Plans FY 92

- Investigate satellite data focused on severe convective environments.
- Develop mesoscale convective climatologies.
- Investigate satellite data focused on tropical storms and mesoscale convective systems.

- Select field experiments, such as Convection and Precipitation Electrification (CaPE) experiment (Florida during the summer of 1991).
- Use satellite data and enhanced mesoscale data sets for improved mesoscale analyses and nowcast product development.
- Evaluate and develop nowcast products for VAS Data Utilization Centers (VDUC) and other state-of-the-art interactive forecast systems.
- Investigate case studies of special research program data sets [(OK–PRE–STORM, Cooperative Huntsville Meteorological Experiment (COHMEX), CaPE, etc].
- Investigate the utility of polar orbiting data, especially microwave, for regional and mesoscale applications.
- Develop mesoscale training aids and techniques.

AIR QUALITY—JOINT RESEARCH WITH THE NATIONAL PARK SERVICE

Accomplishments FY 91

A cooperative effort with the U.S. National Park Service (NPS) and NOAA continued to determine, evaluate, and analyze the visual effects of pollutants on specific scenic vistas.

- Tested and validated the backward scattering Monte Carlo radiative transfer model.
- Developed a particulate data-base management system that incorporates outlier checking, quality assurance, and statistical analysis.
- Produced videos showing the effect of pollution on various national parks.
- Developed added capabilities to produce video presentations of research results.
- Investigated the effects of various sulfur emission reduction scenarios on visibility.
- Provided graphics and video support to the NPS Air Quality Division.

Plans FY 92

- Produce a training video on the use and calibration of visibility monitoring equipment.
- Install and test a new 32-bit video graphics system to provide a method to mix video signals and special effects graphics.
- Identify reasons for differences between reconstructed and measured fine particle mass and light extinction values.
- Complete an NPS management training video depicting sources and types of pollutants that impact specific national parks.
- Produce a video showing the biological effects of pollutants on fauna in national parks.

WMO SHARE PROGRAMME

CIRA has contracted with the World Meteorological Organization (WMO) to participate in the WMO SHARE Programme. SHARE is a 3-year international project to develop meteorological analysis and display software for countries and to train scientists of these countries in the use of SHARE products. Participating scientists from Argentina, Brazil, Jamaica, Kenya, Niger, People's Republic of China, Sri Lanka, Trinidad, Turkey, Venezuela, and Yemen visited CIRA.

Accomplishments FY 91

- Assisted participating countries in training and installing the VAX VMS Version 1.0 software produced by CIRA to enable scientists to instruct their nationals in use of an IBM PC/AT for specific research needs.
- Provided software routines to process and display forecast products.

Plans FY 92

- Continue to train scientists of Third World countries to install software and to train others when they return home.
- Correct any problems during and after installation.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

Norman, Oklahoma
(405) 325-3041
Peter J. Lamb, Director

The University of Oklahoma (OU) and NOAA established the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) in 1978 to promote cooperation and collaboration on problems of mutual interest among research scientists in the NOAA Environmental Research Laboratories, mainly the National Severe Storms Laboratory (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).

A 3-year cooperative agreement between OU and NOAA for CIMMS funding took effect on 1 July 1990. Under this agreement, CIMMS concentrates its efforts and resources on three principal research themes: (1) basic convective and mesoscale research, (2) forecast improvements, and (3) climatic effects of mesoscale processes.

Accomplishments FY 91

Basic Convective and Mesoscale Research

Electrification of mesoscale convective systems

CIMMS scientists, graduate students, and support personnel expanded their research on the electrical aspects of mesoscale convective systems (MCSs), and developed enhanced data processing for mobile laboratory data, especially those obtained with instrumented balloons. CIMMS personnel developed new processing software for comparing the vertical profiles of the electric field with in situ measurements of thermodynamic properties and wind using loran sondes. These developments were used in and after the Cooperative Oklahoma Profiler Studies–1991 (COPS–91) field program. Nearly 40 soundings were collected with the NOAA P–3 and South Dakota School of Mines T–28 aircraft. In several MCSs, multiple soundings were made from two different locations. CIMMS personnel were members of mobile lab crews and also gained experience on the P–3.

In addition, the data acquisition phase of Ph.D. research funded by NSF to obtain in situ measurements of precipitation particle charge and size was completed during COPS–91.

Warm cloud modeling

A warm convective cloud model with explicit microphysics was used to study the effect of cloud condensation nuclei (CCN) on the evolution of cloud microphysical elements. A parameterization of the mass of soluble salts in the cloud droplet growth equation was developed; it is particularly important for stratocumulus cloud modeling. Trajectory analysis of the air motions during convective growth revealed novel mechanisms of cloud top entrainment and cloud droplet recirculation processes. The mechanism of vorticity generation in multicellular clouds was also studied and explained.

Data assimilation

Simulations of mesoscale flows such as dry lines were studied using sophisticated methods to assimilate wind and temperature measurements in a nonhydrostatic model to determine the relative value of high temporal resolution data in the initialization of the models. Results of these studies were presented at the Numerical Weather Prediction Conference in Denver, CO, in October 1991 and have been submitted for publication. The work was accomplished in association with The Pennsylvania State University.

The use of parallel processing machinery to accomplish these assimilations was investigated in collaboration with faculty at the OU Computer Sciences Department. Application of the assimilations to the hurricane tracking problem was made and two papers were submitted for publication.

Boundary layer studies

A parameterization of the convective boundary layer was developed. It is based on a decomposition of statistical moments into nonpenetrative and residual components and on their local similarity. The method was tested by using laboratory, numerical, and atmospheric data to show that the derived similarity functions agree with experimental data.

In a related study, a method was developed to determine the heat flux within the convective boundary layer. The method was tested using data from the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment (FIRE).

Wind retrieval

A few schemes of wind retrieval were developed and tested using synthetic data. All methods employed the variational approach and were based on an assumption that radar reflectivity or radial velocity can be treated as a passive scalar.

Simple adjoint methods were developed for retrieving the time-mean winds over consecutive scans from single-Doppler measurements. The methods were tested on the Phoenix II field experimental data, and the results are very encouraging. In particular, the correlation between the retrieved winds and dual-Doppler observed winds can be higher than 90%. Because of their low computational cost and higher accuracy (than other methods of the same category), the methods are quite promising for operational uses.

Diagnostic model development

The three-dimensional viscous semigeostrophic (VSG) diagnostic model was further developed for real-data uses, which include topography, horizontal adjustment scheme for inertial instability, slantwise adjustment scheme for moist symmetric and/or convective instability, explicit computation of stratiform latent heating, and bulk formulations of eddy viscosity and planetary boundary layer processes. From tests on ALPEX data, NMC eta-model data, and data simulated by the Navy Operational Regional Atmosphere Prediction System (NORAPS) model for a case during the Gulf of Mexico (GUFMEX) field project, the VSG model results were found to be significantly better than those from the conventional ω-equation model. Currently, the VSG diagnostic models are being used for two case studies: the 6–7 May 1985 MSC and its associated vortex and the 21–23 February 1988 frontal precipitation system over the Gulf of Mexico.

New diagnostic formulations and methods

The Q–vector equations were combined with the vertical ageostrophic vorticity equation to form a complete set of QG diagnostic equations in a vector form with a newly introduced geostrophic forcing vector, the C–vector, on the right-hand side. The C–vector is a three-dimensional extension of the rotated two-dimensional Q–vector and shows merit for both qualitative analyses and quantitative computations of three-dimensional ageostrophic circulations. The C–vector formulation and methods of solution were also extended to the SG equations in physical space.

The completeness of the solution for three-dimensional ageostrophic circulations obtained from the psi-equations and the admissible boundary conditions were addressed for the first time. Methods of solution were proposed with examples showing the possible significance of the barotropic ageostrophic wind and the physical implication of the nonhomogeneous boundary conditions in real-data applications.

Mesoscale dynamics and physical processes

The classic theory of density current was extended to include the effects of the environmental shear and negative vorticity generation in association with energy loss along the interfacial layer between the density

current and the environmental flow. Physical insights were gained into the interaction between environmental shear and the cold pool of a thunderstorm outflow (gravity current).

The mass sink of moist air due to condensation is not always negligible, but it has been conventionally neglected in almost all numerical models. The Penn State/NCAR mesoscale model was used to perform a series of numerical experiments to examine the effect of this neglected term, and the results show that this term can significantly affect forecasts of heavy precipitation (e.g., 20% increase in the maximum precipitation).

Forecast Improvements

Thunderstorm initiation

A study was completed to examine the utility of WSR–88D, surface network, and rawinsonde data to determine the location and timing of the initiation of thunderstorms in the vicinity of Kennedy Space Center. A reliable short-term forecast of the initiation of thunderstorms can be made by using high-resolution Doppler radar data, such as will be available from the WSR–88D. The Doppler radar data can be used to detect convergent boundaries and the first echoes aloft near them that are associated with incipient storms. The combination of these two signatures could give a lead time of 8–45 minutes before the first cloud-to-ground lightning strike associated with a thunderstorm.

New observing system technology

An improved version of the FAA Terminal Doppler Weather Radar gust front detection algorithm, which incorporates reflectivity thin line, azimuthal shear, and radial convergence detection to determine the location of gust fronts, was operationally tested in FY 91 by the Massachusetts Institute of Technology (MIT) and NSSL. This algorithm was tested in real time on a system that ingests Doppler radar data, runs the algorithm, and then displays products on top of Doppler radar velocity and reflectivity fields. Use of this real-time system helped determine the strengths and weaknesses of the algorithm, so that timely enhancements could be made.

Work continues on the long-term project of severe storm watch box verification. Specific work this year, presented at the Tornado Symposium, were statistics that elucidate the ability of Severe Local Storms Unit of the National Severe Storms Forecast Center (NSSFC) forecasters to distinguish tornadic from nontornadic severe storms. A related application of this data base will address the question of why the strongest nighttime tornados are strongly confined to the Gulf Coast states.

GUFMEX

A proposal was submitted to the Partners' Program of COMET (Cooperative Program for Operational Meteorology, Education, and Training) to study the operational aspects of return flow forecasting in the Gulf during February and March. This proposal was approved and the study will involve forecasters in the National Weather Service (NWS) Southern Region and researchers at NSSL and CIMMS.

The evolution of the mean characteristics of the marine boundary layer during cold-air outbreaks was described with a slab model and tested against observations collected during GUFMEX by an instrumented NOAA P–3 aircraft and a Cross-chain Loran Atmosphere Sounding System (CLASS) onboard the U.S. Coast Guard vessel *Salvia*. The moistening and heating of air over the Gulf in the cool season was examined in

light of some recent work on the theory of boundary layer processes related to establishment of equilibrium equivalent potential temperature at the air-sea interface. Key results were presented at the Symposium on Air-Sea Interaction and Air Mass Modification, held in Galveston, TX, in January 1991.

Climatic Effects of Mesoscale Processes

Stratocumulus cloud modeling

The general concept and algorithms of a new stratocumulus cloud model that includes the explicit formulation of both microphysical and radiative processes have been developed. Significant effort went into the design of the computer code, which includes 41 additional variables for microphysical description. The new model can run on both the VAX and Cray computers, providing more flexibility for its debugging. A set of experiments is now under way to test the model and to compare its results with the bulk microphysical parameterization model that has been implemented on the OU Geosciences Computer System.

Plans FY 92

- Scientists at CIMMS will work with NSSL scientists to determine methods to forecast lightning at Kennedy Space Center. This will include the analysis of WSR–88D, rawinsonde, and surface network data to determine reliable precursors to thunderstorm initiation.
- Scientists will further test and enhance the gust front detection algorithm, and examine its use on the WSR–88D system.
- Microburst forcing mechanisms will be examined to determine if there are precursors that will give clues to the strength of impending microbursts 5–10 minutes in advance.
- Strong vertical shear of the horizontal winds at low altitudes, which can occur with low-level jets, synoptic fronts, and other meteorological phenomena can be dangerous to landing aircraft. CIMMS scientists will examine Doppler radar data to detect such hazardous conditions.
- CIMMS researchers will work with OU professors to use parallel processing machinery to make the adjoint method more efficient.
- During the next year, major emphasis will be placed on the analysis of the unique and high quality data from COPS–91. The combined areas of analysis for CIMMS scientists and students include precipitation charge structure and its role in overall MCS electrification, time and spatial distribution of the charge structure in MCSs, and differences in the electrical structure of a leading line/trailing stratiform versus a bow-echo MCS.
- We will present initial results at the Fall Annual Meeting of the American Geophysical Union meeting in December in six coordinated papers.
- We plan to begin using in situ measurements to compare and constrain models and to incorporate the initial codes in lightning parameterization.
- The effects of CCN distributions on the radiative properties of a stratocumulus cloud layer will be studied.
- Study of entrainment and drop recirculation mechanisms in convective clouds will be continued.
- Modeling studies of the evolution of air masses over the Gulf of Mexico will continue.

- We plan to work with NMC to study the impact of changes in model parameterizations on predictions of air mass modification over the Gulf of Mexico and the details of moisture transport from the Gulf to the continent.
- Output of a three-dimensional nonhydrostatic model of a warm, oceanic convective cloud with detailed microphysics will be compared with the output of the model with the same dynamic framework and a warm cloud parameterization based on the gamma function.
- Increasing emphasis will be placed on the climatic effects of mesoscale weather phenomena for central North America and sub-Saharan Africa. This work will include attempts to extract regional and mesoscale climate information from GCM simulations of climate change induced by greenhouse gases.

COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH

Ann Arbor, Michigan
(313) 764-2426
Russell A. Moll, Director

The Cooperative Institute for Limnology and Ecosystems Research (CILER) is a joint endeavor between the University of Michigan, Michigan State University, and NOAA's Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor. The CILER administration is on the Ann Arbor campus of the University of Michigan. The Institute has more than 70 Fellows who are affiliated with research institutions throughout the Great Lakes Basin.

The Council of Fellows, which is a subset of the total body of Fellows, provides the primary intellectual guidance to CILER. It comprises individuals from GLERL, the University of Michigan, Michigan State University, the University of Minnesota, the University of Wisconsin, Harza Engineering Company, The Ohio State University, and the State University of New York.

Although CILER is the only joint institute with direct responsibilities for research in fresh water, its activities are not limited to the limnetic environment. CILER has research under way in estuarine and coastal marine environments. In all three aquatic environments, CILER has research foci in three areas: Climate and Global Change, Coastal and Nearshore Processes, and Large-Lake Ecosystem Structure and Function.

CLIMATE AND GLOBAL CHANGE

Accomplishments FY 91

The CILER research program in Climate and Global Change covers four areas: Regional Great Lakes Mesoscale Climate Models, Lake World Climate Studies, Paleoclimate Studies, and Climate-Induced Food Web Changes. Activities in FY 91 covered the first two topics. Through the NOAA Coastwatch Program, funds were made available to continue development of the Lake Erie Information System (LEIFS). This system is intended to provide operational forecasts of three-dimensional current and temperature fields, water levels, deep and shallow water waves, and other physical data from Lake Erie. The information would then be available to the interested and informed public as well as to the scientific community. Until FY 91, LEIFS was supported only by small seed grants and remained in a developmental stage. Through CILER funding,

LEIFS moved into a second, "incubation" stage in FY 91. This second stage of development will expand LEIFS from the research laboratory into the public-use setting.

Another area of CILER activity in FY 91 was in Lake World Climate Studies. Initial funds for this project, from the University of Michigan, were used to deploy a string of instruments in Lake Victoria in East Africa. The rationale behind this approach is to deploy identical instrument strings in large lakes of the world. Comparison of results of measurements from lakes in different climate zones will indicate how these large lakes respond to climate change. The instrument string deployed in Lake Victoria consisted of a thermistor string, sediment trap, and current meter.

Plans FY 92

Regional Great Lakes Mesoscale Climate Model

LEIFS's second stage will link the various models of Lake Erie to yield nowcasts and forecasts of currents, water temperature, waves, and related physical data. Predicted uses of LEIFS include Great Lakes hazard forecasting, enhancement of commercial and recreational activity on Lake Erie, an information base for scenario testing and risk assessment, and resource preservation activities. We will take results that are currently available only in the laboratory and make them more generally available to the public. This activity will include an improvement in the nowcasts and forecasts and the development of a functional distribution system. LEIFS will ultimately be expanded to the entire Great Lakes region, which will also provide a foundation on which to build a Great Lakes mesoscale climate model.

Lake World Climate Studies

CILER investigators will continue to collect data from the moored string of instruments in Lake Victoria and to place a second string of instruments in a North American large lake. Lake Victoria was selected as the initial site because the current data base from this lake is small compared to that from other large lakes of the world. The second site will be a lake with a small data base, but in a very different climate. A candidate lake would be one of the large northern Canadian lakes.

COASTAL AND NEARSHORE PROCESSES

Accomplishments FY 91

The program of study in Coastal and Nearshore Processes supported by CILER has three related topics: Shoreline Responses to Forcing Functions, Wetland/Estuary Structure and Function, and Coastal Exchange Processes. In FY 91 activities were supported only in the last area.

The first project supported by CILER was in a study of the plume of the Mississippi River in the northern Gulf of Mexico. This research is a component of the Nutrient-Enhanced Coastal Ocean Productivity (NECOP) program, part of the NOAA Coastal Ocean Program. Investigations included field studies of the enhancement of plankton and bacterial productivity inside and outside of the Mississippi River plume; exchange of nutrients from the river plume into Gulf of Mexico waters; and physical processes in the immediate vicinity of the river plume front.

A second research project involves the physical, chemical and biological processes surrounding the vernal thermal front in Lake Michigan. This springtime front is a fundamental feature of the warming of all large lakes of the world in temperate climates and appears to play a crucial role in the transition from fully mixed midwinter conditions to thermally stratified summer conditions. A team of six investigators conducted three multivessel research cruises to eastern Lake Michigan in April and May to study the formation and progression of the thermal front.

Plans FY 92

Coastal Exchange Processes

Both the NECOP and thermal fronts projects will continue in FY 92. CILER-sponsored activities under the NECOP program will include several field trips to the Gulf of Mexico where researchers will investigate the importance of the nutrients from the river outfall to the overall productivity of the Gulf of Mexico. Related studies will determine which physical processes are prominent in transporting those nutrients from the river plume into Gulf of Mexico waters.

Thermal front studies planned for FY 92 include an intensive 8-week period of field studies in April and May in eastern Lake Michigan. Using two ships and moored instruments, scientists will investigate subsurface and near-surface currents in the vicinity of the thermal front; identify and characterize the thermal fields, chemical fields and plankton distributions in three dimensions; and measure near-front plankton productivity. Field sampling will be supported by satellite remote sensing of Lake Michigan surface water temperatures.

LARGE-LAKE ECOSYSTEM STRUCTURE AND FUNCTION

Accomplishments FY 91

CILER research in Large-Lake Ecosystem Structure and Function covers five topics: comparative limnology, limnological ecosystem structure and function, ecosystem stresses from toxic substances, effects of exotic species invasions, and fisheries recruitment dynamics. In FY 91, CILER studies were conducted in two topics: ecosystem stresses from toxic substances and effects of exotic species invasions.

Funding from the U.S. Environmental Protection Agency (EPA) supported a study of the lower Saginaw River. The lower section of the Saginaw River is one of the 43 Areas of Concern (AOC) in the Great Lakes. The sediments of the lower 10 km of this river are contaminated with heavy metals and hydrophobic organic compounds (HOCs), particularly PCBs. Beginning in the fall of 1990, sampling was conducted over a 1-year period. CILER researchers and other EPA-sponsored investigators sought to determine if the contaminants found in the sediments of the river were mobilized during large storms into the water column and from there into the aquatic biota. Samples of fish were also analyzed for PCBs to determine if high suspended sediment concentrations are linked to contamination of sports fish.

Through a special Congressional appropriation, GLERL and CILER investigators were able to initiate an ecosystem-based study of Saginaw Bay before and after zebra mussel infestation. In the spring of 1991, a team of investigators from GLERL, the University of Michigan, Michigan State University, Saginaw Valley State University, The Ohio State University, and Bowling Green University began monthly field trips to Saginaw Bay to measure a large suite of variables. These include physical and chemical properties of the water, phytoplankton biomass and productivity, benthic algae biomass and productivity, macrophyte biomass and productivity, macro-benthos biomass, zooplankton biomass and feeding rates, and fish biomass within

wetlands. Timing to date on this project has been excellent in that zebra mussels were found in small numbers in Saginaw Bay in the early spring of 1991 and in abundance by the fall of 1991. CILER administrative staff also have played an important role in coordinating zebra mussel research among different research institutions of the Great Lakes Basin.

Plans FY 92

Ecosystem Stresses From Toxic Substances

The study of the mobilization of contaminated sediments of the lower Saginaw River will continue into early 1992. Field work is slated to conclude in late 1991 and sample analyses in early 1992. The results from the field studies conducted in the CILER-funded projects will be used in two EPA-sponsored contaminate models. A near-field model will determine if contaminants swept into the water column from the sediments settle back onto the river bottom and never reach either Saginaw Bay or the biota living in the bay. A far-field model will determine if these mobilized contaminants leave the river and enter the Saginaw Bay ecosystem.

Impacts of Exotic Species Invasions

The study planned for Saginaw Bay continues the work started in FY 91, and now includes all investigators from last year plus one each from the University of Minnesota and Kent State University. This team of scientists will continue to sample the same aspects of Saginaw Bay, including the plankton, benthic algae, benthos, wetlands, fish, and sediments. In addition to the field sampling, laboratory and field experiments are planned. The primary rationale of this research is to decipher the large-scale changes to Saginaw Bay as the zebra mussel population reaches infestation levels. The zebra mussel population is expected to reach infestation levels during the summer of 1992. Laboratory experiments are investigating the feeding behavior and physiological energetics of zebra mussels.

Limnological Ecosystem Structure and Function

In most deep-water aquatic systems, plankton account for nearly all primary production and herbivory. A major portion of the plankton in the Great Lakes is the calanoid copepod population. A Visiting Fellow will explore the relationship between the quality and quantity of algal food and feeding by an important calanoid copepod. The freshwater copepods will be maintained in cultures and fed algae grown under different nutrient regimes. The copepods will be examined for egg production, adult survival, chemical composition, and lipid content in conjunction with the different algal cultures. The feeding behavior and food selection of the copepods will be observed using microcinematographic techniques.

COOPERATIVE INSTITUTE FOR MARINE AND ATMOSPHERIC STUDIES

Miami, Florida
(305) 361-4169
Joseph M. Prospero, 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). The primary purpose of CIMAS is to provide a mechanism that can facilitate and stimulate cooperative research between the two institutions. There are two research themes in CIMAS: climate variability, and fisheries ecology and ecosystem dynamics. Research is conducted in the CIMAS building, in other laboratories on the RSMAS campus, and in the laboratories of NOAA's Environmental Research Laboratories (ERL) and those of the National Marine Fisheries Service (NMFS).

CLIMATE VARIABILITY

Research on climate variability is primarily conducted in close cooperation with the Atlantic Oceanographic and Meteorological Laboratory (AOML) and focuses on those aspects of ocean dynamics that are considered important for understanding climate mechanisms and for predicting climate change. Many FY 91 activities fell within two major NOAA programs: Subtropical Atlantic Climate Studies (STACS), which has merged with the Atlantic Climate Change Program (ACCP), and Equatorial Pacific Ocean Climate Studies (EPOCS). Many of these efforts now fall within the context of the NOAA Climate and Global Change Program.

The oceanographic component in the CIMAS program is heavily engaged in the ACCP, whose goal 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 recognizes the importance of continuing the observations of the meridional transport patterns in the Florida-Bahamas section of the Atlantic western boundary regime; it places special emphasis on studies of the basic transport 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 transport from the tropics into the northern temperate latitudes.

In addition to the ocean dynamics programs, other programs focus on atmospheric processes that relate to climate. Some of these activities are associated with the Radiatively Important Trace Species (RITS) program, which emphasizes the greenhouse gases. Many of the newer programs are concerned with the role of aerosols in climate. Some continuing efforts in this area are associated with the Pacific Sulfur/Stratus Investigation (PSI). A number of new aerosol programs will begin in FY 92 and will focus on the effects of pollution transport of oceanic aerosols and their radiative effects.

SUBTROPICAL WESTERN ATLANTIC STUDIES

A major focus of the oceanographic program continues to be the time series measurements of transport 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); these support the design of efficient climate monitoring systems. Several complementary techniques are applied to this task. High time resolution is achieved with current meters; these are supplemented in the Straits of Florida by submarine-cable-based measurements of the electromagnetic

induction effects generated by the Florida Current. Intermittently we make high resolution measurements of vertical current structure using current profilers and observations of water mass properties. We now have almost a decade-long record of continuous time series based on cable-derived transport estimates that are 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 (in particular, chlorofluorocarbons or CFCs) complement the direct transport observations and provide information about water mass source characteristics. When combined, these diverse observations constitute an indispensable tool for testing how well the advanced ocean models can duplicate the fluctuations observed in the actual oceanic processes. To determine the degree to which transport conditions at 27°N latitude (the Abaco Section) represent global or local Atlantic processes, the observation domain has been extended into the western tropical Atlantic.

Accomplishments FY 91

We continued our time series measurements of western boundary current variability and thermohaline transports seaward of Abaco, supported by the National Science Foundation (NSF) and AOML. The region is one of the primary sites chosen for possible long-term monitoring. A concurrent study (supported by NSF) is under way in this region using deep-ocean-floats; these data will facilitate the interpretation of our FY 90–91 observations in terms of circulation on spatial scales larger than that of the current meter array.

The analysis of the existing 4 years of moored transport measurements reveals some interesting features including a large variability in the total transport that is dominated by events with time scales of several months. The estimated meridional eddy heat flux is about 20-30% of the total North Atlantic heat transport; this indicates that there may be a serious eddy aliasing problem in the heat flux estimates based on hydrographic section data.

During the past year we observed an annual cycle in the Deep Western Boundary Undercurrent (DWBU) transports that was not observed in the earlier records. This cycle is in phase with the annual cycle predicted by the Anderson and Corry model for this region, with maximum meridional transport in the winter and minimum in the fall. The comparison of results from our moored observations with the results from the National Center for Atmospheric Research (NCAR) model shows a qualitative agreement in both the mean structure of the flow field and its variability. However there were considerable quantitative differences in the mean meridional transports. Apparently the model tends to overestimate the northward heat flux of the Atlantic Conveyor Belt.

Plans FY 92

As part of the ACCP, the mooring array located east of Abaco will be redeployed in a 600-km section east of Abaco for an additional 1.5 years. The long-term goal of this work is to efficiently monitor the volume and temperature transports of the Atlantic Conveyor Belt, and thus provide a continuous, multiyear time series with which to examine interannual variability of climate-relevant flow transients in this region. Some specific objectives of this program are the following:

- To resolve the major components of the thermohaline circulation and associated mass and heat transports on seasonal to multiyear time scales and investigate forcing mechanisms.
- To continue the evaluation of monitoring strategies for the Conveyor Belt circulation and heat transports.

- To continue comparisons of moored current observations with CME modeling results with regard to strength and structure of thermohaline overturning, deep recirculation and wind-driven transients.

TROPICAL WESTERN ATLANTIC DEEP OCEAN STUDIES

Accomplishments FY 91

Studies continue on the DWBU and the offshore circulation, and the major focus is on the analysis of hydrographic and Freon(TM) tracer data collected on cruises to the western tropical North Atlantic during 1987–89. Data show two lobes of recently ventilated (with respect to Freons) Northern Hemisphere water approaching the Equator in the DWBU. The Freon concentrations are relatively high in the interior, showing that the response to high-latitude processes is fast in the interior as well as along the western boundary. The Ceara Rise closes off the equatorward flow, causing the coldest waters to recirculate. Offshore of the DWBU is a band of Southern Hemisphere water at all levels.

Plans FY 92

Field work under two programs funded through the Climate and Global Change Program will measure oceanic heat flux in the subtropics as well as CFC ventilation histories of the DWBU and its interaction with the interior.

One program will take place on a trans-Atlantic section along 24°N as a part of the Spanish contribution to the World Ocean Circulation Experiment (WOCE). The second program complements the first, focusing on the structure of the North Atlantic DWBU. Tracer inventories will be used to assess the extent of ventilation. The CFC data from the Spanish cruise, the first to be taken along 24°N, will provide baseline tracer information across this important heat flux line. The primary objective on this section will be to monitor decadal time scale changes by water mass class. The tracer data will allow a basin-wide study of the extent of ventilation of North Atlantic deep waters and their integration with older waters (e.g., circumpolar waters). The CFC data will also provide an opportunity to examine the downstream properties of recently subducted thermocline waters across the width of the basin in terms of relative age and apparent oxygen utilization.

TROPICAL WESTERN ATLANTIC UPPER OCEAN STUDIES

The cross-equatorial warm water transport into the North Atlantic is subject to strong variations in the transfer paths to the subtropical regions because of the complicated seasonal variability of the North Brazil Current (NBC). Although there is broad agreement between model results and the observed fluctuation characteristics, the available oceanic observations are far from sufficient to quantitatively verify the adequacy of high-resolution ocean models in this respect. Because of the remarkable steadiness in the southward flow of deep water observed off French Guiana, this site would be ideal for a long-term monitoring study. 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.

Accomplishments FY 91

Moored observations of current structure and variability in the western boundary current region of the Tropical Atlantic were continued with AOML support using a three mooring array across the Amazon Cone. These moorings have been maintained for approximately two years in conjunction with a cooperative regional effort between U.S., German, and French researchers. There is a large mesoscale variability in all the current records; periodicities near 30 days and 50 days generally exhibit the highest concentrations of energy.

Plans FY 92

Activities will focus on data analysis. In particular, we will use these data to more fully describe the spatial and temporal variability of the NBC and retroflection into the equatorial zone, including the Equatorial Countercurrent and Equatorial Undercurrent. We also plan to resolve the deep circulation and transport of water in both the upper and lower branches of the Conveyor Belt in this region. The moored data will be used to compare and evaluate model results for this region to further elucidate the important dynamics.

DATA ASSIMILATION IN EQUATORIAL PACIFIC MODELS

This work is conducted at AOML with CIMAS staff participation as a part of EPOCS. However, the results should 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.

Accomplishments FY 91

We installed our data-assimilation system on the new Cray Y–MP at Gaithersburg, Md. Because of the faster CPU and greater memory size, we were able to complete our first steady-state experiment at high resolution in a reasonable length of time using data supplied by the National Meteorology Center (NMC). The comparison between assimilation and spin-up results shows very good agreement. It demonstrates that our assimilation system is working properly, yielding essentially the same results as a model spin-up. We have also compared the performance of several gradient descent methods and we tested the idea of changing the control variables of the GFDL general circulation model (GCM). At this stage, there is little difference in performance between different algorithms. The results may change as we move to more nonlinear (less constrained) models.

Plans FY 92

Our principal focus will be on the weak-constraint steady-state problem.

OCEAN CARBON AND THE CARBONATE/CO_2 SYSTEM

This cooperative program with AOML focuses on the ocean carbon budget and the carbonate/CO_2 system. We are characterizing the behavior of the new analytical techniques for measuring total organic carbon (TOC) in the oceans. The Suzuki high-temperature catalytic oxidation method yields data that suggest that the earlier

measurements using older techniques may have substantially underestimated TOC concentrations, particularly in the upper water column. These new data have seriously challenged the classical picture of the TOC distribution and carbon budgets. However, there are concerns about the validity of these new procedures.

Accomplishments FY 91

We conducted studies on the performance of commercially available TOC instruments. On a RITS cruise to the South Atlantic, we measured TOC using a catalytic oxidation system; concentrations were relatively low and conform to the historical picture of the TOC distribution.

On the same cruise, measurements were made of pH and total alkalinity. These results will be combined with measurements of the partial pressure of CO_2 and total carbonate made by the AOML groups. The combined study will be used to completely characterize the carbon dioxide system in these waters. The studies in the region from the Equator to 40°S are the first to over-determine the CO_2 system in this ocean.

Plans FY 92

These programs will be continued during two carbon/CO_2 cruises that are scheduled for the equatorial Pacific next year.

ATMOSPHERE/OCEAN SULFUR CYCLE AND CLIMATE

A number of studies focus on biogenic sources of sulfur in the ocean, especially dimethylsulfide (DMS), and the effect of these sources on the atmospheric sulfur cycle. Of particular interest is the role of DMS-derived sulfur on the production of sulfate aerosols in the atmosphere; these aerosols can affect cloud formation processes and, hence, the Earth's albedo and climate. Much of this work is carried out in conjunction with PSI in cooperation with AOML and the Pacific Marine Environment Laboratory (PMEL). Within PSI, our goals are to describe the behavior of the biological sources of DMS and its precursor dimethylsulfoniopropionate (DMSP) in ocean waters and to study the chemistry of DMS and its reaction products in the atmosphere and their relationship to the biological sources in the underlying waters.

Accomplishments FY 91

Extensive measurements were made on cruises to the North Pacific and the South Atlantic. Efforts focused on the diurnal variations of DMS and DMSP in marine particles that were representative of different groups of organisms and on the relationships between these variations and microzooplankton grazing. These studies were coordinated with an extensive series of atmospheric chemistry measurements that were carried out using new, faster, and more sensitive analytical instrumentation that we developed.

Plans FY 92

Efforts will focus on the analysis of the samples and data obtained during the cruises this past year.

PRODUCTIVITY STUDIES IN THE SOUTH ATLANTIC

Accomplishments FY 91

Research is directed toward improving our ability to estimate phytoplankton production from measurements obtained with satellite-borne sensors. As in past years, we measured phytoplankton production rates and the light response of the phytoplankton (production versus irradiance curves). We also measured the environmental factors that influence these rates, for example, light availability (surface and subsurface light intensity), light absorption by the phytoplankton (absorption coefficients), nutrient concentrations, and temperature.

Plans FY 92

Activity will focus on data analysis. We will use cruise data to develop a mathematical model that predicts the integrated production rate; the 24-h production rate measurements will be used for model testing and tuning.

ANALYSIS OF GLOBAL SATELLITE SST FIELDS AND CHARACTERIZATION OF THE AVHRR SENSOR (PATHFINDER PROJECT)

Plans FY 92

This is a new cooperative effort with NASA and NOAA to improve the accuracy of satellite products that are used for the long-term monitoring of global parameters. Activities include a study of methods to improve the accuracy of sea-surface temperature (SST) products by analysis of satellite SST day and night differences, the optimization of algorithms used for cloud clearing, and the study of methods for optimum end-to-end SST data reprocessing using interactive computer techniques. This study will provide reference data to determine how present algorithms compare with alternative satellite SST algorithms.

Among other activities we will extract SSTs from the daily NOAA operational SST retrievals, separate them into day and night, and produce weekly maps for the period 1985 to 1990. We will also generate SST fields from historical satellite data and compare them with time series data that we obtain from fixed moorings along the U.S. east coast. These data will provide a more quantitative assessment of long-term changes or offsets introduced through sensor degradation or replacement.

AEROSOL RADIATION EFFECTS OVER THE NORTH ATLANTIC

Plans FY 92

The objective of this program is to make radiation measurements in conjunction with atmospheric chemistry studies to provide data that can be used to improve satellite aerosol retrieval algorithms. This is a new cooperative activity with the Climate Modeling and Diagnostics Laboratory (CMDL) and the National Environmental Satellite, Data, and Information Service (NESDIS) and funded under the Climate and Global Change Program. Measurements will be made at three locations in the North Atlantic: Bermuda, Barbados, and Tenerife, network sites in the Atmosphere-Ocean Chemistry Experiment (AEROCE). Aerosol optical

depth (AOD) will be measured with sun photometers and rotating band shadow radiometers. The study will be coordinated with Advanced Very High Resolution Radiometer (AVHRR) satellite measurements and eventually with data from the SeaWifs and MODIS satellites. We will analyze the spectral components of AOD to see if we can identify spectral signatures for specific aerosol types (pollution, mineral dust, sea salt, background) and for specific aerosol features such as size.

FISHERIES ECOLOGY AND ECOSYSTEM DYNAMICS

Research is conducted in close cooperation with the NMFS Southeast Fisheries Center (SEFC) and with support derived from the Office of Oceanic and Atmospheric Research (OAR) and SEFC. The major activity under this theme is the Southeast Florida and Caribbean Recruitment (SEFCAR) program, a multidisciplinary study of the regional ecosystem on the ocean side of the Florida Keys. The objective of SEFCAR is to investigate the oceanic circulation processes in the boundary region between the Gulf Stream and the Florida Keys and to elucidate the role of these processes on the stock recruitment of spiny lobster and important reef fish species in the region.

Other cooperative efforts include studies of the larval ecology of bluefin tuna in the Gulf of Mexico and the application of satellite remote sensing technology to a range of problems in larval and adult stock distribution modeling.

SEFCAR

The basic research hypothesis in SEFCAR is that the distribution and recruitment of pelagic larval species in the Florida Keys is strongly affected by variations in recirculating gyres that appear periodically off the lower Keys. In the SEFCAR field program, studies of physical processes are closely integrated with biological sampling to determine physical controls that affect the distribution and abundance of target species larvae as well as of zooplankton, which serve as larval food. The physical studies include current measurements from standard moored instrumentation plus bottom-mounted Acoustic Doppler Current Profiler (ADCP) observations and shipboard hydrographic surveys. The field work is complemented in a shore laboratory by the 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 is aimed at elucidating the degree to which local recruitment of spiny lobsters and snappers relies on geographically disperse populations as sources for larvae. SEFCAR will provide information that will assist fisheries managers in the development of efficient management practices.

Accomplishments FY 91

Field investigations were conducted in the Pourtales gyre and the Dry Tortugas. Cold, cyclonic gyres form off the lower Keys between Marathon and Key West (Pourtales gyre) and off the Dry Tortugas (Tortuga gyre). Gyre formation appears to be due to a combination of meandering of the Florida Current, flow curvature at the turning points of the channel, and wind-induced downwelling along the east-west portion of the slope. The Pourtales gyre has a time scale of about 1 month, whereas the Tortuga gyre appears to last for several months. Gyre horizontal scales are on the order of 100 km, with westward flow north of the center and eastward flow south of the center. The circulation in the gyres and local onshore surface Ekman transports combine to concentrate fish and lobster larvae for recruitment into the Florida Keys coral reefs.

Laboratory work continued with the rearing studies of various reef fish and a focus on grunts and serranids. Behavioral studies focused on descriptions of vertical swimming behaviors to provide information for the modeling component of the program.

We continue to use biochemical genetic techniques to determine if larvae and post larvae of reef-related organisms (spiny lobster and snappers) are recruited primarily from adults that spawn locally, from adult populations spawning at more distant sites within the Caribbean, or from a combination of spatially distributed spawning populations. The study of 5 out of 15 adult spiny lobster populations was completed, and thus far the data indicate a very large effective population size and substantial genetic interchange.

Plans FY 92

Physical oceanographic studies will continue in the SEFCAR region using moored arrays, ADCPs, and satellite-tracked drifters. The objective is to describe the average state and variability of the stratification and circulation patterns in the Florida Keys and Dry Tortugas regions in sufficient detail to allow the construction of physical environment models for the regional retention and growth conditions for larval stages of the reef fishes and spiny lobster under study in the overall project. The SEFCAR program will cooperate closely with a large study funded by Marine Minerals Service (MMS) of the physical oceanography of the Florida Straits from Key West to Jupiter, FL. The MMS study will provide valuable observations of the large-scale Florida Current variability, which can be compared with the local observations of the gyre structures.

During the coming year, the biological component of the program will concentrate on the analysis of samples and data obtained during cruises in previous years. We will develop identification guides to the larvae of important declining fishery species such as the snappers. We will also begin fieldwork with light traps to monitor the effects of oceanographic variability on the behavior and settlement of reef fishes, especially groupers and snappers.

Growth studies will focus on the effects of temperature differences on spawning. Rearing studies will begin with grouper, and behavior studies will concentrate on vertical swimming speeds of snapper larvae.

SATELLITE SST CLIMATOLOGY DEVELOPMENT FOR FISHERIES

Accomplishments FY 91

Research continues with longline data processing and development of an oceanographic remote sensing capability at SEFC. A study of the associations between swordfish catches and thermal fronts shows that proximity to a surface thermal front appears to be a necessary, but not sufficient, condition that is required to attain high swordfish catches. We are investigating associations between swordfish relative abundance and specific oceanic and topographic features (e.g., shelf break, warm core rings, shelf water intrusions, and submarine canyons). Swordfish abundance appears to be significantly higher along the shelf break than elsewhere. This might explain why the longliners' fishing tends to concentrate there. We continued to support remote sensing activities at SEFC in various ways, including the training of NMFS staff in the use of the University of Miami image processing system, not only for the analysis of satellite imagery but also for the visualization of fishery data.

Plans FY 92

This program is near completion and work on the above topics is being brought to a close.

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) fosters collaboration between NOAA and the University of Washington's Department of Atmospheric Sciences and School of Oceanography. Its Director reports to the Vice Provost for Research.

JISAO emphasizes four core research areas: climate, environmental chemistry, estuaries, and recruitment of fish stock. Of these four areas, only climate has enjoyed the benefit of ongoing block funding. Of the 25 Senior Fellows associated with the Institute, 16 are involved in various aspects of climate research. Most of the visitors, and all but two of the postdoctoral fellows who have been funded through this program over the past 12 years, have had primary interests in climate. Seven Senior Fellows are currently involved in the Environmental Chemistry core program and two in the Estuaries program.

During the past 3 years, JISAO has played an active role in University and NOAA efforts to establish interdisciplinary research directed toward an understanding of the global climate system and its sensitivity to human activities. The Institute's Environmental Climate Forecast Center falls within the scope of this effort.

JISAO's climate research focuses on two main themes: large-scale atmosphere-ocean interaction in the tropics and planetary-scale wave/mean flow interaction. The existence of JISAO has substantially increased the level of activity in these areas on the University campus, and it has served to promote collaboration between Pacific Marine Environmental Laboratory (PMEL) scientists involved in Equatorial Pacific Ocean Climate Studies (EPOCS) field programs and University scientists and postdoctoral fellows involved in theoretical and modeling studies of the phenomena under investigation in EPOCS. It has also resulted in increased interaction between atmospheric scientists and physical oceanographers on the University faculty.

Accomplishments FY 91

- Simulation of geographic variations in atmospheric $^{14}CO_2$ using a three-dimensional global tracer transport model. The findings will help define the natural geographic distribution of oceanic CO_2 sources and sinks as well as the dynamics of stratosphere-troposphere exchange and the 11-year solar-induced ^{14}C cycle. First results were presented in May at the 14th International Radiocarbon Conference.
- Development of a new global atmosphere model for climate studies in collaboration with Lamont-Doherty Geological Observatory. FY 91 efforts involve development of a planetary boundary layer parameterization for use in the model.
- Investigations of oceanic mixing and convection processes, large-scale thermohaline circulations, and equatorial undercurrents. This effort involves numerical model studies of the role of mixing between Northern Atlantic deep water (NADW) and Antarctic bottom water (AABW) in large-scale ocean circulations in the South Atlantic. A tracer study of a four-layer ocean model suggests that most mixing between NADW and AABW occurs near the mid-Atlantic ridges, which might be one of the factors that control the "retroflection" flow pattern of NADW in the South Atlantic.
- The Experimental Climate Forecast Center studies the predictability of the El Niño–Southern Oscillation (ENSO) phenomenon, and the role of the ocean in determining the predictability of

long-term climate beyond the decadal time scale. A UNIX computer installation was developed at the Center during this year.

- Completion of two case studies of mesoscale storm structures for OCEAN STORMS. Work has been started on a climatological study of the wind forcing of the Bering Sea for Fisheries Oceanography Coordinated Investigations (FOCI). An observational study of the tropical planetary boundary layer supported by the EPOCS program was submitted for publication.
- Numerical study to characterize the 30-day waves of the tropical Pacific as modeled in a climatological run of the Philander-Pacanowski model, and compared with observations taken by PMEL at the equator at 140°W and 110°W from 1984–1987 and the meridional section observations of the Hawaii-to-Tahiti shuttle experiment in 1979–1980.
- Analysis of moored buoy time series data, drifting buoy measurements, expendable bathythermograph data, conductivity-temperature-depth (CTD) data, and ship drift data in support of NOAA's climate mission, with emphasis on tropical Pacific Ocean variability.
- Research on the oxidation products of ocean-derived biogenic dimethylsulfide and the role that these products play in new particle production, with emphasis on the improvement of the following sampling and analysis methods: (1) a tandem sampling system for the collection of gaseous and submicron particulate sulfur species, (2) an impactor for the collection of size-segregated aerosol particle samples, and (3) ion chromatography as applied to the analysis of air sample-derived filter extracts.
- Arctic program emphases in FY 91 have been circulation and climatology of the Chukchi Sea, the outflow of fresh water from the Arctic Ocean, sea ice and convection in the Greenland Sea, and ocean climate variability in the Polar Basin.
- Five separate oceanographic cruises on vessels of Canada, the Federal Republic of Germany, the United States, and the U.S.S.R. In the Chukchi Sea alone, 16 U.S. and 7 U.S.S.R. year-long instrumented moorings were installed.
- Adaptation of a semispectral, primitive equation model for use in hydrodynamic and biophysical studies of Shelikof Strait off Alaska. The concepts developed during this year's analyses of modeling results related to deep convection, which focus especially on the energetics of baroclinic instabilities versus geostrophic adjustment, will be utilized in forthcoming studies of hydrodynamic instabilities in Shelikof Strait. These results were presented at the International Union of Geodesy and Geophysics (IUGG) Symposium in Vienna, Austria, during the summer of 1991.
- Evaluation of numerical modeling techniques for representing open boundary conditions in limited-area vertically integrated models of shelf circulation. The models were tested for the Bering and Chukchi Sea shelves adjacent to Bering Strait, where results of other modeling efforts were available. An eddy-resolving layered basin model has been acquired from the U.S. Naval Oceanic and Atmospheric Research Laboratory (NOARL) for use on the new Cray Y–MP computer at Gaithersburg, MD. The model was installed, some preliminary runs were made, and progress was made toward implementing visualization tools at PMEL.

Plans FY 92

- In response to last year's request for proposals from the Climate and Global Change Program Office, in collaboration with PMEL, JISAO will continue to set up the Tropical Ocean and Global Atmosphere–Tropical Ocean-Atmosphere (TOGA–TAO) Analysis Project, designed to accelerate and enhance the scientific payoff from NOAA's large investment in an ocean observing system; the project addresses the need for immediate and intensive scrutiny of the data from the TAO array in relation to problems of interannual climate variability in the tropical Pacific.

- The Department of Energy, through the National Institute for Global Environmental Change, will fund the design and installation of a monitoring station for assessing the impact of anthropogenic aerosols on climate, resulting in an upgrade of the Cheeka Peak Research Station.
- A new JISAO research scientist/programmer will be involved in the development of user-friendly software for accessing and manipulating the large data bases used in climate research and for preparation of graphical displays of fields of mapped climate variables. Climate Monitoring and Diagnostics Laboratory (CMDL) software will be adapted for use on DEC workstations running under the UNIX protocol, and scientists will be instructed in its use. Analogous software will then be developed for other data sets as well as for more convenient user interface for the part of the NCAR graphics software used to create maps.

JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH

University of Hawaii
(808) 956-8003
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 Science and Technology. The principal research interests of JIMAR are equatorial oceanography, climate and global change, tsunamis, and fisheries oceanography.

Accomplishments FY 91

Fisheries Oceanography

Seamounts/island flow

Analysis and manuscript preparation on the effects of currents on micronekton populations near Hancock Seamount continued. In September 1990, a cruise was made to Palmyra Atoll to study flows near the island and their effect on larval fish populations. Significant progress was made in analyzing physical data from the cruise, and a manuscript is being prepared. Analysis of the biological samples is under way.

North Pacific transition zone

An oceanographic data base on the North Pacific transition zone (NPTZ) is being established. The data base includes Expendable Bathythermograph (XBT) data, conductivity-temperature-depth (CTD) data, currents, and satellite-derived sea-surface temperature (SST). The scope of the project is being broadened so that it can be included in a CoastWatch proposal for a data node in Hawaii.

Lobster larvae and sea level

A significant correlation was found between interannual sea level variability and lobster larval recruitment in the Hawaiian Archipelago. Major geographic variations were found. Sea level variations appear to be useful for predicting variability of adult lobster populations up to 4 years in advance. GEOSAT altimeter data were used in this study.

Tsunami Research

Inundation maps

Revised tsunami inundation evacuation maps were completed. These charts are now published in the telephone directories of each of the Hawaiian islands.

T–phase (acoustic) spectral amplitudes

Preliminary work on the relationship of T–phase spectral content and the occurrence of tsunamigenic earthquakes was completed. Alaskan and Aleutian earthquakes were studied. Both seismic moment and T–phase strength in the 10–35 Hz frequency band are larger for tsunamigenic than for nontsunamigenic earthquakes. The use of T phase to estimate seismic moment in near real time is being studied.

Tsunami modeling

Pacific basin-wide tsunami modeling in support of Pacific Tsunami Observing Program (PacTOP) continued. A new modeling study of Hilo Harbor was undertaken. A variable grid is used to model the inundation on increasingly finer scales as the waves come in. The 1946, 1960, and 1964 Hilo tsunamis are being modeled.

Climate and Equatorial Oceanography

Modeling and analysis

An observational study of El Niño–Southern Oscillation (ENSO) variability in the atmosphere, focusing on the 1982/83 and 1986/87 warm episodes, was completed. The data set for this study spanned 11 years, 1979–1989. The structure of the ENSO anomaly was explored using empirical orthogonal function analysis. The 30–60 day oscillations between the western Pacific and the Indian Ocean were analyzed and documented using pentad means, plus winds at both 200 and 850 mb levels. A numerical study on the drift of tropical cyclones was completed. The phase relationships among outgoing longwave radiation and other meteorological variables along the Equator were investigated.

A noncontiguous rain-gauge method for calibrating satellite-based rainfall algorithms was developed, and the method was applied to two algorithms.

Sea level network

The first satellite transmitting sea level gauge in the Indian Ocean network was installed at Salalah, Oman. This gauge reports through METEOSAT. A satellite station was installed at Guadalupe in the Pacific. Numerous data requests were filled by the Tropical Ocean and Global Atmosphere (TOGA) Sea Level Center. Progress was made on understanding the errors in tide-gauge measurements and developing new satellite orbit error algorithms for sea level height using water vapor and rainfall corrections.

Hawaii ocean time series station

Monthly cruises to the site to collect hydrographic data, acoustic Doppler current profiles, and biogeochemical data in support of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) were carried out. Dissolved inorganic carbon, alkalinity, and pH were added to the list of observed properties.

Equatorial observations and theory

Analysis continued on data sets from a variety of equatorial programs, including the U.S./Peoples' Republic of China TOGA project, the Western Equatorial Pacific Ocean Circulation Study (WEPOCS), and the Line Islands Array. A WEPOCS cruise to measure temperature and current profiles in the Mindanao Current and the New Guinea Coastal Undercurrent was made in the spring of 1991.

Planning for the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE) continued. The COARE science plan was completed.

Conductivity sensors were added to four ATLAS moorings on the 156°E line.

A new study to understand deep equatorial circulation was begun. Simple thermohaline forcing was used to drive a high-resolution numerical model, and the results were extensively analyzed.

A WEPOCS workshop was held in the spring of 1991 to discuss recent results of studies of low-latitude western boundary currents. This workshop represents an effort to initiate serious intercomparison of WEPOCS data and numerical modeling simulations.

Plans FY 92

Fisheries Oceanography

- Manuscripts on the effect of currents on micronekton populations near Hancock Seamount will be completed and submitted.
- The analysis of data on the flow near Palmyra Atoll and its relation to larval fish populations there will be completed. Another cruise to the same area is scheduled for February 1992 during the annual minimum of the North Equatorial Counter Current.
- A CoastWatch proposal including expansion of the NPTZ data base will be submitted.
- Studies of the relationships between localized eddies near the Hawaiian Island chain, sea level variability, and lobster larval abundances will continue.

Tsunami Research

- The relationship between T–phase and seismic moment will be investigated in Pacific regions other than those already studied. The feasibility of using T–phase information to improve warning system reliability will be investigated.
- The Hilo Bay modeling effort will continue. High-resolution models with individual buildings and structures will be used to study the details of the flooding, focusing on the 1952 and 1957 events. The effect of the islands in focusing and shadowing tsunamis that have distant sources will be studied as well.

Climate and Equatorial Oceanography

Modeling and analysis

- The development of a model that includes a free atmosphere and atmospheric and oceanic boundary layers, applicable to both ENSO and seasonal variability, will continue. Observational studies of annual and ENSO variability of the coupled ocean-atmosphere climate system will be carried out. A theoretical study of the influence of the monsoon basic flow on the intraseasonal wave will be undertaken. The existing model for tropical cyclone drift will be extended to include the effects of large-scale background flows.
- The development of the monsoon over southern equatorial Africa and its relation to the 30–60 day oscillation and ENSO variability will be analyzed from available wind, pressure, and convection data.

Sea level network

- The Pacific Ocean and Indian Ocean sea level networks will continue. Additional Indian Ocean satellite gauges will be installed at Gan, Port Louis, and Zanzibar.
- The TOGA Sea Level Center will continue to archive data and fill data requests. Research efforts will concentrate on developing methods for blending in situ sea level data and GEOSAT altimetry data.

Hawaii ocean time series

- The monthly observations in support of WOCE and JGOFS will continue. A data report for the first year's work will be published.

Equatorial observations and theory

- WOCE hydrographic cruises, to map hydrographic and tracer data on a large number of sections (20 in the Pacific), will begin. These data will be used in inverse models to infer the general (mean) ocean circulation. Acoustic Doppler current profiles will be made on these sections, as an ancillary measurement, not central to the WOCE objectives.
- The COARE planning will continue. The experimental design for COARE will be finalized. Planning for JIMAR involvement in the maintenance of the TOGA–TAO array will be pursued.

- Analysis of WEPOCS and Line Island Array data will continue.
- The equatorial deep circulation modeling effort will continue. Model results using three different models will be analyzed to seek common features and understand model differences.

APPENDIX: Acronyms and Initialisms

AABW	Antarctic bottom water
AASE	Airborne Arctic Stratospheric Expedition
ACARS	ARINC Communications Addressing and Reporting System
ACCP	Atlantic Climate Change Program
ACM	Asymmetric Convective Model
ADCP	Acoustic Doppler Current Profiler
AEGIS	Atmosphere-Ecosystem Gas Interchange Study
AEROCE	Atmosphere-Ocean Chemistry Experiment
AES	Atmosphere Environment Service
AFC	Alaska Fisheries Center (NMFS)
AFGWC	Air Force Global Weather Central
AGASP	Arctic Gas and Aerosol Sampling Program
AGFS	Aviation Gridded Forecast System
AI	artificial intelligence
AL	Aeronomy Laboratory (ERL)
AMEX	Australian Monsoon Experiment
ANICA	Atmosphere Nutrient Input to Coastal Areas [project]
AOD	aerosol optical depth
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
AOS	Atmosphere and Ocean Sciences [Program]
APARE	[East] Asian-[North] Pacific Regional Experiment
ARINC	Aeronautical Radio Incorporated
ARL	Air Resources Laboratory (ERL)
ARM	Atmospheric Radiation Measurements [Program]
ARO	Army Research Office
ARS	Aerosol Research Section (ARL)
ASCOT	Atmospheric Studies in Complex Terrain
ASD	aircraft situation display
ASHOM	Airborne Southern Hemisphere Ozone Mission
ASMD	Atmospheric Sciences Modeling Division (ARL)
ASOS	Automated Surface Observing System
ASTER	Atmosphere-Surface Turbulence Exchange Research [facility]
ASTEX	Atlantic Stratocumulus Transition Experiment
ATDD	Atmospheric Turbulence and Diffusion Division (ARL)
ATI	area-time-integral [technique]
ATMS	Advanced Traffic Management System
AU	astronomical unit
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AVS	Advanced Visualization System [program]
AWIPS–90	Advanced Weather Interactive Processing System for the 1990s
BAO	Boulder Atmospheric Observatory
BAPMoN	Background Air Pollution Monitoring [program]
BOREAS	Boreal Ecosystem-Atmosphere Study

BPR	bottom pressure recorder
BSRN	Baseline Surface Radiation Network
CaPE	Convection and Precipitation Electrification [experiment]
CAPS	Center for Analysis and Prediction of Storms
CART	Cloud and Radiation Testbed [network]
CASE	Coordinated Air-Sea Experiment
CASTNET	Clean Air Status and Trends Network
CAT	clear air turbulence
CDMS	Cryospheric Data Management System
CEAREX	Coordinated Eastern Arctic Experiment
CFC	chlorofluorocarbon
CFCF	Central Flow Control Facility
CG	cloud to ground
CGCP	Climate and Global Change Program
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
CLIPER	Climatology and Persistence [model]
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
COHMEX	Cooperative Huntsville Meteorological Experiment
COMET	Cooperative Program for Operational Meteorology, Education, and Training
COPS–89	Cooperative Oklahoma P–3 Studies–1989
COPS–91	Coperative Oklahoma Profiler Studies–1991
COS	carbonyl sulfide
C–SCAT	C–band Scatterometer
CSCS	Consolidated Scientific Computing System
CSI	conditional symmetric instability
CSU	Colorado State University
CSU–RAMS	CSU Regional Atmospheric Modeling System
CTD	conductivity, temperature, depth
CWB	Central Weather Bureau
DARE–II	Denver AWIPS Risk Reduction and Requirements Evaluation [workstation]
DIAL	Differential Absorption Lidar
DMS	dimethylsulfide

DMSP	dimethylsulfoniopropionate
DMSP	Defense Meteorological Satellite Program
DOC	dissolved organic carbon
DOD	Department of Defense
DOE	Department of Energy
DSV	Deep Submersive Vehicle
DWBU	Deep Western Boundary Undercurrent
ECC	electrochemical concentration cell
EC–GC	electron capture gas chromatograph
ECMWF	European Centre for Medium-Range Weather Forecasting
EEZ	Exclusive Economic Zone
ENSO	El Niño–Southern Oscillation
EOF	empirical orthogonal function
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPOCS	Equatorial Pacific Ocean Climate Studies
EPOS	Earthquake Phenomena Observation System
ERBE	Earth Radiation Budget Experiment
ERICA	Energetics of Rapidly Intensifying Cyclones over the Atlantic
ERL	Environmental Research Laboratories (NOAA)
ERS	Earth Resources Satellite
EUV	extreme ultraviolet
FAA	Federal Aviation Administration
FARA	French American Ridge Atlantic [program]
FD	Facility Division (FSL)
FERRET	[interactive display and analysis system; not an acronym]
FGGE	First GARP Global Experiment
FIB	Field by Information Blending [procedure]
FIRE	First ISCCP Regional Experiment
FIRS	Fourier transform Infrared Sounder
FLARES 22	Flare Research in Solar Cycle 22
FLAT	First Look by ASTER at Turbulence [experiment]
FNOC	Fleet Numerical Oceanographic Center
FOCI	Fisheries Oceanography Coordinated Investigations (NOAA)
FRD	Field Research Division (ARL)
FRG	Forecast Research Group (FSL)
FRLAB	Front Range Lidar and Balloon [experiment]
FSL	Forecast Systems Laboratory (ERL)
FWS	Fish and Wildlife Service
GARP	Global Atmospheric Research Program
GAW	Global Atmosphere Watch
GC	gas chromatograph
GCE	Global Change Expedition

GCIP	GEWEX Continental-scale International Project
GCM	general circulation model
GCTM	Global Chemical Transport Model
GEOSAT	Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory (ERL)
GIS	Geographic Information System
GLERL	Great Lakes Environmental Research Laboratory (ERL)
GLOSS	[global sea level observing system; not an acronym]
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRAF	Gridded Representation of Analyses and Forecasts [system]
GRIB	Gridded Binary [data]
GTS	Global Telecommunication System
GUFMEX	Gulf of Mexico [project]
HARM	Hazardous Atmospheric Release Model
HARP	Hawaiian Rainband Project
HCFC	hydrochlorofluorocarbon
HEPAD	High Energy Proton and Alpha Detector
HOC	hydrophobic organic compound
HPCC	High Performance Computing and Communications
HRD	Hurricane Research Division (AOML)
HY–SPLIT	Hybrid Single Particle Lagrangian Integrated Trajectories [model]
IFREMER	Institut Francais de Recherche pour l'Exploitation de la Mer
IGAC–MAGE	International Global Atmospheric Chemistry–Marine Aerosol and Gas Exchange [program]
IGM	Interplanetary Global Model
IGY	Interplanetary Geophysical Year
INEL	Idaho National Engineering Laboratory
INSAT	Indian Satellite
IPCC	Intergovernmental Panel on Climate Change
IPS	interplanetary scintillation
IR	infrared
ISCCP	International Satellite Cloud Climatology Project
ISPAN	Information Stream Project for AWIPS/NOAAPORT
ISS	Integrated Sounding System
ITCZ	intertropical convergence zone
JGOFS	Joint Global Ocean Flux Study
JIMAR	Joint Institute for Marine and Atmospheric Research
JISAO	Joint Institute for Study of the Atmosphere and Ocean
LAI	leaf area indices
LAPS	Local-scale Analysis and Prediction System

LAWS	Laser Atmospheric Wind Sounder
LEADEX	Leads Experiment
LEIFS	Lake Erie Information System
LMOS	Lake Michigan Ozone Study
loran	long-range aid to navigation
LOWS	Lake Ontario Winter Storms [project]
MAP3S	Multistate Atmospheric Power Production Pollution Study
MAPS	Mesoscale Analysis and Prediction System
MARA	Multimode Airborne Radar Altimeter
MASS	Mobile Atmospheric Sounding System
MCAQRI	Mexico City Air Quality Research Initiative
MCC	mesoscale convective complex
M–CLASS	mobile CLASS
MCS	mesoscale convective system
MFP	Mobile Flux Platform
MJO	Madden-Julian Oscillation
MIT	Massachusetts Institute of Technology
MLO	Mauna Loa Observatory
MM4	Mesoscale Meteorological Model–Version 4
MMM	Multiply nested Movable Mesh [hurricane model]
MMS	Marine Minerals Service
MODELS–3	[third-generation air quality modeling system]
MOHAVE	Measurement of Haze and Visual Effects [study]
MS	mass spectrometer
MVK	methyl vinyl ketone
MWSR	Microwave Water Substance Radiometer
NADP	National Atmospheric Deposition Program
NADW	North Atlantic deep water
NARE	North Atlantic Regional Experiment
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAWAU	National Aviation Weather Advisory Unit
NBC	North Brazil Current
NCAR	National Center for Atmospheric Research
NCSA	National Center for Supercomputing Applications
NDREX	[Doppler display and editing system; not an acronym]
NDSC	Network for Detection of Stratospheric Change
NECC	North Equatorial Counter Current
NECOP	Nutrient-Enhanced Coastal Ocean Productivity [program]
NESDIS	National Environmental Satellite, Data, and Information Service (NOAA)
NGDC	National Geophysical Data Center (NOAA)
NGM	Nested Grid Model
NHC	National Hurricane Center (NWS)
NIST	National Institute of Standards and Technology
NMC	National Meteorological Center (NOAA)

NMFS	National Marine Fisheries Service (NOAA)
NMHC	nonmethane hydrocarbon
NOAA	National Oceanic and Atmospheric Administration
NOAAPORT	[access to NOAA real-time data base system; not an acronym]
NOARL	Naval Oceanic and Atmospheric Research Laboratory
NOCN	National Ocean Communications Network
NORAPS	Navy Operational Regional Atmospheric Prediction System
NOS	National Ocean Service (NOAA)
NPS	National Park Service
NPTZ	North Pacific transition zone
NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSFC	National Severe Storms Forecast Center
NSSL	National Severe Storms Laboratory (ERL)
NUAMP	NOAA Utah Atmospheric Modification Program
NURP	NOAA Undersea Research Program
NWS	National Weather Service (NOAA)
NWSFO	NWS Forecast Office
NWSTG	NWS Telecommunications Gateway

OAR	Oceanic and Atmospheric Research (NOAA)
OCEAN STORMS	[JISAO field experiment; not an acronym]
ODW	Omega dropwindsonde
OLR	outgoing longwave radiation
ONR	Office of Naval Research
OSCAR	Oxidizing and Scavenging Characteristics of April Rains [experiment]
OU	University of Oklahoma

PacTOP	Pacific Tsunami Observation Program
PAH	polycyclic aromatic hydrocarbon
PAN	peroxyacetyl nitrate
PAPI	Precision Approach Path Indicator
PBL	planetary boundary layer
PCB	polychlorinated biphenyl
PICES	[North Pacific Marine Science Organization; not an acronym]
PMEL	Pacific Marine Environmental Laboratory (ERL)
PRE–STORM	Preliminary Regional Experiment for STORM
PRL	Physical Research Laboratory (India)
PROTEUS	Profile Telemetry of Upper ocean currents
PSC	polar stratospheric cloud
PSI	Pacific Sulfur/Stratus Investigation

RADM	Regional Acid Deposition Model
RAMM	Regional and Mesoscale Meteorology (NESDIS)

RASS	Radio Acoustic Sounding System
RELMAP	Regional Lagrangian Model of Air Pollution
RISC	Reduced Instruction Set Computer [workstation]
RITS	Radiatively Important Trace Species [program]
RNN	Regional NOCN Node
ROM	Regional Oxidant Model
ROSE	Rural Oxidants in the Southern Environment
RPM	Regional Particulate Model
RSMAS	Rosenstiel School of Marine and Atmospheric Sciences
SAFER	Spectral Application of Finite Element Representation
SAGA	Soviet-American Gas and Aerosol [experiment]
SAR	Synthetic Aperture Radar
SAV	state-of-the-atmosphere variable
SBUV	Solar Backscatter Ultraviolet [satellite]
SDD	Systems Development Division (FSL)
SEFC	Southeast Fisheries Center (NMFS)
SEFCAR	Southeast Florida and Caribbean Recruitment
SEL	Space Environment Laboratory (ERL)
SELDADS	SEL Data Acquisition and Display System
SELRAS	SEL Retrieval and Analysis of Scientific data system
SEM	Space Environment Monitor
SEP	solar energetic particle
SESC	Space Environment Services Center (SEL)
SFC	Space Forecast Center
SFMR	Stepped Frequency Microwave Radiometer
SKYHI	[GFDL GCM; not an acronym]
SLW	supercooled liquid water
SOLERS	Solar Electromagnetic Radiation Study
SOLTIP	Solar Connection to Transient Interplanetary Processes [program]
SOS	Southern Oxidant Study
SPAN	Solar Physics Analysis Network
SPEM	Semispectral Primitive Equation Model
SRA	Scanning Radar Altimeter
SSM/I	Special Sensor Microwave/Imager
SST	sea-surface temperature
STACS	Subtropical Atlantic Climate Studies
STAGMAP	Stagnation Model Analysis Program
STEP	Stratosphere-Troposphere Exchange Project
STOIC	Stratospheric Ozone Intercomparison Campaign
STORM	Stormscale Operational and Research Meteorology
STORM–FEST	STORM Fronts Experiment Systems Test
STORMTIPE	Storm Type Operational Research Model Test Including Predictability Evaluations
SWADE	Surface Wave Dynamics Experiment
SWAMP	Southwest Area Monsoon Project
SXI	Solar X-ray Imager

TAO	Tropical Atmosphere-Ocean [project]
TDWR	Terminal Doppler Weather Radar
TELESONDE	[project; not an acronym]
TIROS	Television and Infrared Observation Satellite
TOC	total organic carbon
TOGA	Tropical Ocean and Global Atmosphere [project]
TOMS	Total Ozone Mapping Spectrophotometer
TOVS	TIROS Operational Vertical Sounder
TPOME	Tropical Pacific Ozone Minimum Experiment
TRACIR	Tracking Air with Circularly polarized Radar [technique]
TRIAD	[computer dispersion model; not an acronym]
TSC	Transportation Systems Center
TSEM	Tagged Species Engineering Model
UARS	Upper Atmospheric Research Satellite
UCAR	University Corporation for Atmospheric Research
UNEP	United Nations Environment Program
UV	ultraviolet
VACM	Vector Averaging Current Meter
VAD	Velocity-Azimuth Display
VAFTAD	Volcanic Ash Forecast Transport and Dispersion [model]
VALPUFF	[model; not an acronym]
VAS	VISSR Atmospheric Sounder
VDUC	VAS Data Utilization Center
VENTS	[hydrothermal venting program; not an acronym]
VICBAR	[barotropic hurricane track prediction model; not an acronym]
VISSR	Visible and Infrared Spin-Scan Radiometer
VOS	Volunteer Observing Ship
WAPP	Weather Analysis and Prediction Program (FSL)
WATEX	Waves and Turbulence Experiment
WATOX	Western Atlantic Ocean Experiment
WDC	World Data Center
WEPOCS	Western Equatorial Pacific Ocean Circulation Study
WISE	Weather Information and Skill Experiment
WISP	Winter Icing and Storms Project
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WODC	World Ozone Data Center
WPDN	Wind Profiler Demonstration Network
WPL	Wave Propagation Laboratory (ERL)
WSR–88D	Weather Surveillance Radar
XBT	expendable bathythermograph

☆U.S. GOVERNMENT PRINTING OFFICE: 1992-674-130