ENVIRONMENTAL RESEARCH LABORATORIES PROGRAMS AND PLANS

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

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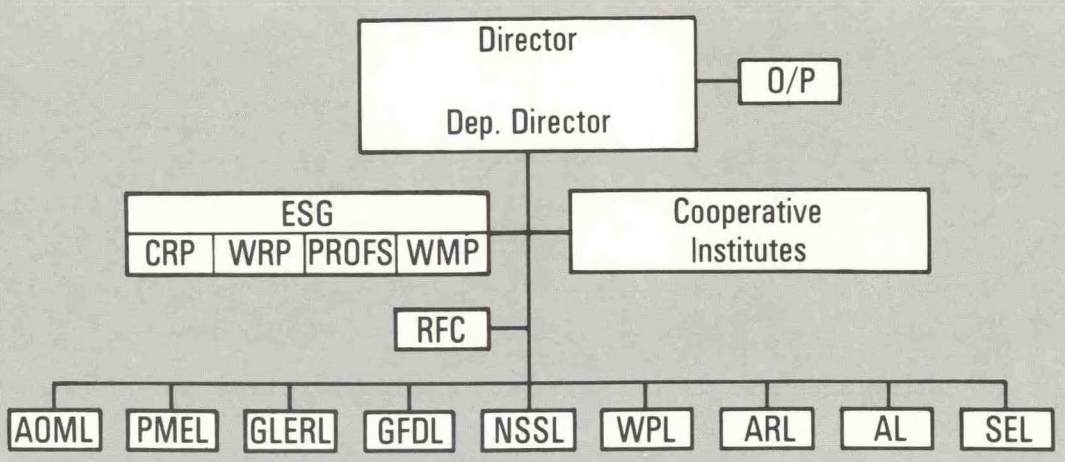


The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere,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

CONTENTS

These are highlights of Laboratory accomplishments and abbreviated summaries of immediate objectives. More comprehensive and detailed descriptions of activities and plans may be found in the Laboratories' annual reports (and other documents), which may be obtained directly from the Laboratories.

ENVIRONMENTAL RESEARCH LABORATORIES

The Environmental Research Laboratories (ERL) are organized within NOAA's Research and Development arm and have their headquarters in Boulder, Colo. They include major units located throughout the United States:

Aeronomy Laboratory (AL)	Boulder, Colo.
Atlantic Oceanographic and Meteorological Laboratory (AOML)	Miami, Fla.
Air Resources Laboratory (ARL)	Rockville, Md.
Geophysical Fluid Dynamics Laboratory (GFDL)	Princeton, N.J.
Great Lakes Environmental Research Laboratory (GLERL)	Ann Arbor, Mich.
National Severe Storms Laboratory (NSSL)	Norman, Okla.
Pacific Marine Environmental Laboratory (PMEL)	Seattle, Wash.
Space. Environment Laboratory (SEL)	Boulder, Colo.
Wave Propagation Laboratory (WPL)	Boulder, Colo.
Environmental Sciences Group (ESG)	Boulder, Colo.
Research Facilities Center (RFC) (abolished 1 October 1983)	Miami, Fla.

In addition, institutes administered jointly by ERL and universities undertake research for ERL. ERL also sponsors research through contracts and grants to universities, State and Federal agencies, and private enterprise.

ERL's research program includes fundamental technology development and services to the public. Samples of outputs are Doppler radar technology (to improve tornado detection and warnings), mathematical models (to predict climate variations), ocean current forecasts (to minimize ship operation costs), observations of ocean upwelling (to maximize fish catches), and solar activity forecasts (to protect, for example, radio communications).

Users of ERL outputs include the atmospheric and marine research communities, NOAA service components (National Weather Service, National Ocean Service), Federal, State and local governments, and the private sector.

The ERL program is a broad one, embracing studies relating to the oceans and Great Lakes, the lower and upper atmosphere, and the solar-terrestrial environment. Studies and activities have focus in eight subject areas:

Weather observation and prediction
Cloud physics research and technology development
Air quality research and technology development
Climate research
Solar-terrestrial research and services
Marine observation and prediction
Marine assessment research and services
Marine resources research and services

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 other units. The Appendix lists acronyms and abbreviations used in those sections.

WEATHER OBSERVATION AND PREDICTION

Weather Observation and Prediction includes programs of AL, AOML, GFDL, NSSL, WRP, PROFS, WPL, and the joint institutes. These programs interact directly with those of GLERL's Ocean and Lake Services R&D and with Solar Terrestrial Research and Services programs dealing with the lower and upper physical boundaries of the atmosphere, with Air Quality programs relating to the short term, and with Climate programs relating to the long term. The programs include these elements: research on observational systems, modeling and prediction, severe storms, hurricanes, sea-air interaction, cloud and precipitation processes, and mesoscale meteorology, and transfer of technology.

A research facility used in several of these program elements is the Boulder Atmospheric Observatory, which includes a 300-m-high meteorological tower and associated remote sensors. The atmospheric research conducted at this facility includes micrometeorological and boundary layer studies, and meso-beta-scale (i.e., scales up to 200 km) research. The latter research includes downslope wind situations and studies of clouds and precipitation under upslope conditions.

Observational Systems

The most versatile and successful observational tools are radar and lidar. Techniques being developed using radar remote sensing include optical and infrared scintillation for measurement of wind (path-averaged values), refractivity fluctuations, heat and moisture flux, rainfall rate, and drop-size distribution. Doppler radar research on flow and precipitation fields within severe thunderstorms has led to the interagency NEXRAD Program, whose goal is to design a new national Doppler radar network during the 1980's. In development are optical and infrared lidar techniques for the remote measurement of winds, temperature, humidity, and aerosols; passive microwave techniques for the measurement of temperature and humidity profiles and cloud liquid; and active radar techniques for the measurement of winds, clouds, precipitation, turbulence, and refractivity fluctuations. As techniques are developed, they are transferred to operational programs.

A high-power, large-antenna VHF Doppler radar technique for measuring winds, turbulence, and gravity waves is being used at Poker Flat, Alaska, to measure these parameters continuously throughout the lowest 100 km of the atmosphere. Radar systems at Platteville, Colo., and Stapleton Field, Denver, and three other sites in Colorado are used by PROFS for real-time windspeed and wind direction data. Microwave radiometer devices for vertical sensing of water vapor and liquid water are also part of the PROFS Colorado network.

Remote techniques are being developed to map electrical discharges in three-dimensional space, for correlation with storm dynamics and precipitation and with changes in electric fields.

Modeling and Prediction

Modeling and prediction programs in ERL have several goals. In the large scale, goals include the following: to develop or improve atmospheric prediction models suitable for the 5- to 30-day time frame (for application in NWS), to identify external forcing mechanisms that models must include to simulate the evolution of macroscale atmospheric disturbances over the range of several weeks to 4 months, and to search for a physically based, probabilistic approach for long-range simulation of atmospheric variations. In the mesoscale, goals include understanding of hurricane dynamics, including the genesis, development, and decay of tropical depressions and the study of small-scale features within hurricane systems; production of accurate numerical simulations of mesoscale processes, to understand what role synoptic-scale parameters play in hurricane generation and evolution; understanding of internal gravity waves including their generation, interaction, and breakdown; and development of three-dimensional numerical models.

Severe Storms

The severe-storms research acquires severe-storm data with specially developed instruments and analyzes these and conventionally acquired data to obtain a more comprehensive understanding of severe storms, to develop models of convective storms, to compare models with observations, and ultimately to improve prediction of severe storms.

The instrumentation developed in ERL for this research includes a 50-station surface network, an instrumented television tower, two large 10-cm Doppler radars, an atmospheric electricity measurement system, two 3-cm transportable Doppler radars to measure three-dimensional velocity fields in convective storms, and pressure sensor arrays to detect and monitor gust fronts in the vicinity of airports.

Hurricanes

The hurricane research element involves three major activities. (1) The hurricane field research program's basic objective is to assemble the descriptive data needed to support analytical and theoretical studies that are designed to provide the best possible understanding of the structure and behavior of hurricanes. The ultimate purpose is to improve prediction of hurricanes. The program makes use of air- and ground-based radar, aircraft, and satellite observations. Flights are made for approximately 200 hours per year using the uniquely well-equipped NOAA aircraft. Investigations include boundary layer processes, evolution of convection and associated wind fields, hurricane motion and internal dynamics, cloud microphysics, and flow characteristics in and near the eyewall and spiral rainbands. (2) The hurricane modeling activity is developing or improving models for hurricane track prediction, mesoscale dynamics, and statistical track forecasting. (3) The

hurricane research project involves a combination of efforts on pre-hurricane disturbances, hurricane genesis and development, hurricane climatology, general tropical meteorology, radar precipitation measurement, analysis of Seasat satellite data, and hurricane sea-air exchange processes.

Sea-Air Interaction

The sea-air interaction element involves the experimental study and numerical modeling of sea-air interactions, especially under extreme weather conditions such as hurricanes. The experimental studies use a series of aircraft observations of sea- (or lake-) air interactions, such as surface wind and wave fields under a wide range of meteorological and coastal conditions. These observations are compared with the wave and storm surge predictions by models in order to validate or improve the models.

Cloud and Precipitation Processes

Research on cloud and precipitation processes involves numerical modeling of and experiments in convective clouds to predict precipitation and phenomena such as downbursts that are hazards to aviation. In support of the experimental programs, optical, infrared, and microwave radar and lidar systems systems are used to measure cloud-echo intensities at three optical and three radio frequencies as a function of three-dimensional space and time. These echo-intensity fields can be measured as a function of both wavelength and polarization. The Doppler effect is used at radio frequencies to determine velocity fields and fields of turbulent kinetic energy dissipation rates. The multifrequency approach provides information on droplet size, and the dual polarization capabilities permit identification of the cloud or precipitation particles as spherical water droplets or nonspherical ice crystals. Microwave radiometric techniques are used to measure line integrals of cloud liquid water and water vapor.

Mesoscale Processes

The mesoscale research includes basic and applied research on mesoscale processes of the atmosphere, with particular emphasis on large meso-alpha-scale convective complexes. This includes work to improve the understanding of excessive convective rainfall and to develop techniques for forecasting flash-flood-producing storms. Other activities are development of mesoscale numerical models, conduct of theoretical and diagnostic studies, analyses of mesoscale weather systems, participation in meteorological field experiments, and studies of the microstructure and turbulence of the atmospheric boundary layer using airborne and remote-sensing measurement techniques.

Technology Transfer

ERL develops and tests operational sensing systems that are transferred to service components of NOAA such as NWS, and to other Federal agencies such as the Federal Aviation Administration (FAA). Doppler radar for identification and warning of severe thunderstorms and tornadoes has been tested for

the Air Force and the FAA. These tests indicate that Doppler radar reliably detects the greatest majority of destructive tornadoes tens of minutes before they produce damage. The flash-flood-forecasting research is conducted in close cooperation with NWS.

In the PROFS program, NWS, NESS, and ERL cooperate to improve local weather information service systems for NWS. The system design incorporates many of the advances made in the past decade in satellite- and ground-based remote sensing, in automated and surface weather stations, in data processing and display, in mesoscale analysis and forecasting, and in dissemination of data and forecasts.

CLOUD PHYSICS AND WEATHER MODIFICATION RESEARCH & DEVELOPMENT

All NOAA's weather modification programs except the Federal-State Cooperative Program were eliminated by Congress in its FY-1983 Continuing Resolution.

The Federal-State Cooperative Program is developing criteria for the effective evaluation of operational cloud seeding. The research and development needed to establish these criteria are carried out through contracts to five states under a Congressional mandate. NOAA manages the contracts and coordinates the research.

The program provides cost-effective research opportunities to develop technologies that address goals in agriculture, energy, and water resources. Current activities include studies on midwestern summer rainfall enhancement for corn and soybean production, by Illinois; the importance of western seeding programs to water supplies in downwind acid-rain regions, by Nevada; the physics of hailstorms and the enhancement of rain over the Great Plains, by North Dakota; and the enhancement of intermountain snowfall for irrigation and energy uses, by Utah.

The only cloud physics research remaining within NOAA is focused on hurricanes and related convective cloud systems, and the acidity of precipitation. Although the last actual seeding of a hurricane was in 1969, annual investigative field programs are conducted in which the research aircraft penetrate hurricane circulations to gather data on the structural characteristics of hurricanes, including cloud microphysical data and digital radar data. The observational efforts are complemented by a strong program that is developing numerical models of hurricanes.

AIR QUALITY RESEARCH & DEVELOPMENT

The goal of this program of research in meteorology and air and precipitation chemistry is to determine sources, transport and dispersion, and fates of trace constituents and pollutants to enable government and industry to reduce adverse impacts and maintain the chemical health of the atmosphere.

Air quality has a great effect on human health and ecology, and possible short-term and long-term effects on global weather/climate. NOAA has the responsibility to develop measurement techniques for important atmospheric constituents, to measure the spatial and temporal distribution of the constituents, to measure cross sections for the interactions involving and affecting important atmospheric constituents, and to perform modeling studies to understand the physics and chemistry of the atmosphere and the long-term impact of human-induced changes. NOAA carries out the tasks of ascertaining the sources of pollutants in nature and in human activities. It explores the fate of atmospheric constituents such as aerosols, particulates, and gases, and assesses the geophysical consequences of energy production. This research provides the scientific basis for regulating industrial, agricultural, and other polluting but economically necessary activities.

The Aeronomy Laboratory (AL) conducts research on chemical and physical processes of the Earth's atmosphere to advance the capability of monitoring, predicting, and controlling the quality of the atmosphere. The research concentrates on the stratospheric and tropospheric regions of the atmosphere. Research methods involve both in situ and remote measurement of critical atmospheric parameters, including chemical and composition and dynamic properties, such as wind velocities, turbulence, and wave motions. 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 Air Resources Laboratory (ARL) operates baseline stations for measuring atmospheric constituents important in air quality variation (see also Climate Research); conducts field and laboratory investigations into the physics and chemistry of formation of natural and anthropogenic particles and gases, the dispersion, transformation, and sinks of these particles, and the scavenging of particles and gases by clouds; and develops and disseminates air quality simulation models for inert and reactive pollutants on all temporal and spatial scales.

The Wave Propagation Laboratory (WPL) and the Geophysical Fluid Dynamics (GFDL), respectively, contribute remote-sensing measurement and atmospheric circulation and chemical modeling capabilities to aid in solution of the air quality problems of transport and transformation. Currently the focuses of their air quality programs are Ozone, Acid Rain, Transport and Diffusion, and Modeling. There is a close association with the program of Geophysical Monitoring for Climatic Change (GMCC; see Climate Research) and the programs of Weather- and Marine Observation and Prediction, and Solar-Terrestrial Research and Services.

Ozone

In recent years, the chemistry of the stratosphere has been of great interest because of the recognition of human potential for inadvertently affecting the ozone layer, with disastrous consequences. First, the possibility of an ozone reduction from water and nitrogen oxides released in stratospheric flights of supersonic transports was considered. This problem

brought worldwide attention to the potential for global air pollution problems. More recently, chlorine-containing halocarbons and nitrogen fertilizers have been labeled potential threats to stratospheric ozone. In addition to the effects on biological systems, ozone loss may also precipitate climatic changes.

The ARL monitoring program calibrates ozone measurement devices used at three ARL sites and other worldwide ozone-monitoring sites. AL is conducting measurement and studies of transport and chemistry affecting ozone. One radical important in ozone chemistry is NO_3, formed when nitrogen dioxide reacts with ozone. Research is under way to understand the chemistry of NO_3 required to interpret the role of nitrogen oxides in the stratosphere and troposphere.

There is still considerable uncertainty about pathways of pollutants to the stratosphere, where ozone is important to ultraviolet absorption of solar radiation. AL has demonstrated that towering cumulus development in the western Pacific is a source of stratospheric water vapor, and hence a potential path for pollutants to enter the stratosphere and interact with the ozone. Further quantitative measurements are in progress.

AL has also developed laser magnetic resonance and laser-induced fluorescence techniques to measure important reaction rates and cross sections. The fluorescence technique is being used to measure various NO_3 reaction parameters and kinetics. In other measurement programs tropospheric profiles of nitrogen oxide and nitrogen dioxide were measured with sensitive chemiluminescent detectors. Current measurements relevant to ozone chemistry include balloon-borne measurements of global atmospheric profiles of N_2, NO, NO_2, CO, H_2O, O_3, and chlorofluoromethanes.

Acid Rain

The principal issues in the Acid Rain program are (1) the gradual acidification of surface waters and soils by acid rain and dry deposition, and (2) the transboundary (especially U.S./Canada) transport of acidifying pollutants. NOAA is one of the lead agencies in the National Acid Precipitation Assessment Program (NAPAP) and has the principal research responsibilities in three areas:

(1) Assessing natural sources or causes of acidity and their importance relative to human-activity sources, to facilitate control strategies.

(2) Defining and assessing atmospheric processes of transport, dispersion, and transformation that link emissions of pollutants with acid deposition.

(3) Interpreting deposition mechanisms that bring acidic pollutants to the Earth's surface, and assessing the consequent severity and extent of the acid deposition phenomenon.

ARL is in the process of setting up a series of monitoring sites to determine the quantity and type of acid material that is being deposited in North America. One of these, operated by AL, is a remote site at the

10,000-ft level on Niwot Ridge, in Colorado. This location has the valuable feature that, depending on wind condition, it can be used to examine both the "clean-air" from the west and the relatively polluted air from the Denver metropolitan area to the east. The Niwot site is being used to test the current understanding of the photochemistry whereby NO_3 is formed from NO and NO_2. It has been found that, for given NO_2 levels, HNO_3 levels are higher in summer than in winter. Other studies permit estimates of the seasonal dependences of the dry removal rates of HNO_3, which appear to be much faster in summer than winter.

Natural sources of acid rain precursors have been found in the Gulf and the North Pacific Oceans by AOML and PMEL scientists. Research on these natural sources includes water and atmospheric sampling for volatile sulfur species to assess exchange rates and source/sink relationships for these gases, sulfur metabolism studies at sea using radio-sulfur and natural phytoplankton populations, and studies of the influence of ocean-emitted gases on the acidity of marine-derived precipitation. In addition to this research, ARL is planning measurement of pre-acidic material transported across the coastal boundaries.

Transport and Diffusion

The problem of transport and diffusion is important to a larger class of air quality programs. NOAA research in this area includes field programs and modeling. Major field programs completed or in progress are the Cross-Appalachian Tracer Experiments (CAPTEX 1982 and 1983), the Atlantic Coastal Unique Regional Atmospheric Tracer Experiment (ACURATE), and the Metropolitan Tracer Experiment (METREX). These are multi-agency experiments and include ARL, WPL, and NWS from NOAA. The objective of these field programs is to develop and verify models that can determine the effect of surface roughness and complex mountainous terrain on the measurement of air trajectories, and the effects of atmospheric anomalies (i.e., inversions) on transport and diffusion.

Modeling

The main goal of ERL modeling research is to understand the formation, transport, and chemistry of atmospheric trace constituents. Such understanding requires judicious combinations of theoretical models and specialized observations. The understanding gained will be applied toward evaluating the sensitivity of the atmospheric chemical system to human activities. Ongoing chemical modeling work at GFDL includes analyses of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Models will be developed to include a number of trace constituents simultaneously. This capability will be used to run interdependent experiments involving ozone and its precursors, partitioned components of total reactive nitrogen, carbon monoxide, and so forth.

ARL is developing transport models to simulate and/or predict local, regional, and global transport and diffusion of pollutants injected into the atmosphere. The models are used to evaluate the environmental effects of various kinds of energy production (e.g., nuclear fuels or fossil fuels) and

of volcanic eruptions, and to predict the path of radioactive debris from various atmospheric nuclear tests. In the acid rain program, a major goal is to establish the source-receptor relationships for sulfur emissions and acid deposition.

CLIMATE RESEARCH

Climate Research includes programs involving eight Laboratories, the Office of Programs, the Office of Aircraft Operations, and four joint institutes. The climate programs interact directly with other major programs such as Air Quality, Solar-Terrestrial, and Ocean and Lake Services, and on the short-term time scale, with Weather Observation and Prediction. Elements of the climate programs include ocean-atmosphere studies; observation and analysis of solar, atmospheric, and stratospheric variability; and climate modeling.

Ocean-Atmosphere Studies

The ocean-atmosphere studies include several projects. One of these, the Equatorial Pacific Ocean Climate Studies (EPOCS) program, is investigating the physics and dynamics of the coupled ocean-atmosphere system in the equatorial Pacific. Understanding this system is vital to comprehending global fluctuations of climate on interannual time scales. A broad spectrum of oceanographic and atmospheric parameters is being monitored by a variety of sensors to create an integrated data base. Satellites are continuously monitoring winds and sea surface temperatures. Research vessels are using XBT's and current profilers to determine vertical thermal and dynamic cross sections. Moored arrays at or near the Equator are used to determine the major time scales of variability of ocean parameters such as current, temperature, and salinity. Drifting buoys are used in the Pacific equatorial current system to determine the larger scale current patterns as well as other spatially distributed parameters. Other projects are using aircraft to measure vertical fluxes of heat, moisture, and momentum over the tropical Pacific.

The Subtropical Atlantic Ocean Climate Studies (STACS) is another major program, which seeks to identify the processes that contribute most to the poleward transport of heat in the North Atlantic Ocean and to develop the technology to monitor these processes operationally. The initial emphasis of STACS is on the development of techniques to monitor the mass transport and heat content of the Florida Current. Several techniques are being tested to determine the most efficient approach for long-term monitoring of the Florida Current. Among these are electromagnetic induction measurements from communications cables, use of coastal tidal stations, Doppler radar observations of surface flow, and acoustic measurements.

In addition to EPOCS and STACS, a broad range of research is conducted on the temporal and spatial variability of water mass structure, sea level, currents, and general circulation of deep ocean and coastal waters. Vertical mixing processes in the upper ocean, wind-generated response of middle-latitude upper ocean currents and temperature fields, and methods of inferring surface wind stress fields from satellite data are specific concerns of projects within the climate program.

In a technology development project, the potential of using low-frequency sound sources and detectors (acoustic tomography) to measure the structure of the ocean is being investigated.

Climate Variability

Projects relating to climate variability include airborne measurement of solar radiation over the equatorial Pacific; determination of the intensity and time scales of variations in the solar ultraviolet radiation as a function of wavelength in the 110- to 400-nm range; and determination of the significance of such variations in molecular dissociation atmospheric chemistry, upper atmosphere heating, and measurements of atmospheric constituents. Global levels of atmospheric trace constituents that have significant effect on the Earth's radiation budget, including carbon dioxide, ozone, aerosols, and water vapor, are monitored and analyzed. Four monitoring stations (Alaska, Hawaii, Samoa, and South Pole)--one tropical and one high-latitude in each hemisphere--provide baseline observations for monitoring global air quality. These stations are supplemented by several specialized monitoring networks operated by groups from the United States and other nations. These monitoring stations, which perform measurements for research related to climate change, are supported by instrument calibration and development in ERL. Analysis and interpretation of the data from the stations emphasize air quality changes, with special emphasis on carbon dioxide, that might affect climate. ERL undertakes additional reimbursable work involving the measurements of solar radiation, temperature, and other parameters above a forest canopy in order to improve understanding of the biosphere as a component of the climate system. (Atmospheric chemistry and stratospheric sampling programs, which also relate to climate research, are described in the Air Quality section.)

Climate Modeling

The modeling element is focused on constructing mathematical models of the atmosphere, the oceans, and the coupled fluid system that simulate the large-scale features of climate variability. Emphasis in atmospheric studies is on dynamical interaction between large-scale wave disturbances and the general circulation of the atmosphere, identification of the physical and dynamical mechanisms that maintain climate and cause its variation, and evaluation of the impacts of human activities on climate. The ocean circulation studies are also central to climate research. They focus on the large-scale response of the ocean to atmospheric forcing over a range of time scales from weeks to decades, ocean observational studies of the density structure and fields of various tracers, development of models of the world's oceans, interpretation of results in terms of a coherent hydrodynamical framework, and development of a capability to predict the large-scale behavior of the world's oceans in response to changing atmospheric conditions. The aim of observational studies is to identify and evaluate the physical processes by which atmospheric and oceanic circulations are maintained and to compare observational results with diagnostic studies of atmospheric and oceanic models.

SOLAR TERRESTRIAL RESEARCH & SERVICES

The solar-terrestrial program is accomplished in SEL. The program is unique in ERL because it contains both research and service components, and because the major user of the research program is the service program. The solar-terrestrial program interacts strongly with other government agencies, especially DOD and NASA. The goals of the program are to promote efficient, safe, and economic utilization of extraterrestrial space for civilian and military activities, vehicular operations, and communications; to support effective operation of essential public services that are subject to disruption by magnetic storms or solar events; and to increase understanding of the physical processes in the near-Earth space environment and their relation to human activities.

The program is designed to maintain continuous operation of the Space Environment Services Center (SESC) at Boulder, Colo., for monitoring and predicting solar activity and events in the upper atmosphere and their effects on communications, electric power systems, and air and marine navigation; and to maintain continuous acquisition and processing of data from the Geostationary Operational Environmental Satellites (GOES) and the polar-orbiting TIROS-N and NOAA satellites. SESC, jointly operated with the United States Air Force Air Weather Service, is both the national and international center for operational space and upper atmosphere information. SESC provides forecasts and warnings of solar disturbances and their effects to government agencies, industries, universities, foreign governments, and other foreign and domestic users. These forecasts and warnings help to prevent failure of some aircraft and marine navigation and communications systems at high latitudes, and they help to improve the efficiency of all telecommunications systems, the effectiveness of military operations and solar-disturbance-sensitive research programs, and the reliability of electric power networks. Real-time observations of the Sun and space environment are the basis for forecasts and warnings.

Research is undertaken to understand and model the fundamental physical processes responsible for the observed energy release, in the form of electromagnetic radiation and charged particles, from the solar surface during solar disturbances; the propagation and modification of this energy through interplanetary space to the near-Earth environment; the transfer of this energy into the Earth's magnetic field; and the behavior and subsequent effects of this energy within the magnetosphere, the ionosphere, and the upper atmosphere. These studies use data from satellites, rocket-launched instruments, and ground stations. The ultimate goal of this research is to develop numerical models that can be used by SESC to predict, with increasing accuracy, the timing and geographic distribution of the effects of solar disturbances on the Earth's environment and on human activities.

MARINE OBSERVATION AND PREDICTION

The ocean and lake observation and prediction program is accomplished at AOML, GFDL, GLERL, PMEL, WPL, and joint institutes. The program interacts strongly with the Climate, Air Quality, and other marine program areas. This research improves the capability for providing services to the marine community through increased understanding and improved observations of the

behavior of the atmospheric boundary layer over the ocean, the wave and current motions in surface layers, and the physical properties of the surface and subsurface waters of the ocean. Subjects of study include winds, waves, storm surges, ocean properties, tsunamis, and ice.

Winds

ERL conducts research to improve the observation and forecasting of hazardous winds that affect coastal populations including homeowners, fishermen, recreational boaters, the oil and gas industry, and commercial transportation. The most common methods of estimating winds over water use statistical relations between winds observed by ships of opportunity or the output of numerical weather prediction models. The former method is useful in hindcasting or climatological studies, but requires a long time series for statistical reliability. The numerical prediction method uses operational models to forecast wind over water. The major weakness of numerical weather prediction models is the large grid (from 90 to 180 km), which cannot resolve the data for the coastal zones and Great Lakes on a small enough scale. Greater resolution in these models and in observational networks is required because at land-water boundaries, strong contrasts in heating, friction by coastal boundaries, and channeling of winds by mountains can induce local and regional wind patterns, such as the reported nearshore winds in excess of 100 miles per hour along the Alaskan coast.

Surface winds provide the driving force for the generation of other phenomena such as waves, currents, upwelling, and storm surges. Until the wind stress, which provides the major driving force, can be measured directly, it must be computed from the wind field in the boundary layer immediately above the water surface. Since winds measured at coastal weather stations are often not representative of nearby over-the-water winds, increased emphasis is placed on developing in situ and remote-sensing techniques for directly measuring the latter.

Waves

Research on marine waves is conducted to improve forecasts and warnings of hazardous coastal wave conditions. Waves are generated by the action of the wind stress on the surface of the water. The highest priority research is in the prediction of wave fields for coastal and continental shelf regions. This prediction capability requires knowledge of the characteristics of the wave field moving from the deep oceans, and of modification of the deepwater wave field as it moves into shallow waters and onto the shore. Improved prediction of deepwater waves requires an increased understanding of the processes affecting the generation and growth of these waves. Present prediction capability is being significantly improved by the development and application of both discrete spectral and parametric models. In addition to improving the models used for wave predictions and improving the understanding of wave dynamics, this research is developing and applying new techniques such as ground-based radar, airborne imaging radar, airborne laser wave profilometry, and satellite observations to observe the sea state or parameters for predicting sea state.

Storm Surges

Storm surge research develops models that predict water impacts due to storms on coastal regions. This type of information is needed for both coastal planning and for real-time forecast and warning. The planning activities include both the establishment of criteria to guide coastal development and the preparation of plans for evacuating coastal communities. Hurricanes and other violent wind storms cause surges of water that are often 15-20 ft above the normal water level and are especially dangerous when combined with a high tide or high-wave conditions. Present techniques for forecasting the timing, extent of coastline affected, and magnitude of the inundation are inadequate to ensure the safety of coastal populations. Research to address these deficiencies must consider topographically complex areas like bays and inlets, and complicating factors such as inhomogeneities in the wind field, variations in water depth offshore, and the effects of waves and currents.

Ocean Properties

Research on properties of oceans involves observations of currents, upwelling, and thermal properties. Improved understanding and forecasts of ocean currents are an important focus of research. Ocean currents play key roles in shipping, fishing, pollutant transport, search and rescue operations, and climate variability. For example, forecasts of the short-term location and movement of the Gulf Stream could increase operational efficiency of ships and oil tankers. Increased efficiency in fishing operations and management of fisheries stocks is dependent on improved knowledge and forecasting of shelf currents and upwelling conditions. Knowledge of currents is essential in forecasting the movement of pollutants such as oil and chemicals released into marine waters. Knowledge of upwelling conditions is necessary to forecast coastal fog. Research on improving the accuracy of measuring and forecasting sea surface parameters is also undertaken in this program element. More accurate and higher resolution measurement of sea surface temperature fields would allow more accurate location of boundaries of different water masses and upwelling regions, and establishment of air-sea temperature differences, which affect the stability of the atmospheric boundary layer over the water and, in turn, the surface wind field that generates waves and currents.

Tsunamis

A goal of ERL tsunami research is improved prediction and monitoring of earthquake-induced ocean waves. These waves can travel great distances at high speeds and can cause extensive damage to coastal communities. Improved forecasts and warnings require the capability to determine in real time the expected tsunami height and runup at various coastal locations. Qualitative forecasts based on historical data are now possible but quantitative forecasts are not. Key areas of research include tsunami generation, numerical tsunami modeling, and instrument development to monitor micro-tsunamis for analytical and numerical models and to detect tsunamis before landfall for operational warnings. The successful areas of research will be incorporated into an operational warning system to provide reliable (low false-alarm rate) and accurate warnings.

Ice

Ice research in ERL seeks to improve monitoring and prediction of growth, movement, and breakup of ice in the Bering Sea, along the Alaskan Arctic coast, and in the Great Lakes. In the Great Lakes, accurate forecasts of ice thickness and extent in nearshore areas and connecting channels would allow extension of the commercial navigation season and improved design of nuclear reactor coolant intakes and shore property. Ice formation and growth occur by in-place thermal growth or movement of ice from other areas by wind and waves. Thermodynamic models of ice cover indicate that optical properties of ice are extremely critical to accurate forecasts of ice cover. Hence, a knowledge of light transmission, absorption, and reflection characteristics of the various ice types common to the Great Lakes is essential for modeling, remote sensing, and energy budget studies. Regional models for ice forecasts are being developed and transferred to the National Weather Service for operational use. These models incorporate ice and wind dynamics and ice thermodynamics as well as local coastal geometries and site-specific user requirements.

MARINE ASSESSMENT RESEARCH & SERVICES

The marine assessment program includes contributions from AOML, GFDL, GLERL, PMEL, and joint institutes. ERL conducts process-oriented research to improve our understanding of natural oceanic and Great Lakes systems and the ecological impacts of human-induced stresses on these systems. ERL's problem-oriented research leads to improved assessment capabilities. ERL develops and transfers scientific information to support decisions pertinent to marine pollution, exploitation of living and nonliving marine resources, water utilization, coastal power generation, and other activities affecting marine ecosystems. Research activities focus on coastal regions, estuaries, and the Great Lakes. Primary topies of concern include dynamics and kinematics of water circulation; transport, transformation, and fate of pollutants, and effects of pollutants on marine ecosystems; ecosystem and nutrient dynamics; the effects of physical and biochemical processes on marine productivity; water supplies, lake levels, and flows in the Great Lakes system; and the development and application of marine prediction models, risk analysis techniques, and advisory services.

Ocean Systems

Research on the effects of ocean use consists of field investigations and supportive laboratory research to determine the consequences of ocean dumping of dredged material and municipal and industrial wastes. Emphases are on pollutant effects and the development of techniques to measure pollutants. A comprehensive program of research is conducted to detect changes in the oceans and the Great Lakes that are caused by human activities and that may have long-term adverse consequences. The research focuses on the interaction of trace metals, synthetic organics, and hydrocarbons with marine ecosystems. The role of particulates as pollutants or as a transport mechanism for harmful compounds is emphasized. Studies at AOML seek to determine which natural or pollutant organic materials in seawater complex or bind

toxic or essential trace metals, and what effect such complexing or binding has on marine productivity. Other research at this Laboratory seeks to determine the mechanisms by which particulate matter in marine ecosystems functions in the transport and removal of pollutants. This research investigates the extent to which mineral and biogenic particles scrub large river outflow systems of pollutants and bury them in deltaic sediments, and the extent to which this burial can be reversed by resuspension events such as storms. Current work focuses on the Mississippi River outflow.

Research conducted by PMEL describes and quantifies the physical and chemical processes affecting the transport, transformation, and fate of pollutants in marine estuaries and coastal systems. Studies focus on pollutant levels and distributions; chemical transformation of pollutants and uptake by particulates; pollutant source/sink distributions; and estuarine and coastal circulation patterns and mixing processes. The primary effort is in the Puget Sound System. PMEL also conducts research to develop models of mass fluxes of trace metals and toxic organics in coastal and estuarine systems. Research stresses the incorporation of information on pollutant loading and on physical and chemical processes obtained from field studies into dynamic models of water movements and pollutant distributions and fluxes. PMEL provides information on coastal and estuarine processes that affect the ability of marine systems to accommodate contaminants without unacceptable damage. This information synthesizes the results of field studies and models to determine relationships, useful for decision-making purposes, among pollutant types, distribution and levels of loading, pollutant transport and dissipative processes, and ecological consequences.

At GFDL, research related to the quality of the marine environment has as its objective the simulation of oceanic conditions in coastal zones and in estuaries, and the modeling of the dispersion of geochemical tracers (e.g., tritium, radon) in the world oceans. Two- and three-dimensional models of estuaries such as the Hudson-Raritan and Delaware Estuaries 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.

Great Lakes Systems

GLERL conducts research in the Great Lakes on water movement and temperature, particle dynamics, cycling of toxic organics, planktonic succession, eutrophication and nutrient cycling, and the development of environmental information services and environmental engineering models and applications. The water movement and temperature research develops improved climatological information (by means of observations, new instrumentation, and improved analysis) on the distribution and variability of coastal and offshore currents and temperature, develops and tests improved numerical hydrodynamic models that can simulate and predict lake currents and temperatures, and extends models to simulate and predict the transport and diffusion of pollutants. Research in the Great Lakes also emphasizes the interaction of particulates and pollutants, particularly the pollutant source/sink characteristics of bottom sediments. GLERL also develops ecosystem models that simulate the passage of toxic pollutants through the Great Lakes food chain.

A major effort at GLERL develops, tests, evaluates, and applies water quality and water quantity management models and improved environmental systems engineering methods to estimate pollutant and nutrient loading; to estimate effects of diversions, consumptive use, human-induced changes in lake water levels, and levels and flows in the connecting channels; and to organize and disseminate environmental information for decision purposes.

MARINE RESOURCES RESEARCH & SERVICES

The marine resources research program is accomplished through projects at AOML, GLERL, PMEL, and joint institutes. The program is designed to accelerate rational marine industrial development through research into the optimum use, development, and protection of living and mineral marine resources; to improve, through applied research, the technologies needed for efficient use of marine resources; and to provide significant information on the social, economic, and legal impacts of present and projected marine development. Among the program's elements are marine resource development, marine environmental research, and marine advisory services.

Marine Resources Development

Resource development is directed toward discovering and developing marine mineral resources. Mineral resource development consists of studies relating to discovery, availability, recovery, and processing techniques, and the legal implications of offshore mining of sand, gravel, polymetallic sulfides, and other marine minerals. ERL conducts a metallogenesis program in support of NOAA's mission in the areas of ocean pollution and marine mining. NOAA scientists conducting studies for the program have been joined by other Federal and academic scientists and a variety of international sponsors and participants. In support of NOAA research focused on marine mining, the metallogenesis program objectives are to determine the processes of concentration of metallic mineral deposits, with emphasis on polymetallic sulfides; identify types of metallic deposits and delineate their distribution; establish guidelines for seabed mineral exploration; and characterize the environment before, during, and after marine mining. In support of ocean pollution research the metallogenesis program determines the role of hydrothermal processes in controlling the chemistry of seawater and seabed; defines the natural transport of metals from active sources in ocean basins; traces the interaction of the metals with the biosphere; and develops capabilities to evaluate the feasibility of radioactive-waste disposal and geothermal-energy utilization at sites in ocean basins.

Marine Environmental Research

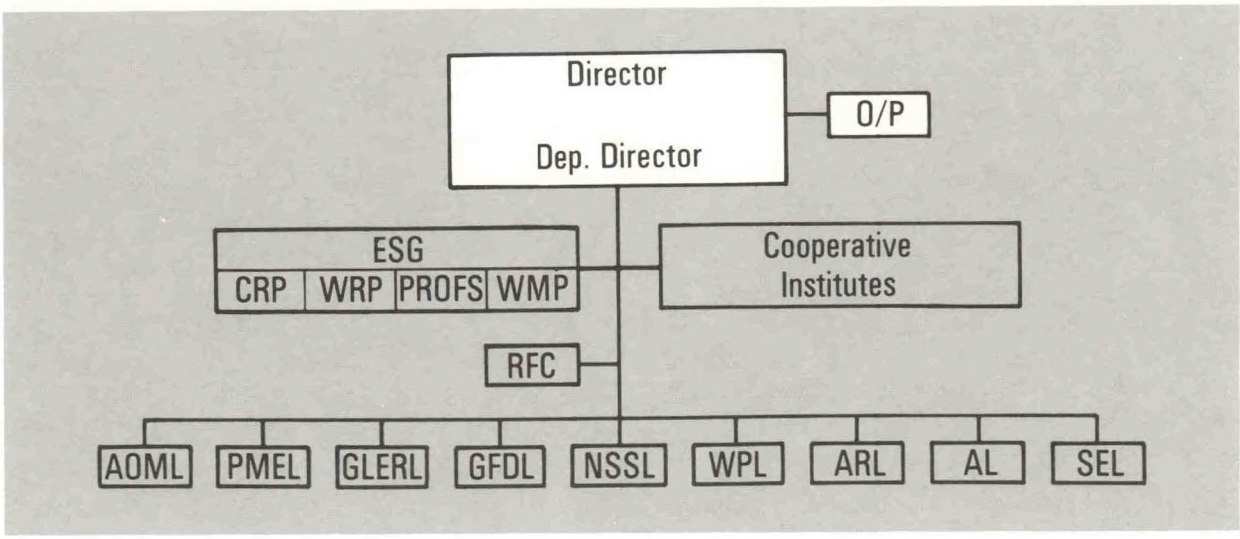
Marine environmental research attempts to manage and protect coastal resources in the face of increasing multiple-use conflicts. Projects and studies focus on understanding the effects of various uses (e.g., waste disposal, industrial and commercial activities, food production, and residential and recreation uses) on marine and estuarine ecosystems. This understanding is essential to the wise use and protection of these resources.

Marine Advisory Services

Marine advisory services include informal education of the general public, technical advice and instruction in marine areas, identification and communication of local marine community needs, and dissemination of research findings through seminars, workshops, publication, and personal contacts. The marine advisors work with communicators to reach the general public through press, radio, television, and other media.

OFFICE OF THE DIRECTOR
Boulder, Colorado

Vernon E. Derr, Director
Deputy Director (Vacant)



The Director, assisted by the Deputy Director, establishes basic policies and manages the overall activities of the Environmental Research Laboratories. Within the Office of the Director, the Office of Programs provides advice and services to the Director as well as to the Laboratories and ESG. The Office of Programs provides policy, program, and management advice and support in areas such as program planning, budgeting, and analysis; program coordination and review; and implementation of management decisions. Budget, ADP Planning and Telecommunications, and editing services are part of the Office of Programs.

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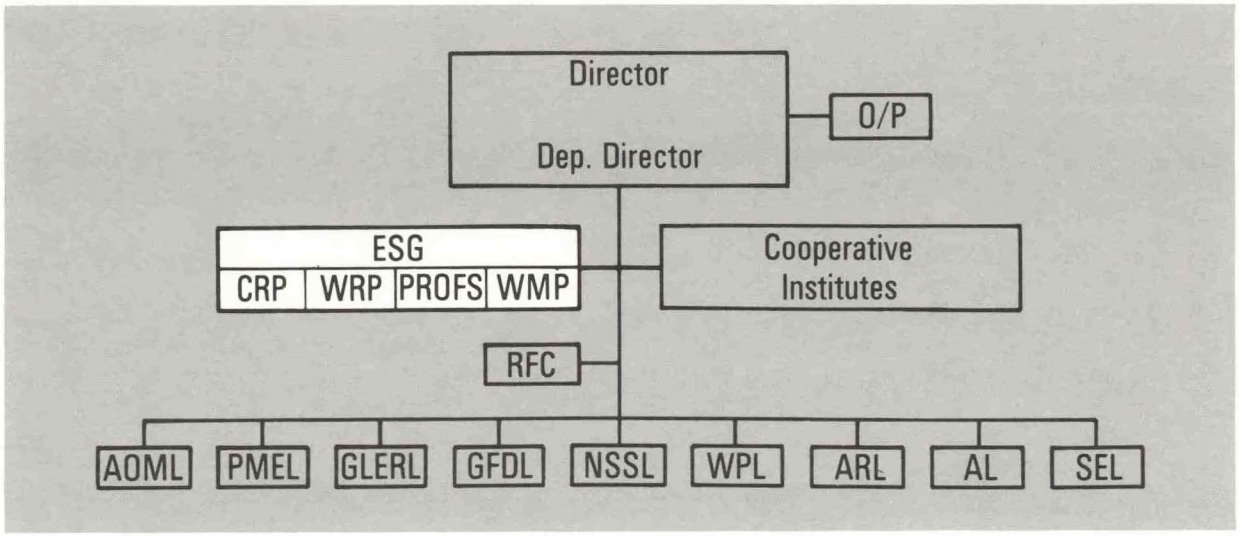
ENVIRONMENTAL SCIENCES GROUP
Boulder, Colorado

Vernon E. Derr
Acting Director



The Environmental Sciences Group (ESG) plans, develops, and conducts programs of basic and applied research and technology transfer that cut across Laboratory or program area missions, are less permanent than existing line elements within ERL, or are in the formative stages of development. In addition to planning and coordination, ESG provides technical support and documentation. The four components of ESG in FY 1983 were the Climate Research Project, the Weather Research Program, the Program for Regional Observing and Forecasting Services, and the Weather Modification Program.

ESG
CRP

CLIMATE RESEARCH PROJECT

The Climate Research Project (CRP) has three broad objectives:

- Construction of a global data set to describe climatic fluctuations during the past 130 years over oceans and continents.
- Interpretive diagnostic studies of those climatic fluctuations on time scales ranging from one month to decades.
- Modeling studies of polar ice sheets to clarify their evolution and their responses to climatic change.

Accomplishments FY 1983

CLIMATE RECORD CONSTRUCTION

Marine Data Base

The Comprehensive Ocean/Atmosphere Data Set is being constructed from more than 100 million individual marine observations from 1854 through 1979. Principal products in FY 1983, obtained in cooperation with the National Center for Atmospheric Research (NCAR) and the National Climatic Data Center (NCDC), include the following:

- Individual reports in two different forms: (1) the full observation record and (2) an abbreviated record of frequently used variables, both using packed-binary techniques to minimize storage. These reports were sorted and quality-controlled; possible duplicates were eliminated or flagged.

- Monthly summaries for 2° × 2° boxes, giving 14 statistics for each of 8 observed variables.

- Decadal summaries for 2° × 2° boxes.

All these products include the "untrimmed" data, resulting from a standard set of quality controls. A "trimmed" data set will be constructed next, in which more stringent tests will be applied to remove apparent outlier values.

Climatic Data for Land Stations

Atmospheric data for describing the Northern Hemisphere land climate for the period 1851-1980 have been assembled under a U.S. Department of Energy (DOE) grant. The purposes are (1) to refine the current data base which covers the period 1881 to present and (2) to extend the record back to 1851. This project is a cooperative venture of NOAA, the University of East Anglia (U.K.), and the University of Massachusetts.

The spatial coverage of the data was increased by amounts ranging from 5%-10% of the original grid points in the recent decades, to 25%-30% about 1920, to 40%-60% in the early decades (1880-1900). Digitized data from 1851 to 1880 represent a valuable new addition to our data archives.

Highly Reflective Clouds

The monthly incidence of subjectively identified Highly Reflective Clouds (HRC) was shown to provide a good measure of tropical rainfall. The HRC data set was completed for the 1971-1980 period, as well as for recent months. Analysis of HRC data allowed timely detailed comparisons of the patterns of tropical convection for the 1982-83 El Niño event with those of the 1972-73 and 1976-77 El Niño events.

HRC data were also used in studies of monsoon circulation, of the large-scale relationship between tropical convective activity and sea-surface temperatures, and of tropical-extratropical interactions.

Stratospheric Aerosols

Global stratospheric aerosol loading was estimated from observed brightnesses of the moon during total lunar eclipses. A time series of these estimates, based on observations of 22 lunar eclipses between 1960 and 1982, indicates an approximate equivalence of the aerosol loadings due to the eruptions of Agung (1963) and El Chichón (1982) volcanoes.

DIAGNOSTIC STUDIES OF CLIMATIC FLUCTUATION

El Niño/Southern Oscillation Events

The spatial and temporal differences and similarities associated with the evolution of the three most recent El Niño/Southern Oscillation (ENSO) events (1972-73, 1976-77 and 1982-83) were the subject of an intensive research effort.

The identification of characteristic features associated with ENSO events may provide a major opportunity for increasing our capability (skill) in predicting climate at the monthly and seasonal time scales. Observational studies began on the effect of anomalous tropical heating, through enhanced precipitation, on the Northern Hemisphere circulation; the long-term ocean and land data were used to extend the recent ENSO record back to the 19th century.

Monsoon Changes

CRP

The main focus of this research effort is to understand the changes in global atmospheric and oceanic circulation associated with anomalies of global climate. Specific aspects investigated include the annual, interannual, and secular changes of the monsoon circulation over the Indian and Western Pacific Oceans, and their relationship to atmospheric circulation anomalies occurring elsewhere, both at the surface and at upper levels.

One area of interest dealt with the differences in the monsoon regime associated with a dry/wet India monsoon compared with a wet/dry China monsoon. It was found that, in general, a dry monsoon season over the Indian subcontinent is associated with a wet China monsoon and vice versa. This relationship appears to break down during moderate-to-strong ENSO episodes.

Meteorology of the Asian Summer Monsoon and Equatorial Pacific Ocean

Work continues on boundary layer (BL) flow over the eastern Arabian Sea during the summer monsoon. New results show unique features not observed in earlier BL studies around Barbados and the tropical Atlantic.

Using the HRC data set, adjusted for diurnal variation, a study of convective activity over the Arabian Sea compared with convective activity over

India is near completion. Preliminary results indicate that monsoon convective activity over the ocean exceeds that over land when considered from a total area or a per-unit-area viewpoint.

The CO_2-turbulence analysis from the Barbados flight missions is under way, and planning is in the final stages for an aircraft investigation of BL budget and saturation point BL parameterization in the equatorial Pacific near Christmas Island.

DIAGNOSTIC STUDIES OF SYNOPTIC ASPECTS OF CLIMATE

Western Aspects of the Southern Oscillation

The Australian digitized daily surface weather charts and 200-mb wind fields were put into a form that permits their rapid scanning for an identification of significant blocking episodes and their antecedents. Pending the updating of the series to cover the 1982-83 event, analyses of the Niño sequence of 1975 (aborted) and 1976 were begun.

Empirical Orthogonal Function Analysis

A detailed and explicitly elementary description of empirical orthogonal function (EOF) concepts and techniques was prepared to accompany a battery of annotated computer programs designed to handle the material of the Comprehensive Ocean/Atmosphere Data Set. Some of the data were used to test the software. A library of application programs is being built to aid in analysis of the data.

Equatorial Synoptic Events During 1982-83

The sequence of synoptic-scale circulation patterns and convective outbreaks in the equatorial Pacific during 1982-83 was compared with the progression of the high-SST (sea-surface temperature) anomaly. The results of this comparison form the basis of a conceptual interactive model, involving a two-layer atmosphere and the ocean surface, which may help explain the extreme nature of the 1982-83 ENSO event. One interactive link in this model is the generation of oceanic Kelvin waves by surface equatorial westerly winds; this process is being examined quantitatively in collaboration with the Joint Institute for Marine and Atmospheric Research (JIMAR).

Transient Tropical-Extratropical Interactions

With funding from the National Science Foundation, synoptic-scale aspects of the atmospheric teleconnection between the tropical Pacific and North America were examined for the 1982-83 ENSO event and for earlier years. Synoptic sequences, in which convective outbreaks over the tropical Pacific are followed by localized intensifications of the subtropical jet and cyclogeneses over North America, were particularly common during 1982-83. Individual cases of these synoptic sequences are being examined along with the climatology of their occurrences in order to determine their effect on the atmospheric circulation over North America.

ICE SHEET MODELING

The future of the ice sheet modeling project, initiated with NOAA funding for FY 1981 and FY 1982, remained uncertain while the Department of Energy considered a proposal for continuing the work. More of the 1982 results were written up for publication. Major efforts went into organizing a workshop on CO_2-induced changes in the environment of West Antarctica, for the Polar Research Board of the National Academy of Sciences, and into preparing the report on the workshop (held at Madison, Wis., in July 1983). A section of another Academy report ("The Polar Regions and Climatic Change") treating the Role of Polar Regions in Climate Dynamics was completed.

MISCELLANEOUS PROJECTS

Fluxes of Heat, Water Vapor, Momentum, and CO_2 Over the Tropical Oceans

Bulk transfer coefficients were obtained for the central and eastern Pacific to be used in the bulk aerodynamic modeling of the air-sea transfer of heat, moisture, and momentum. The dependence of these coefficients on SST and atmospheric stability was determined from flights over the south equatorial current and the upwelling region off the west coast of South America. These results are important for understanding the modifications to air-sea transfers due to large SST anomalies that occur during El Niño events. Updrafts and downdrafts over the central equatorial Pacific Ocean were studied by applying conditional sampling to the aircraft turbulence data. Statistical properties obtained included average event size, number density, and the proportion of horizontal area occupied. In addition, the conditional averages of moisture, temperature, and horizontal momentum were obtained along with the proportional contribution to the total fluxes by updrafts and downdrafts. The analysis provides a framework for modeling the turbulent structure of the atmospheric boundary layer over the tropical Pacific Ocean. The ultimate goal is a parameterization of the transports of moisture, heat, and momentum in the sub-cloud and cloud layers, based on large-scale data obtained from satellite and other remote-sensing instrumentation. **CRP**

Data taken by a fast-response CO_2 instrument, developed at Lawrence Livermore Laboratory, and the NOAA/ERL gust probe over the Caribbean Sea aboard a NOAA aircraft were analyzed. Vertical profiles of the eddy flux of CO_2 were obtained and compared with estimates of the surface flux based on CO_2 differences across the air-sea interface and a transfer velocity derived from observed deficits of radon-222 in the upper-ocean mixed layer.

Assessment of the Effects of U.S. Population Shifts on Demand for Heating, Cooling, and Water

A study has been completed that documents the shift and growth of U.S. population toward warmer (the South and Southeast) and drier (the West and Southwest) climates during the past five decades (1931-1980). The study determined that this shift has modified the relative demands for heating and cooling as measured by population-weighted indices of heating and cooling degree days (fewer national population-weighted HDD's but more CDD's). Of course, the absolute demand has grown drastically, owing to a number of other

nonclimatic factors such as economic, technological, and total population growth.

The proportion of the U.S. population living in drier (West and Southwest) climates grew substantially during this period. Because these population trends are expected to continue into the next century, the effects of climate variations such as drought and floods as well as protracted cold or hot weather are likely to increase solely as a result of the changes in the geographic distribution of the U.S. population.

P-3 Flights to the Eastern Pacific

Members of the Climate Research Project participated in three research missions on the NOAA P-3 aircraft to the eastern tropical Pacific during January, July, and September. Analysis of the data obtained is providing a detailed cross-sectional view of the near-equatorial convergence zone at different stages of the 1982-83 El Niño. Special emphasis is being placed on saturation point analysis of the dropsonde data.

Plans FY 1984

CLIMATE RECORD CONSTRUCTION

Marine Data Base

The Comprehensive Ocean/Atmosphere Data Set will be completed. Distribution of the products will be handled by NCAR and NCDC. Additional products will include the following:

- Individual reports in NCDC's standard character format.
- Trimmed monthly summaries for 2°× 2° boxes, giving 14 statistics for each of the 8 observed and 11 derived variables; trimmed decadal summaries for 2° × 2° boxes.

In addition, the monthly summary products will be sorted by time, and then broken up into convenient-size component files containing fewer variables and statistics to isolate data necessary for specific research.

The climatic data base of land stations in the Northern Hemisphere has been completed. Work during FY 1984 will concentrate on gridding the data and merging it with the marine record. The resulting merged data set of monthly mean surface air temperatures will be the first truly comprehensive record of global-scale surface air temperature variations covering the past 130 years. It is anticipated that the analysis of regional and hemispheric scale changes in temperature anomaly patterns will be of great use in testing numerical models for the effects of CO_2, aerosols (volcanic and otherwise), and solar variability on secular climate variations.

Highly Reflective Clouds

The HRC data set will continue to be updated. An Atlas of Highly Reflective Clouds for the global tropics will be produced and distributed to the research community. The HRC data will be analyzed in a global context to determine the major characteristics of tropical convection. Efforts will also continue in calibrating HRC-derived rainfall estimates with estimates from other techniques, and in using HRC data in other studies of tropical-extratropical interaction and monsoon circulation.

DIAGNOSTIC STUDIES

ENSO Variability

There is abundant evidence that the 1982-83 ENSO event was quite unlike previous ENSO events. The responses of the tropics to variable heat sources and the teleconnected patterns of middle-latitude response have been shown to vary depending upon the location of the heat source in the equatorial Pacific Ocean. The 130-year Northern Hemisphere data base will be used in formulating an ENSO classification, both in terms of the middle-latitude response in the Northern Hemisphere and in terms of the tropical characteristics.

Results of the 1983 El Niño research flight data analysis will be published.

Diagnostic Interpretation of the Ocean Climate Record

Several variables will be available for comprehensive analysis. These include surface wind components, air and sea surface temperature, and sea level pressure. Analysis will concentrate on defining the temporal and spatial characteristics of short- and long-term trends and variability. **CRP**

Empirical Orthogonal Function Analysis

EOF analysis will be used to compare winds and surface pressure gradients (geostrophic winds) of the Comprehensive Ocean/Atmosphere Data Set (COADS) for different periods and regions. Monte Carlo experiments will be undertaken to assess the statistical significance of higher order EOF's.

Analysis of Secular Climatic Fluctuations Over the Western Northern Hemisphere

The merging of the marine (COADS) and continental data bases will permit the first comprehensive analysis of the morphology of secular temperature trends over the Northern Hemisphere during the past century. Emphasis will be placed on explaining the regional responses and differences associated with various epochs or climate regimes.

ICE SHEET MODELING

Assuming that the proposal to the Department of Energy will be funded to start on 1 January 1984, the remainder of the fiscal year will be devoted primarily to preparing a full physical description of the West Antarctic ice sheet on a 20-km grid. The sensitivity of streamline models to different sliding parameterizations will also be investigated.

MISCELLANEOUS PROJECTS

Utilization of Satellite Data in Tropical-Extratropical Climate Studies

Investigations are being planned which will explore the utility of satellite sounding data for understanding factors controlling the location and intensity of convection in the Pacific near-equatorial convergence zone (NECZ), especially during El Niño events. Specifically, the Man-computer Interactive Data Access System (McIDAS) will be used to determine if the midtropospheric minimum in moist static energy can be detected in satellite soundings produced from the polar orbiting and geostationary meteorological satellites. If this minimum, which limits convection in the central and eastern Pacific, can be measured from space, relationships between its strength and convection in the NECZ will be studied.

Satellite data will also be examined for possible supplementary input to studies of tropical-extratropical interactions associated with cirrus flares. At times during the winter months Northern Hemisphere disturbances appear to interact with tropical convection, producing a surge in the subtropical jet (STJ). Satellite sounding data will be used to determine whether these disturbances destabilize the tropical atmosphere, in effect drawing energy out of the tropics, or whether deep tropical convection must already exist which then forces the STJ.

WEATHER RESEARCH PROGRAM

The Weather Research Program (WRP), previously a part of the Office of Weather Research and Modification (OWRM), conducts research to increase the understanding of, and improve prediction of, mesoscale weather systems. The research emphasis is on the genesis, evolution, and structure of convectively driven systems; the scale of interest extends from individual thunderstorms to large mesoscale precipitation systems. The program is actively involved in transferring research findings and related weather prediction techniques to the National Weather Service (NWS) and other user groups.

Two groups have been established within WRP, the Mesoscale Research Group (MRG) and the Mesoscale Applications Group (MAG); they carry out basic and applied research with emphasis on these subjects:

- The relationships of thunderstorm-scale and mesoscale precipitation elements and their variation as a function of time and life cycle.

- The dynamics and thermodynamics associated with mesoscale convective weather systems and interactions between mesoscale and both larger and smaller scale processes.

- The ways in which remote-sensor data streams, which are becoming available within ERL, might be integrated into basic research efforts and advanced prediction techniques.

Accomplishments FY 1983

A 3-month cooperative experiment to forecast mesoscale convective systems ended August 31. Several researchers from WRP and members of the Kansas City Satellite Field Service Station staff participated in this exercise in which once-daily forecasts were produced using morning data and prognostic products. The forecasters attempted to define the character of any anticipated mesoscale convective systems (e.g., as circular or linear) as well as timing, duration, and affected areas of the Central States for a forecast period from 0000 GMT to 1200 GMT.

A detailed analysis of a 10-day period (11-20 May 1982) of 651 severe-weather events and heavy precipitation was completed using operational data sets. To determine the large-scale pattern, mean charts for 0000 GMT and 0012 GMT at 850 mb, 700 mb, and 500 mb were constructed. "Perturbation" charts for each level and time were completed as a means to identify meso-alpha-scale disturbances embedded in the large-scale pattern. The following results were obtained:

- It was demonstrated that perturbation analysis can be useful in delineating areas of potentially significant convection. When plotted on composite charts, the low-level (850-700 mb) thermal and moisture perturbations, as well as the wind (but not the height--thus, ageostrophic) perturbations, appear to have a degree of organization that is not present when severe weather is absent or is "random." **WRP**

- Atmospheric structure on days with and without heavy precipitation accompanying severe weather was compared. Changes in the vertical wind profile and thermal/moisture structure revealed in soundings, but not clearly in constant pressure level analyses, appear to provide important clues to formation of heavy rain.

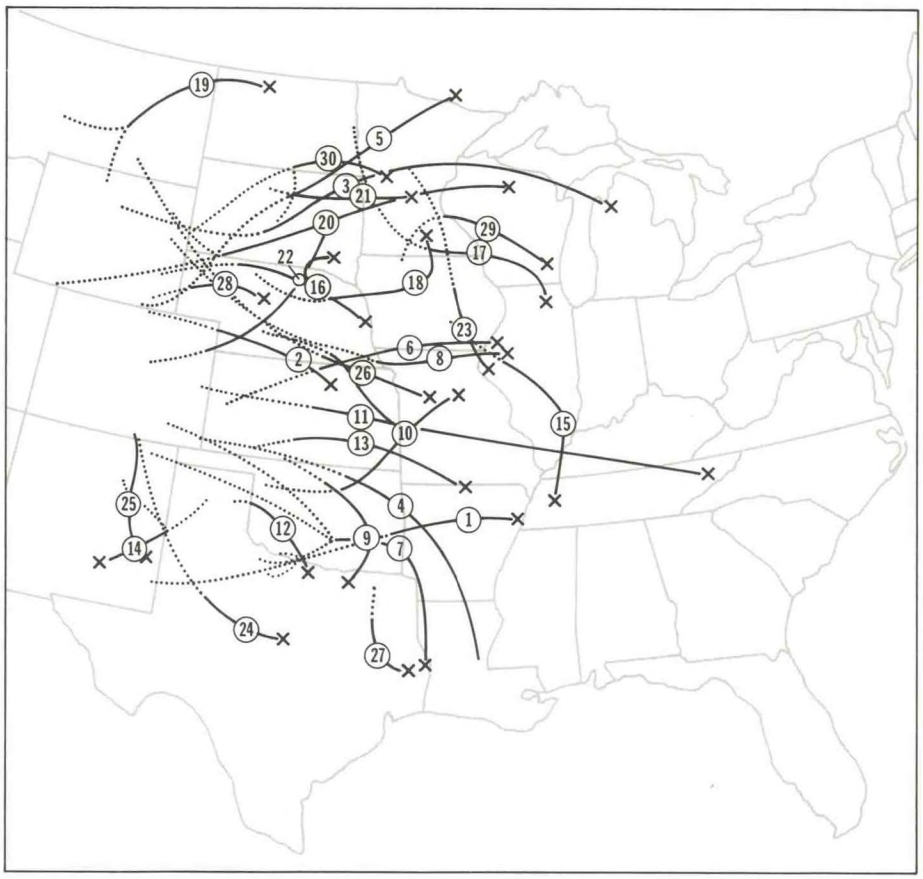
Analysis of the data set for 20 May 1979 began, to investigate the dynamical and thermodynamical changes and interactions occurring in the large mesoscale convective system that formed in the SESAME (Severe Environmental Storms And Mesoscale Experiment) research area on that day.

A theoretical study of frontogenetic kinematics was completed. It was shown how the nonlinear aspects of the wind field yielded a role for vorticity in frontogenesis, despite its absence in classical frontogenesis theory. The non-scale-dependent behavior of a scalar quantity within a steady-state nondivergent vortex was explored with respect to frontogenesis.

Analyses of the Topeka tornado case of 6 May 1983 show that an apparently nonconvective mesohigh played a key role in this event. The origins of the mesohigh seem to reflect a subtle interaction of atmospheric processes on several scales.

Work continued on studying the relationship between the so-called Denver-area convergence vorticity zone (or "Denver-cyclone," frequency noted when low-level synoptic-scale flow over eastern Colorado is from the southeast) and severe weather over northeast Colorado. A relationship is suspected because thunderstorm updrafts in this vorticity-rich zone would potentially contain substantial rotation by virtue of the concentration of vertical vorticity that must occur in their lower levels. However, preliminary analysis does not support the existence of such a relationship.

Preparation began of a climatology of convective weather systems over much of the Midwest and High Plains, based on satellite data. The period of interest is April through July of 1979 through 1983 (WRP Fig. 1).



WRP Figure 1.--Tracks of the 30 Mesoscale Convective Complexes (MCC's)--large convective systems--that occurred between June 16 and June 30 in a 5-year period (1978-1982) over the whole continental United States. MCC's were typically most frequent during the two weeks represented. These systems produce more than half the rain in the area affected. The tracks are part of WRP's satellite-data-based climatology of convective weather systems.

The collection of lightning ground strike data from the PROFS-Air Force network in eastern Colorado continued. A significant amount of time has been spent in assuring that data quality is high. Most of the meteorological regimes in the Western States, ranging from dry and suppressed to the moist monsoon, are represented in these PROFS data. The response of lightning ground strike activity to prevailing synoptic flow patterns and to topographic forcing will be systematically explored for up to 120 days over the summers of 1982 and 1983 in the PROFS area.

For the purpose of research oriented to improved short-term forecasting techniques for the Kennedy Space Center, digitized radar data were collected at the Daytona Beach NWS station from 15 July to 30 September, between 0600 and 2200 EDT. Software was developed to start the processing and analysis of this radar information. The main objective is to determine the relationships between lightning flashes and radar echoes in the Kennedy Space Center area, as well as between lightning flashes and upper-air meteorological parameters in the region. Additional planning occurred to advise Air Force and NASA personnel on the possible enlargement of the current Cape surface wind network to test convergence-rainfall concepts developed previously in south Florida.

The dissolution of OWRM and the accompanying shortage of money for computing forced a drastic reorientation of the mesoscale modeling effort in WRP. Work began on upgrading the existing two-dimensional version of the OWRM model through installation and checkout of current numerical procedures. When complete, this upgraded model will be used as the basis for studies of mesoscale convective systems. The Asselin time filter was successfully installed and tested, and various "radiation" formulations for the lateral boundary conditions were coded and tested. Work began on refinement of boundary conditions for use in hydrostatic fine-mesh numerical models.

Detailed analyses of a convective storm from data collected in south Florida indicated that the feedback mechanisms between developing convective systems and their environment, which result in environmental subsidence, may cause a convective system to evolve from the mature to the dissipating stage. The warming, drying, and net downward motion induced by the developing convective system may act to weaken the newly developing convection. This causes a weakening of the convectively induced low-pressure area beneath the convection, which results in a decrease of the inflow into the convective system. This allows the downdraft-outflow boundary to move away from the convective system, causing the system to evolve from the mature to the dissipating stage.

WRP

To investigate the downburst phenomenon, preliminary sounding data (four soundings per day) for Denver were assembled for the period of the entire 1982 JAWS (Joint Airport Weather Studies) project. The data suggest a strong pattern of moisture (dew point depression $\leq 8°C$) at 700 mb in the 1200 GMT pre-microburst soundings. In fact, on the basis of the wet-dry sounding pattern, about 80% of the JAWS project days are correctly classified as to the occurrence or non-occurrence of microbursts.

The meteorological study of Pan American flight 759 (New Orleans, 1982) was completed, and a report issued that identified the major cause as a "microburst."

Analysis was completed of the diurnal variation of satellite-derived rainfall over the tropical Pacific Ocean for August 1979. Significant differences among the diurnal rainfall variations were found from the detailed statistical and harmonic analyses performed over the five time zones.

A satellite-based cloud census for the Great Plains was completed for August 1979. Frequencies of cloud occurrence as a function of time of day, day of the month, geographical location, and cloud size were compiled.

Plans FY 1984

MESOSCALE RESEARCH GROUP

A main research area within MRG will be the continued detailed analysis of the SESAME case study for 20 May 1979. On this day a large mesoscale convective system (2 km-300 km) formed in the SESAME stormscale network, moving over a portion of the dense surface mesonetwork. Although this storm system was neither severe in the classic sense nor large enough to be classified as a Mesoscale Convective Complex, it produced rainfall in excess of 4 inches over a large portion of eastern Oklahoma. Investigations will focus on the evolution of the precipitation structure of the system and on determining the interactions and feedbacks between the convective system and its environment during the life of the storm complex.

Another main research activity within MRG will be the airborne observation program of Mesoscale Convective Systems (MCS's) using one of the NOAA P-3 aircraft. A total of 50 flight hours has been allocated for the program's operational phase from 15 June to 15 July 1984. The program has two main objectives: (1) to assess the operational capability of the research aircraft in an MCS environment, which is extremely important for planning aircraft operations in the national STORM (Stormscale Operational and Research Meteorology) program; (2) to investigate the evolutionary characteristics of an MCS and the interactions with its larger scale environment using the basic aircraft sensors as well as the 5-cm lower fuselage radar and the 3-cm Doppler tail radar.

Although numerical modeling activities within WRP have been seriously restricted by budget cuts and limited computing resources, MRG maintains a small effort emphasizing studies that may lead to improvements in operational models and weather forecasting. Specifically, during FY 1984 we plan to examine and evaluate improved convective parameterization schemes within the framework of a two-dimensional numerical model.

MESOSCALE APPLICATIONS GROUP

A principal research activity will develop and document pattern recognition techniques, and process models and climatological data sets for improved prediction of rainfall and other severe weather produced by mesoscale convective precipitation systems, using conventional large-scale data and forecast guidance products. Special emphasis will be given to studies of the precipitation structure of mesoscale convective systems and to examination of ways

to improve forecasts of severe thunderstorms. In addition, research will be conducted to consider how remote-sensor data streams that are becoming available (from WPL Profilers, satellites, radars, and lightning ground-strike detectors) might be integrated into advanced prediction techniques by studying how they relate to conventional data.

MAG will maintain and strengthen the previously developed synergetic interactions with operational and training units of NWS and other agencies. MAG personnel will teach at the NWS Training Center in the flash-flood forecasting course on at least five occasions during the coming year. In addition, MAG will implement several innovative exchanges of staff in an attempt to foster communications between NWS operational forecasters and ERL researchers.

Studies will continue to examine ways of improving the detection and forecasting of meteorological conditions that negatively affect aviation operations. Emphasis will be on continued participation in studies of JAWS data showing various-scale downdrafts and associated low-level wind shear, and, in the NASA MERIT (Minimum Energy Routes using Interactive Techniques) project, on ways to improve winds-aloft forecasts and en route fuel economy.

PROGRAM FOR REGIONAL OBSERVING AND FORECASTING SERVICES

The mission of the Program for Regional Observing and Forecasting Services (PROFS) is to improve operational weather services by testing and transferring advances in research and technology. PROFS, using the results of ERL basic research, develops operationally feasible forecast techniques that incorporate available observations, computer processing, and human interaction. PROFS integrates capabilities into specific systems, then tests and evaluates those systems in forecasting exercises. The evaluation results, both quantitative and qualitative, are translated into recommendations for the direction of research and operational activities.

PROFS

PROFS works closely with the weather research community, for example, the National Severe Storms Laboratory and the National Center for Atmospheric Research (NCAR), soliciting their ideas on forecasting workstations and consulting them on plans for test exercises. PROFS also works with the three major operational services, the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the United States Air Force (USAF) Air Weather Service, on their present and future forecasting needs.

SYSTEM ANALYSIS AND DESIGN

System Analysis and Design (SA&D) is responsible for the analysis and design of improved weather information systems. It provides the design methodologies to be used by all the PROFS staff, trade-off studies to determine future system elements, and conceptual designs for operational systems.

Accomplishments FY 1983

During FY 1983 SA&D provided the system design for PROFS' advanced processing system, which was used for the Summer Exercise and MERIT (Minimum Energy Routes using Interactive Techniques) product evaluation; it will be the core system for future exercises. SA&D completed the design and implementation of the product generation subsystem and also assumed full responsibility for PROFS operational workstation development. SA&D provided guidelines and standards for software design and system documentation throughout PROFS.

Plans FY 1984

SA&D will provide additional capabilities in product generation for the advanced processing system and the operational workstation. Further, SA&D will perform the system integration for the major projects within PROFS, as well as for internal exercises.

Under SA&D leadership, PROFS will develop the AWDS driver, the major component of the USAF system for dissemination and display. Both the driver and products will be used in two tests: the Development Test and Evaluation, and the initial Operational Test and Evaluation.

EXPLORATORY DEVELOPMENT FACILITY

The Exploratory Development Facility (EDF) is responsible for the design, development, operation, and maintenance of the hardware and software used for weather information systems and for component development, testing, and demonstration.

Accomplishments FY 1983

EDF continued to receive almost uninterrupted real-time meteorological data through existing interfaces to conventional radar, satellite, Mesonet, lightning, local hydrology, upper air, and surface aviation observations. EDF developed and implemented new interfaces to the WPL Profiler, Aviation Digital Forecasts, pilot reports, and AFOS (Automated Field Observing System), the last of which delivers graphic national guidance products and text messages as well as data. The interface to the NCAR Doppler radar was upgraded significantly to increase speed and reliability. Two advanced workstations based on 32-bit computer architecture with touch-screen menu selection were integrated into EDF. System reliability of 95% was achieved during the 1982 Summer Exercise. EDF continued to supply Mesonet, Limon radar, and Profiler data to the NWS Denver Forecast Office, the FAA Longmont Air Route Traffic Control Center, and the Department of Energy's Rocky Flats operations.

Plans FY 1984

- Upgrade the EDF computer network with the VAXcluster high-speed interconnect, allowing better and more efficient use of computer resources.

- Improve user access to the computer facility by implementing Ethernet local-area network.

- Enhance and upgrade our data acquisition capabilities: expand the AFOS tap interface, establish a link to the University of Wisconsin for ingesting VAS (VISSR Atmospheric Sounder) data, and acquire Limited Fine Mesh data through the new National Meteorological Center high-speed distribution circuit.

- Reconfigure the facility to support workstation realizations for projects such as USAF AWDS, NASA MERIT, and FAA Central Weather Processor.

- Continue supporting researchers in ERL, NCAR, and elsewhere by distributing PROFS-archived Mesonet, lightning, and surface observation data.

EXPLORATORY DEVELOPMENT GROUP

The Exploratory Development Group (EDG) selects new technologies and tailors them for use in advanced system testing. Specifically, EDG develops software for a meteorological workstation, which forecasters can use to assess the current state and near-term future of the atmosphere, with emphasis on the local area. The work involves not only the interface between forecasters and data but also the ways in which the data are displayed on the color screen.

Accomplishments FY 1983

The main accomplishments were a complete redesign of the forecaster workstation and a comprehensive test of its operation conducted during the Real-Time '83 Summer Exercise with the cooperation of experienced forecasters from around the country. A touch-screen was added to the workstation. Three types of data, new to the workstation, were also added for the summer test: 10-cm Doppler radar data from the CP-2 radar operated by NCAR, Research Rapid-Scan Data (RRSD) from the GOES-East meteorological satellite, and Profiler data from the Wave Propagation Laboratory providing hourly soundings of temperature, wind, and moisture. All data were available for on-the-spot forecasting as the weather unfolded.

Comprehensive data were collected during the summer experiment, not only for objective verification of probability forecasts, but also for evaluation of the ways in which forecasters used the available information to make decisions.

Plans FY 1984

- EDG will write a detailed report of the 1983 Summer Exercise, concentrating on the subjective evaluation of the workstation by the forecasters who used it. The report will be available early in 1984.

- EDG will conduct a cold-season experiment to learn what the PROFS operational workstation can tell about nonconvective weather. A secondary goal will be to issue and verify aviation and public forecasts for the local area.

- Finally, EDG will participate extensively in a number of outside projects. Funded by the National Weather Service, the Federal Aviation Administration, and the U. S. Air Force, these projects will lead to modernized and more sophisticated weather services for these agencies.

ADVANCED DATA SYSTEMS

Advanced Data Systems (ADS) designs and implements hardware and software subsystems which incorporate advanced atmospheric sensing devices, such as Doppler radar and satellite (VISSR and VAS) sources, into PROFS systems, where diagnostic products derived from these data sources are evaluated.

Accomplishments FY 1983

ADS worked with the NEXRAD Joint System Project Office to interpret, code, test, and document a group of eight algorithms which will be part of NEXRAD's Doppler radar product package. The final report on the work will be issued as a Technical Memorandum.

ADS made two other contributions to Doppler radar use: a provision for receiving Doppler data in real time and the accompanying simple but effective technique to suppress ground clutter. Even though the system can receive only a subset of the total data set (because of communications bandwidth limitations), forecasters found the imagery created from these data to be highly useful for warnings and short-term forecasts.

Satellite data ingest activities were expanded to include real-time ingest, processing, and display of both Research Rapid-Scan Data, with a time interval averaging about 5 minutes, and VAS imagery. Because of difficulties with the orbiting satellites, it was rather late in the '83 Summer Exercise before the data were available at the workstations. However, at least two meteorologically very interesting cases illustrated the value of combined real-time information derived from RRSD satellite data, Doppler radar data, Profiler data, and Mesonet surface data all used in conjunction with other real-time conventional data sources.

Plans FY 1984

ADS will direct its resources into four major activities:

- Upgrade, finish, and document both hardware and software for the satellite ingest system. This effort will largely finish the ADS involvement with this system, which will then be handed over, fully tested and documented, for routine operation by EDF. The documentation will also facilitate duplication of the system by any other agency.

- Participate in the NOVA Program. The NOAA Operational VAS Assessment (NOVA) Program will illustrate the potential usefulness of VAS data in operational forecasts. Also involved in the assessment will be NWS, Colorado State University, and the National Environmental Satellite, Data, and Information Service (NESDIS).

- Continue and expand the work with NEXRAD. Through continuing use of the NCAR CP-2 Doppler radar, the group will contribute to the procurement of NEXRAD radar systems by providing some critical test data sets for acceptance testing of contractors' software. ADS will also provide guidance for new algorithm implementation, data resolution, and parameter sensitivity analysis, and will formally report its findings.

- Expand PROFS' real-time Doppler ingest capabilities. Although real-time processing and display of Doppler data were part of the '83 Summer Exercise, there is ample evidence that the number of altitudes currently available and probably the present spatial resolution are not adequate to resolve important meteorological events. To remedy this shortcoming, ADS will implement a wide bandwidth communication system to link CP-2 with PROFS. This improvement will not only provide valuable information to NEXRAD but, in addition, will allow PROFS to address, in a more systematic manner, future NEXRAD/AWIPS-90 interface questions.

PROFS

TEST AND EVALUATION

Test and Evaluation (T&E) designs and implements nowcasting and forecasting experiments; evaluates forecast results and nowcasting improvements by use of objective, quantitative analysis techniques; and prepares articles and reports for NOAA management and the open literature.

Accomplishments FY 1983

The major accomplishment was the design and implementation of a forecasting experiment, the Summer Exercise, which took place from 1 June to 12 August 1983. A large verification effort was a significant part of the Exercise. Three types of forecasts were prepared daily: severe thunderstorm and tornado warnings as required; bi-hourly probability forecasts of strong winds and low visibilities (2:00, 4:00, and 6:00 p.m.) and precipitation rates (1:00, 3:00, and 5:00 p.m.); and convective outlook forecasts for the day. The staff of forecasters who participated in the experiment was a combination

of highly skilled and experienced operational forecasters and research meteorologists. The preliminary results already provide solid evidence of the value of advanced workstation capabilities in improving local short-term forecasts and severe weather warnings. The forecasters learned to use the system very effectively in a few days of hands-on training, a testimonial to the "user-friendly" workstation design implemented by EDG and SA&D personnel.

A draft manuscript on the 1982 exercise was completed during the summer and is now circulating to reviewers. The report on the '83 Summer Exercise is now complete and in the review process.

A joint analysis of a hail detection algorithm tested in Oklahoma City during the spring of 1983 was completed. This effort, pursued by T&E and Oklahoma City National Weather Service personnel, was a significant example of cooperative studies between operational and research meteorologists with the goal of improving weather services.

Plans FY 1984

- Publication efforts will claim a large portion of T&E resources in FY 1984. Results from the 1982 and 1983 exercises and from the joint analysis of the hail detection algorithm test at Oklahoma City will be the most important issues.

- In addition, T&E will design and implement a test to study the effect of temporal and spatial resolution of Doppler radar data on severe weather warning operations. The results of this study are expected to provide guidance for establishing interface requirements between the NEXRAD and AWIPS-90 systems.

- T&E is also designing a pilot study for summer 1984 to gain preliminary information of the relative effectiveness of nowcasts and very short-range forecasts. This study will probably concentrate on a small group of carefully selected users of weather information in metropolitan Denver. A prime motivation for this pilot study is to gain guidance for a larger nowcast experiment being planned jointly by PROFS and Denver WSFO personnel for FY 1985.

PROJECT COORDINATION AND LIASON

Project Coordination and Liaison (PCL) is responsible for providing coordination and liaison between PROFS and other government agencies, universities, and the private sector. PCL demonstrates and analyzes local weather service requirements of these external groups. It provides an extensive visitor coordination program involving both casual visitors and those participating directly in PROFS' various projects and exercises.

PCL provides the results of PROFS development, demonstration, and evaluation projects to other groups, and facilitates an internal exchange of information about other-agency, university, and private sector programs.

Accomplishments FY 1983

- Economic value analyses of short-range forecasts for urban snow removal operations and energy management were completed. A special report, "Urban Snow and the Potential Value of PROFS," was published.

- Cooperative demonstration programs were continued with the FAA and NASA to evaluate the utility of various mesoscale service products in aviation operations. The FAA program involves the display of observations from Weather Service radars, and Mesonet and Profiler data for operational evaluation at the FAA Denver Air Route Traffic Control Center. The NASA MERIT project involves the development of interactive techniques for improving winds aloft forecasts for aviation flight planning.

Major visitor coordination and liaison activities were conducted as part of the PROFS '83 Summer Exercise. Many of the visitors were Exercise participants who were briefed in depth on the overall exercise, and trained to use the PROFS workstation. They participated as forecast team members and provided detailed critiques of our activities. Some visitors came from local and national news media. Over 200 demonstrations and briefings were provided to 330 visitors.

Consultation was provided to the FAA's Weather Systems Development Program. The group chief prepared a National Aviation Weather Requirements Document and a National Aviation Weather System Plan.

Plans FY 1984

- The visitor coordination program will be expanded. Winter and summer exercises with extensive visitor participation are planned.

- User requirements documentation will be updated.

- The FAA demonstration program will be expanded. The NASA MERIT program will be completed.

- Consultation services to the FAA's Aviation Weather System Program will be continued at least through 1984.

WEATHER MODIFICATION PROGRAM

The Weather Modification Program (WMP) was formed from the Weather Modification Program Office (WMPO). WMP oversees the Federal-State Cooperative Research Program in Weather Modification which began in 1979 when the U.S. Congress appropriated funds for a Federal-State cooperative evaluation of two ongoing programs, a North Dakota summertime program and a Utah wintertime program. Such Federal-State cooperative programs were one of many recommendations to the Secretary of Commerce in 1978 by an independent Weather Modification Advisory Board appointed in response to the passage of Public Law 94-490, which required that the Secretary of Commerce develop a plan at the Federal level whereby weather modification research activities could be coordinated.

The responsibility for the performance of this Federal-State cooperative program was assigned to NOAA. NOAA in turn contracted with Colorado State University in 1979 to develop a design for the conduct of the first two programs approved (i.e., the North Dakota and Utah programs). Various committees provided recommendations for the conduct of field research programs in North Dakota in 1980, 1981, and 1982 and in Utah in 1980-81 and 1982-83. In FY 1983, Nevada was added to the program.

Each state has different interests in weather modification. North Dakota is concerned about the scientific evolution of rain increase and hail modification of the northern Great Plains; Utah's interests are in the scientific assessment of winter snow enhancement efforts in the mountains; and Nevada's research interests are the downwind effects of seeding for winter snow in California. All three programs, which are in different climatic regimes, are of broad regional and national interest and represent sizable State investments. There is little scientific duplication in the three efforts, and there is close cooperation among scientists and administrators of the programs and with the NOAA Program Manager.

Accomplishments FY 1983

COOPERATIVE RESEARCH–NORTH DAKOTA

Data from the FY-1981 and FY-1982 field programs were analyzed. The main benefit was the ability to define testable hypotheses using radar observations, cloud models, statistical analyses of rainfall, and physical cloud measurements. Strong correlations (>0.60) were noted between maximum radar echo heights and radar-estimated rainfall, indicating (1) that the taller a storm is the more rainfall it will produce, and (2) that the increase in bulk of a storm provides an increase in rainfall. These correlations tend to support a dynamic-seeding hypothesis. Analysis is continuing, to determine which hypothesis (i.e., static or dynamic) is appropriate for North Dakota.

COOPERATIVE RESEARCH–UTAH

A field program directed at defining the supercooled liquid water in Utah storms and the trajectories of cloud hydrometeors and potential seeding material trajectories was conducted during January and early February 1983. The program was terminated early because of excessive precipitation over all of Utah.

Analyses of the limited data sets revealed (1) the existence of supercooled liquid water (approaching 1 g m^{-3} in one case), primarily in the lower portions of the cloud system, and (2) the presence of silver in concentrations above the natural background in snow samples collected in the target area. Synoptic weather types and echo patterning were also documented.

COOPERATIVE RESEARCH–NEVADA

This program studies the microphysical and dynamical aspects of the problem of "area of effect" in a region of the Central Sierra Nevada when operational and semi-operational seeding programs are being conducted and where there is a potential for downwind effects of these programs to become manifest.

Approximately 900 snow samples were collected downwind of seeding operations in the Central Sierra Nevada during the winter and spring of 1983. These samples are being analyzed. In addition, several atmospheric dispersion models were investigated as possible estimators of the amount of silver iodide to be expected downwind of the seeding source.

Plans FY 1984

COOPERATIVE RESEARCH–NORTH DAKOTA

Analyses to determine whether the dynamic-seeding hypothesis is appropriate for North Dakota will continue. Emphasis will be placed on the quantity and persistence of supercooled water, the amount of natural ice and its relationship to cloud water, the potential increase in cloud growth and duration from seeding, and the number and dispersion of active artificial ice nuclei within the cloud. Models will be used to assess potential seeding effects and the model results will be compared with observations. Analysis of covariance modeling will also be continued in an attempt to assess the impact and effectiveness of North Dakota's operational weather modification project. Rates of nucleation of the seeding agents used in North Dakota will be tested in the cloud chamber at Colorado State University. A field program to fill in gaps in past data collection programs is planned for the summer of 1984.

COOPERATIVE RESEARCH–UTAH

WMP

The analyses in progress in FY 1983 will continue in FY 1984, and an intensive field program of limited size will be conducted during the winter and spring of 1984. Attention will be focused on the distributions of water and ice in clouds over the Tushar Mountains and on the concentrations of silver and indium in snow falling in the target area; emphases will depend on the results of the completed analyses.

COOPERATIVE RESEARCH–NEVADA

Work on these tasks will continue in conjunction with a field program during the winter and spring of 1984: (1) studies of the spatial and temporal dispersion of seeding aerosols, (2) studies of the temperature range over which the water has frozen to form the ice crystals and snowflakes reaching the surface in the project area, (3) measurements of rime ice accretion as an indicator of the amount of supercooled liquid water in the clouds, (4) development of new exotic chemical and isotope techniques for seeding assessment,

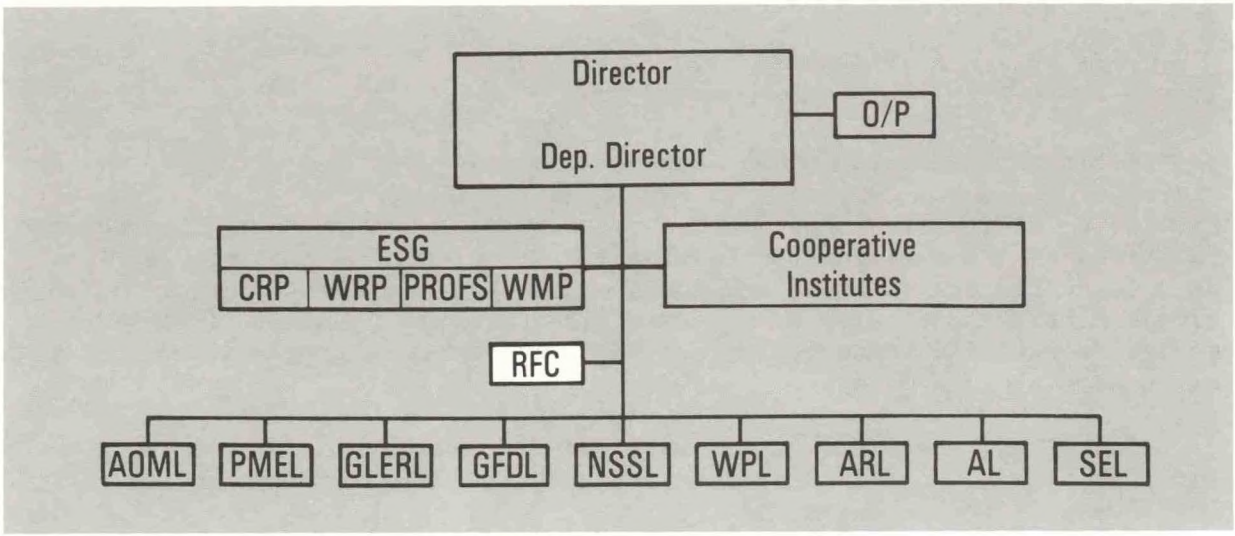
(5) determination of the precipitation, supercooled liquid water, and ice across the Sierra Nevada crest, using a surface network that includes radars and a microwave radiometer, (6) determination of the chemical makeup of the snow falling downwind of the Sierra Nevada crest.

COOPERATIVE RESEARCH–ILLINOIS

The FY-1984 budget includes the addition of Illinois to the Federal-State Cooperative Research Program. Illinois has been involved in weather modification research as a part of its Precipitation Augmentation for Crops Experiment (PACE) which has as its goal determining whether midwestern summer rainfall can be modified for the benefit of grain production. The Federal-State Cooperative Research Program would contribute significantly to the PACE effort. The addition of Illinois to that program depends on congressional action. A decision is expected early in FY 1984.

RESEARCH FACILITIES CENTER
Miami, Florida

C. B. Emmanuel
Director



The Research Facilities Center (RFC) maintains, instruments, and operates aircraft to support a variety of environmental and severe-weather research and reconnaissance programs of NOAA and other government agencies. RFC's mission is carried out through four groups:

- The Flight Operations Group maintains and operates the aircraft and oversees all matters relating to flight safety.
- The Scientific Instrumentation Group provides, installs, and operates the aircraft research instrumentation.
- The Research Systems Group provides liaison with users; calibrates all sensors; writes, maintains, and upgrades software for the aircraft data systems, and processes collected data to meet user requirements.
- The Helicopter Operations Group maintains and operates four UH-1 helicopters in support of NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) in Alaska.

During FY 1983, RFC operated two WP-3D (P-3), four-engine turboprop aircraft and four UH-1 helicopters. The P-3 aircraft carry a multitude of sophisticated research systems capable of measuring a wide range of atmospheric and oceanographic parameters.

The Administrator of NOAA has deemed it proper to create the Office of Aircraft Operations (OAO), thereby consolidating all of NOAA's aircraft activities. Effective 1 October 1983 (FY 1984), RFC was abolished and its current activities and personnel were placed within the Office of the Administrator.

Accomplishments FY 1983

FLIGHT OPERATIONS GROUP

Hours flown in FY 1983 totaled 678.1.

El Niño: 95.9 hours

One P-3 aircraft was utilized to monitor oceanographic and atmospheric conditions in the eastern tropical Pacific during the current El Niño in support of the Equatorial Pacific Ocean Climate Studies (EPOCS) program. Concurrent with this activity, the aircraft acquired data for the description of the near-equatorial convergence zone (NECZ), and the budgets of atmospheric momentum, heat, and moisture.

Altogether, seven tracklines were flown from Acapulco (Mexico) and Panama at the northern ends of the patterns and from Guayaquil (Ecuador) and Lima (Peru) at the southern end.

Arctic Gas and Aerosol Sampling Program (AGASP): 143.6 hours

Observations of the nature, distribution and radiative properties of Arctic aerosols were made in the period 11 March to 10 April 1983 by one of the P-3 research aircraft. The flight program was conducted from Anchorage, Thule (Greenland), and Bodo (Norway).

Extensive instrument installations permitted gas and aerosol sampling and measurement. During the last portion of the program, turbulent flux measurements were made using the ERL gust probe system. In concert with the turbulence measurements, the flux of CO_2 above the ocean was determined by a newly developed optical CO_2-measuring instrument.

These measurements will (1) document the extent of the Arctic haze and relate the results to those in the Arctic Air-Sampling Network, and (2) document globally significant sources and sinks of atmospheric CO_2. These data will serve as inputs to global climate models that suggest the Arctic is particularly sensitive to atmospheric perturbations capable of producing climatic warnings.

Cook Inlet Wind Study/Bering-83: 103.1 hours

The objective of this study, using one P-3 aircraft, was to determine the mesoscale wind field and planetary boundary layer in the lower Cook Inlet; interpret the dynamics and kinematics of the regional flow field in terms of the interaction between the orography and the large-scale weather pattern; and map the change in heat, momentum and moisture flux, low-level winds, and planetary boundary layer across the marginal ice zone. All flights in support of this program were carried out from Anchorage.

Study of East Offshore Cyclogenesis: 39.7 hours

This was a joint NOAA-NASA effort, and research aircraft of both agencies participated during a 10-day period in January 1983. The aircraft operated out of Wallops Island, Va. The objectives of this research effort were as follows:

- Measure the surface fluxes in two-dimensional roll and three-dimensional cellular convection offshore during a cold outbreak and determine the vertical distribution within the planetary boundary layer.
- Validate models that estimate the fluxes of sensible and latent heat from the ocean to the atmosphere during cold outbreaks.
- Perform a pilot study of the heat balance, including radioactive components, at the ocean surface.
- Determine sea state behavior in fetch-limited situations, and changes of drag coefficient with changing sea state.

Calibration and Critical Test of the NOAA-LLNL Gust Probe CO_2 Flux Sensor: 27.7 hours

The NOAA/ERL gust probe system usually carried by the P-3 aircraft was mated to the highly sensitive CO_2 system developed by the Lawrence Livermore National Laboratory (LLNL). This configuration was test flown to measure CO_2 fluxes in the marine boundary layer.

The December 1982 test flight required the aircraft to make multiple traverses over the Woods Hole Oceanographic Institution research vessel Knorr in the vicinity of Barbados. The test was also a prerequisite to the Arctic Gas and Aerosol Study Program. Highly detailed measurements were made, and the objectives of the study were fully realized.

The Hurricane Research Program: 24.6 hours **RFC**

The specific projects in the hurricane field program are as follows:

- Vortex Dynamics and Track Experiment
- Convective Dynamics Experiment
- Hurricane Air-Sea Interaction Studies

These sub-programs represent an ongoing effort of ERL to understand the physical processes of the hurricane environment.

The Vortex Dynamics and Track Experiment requires continuous high-density observations of a rapidly intensifying storm for 24 to 36 h. These observations are required for the evaluation of conceptual models of spiral-mode asymmetrics and eye dynamics and the utility of these measurements for track prediction.

The Convective Dynamics Experiment attempts to determine what controls the rate of eyewall contraction, whether momentum transports are important, and if the dynamics of the convective bands differ in weaker storms. In addition, the experiment attempts to document the microphysics of the stratiform precipitation regions from the melting layer and above. This appears to be important in the dynamics of tropical convective systems.

The Hurricane Air-Sea Interaction Studies attempt to define the structure of the marine boundary layer and the role it plays in the hurricane dynamics, and the response of the ocean to wind forcing in terms of wind-wave and surge. The description of the marine boundary layer requires spatial and temporal measurements of the fluxes of heat, momentum, and moisture as well as the mesoscale variability of mean quantities of temperature, wind speed and direction, and humidity. The wave and surge studies are directed toward developing improved wave prediction and storm surge models and understanding the complex role of waves in the transfer of momentum from the atmosphere to the ocean.

Tomography Experiment: 16.9 hours

This experiment was an extension of the U.S. Navy 1981 airborne expendable bathythermograph (AXBT) program. The experiment was designed to allow an independent estimate of the geostrophic flow field in an area of the Atlantic Ocean, based on ocean temperature profiles as obtained from NOAA P-3 measurements. Extensive use of the AXBT drop capability of the aircraft was made in profiling the temperature structure of the ocean from the surface to a maximum depth of 800 m.

Aircraft Doppler Radar Development: 32.4 hours

RFC completed the initial phase of the tail X-band radar modifications to operate in the Doppler mode. Several flights were conducted in Oklahoma to ascertain Doppler signatures for comparison with signatures from the NSSL ground-based Doppler radar system. The results were most encouraging, and RFC plans to use the radar in the Doppler mode during the FY 1983 hurricane season in support of the Hurricane Research program.

Hurricane Reconnaissance: 119.5 hours

Training, Calibration, Maintenance, and Sensor Development: 74.8-hours

SCIENTIFIC INSTRUMENTATION GROUP

ASDL5

A fifth-generation Aircraft to Satellite Data Link (ASDL5) was designed and fabricated for both P-3 planes. In addition to automatically transmitting the 1-min flight level summaries to the user via the GOES satellite, the

new system automatically generates formatted reconnaissance messages required by the Chief, Aerial Reconnaissance Coordination, All Hurricanes (CARCAH) during hurricane reconnaissance operations. Prior to ASDL, these transmissions were made by voice on the aircraft's HF SSB radios. The voice link was often noisy and unreliable, and frequently nonexistent. The voice transmissions also interfered with many of the on-board sensors, thereby contaminating the data.

The most innovative feature of ASDL5 is the capability of transmitting a frame of digitized radar data to the National Hurricane Center (NHC) in near-real time. Once the data are received (a few minutes after transmission), a radar picture can be reconstructed to give ground-based meteorologists a first-hand view of the storm's structure. The hardware portion of the system has been completed and tested. The remaining effort centers on software development for NHC's display computer.

Pilot Radars

Nose radar systems were procured and installed on each aircraft primarily for weather detection and navigation. The systems are commercially developed C-band designs and include a forward-scanning antenna, a dual receiver/transmitter package, three color displays, and appropriate control electronics. In addition to displaying weather targets (reflectivity), the systems are also capable of groundmapping and Doppler turbulence detection.

Meteorological Radars

The aircraft meteorological radar systems underwent considerable refurbishment. The nose receiver/transmitters, made available from the above installation, were modified for use as spares for the lower fuselage units. The antenna pedestals and servos were reworked to afford greater reliability and improved performance. The prototype tail Doppler system proved to be of significant benefit to the research community, and plans are under way to develop two operational systems for permanent installation by 1985. Plans also include replacement and upgrade of the entire radar data system at the same time. **RFC**

Aircraft Navigation Computers

The primary aircraft navigation computers, which process real-world Omega signals for inertial reference and update, are being upgraded with expanded memory and improved operational software. The changes are a result of a reconfiguration of the Omega navigational network and recent improvements in the global propagation model. Other changes to the system are adding telemetry output parameters for input to the scientific data collection system. All aircraft systems and spares will be completely upgraded by the end of FY 1984.

Developmental Aircraft Data System

Owing to the obsolescence of the existing scientific aircraft data system and resulting lack of manufacturer support, a replacement data collection and recording system is being developed. The new system will consist of the latest technology microcomputer hardware, which will afford the user improved real-time data collection, processing, and interactive graphics capabilities with significant increases in system capacity, speed, reliability, and overall performance. The target date for completion of the new system is 1985, when both aircraft are scheduled for depot level maintenance.

AGASP Aerosol System

A massive instrumentation effort was mounted to support AGASP. A major redesign of the aircraft's aerosol sampling system was necessary in order to accommodate the high flow rates required by the large amount of air chemistry and aerosol instrumentation attached to the system. Additionally, an array of gas-sampling inlets was installed in place of one of the aircraft windows. Its supporting pumps, controllers, and instrumentation were located in available spaces throughout the aircraft. An added capability was also incorporated in the wing-mounted particle measuring system. A new Active Scattering Aerosol Spectrometer Probe (ASASP), with smaller particle size range, was procured and integrated into the data collection system.

Two major external installations were also accomplished in support of the project. The first was the design, fabrication, and installation of a wing-mounted pod used to house a nephelometer provided by Georgia Tech. The second installation was that of a multiple channel zenith- and nadir-looking IR radiometer, which was housed in the aircraft's right wingtip. The unit was fabricated by NASA and subsequently installed and flight tested by RFC.

RESEARCH SYSTEMS GROUP

The Research Systems Group (RSG) prepared an unusually large amount of documentation. For the first time, RFC systems and software information is published and readily accessible by users.

RSG participated in development and installation of the ASDL5, providing automatic routines to minimize errors during hurricane reconnaissance and to increase overall reliability of the system.

Data quality control work included a detailed study of IR radiometer calibration accuracy. Work on the pressure transducers led to the installation of new Rosemount units as backups for the Garretts.

Ground-based data system upgrades included installation of new nine-track drives and enhanced graphics capabilities to speed data reduction, and power conditioning to reduce system downtime.

HELICOPTER OPERATIONS GROUP

During FY 1983, the RFC Helicopter Operations Group flew 1,457 hours in support of OCSEAP and other projects. These projects lasted from 1 to 73 days. Flight operations included remote area transport, aerial surveys, pinnacle landings, shipboard operations, slingloading, aerial photography, and wildlife capturing. The major projects supported with helicopter operations are summarized below.

Peard Bay: 198 hours

This project is a multiseasonal, multidisciplinary research effort in a lagoon 40 nmi southwest of Barrow, Alaska. Subjects of interest include birds, marine mammals, fish, ocean chemistry and currents, bottom geology, and ice formation. Helicopters were used to set up and support three camps for aerial surveying and photography.

Beluga Whales: 110 hours

The distribution, behavior, and biology of beluga whales in Bristol Bay were studied from a camp near Dillingham, Alaska. The helicopter was used in camp setup and support, aerial surveying, and capturing specimens for radio tagging. Captures were attempted using a combination of nets, inflatable boats, the helicopter, and the tides.

Ring Seals: 147 hours

The distribution, habitats, behavior, and dens of ring seals were studied in Norton Sound, the Chukchi Sea, and the Beaufort Sea. In addition to other work on this project, the helicopter was used to transport two dogs and a snowmobile out onto the pack ice. The specially trained dogs were then deployed in selected areas to locate seal dens, which they were able to do with great success.

Seismic Network: 27 hours

The Shumagin Islands/Alaska peninsula seismic activity detection network was serviced with new batteries and electronic equipment. The base for this network is at Sand Point, Alaska.

Porpoise Behavior: 118 hours

The size of the North Pacific porpoise population, and reactions of porpoise schools in contact with fishing and survey vessels were studied by the National Marine Fisheries Service (NMFS) Southwest Center with the aid of an RFC helicopter operating from the NOAA Ship Surveyor. Observations were also made with the Surveyor in conjunction with the NOAA Ship David Starr Jordan.

Polar Bears: 236 hours

The size, range, and habits of the Alaska polar bear population were studied by tranquilizing bears between Cape Lisburne and Barter Island. The drugged bears were examined, and fitted with radio collars for tracking by aircraft.

Hydrography: 18 hours

The NOAA Ship Whiting was supported in a hydrographic survey of the water south of Long Island in the Bahamas. The helicopter was used to set up and support navigation stations and associated camps on remote islands, and for direct ship support.

Columbia River Fisheries: 75 hours

The Northwest Center of the NMFS used the helicopter to monitor the fishing activity on the Columbia River during salmon runs. The area survey included approximately 200 nmi of river, starting from the mouth.

Shoreline Ice Damage: 45 hours

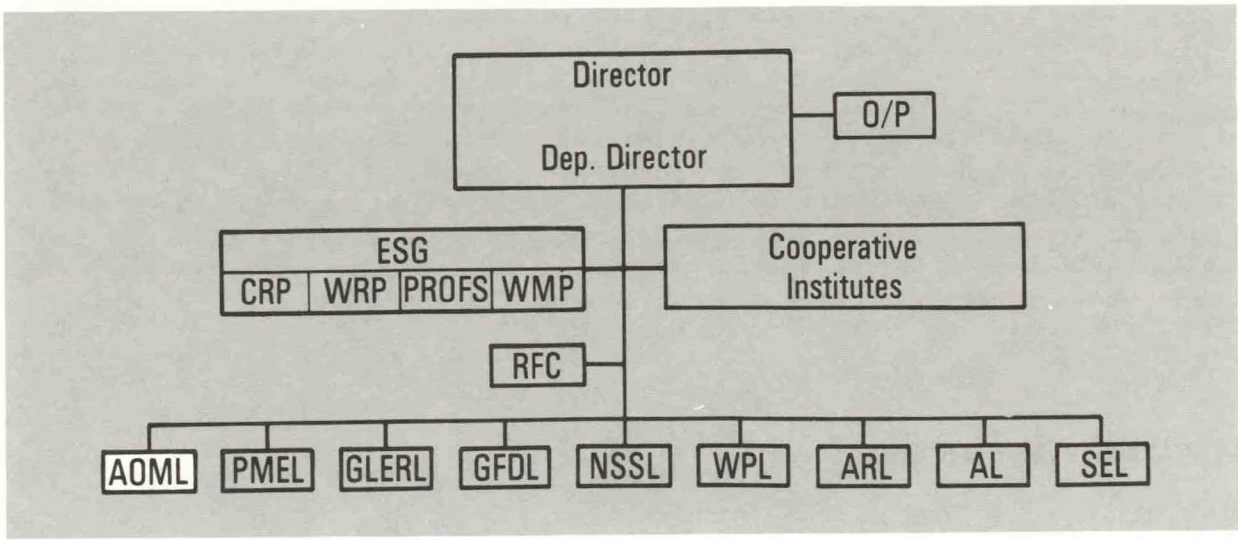
Under-ice nets were set between Point Barrow and Cape Lisburne in the late winter and early spring in an effort to expand very sparse knowledge of the fish stock in the Chukchi. In spite of the difficulties with very thick ice (7 ft) in the bay areas, the project was successful.

Navarin Basin: 34 hours

Marine mammal and bird surveys were conducted by a helicopter operated from the NOAA Ship Surveyor during October and November of FY 1983 in the Navarin Basin area of the Bering Sea.

ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY
Miami, Florida

Hugo F. Bezdek
Director



The Atlantic Oceanographic and Meteorological Laboratory (AOML) is organized to pursue basic and applied research programs in oceanography and tropical meteorology. Oceanographic investigations center on fluxes of energy, momentum, and materials through the air-sea interface; the transport and composition (thermal and chemical) of water in the ocean volume; and hydrothermal processes of mineralization at seafloor spreading centers. Meteorological research is carried out to improve the description, understanding, and prediction of hurricanes and to determine their potential for beneficial modification. 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

AOML's current research program concerns processes relating to climate, marine assessment (including air quality/acid rain considerations), marine observation and prediction, marine resources, and weather observation and prediction. CIMAS scientists currently conduct research in climate and tropical meteorology.

CLIMATE RESEARCH

Climate research at AOML is increasingly focused on investigations of the role of the oceans in determining large-scale climate and climate variability. The emphasis is on observational projects, based primarily on the NOAA research vessels, but making extensive use of data from satellites, buoys, and other instrument systems. Because of the large scale of many of the phenomena and the diversity of the observations required, much of the

work must be done through cooperative arrangements with investigators in other NOAA laboratories (primarily PMEL and GFDL) and university laboratories, and with overseas investigators, particularly in western Europe and South America. During FY 1983, and continuing for FY 1984, AOML's climate research program focused primarily on the oceanographic aspects of two major research investigations: (1) EPOCS, the Equatorial Pacific Ocean Climate Studies, initiated in 1979 as a multi-year investigation of the genesis, evolution, and large-scale atmospheric consequence of interannual sea surface temperature anomalies in the tropical Pacific Ocean, concentrated its research efforts on documenting the 1982-1983 El Niño, and (2) STACS, the Subtropical Atlantic Climate Studies, initiated in 1981 with the long-term objective of understanding the role that ocean circulation in the North Atlantic Subtropical Gyre plays in the heat balance of the Earth, focused efforts on developing an economical methodology for monitoring the Florida Current (Gulf Stream) over extended periods.

Accomplishments FY 1983

EPOCS

The expectation in late FY 1982, that FY 1983 might bring exciting developments in the equatorial Pacific Ocean, was more than fully realized. By midwinter it was clear that we were in the midst of one of the greatest El Niño events of record, an "event of the century." Furthermore, because of pre-existing plans for observations in the eastern equatorial Pacific, and our ability to enhance these plans rapidly, the El Niño-Southern Oscillation event of 1982-1983 will be the best sampled such event in history. Vessel operations planned from the NOAA Ship Researcher were expanded, observations from vessels operated by other agencies and other countries were added or enhanced, and special El Niño missions were flown by aircraft of the NOAA Research Facilities Center in order to fill gaps that appeared in the planned vessel operations. A fleet of about 20 drifting buoys was maintained in the near-equatorial waters for real-time observations of sea surface temperatures and current. Arrangements were made to disseminate the buoy data through the Global Telecommunications System for synoptic use in the major meteorological centers. Close liaison was maintained with the National Weather Service Climate Analysis Center (NWS/CAC) and with scientists in South America throughout the event. At the end of FY 1983, the event seems to be coming to an end, but sampling activities will continue to document the return to normal.

STACS

During FY 1983, AOML conducted an intensive program of data collection activities aimed at developing an economical and efficient sampling strategy for monitoring the heat transport of the Florida Current. STACS investigators obtained a continuous, 1-year time series of (1) voltage/potential differences, (2) tidal height differences, and (3) subsurface pressure differences across the Straits of Florida. In addition, five current meter moorings provided a continuous record of currents at various depths.

During July 1983, an intercalibration experiment was conducted involving electromagnetic cable measurements, current meter measurements, coastal tide gage data, free-falling current probe (Pegasus) data, CODAR (coastal ocean dynamics applications radar) data, and acoustic measurements. Good correlations were found to exist between directly observed transports and transports derived from tidal and cable observations.

Coastal tide gages at Haulover, Fla., and Cat Cay, Bahamas, operated by NOS, provided data from April 1982 through March 1983; bottom pressure gage data from near Jupiter, Fla., for April 1982 through January 1983 and from Memory Rock, Bahamas, for June 1982 through April 1983 were processed and transcribed to computer format. All data sets were low-pass filtered. High correlations with the Pegasus transport data ($r = 0.87$ and 0.96) suggest that sea-level monitoring is a strong candidate for long-term climate research.

To supplement the time-series data, AOML conducted nine Pegasus cruises between November 1982 and August 1983 to collect additional data on current profiles. A data analysis package was developed to permit shipboard reduction of Pegasus data using the HP-85 computer. A model was also developed to remove the barotropic tidal signal from Pegasus observations.

Significant progress was made in determining the optimal configuration of an acoustic tomography system for remotely sensing the transport of the Florida Current. A new technique for studying acoustic propagation in a random ocean was developed. Two important computer programs for describing pulsed acoustic propagation in the ocean, the Pulsed Parabolic Equation Model and the Penn State Pulsed Normal Mode Program, were implemented at AOML.

Linear estimation theory was applied to STACS data in order to determine the best mix of technologies for monitoring the Florida Current. An empirical orthogonal function (EOF) analysis of STACS data identified five primary modes of variability in the Florida Current.

FGGE

Data collected from the equatorial Atlantic Ocean during the 1979 FGGE (First GARP Global Experiment) were used to generate mean monthly maps, on a 2° x 2° grid, of sea-surface temperature, cloud cover, wind speed and direction, specific humidity, air temperature, sea-level pressure, latent and sensible heat fluxes, net surface shortwave and longwave radiation balances, and net oceanic heat gain. Also generated were monthly time series, on a 6° latitude by 10° longitude grid, of mixed-layer depth, heat storage in the mixed layer, and surface currents. **AOML**

Plans FY 1984

EPOCS

AOML's main emphasis will be on documentation and analyses of the 1982-1983 El Niño event. AOML will conduct a national workshop on this event in November 1983 and publish a report in early 1984. Our investigations will

lead to publications on the following topics: the physical oceanography of the 1982-1983 event in the eastern Pacific; a quantitative description of the physical changes that occurred, in terms of EOF's or dynamical modes; use of Ametek/Straza data to describe how the equatorial undercurrent passed through the Galápagos islands during October/November 1982; evaluation of shipboard navigation systems for use with the Ametek-Straza system to determine absolute currents in the eastern Pacific.

A cruise will be undertaken on the Researcher to study upwelling processes along the Equator during June/July 1984. Research will be conducted to explore the use of acoustic tomography to monitor deep ocean thermal structures.

Drifting buoy data will be analyzed to determine the surface current patterns of the 1982-1983 El Niño. Further analyses will be conducted to determine the dynamics of 30-day waves that occurred during the same period, and to consider methods of compensation for drogue loss.

Arrangements have been made to collect current measurements across the Equator at 85°W using the Ecuadorian research vessel Orion and existing Pegasus transponders. These measurements will be made on a quarterly basis throughout 1984. Regional vessels will also be used to deploy additional drifting buoys and to maintain a regular sampling program with expendable bathythermographs.

STACS

During FY 1984, the 2-year intensive observing period in the Straits of Florida will be completed. Strategies will be developed for long-term monitoring of the Florida Current and extending STACS to studies of mid-basin heat flux components. The time and space scales of important variability in the Florida Current will be characterized and related to possible forcing functions.

The coastal tide gages at Haulover, Fla., and Cat Cay, Bahamas, will continue to be operated by the National Ocean Service (NOS), with partial support from STACS. Two bottom pressure gages will be maintained in the vicinity of the Florida Current's east and west boundaries, and a third coastal tide gage and meteorological station will be installed by April 1984, all near the latitude of Jupiter, Fla. Project oceanographers will participate in approximately five STACS Pegasus cruises to measure transport and two cruises to service bottom pressure gages. Data analysis will emphasize improving the correlation between coastal tide gage values and transport values by examining the role of local meteorology on the sea levels; bottom pressure gage data analysis will be directed toward correlation with Pegasus transport data and further understanding of Florida Current dynamics.

FGGE

The FGGE data from the tropical Atlantic Ocean will be analyzed and compiled to generate an atlas of climatic and heat budget variables, and a manuscript on the heat budget of the equatorial Atlantic Ocean will be prepared.

FGGE data from the western Indian Ocean will be collected and analyzed to generate monthly maps of surface oceanic and meteorological variables and heat budget terms. The mixed-layer depths and surface current fields will also be developed in order to determine the mixed-layer heat budget terms.

MARINE ASSESSMENT

A major goal of the AOML research program in marine assessment is to develop an understanding of ocean processes, their variations, and the effect of these variations on ocean resources, especially living marine resources. Present research projects include (1) Transformation and Assimilation of Pollutants by Natural Processes (TAP), (2) Pollutant-Particle Relationships in the Marine Environment (P-PRIME), and (3) the program on Natural Marine Sources of Acid Rain Precursors, in which natural processes are studied to develop information essential to addressing specific environmental problems. In addition, AOML conducts a vigorous program in acoustical research aimed at a variety of marine assessment applications.

Accomplishments FY 1983

Marine assessment programs accomplished the following:

TAP

- Synthesized marine humus from several natural marine oils, and showed that marine humus does not protect plankton from radionuclide uptake; determined the molecular weight of marine humus as between 600 and 900; devised a technique using nuclear magnetic resonance (NMR) and equivalent weight data to predict the complexing capacity of fulvic and humic acids; showed that synthetic as well as natural fulvic acids can protect the photosynthetic capacity of plankton against Cu toxicity; discovered that the formation of marine humus from unsaturated lipids involves a very large carbon isotope fractionation, in fact, the largest ever observed.

- Documented biological aspects of El Niño; documented zone of enriched plankton productivity at the Mississippi outflow and correlated it with larval fish abundance; defined methodology of delineating diel variability in phytoplankton physiology; completed development of a biochemical analysis permitting investigation of in situ growth rates in zooplankton.

- Developed and presented, at the 1983 Gordon Conference in Chemical Oceanography, a theory of metal/organic interactions in seawater as a function of ligand structure based on spectroscopic and experimental data obtained over the past three years; completed upwelling region cruise and found some evidence for very strong and/or unique complexation in such waters even though high productivity was not encountered.

P-PRIME

- Completed cruise to the Mississippi River/Delta area for program-related field work.

- Documented the first clear recognition of the extensive role of biopackaging of lithogenic/biogenic material at mid-shelf, and essentially pure biogenic material at outer-shelf and shelf-edge stations.

ACID RAIN

- Identified dimethylsulfone in rain; found a major source of formic acid in atmosphere and rain in a homologous series of 1-alkenes; discovered that poisoning samples with mercury destroys 1-alkenes.

- Completed cruise to a high-productivity region. Even though bloom conditions of a phytoplankton species thought to produce dimethyl sulfide (DMS) were encountered, levels of DMS found in the water were similar to levels found in regions of low productivity; during the cruise to the Peru upwelling region we were able to document, as they were occurring, rapid changes in the hydrographic and chemical structure of the water, suggesting a relaxation of El Niño off the Peru coast.

ACOUSTICAL RESEARCH

- In the Sulu Sea Internal Wave Experiment, studied 17 soliton wave packets having wave amplitudes from 10 m to 90 m. A detailed study of the generation mechanism of the waves was completed; the tides form a hydraulic jump which upon reversal of the tides propagates northward into the sea as a single shallow-water internal wave.

- Completed a theoretical interpretation of acoustical calibration study results. A study of backscattered acoustical intensity versus concentration for three different narrow sand grain distributions was also conducted; essentially, a linear relationship was determined between backscattered acoustical intensity and concentration.

Plans FY 1984

Marine assessment plans include the following:

TAP

- Test toxic-metal/organic-matter/plankton interaction model in cold productive waters; determine if raw fish oil, allowed to autoxidize at sea, could ameliorate the toxic effects of disposed chemical wastes.

- Investigate the mechanism supporting enhanced productivity at the Mississippi plume and its relation to sedimentation rate of suspended

particles, during the Oregon II cruise scheduled for November-December 1983; measure phytoplankton productivities and abundance, and zooplankton distribution in support of the Researcher cruise scheduled for January-February 1984 by AOML's Ocean Chemistry Division in cooperation with the Southeast Fisheries Center (SEFC); continue sample analysis and data workup from previous cruises.

- Investigate trace-metal/organic-matter interactions in temperate waters in winter to test hypotheses developed regarding kinetics of formation of organic ligands important in trace-metal speciation in seawater; study metal/organic-matter interactions in anthropogenically impacted waters, specifically the New York Bight region.

P-PRIME

- Intensify efforts on P-PRIME cruise IV: (1) investigate the role of biopackaging of lithogenic particles and apparently related river plume disappearance (to be performed in conjunction with SEFC); (2) initiate simultaneous current meter/transmissometer observations to improve understanding of co-variability of currents and suspended particulate matter.

ACID RAIN

- Conduct a joint ship and aircraft field program in the equatorial Pacific Ocean to study tropospheric chemistry, particularly as it relates to volatile sulfur species in the atmosphere.

- Determine concentrations and fluxes of natural acid rain precursors in the equatorial Pacific Ocean.

- Develop methods for trace organic sampling from aircraft.

- Complete sample analysis and data workup from Peru cruise.

ACOUSTICAL RESEARCH

AOML

- Continue development of a model for oceanic pollution transport mechanisms. Emphasis will be placed on evaluating the ability of a stratified water column to effectively convert three-dimensional turbulent dispersion processes into two-dimensional, thin-layer turbulent dispersion processes along constant density surfaces.

MARINE OBSERVATION AND PREDICTION

AOML research in marine observation and prediction is concentrated on surface effects at the air-sea interface. These effects, especially under extreme conditions, are important to short-term forecasting of coastal and marine weather and wave conditions (sea-state heights and storm surge). Additional research is aimed at improving the observational equipment and

techniques that are used to collect data on the marine environment; particular emphasis is on ocean acoustical and airborne radar techniques.

Accomplishments FY 1983

During FY 1983, AOML participated in the Bering Sea Marginal Ice Zone Experiment (MIZEX) in collaboration with PMEL. Radar imagery of the marginal ice zone (MIZ) and interior ice pack was obtained simultaneous to ice profile measurements with a laser altimeter and vertical photography. These data will provide unique insight about the ice-banding processes within the MIZ that lead to advance and retreat of the MIZ and penetration of the MIZ by ocean waves. The high-resolution, side-looking airborne radar (SLAR) imagery obtained during these flights is the first ever collected from grazing angles and will be an important test of radar backscatter theory.

Construction of computer programs to compute the ocean surface wave fields everywhere on the globe was initiated. The programs are based on mathematical groundwork laid in FY 1982. Preliminary testing of data handling and wave growth packages was completed.

The first storm surge atlas was completed in March 1983. This prototype was developed from the storm surge computer simulations in the Charlotte Harbor, Fla., basin. The atlas will be used by hurricane forecasters to determine what high-water values to use in forecasts and will supply information for regional planners. One SLOSH (sea-lake overland surges from hurricanes) model, Biscayne Bay, was developed, tested, and put in an operational status in 1983. SLOSH computer simulations were also completed for Charleston Harbor, S.C., Sabine Lake, Tex., and Lake Pontchartrain, La.

A manuscript was prepared documenting a new interpretation of the mechanism by which sea state appearance is related to wind speed. This interpretation was based on qualitative aspects of the sea state catalog together with existing quantitative measurements. Hydrodynamic forces proportional to wave energy dissipation are hypothesized to be responsible for an approximately cubic dependence of white-water coverage on wind speed for speeds lower than 14 m s^{-1}. Aerodynamic forces proportional to surface wind stress are hypothesized to be responsible for an approximately square law dependence of white water coverage on wind speed for speeds greater than 14 m s^{-1}. New regression relations were formulated to guide subjective estimates of surface wind speed from sea state appearance. These relations should also provide guidance for algorithms relating surface wind speed to microwave radiometer and scatterometer measurements.

More than 200 slides were prepared, to illustrate sea state for surface winds up to 50 m s^{-1}. These are to be used as training material in workshops for aircrews responsible for sea state wind estimates.

AOML successfully demonstrated the transverse Doppler current-profiling technique in the Bear Cut channel at Miami, Fla., by measuring currents of 100 cm s^{-1} with 37-cm range resolution (in the horizontal), using a side-looking configuration to a range of 20 m in water 3 m deep. This is several times the maximum range and maximum velocity of other coherent Doppler

systems, and several times the resolution in both range and velocity of single-pulse systems. Properly scaled, transverse Dopplers should permit measurement of currents within shipping channels using transducers mounted at the edge of the channel. Transverse Doppler profilers should also be useful in estuarine flow research in the upward-looking mode.

Plans FY 1984

During FY 1984, AOML will participate in hurricane research flights and in a polar cyclone flight experiment. Both experiments have the objective of experimentally observing the height and direction of ocean waves generated by relatively small but fast-moving (about 30 knots) cyclones whose principal characteristic is a strongly curving wind field. Such storms represent a dilemma since they are relatively rare and it is not known if the generated wave field is significantly higher or lower than storms moving at slower velocities. If they do generate higher waves, they represent a significantly greater threat than ordinary storms.

Storm surge atlases will be completed for Corpus Christi, Tex.; Tampa Bay, Fla.; and Sabine Lake, Tex. Atlas work will begin for Charleston Harbor, S.C.; Lake Pontchartrain, La.; and Laguna Madre, Tex. Hypothetical storm surge simulations will be made for Laguna Madre, Tex.; Mobile Bay, Ala.; Pensacola, Fla.; and another basin not yet determined.

Photographs in the recently published sea state catalog will be digitized with the use of equipment at the Jet Propulsion Laboratory. This process will enable us to estimate percentages of white water coverage from flight-level wind speed measurements and to verify the two different power law relations hypothesized to exist for low winds and high winds, respectively. These wind speed measurements will complement measurements of microwave brightness temperature by an airborne radiometer system, also planned for FY 1984.

AOML plans to develop an objective analysis procedure capable of using data from an ERS-1-type satellite, as well as all conventional weather observations, to generate in near-real time the best possible estimate of the global state of the atmosphere for initializing numerical weather prediction runs. By-products of this procedure will be surface wind and wave climatologies for engineering applications, and time histories of surface wind and wave fields for general ocean circulation studies relating to climate research. **AOML**

The prototype transverse Doppler current measurement system will undergo testing and evaluation. The initial data set from the Bear Cut experiment was presented to the NOS Water Levels Branch, the Port of Miami, and the Biscayne Harbor Pilots Association to suggest research possibilities for addressing problems associated with horizontal shear flow in Government Cut (Port of Miami). Deployment of an experimental, within-channel flow-monitoring system in the Miami Harbor is planned.

MARINE RESOURCES

AOML research in marine resources is investigating hydrothermal processes at seafloor-spreading centers with reference to the role of these processes in concentrating metallic mineral deposits and in controlling the heavy-metal chemistry of seawater. Research is closely coordinated with research at PMEL, NOS Office of Ocean Minerals and Energy and Office of the Chief Scientist, and the National Marine Fisheries Service as part of the NOAA 5-year research plan, "Deep-Sea Metals: Polymetallic Sulfides."

Accomplishments FY 1983

The investigation of the Trans-Atlantic Geotraverse (TAG) Hydrothermal Field revealed the first unequivocal evidence that high-temperature "black smoker" hydrothermal discharge has occurred on a slow-spreading oceanic ridge and determined both the duration and periodicity of that "black-smoker" activity.

Laboratory analysis of samples recovered from the TAG Hydrothermal Field revealed the chemical and mineralogical characteristics of the largest hydrothermal deposits discovered on a slow-spreading oceanic ridge in an open ocean basin.

Hydrothermal vent-type clams were identified in bottom photographs made by AOML in the TAG Hydrothermal Field. This is the first documented occurrence of such fauna outside the fast-spreading oceanic ridges of the Pacific.

Plans FY 1984

Data analysis, interpretation, and documentation will be completed, detailing the results of the July 1982 Researcher/Alvin-Lulu cruise to the Mid-Atlantic Ridge. Results will concern the cooperative submersible investigations conducted at the TAG Hydrothermal Field by co-investigators from NOAA, Woods Hole Oceanographic Institution, and the Massachusetts Institute of Technology. An additional study, conducted jointly by NOAA and the University of Stockholm, will discuss deep crustal processes on the Mid-Atlantic Ridge.

WEATHER OBSERVATION AND PREDICTION

AOML is NOAA's primary focus for research in tropical meteorology and hurricanes. Research teams concentrate on field programs, numerical hurricane modeling, and theoretical studies of hurricanes. The Laboratory's hurricane field program makes use of NOAA research aircraft to acquire unique data sets.

AOML interacts with the National Hurricane Center (NHC) and the National Meteorological Center (NMC) in problems of hurricane prediction and with the

National Center for Atmospheric Research on scientific investigations of the inner cores of hurricanes.

Accomplishments FY 1983

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

Studies of drop size distributions in hurricane clouds indicate some departure from the Marshall-Palmer drop size distributions. Better fits to the data are obtained with a gamma distribution function.

Analysis of data from Hurricanes Irene (1981) and Allen (1980) indicates the presence of large quantities of ice in every region of the hurricane including the eyewall.

A detailed study of a selected maritime cumulus was completed. Complete number density size distributions of cloud particles were computed for portions of the cloud with well-defined updraft/downdraft and radar echo conditions.

These studies show that once precipitation is well developed, water is depleted faster than it can be supplied by condensation. Thus, once precipitation is well developed the clouds cannot grow or even maintain a steady state.

Convective and Mesoscale

All data processing and analysis of the hurricane rainband experiments in Hurricanes Allen (1980) and Floyd (1981) were completed. These studies provide a better understanding of the structure and dynamics of mature hurricane eyewalls as well as outer rainbands. In particular, there is a distinct difference in the organization of vertical motion between the eyewall and rainband. In the strongly convective rainband of Hurricane Floyd, boundary layer air was thermodynamically modified by the convection so that the energy content was reduced. This energy reduction influenced the structure of the eyewall and strength of the storm. Analysis of the Hurricane Debby data revealed similar evidence of modification, although the reduction was much weaker. This difference presumably was caused by the more stratiform nature of the Debby rainfall. **AOML**

A study using data obtained in Hurricane Allen (1980) revealed marked asymmetry in the three-dimensional precipitation distribution within the eyewall. During the research flight on 7 August 1980, the P-3 aircraft circled within the eyewall of Hurricane Allen three times for 20-30 minutes, enabling the tail radar to map the reflectivity structure of the eyewall in detail. Several features of the reflectivity structure were common in each time composite:

(1) In the horizontal, the strongest reflectivity was observed in a portion of the eyewall centered on the direction of storm motion.

(2) In the vertical, the strongest reflectivity occurred in the eyewall near the height of the 0°C isotherm (~5.5 km).

(3) The high-reflectivity regions in the eyewall tended to slope upwind and outward with increasing altitude.

(4) Azimuthal cross sections of reflectivity in the eyewall showed evidence of a "bright band" in the portion of the eyewall containing the strongest reflectivities.

The study also indicates that the eyewall precipitation distribution in Hurricane Allen was primarily a result of mesoscale motions superimposed over convective-scale motions.

A summary of the airborne Doppler measurements in Hurricane Debby (1982) indicates that the NOAA airborne pulsed-Doppler radar is a very good tool for determining mesoscale wind fields over large regions in a hurricane environment. The pseudo-dual Doppler analysis method provides realistic wind fields on spatial and temporal scales sufficient for kinematic analyses of the mesoscale flow patterns that were present in the northwest quadrant of Hurricane Debby.

The analyses of the airborne Doppler data were used to provide three-dimensional patterns of reflectivity, wind, and divergence in two contrasting regions of the storm while it was developing to hurricane intensity. The regions examined were the developing eyewall and a region of stratiform precipitation lying outside the developing eyewall. The three-dimensional patterns in these regions were consistent with structures anticipated from previous two-dimensional analyses of flight-level data obtained in hurricane eyewalls and rainbands, and from studies of wind data obtained in tropical cloud clusters.

The consistency of the structure observed in the developing eyewall with eyewalls seen in previous studies of mature storms indicates that eyewall structure may already be present in storms still in the process of developing to hurricane intensity.

Single sweeps of radar reflectivity gathered from the WSR-57 at Slidell, La., during the landfall of Hurricane Frederic were processed at 2-min intervals for a 12-h period that includes landfall.

A color movie was made of the radar images at 2-min intervals during landfall.

Synoptic Scale

Processing of the Omega dropwindsonde (ODW) data for Hurricane Debby (September 1982) was completed in early April, and data were distributed to scientists at several laboratories and universities. Processing of the data

from Hurricane Olivia (eastern Pacific, September 1983) will be completed by the end of February 1984. The wind, temperature, and humidity data sent during the flights were of reasonable quality for operational use. The accuracies of the processed wind, temperature, humidity, pressure, and geopotential height data appear to be very high.

Analysis of the impact of the Debby data on the operational objective analyses and the dynamical hurricane track models is being completed in a cooperative program with NMC and NHC. On the basis of just two Atlantic cases, it is not yet possible to make meaningful statements about improvements in hurricane track forecasts resulting from the ODW data. Nevertheless, some assessment of the impact of the data can be made. Both global objective analyses at NMC (the Hough and the optimum interpolation) failed to provide satisfactory analyses for the operational ODW data. Differences between the ODW winds and the analysis winds were not randomly distributed in space. Errors in the objective analysis wind fields approached magnitudes of 10 m s^{-1}, and the error vectors had patterns with a relatively large scale.

Air-Sea Interactions

Initial results were obtained in a study dealing with the differences in planetary boundary layer (PBL) wind profiles on the inflow and outflow sides of a rainband and a comparison with other hurricane PBL profiles.

The processing of Hurricane Allen SFMR (stepped-frequency microwave radiometer) data was completed, and a revised algorithm for computing surface wind and integrated rainfall rates from surface emissivities and atmospheric transmissivities was devised. Surface winds accurate to 2 m s^{-1} were calculated.

The 70-mm Hasselblad camera system was installed on the NOAA 43RF aircraft together with a data annotation system. The first well-documented sea state photographs in color were obtained in Hurricane Alicia for surface wind speeds of 17 m s^{-1} and 25 m s^{-1}. These will be incorporated in revisions of our sea state catalog and color-related descriptors as a function of wind speed within the next 3 to 5 years.

AOML

Seasat SMMR (scanning multi-channel microwave radiometer) data were acquired in a format that retains the original sensor resolution of the measurements at each microwave frequency. A scheme was devised to map low rainfall rates (7 mm h^{-1}) with the high-resolution (15 km) 37-GHz sensor and to merge these data with data from the lower resolution (30 km), but greater dynamic range, 18-GHz sensor. The composite maps of rainfall rate computed for Hurricane Fico (1978) showed a factor-of-4 improvement in resolution over previous Seasat SMMR rainfall maps.

HURRICANE TRACK PREDICTION

A new revision of the SANBAR (Sander's barotropic) model package (SAN82), which has a scan analysis capable of utilizing ODW data, produced a 25% (1982 storms) decrease in the 72-h average forecast error, compared with the operational SANBAR package.

A movable grid version of SANBAR (EPSAN82) was implemented for eastern Pacific storms during the latter part of the 1982 season. EPSAN82 was run simultaneously with an eastern Pacific version of the original SANBAR (EPSNBR). For the 1982 cases, EPSAN82 performed better than EPSNBR.

In cooperation with NESDIS (National Environmental Satellite, Data, and Information Service) Developmental Laboratory (Madison, Wis.), wind data were derived from the VISSR (visible infrared spin scan radiometer) Atmospheric Sounder (VAS) during the 1982 North Atlantic hurricane season. VAS-derived winds have already been used in analysis for 15-16 September 1982, 0000GMT (during Hurricane Debby) as part of the first-guess field and as bogus station data. The 72-h forecast error for the cases of 16 September was only 283 nmi with the VAS data, versus 340 nmi with the standard first-guess field. The other available 1982 cases are being verified. The SAN83 package (SAN82 plus some additional numerical improvements) was modified for use with the VAS data and was implemented for semi-operational runs during the 1983 season.

Statistical models for predicting tropical cyclone motion have traditionally been formulated in a coordinate system oriented with respect to zonal and meridional directions. We investigated the forecast-error-reducing potential of a grid system reoriented with respect to initial storm heading. The developmental data represent Atlantic forecast situations from 1965 through 1980 on storms initially north of 25°N. Reorientation of the coordinate system reduces the total variance in 24-h storm motion by 40%, projects most of the motion onto one (along-track) component of displacement, and makes the components nearly independent of each other. For 48- and 72-h displacements, however, these advantageous effects are substantially diminished or eliminated.

For the developmental data, grid reorientation lowers the 24-h forecast error by 13%, and reduces the speed bias by a factor of 2/3.

HURRICANE VORTEX DYNAMICS

Development and validation of the nonhydrostatic hurricane model are complete, and a series of experiments has been carried out. The model was used to explore the detailed dynamics of the vortex core and the influence of microphysical processes upon the storm as a whole. It was particularly successful in simulation of features observed in nature from research aircraft. The microphysical parameterization may include either two water phases (rain and cloud water) or the water phases plus three ice phases (graupel, snow, and cloud ice).

The role of microphysics is especially significant. With liquid water processes alone, the simulated hurricane exhibits occasional concentric eye cycles in which an outer ring of convection supplants a pre-existing eye wall, but with ice processes added these cycles become more frequent and more pronounced. A detailed analysis of the dynamic, thermodynamic, and microphysical budgets shows that, with ice microphysics included, cloud processes influence vortex-scale motions through stronger, longer lasting, precipitation-induced downdrafts. In addition, inclusion of ice processes leads to more realistic simulation of the structure, position, motion, and intensity of the convective rings.

Analysis of data obtained from Hurricanes Gert (1981), Floyd (1981), and Debby (1982) is largely complete and yields a consistent picture of the dynamics of asymmetric hurricanes. Such storms are characterized by divergence, outflow, low humidity, and sparse precipitation on the west side, and convergence, inflow, near-saturation, and heavy precipitation on the east side. The asymmetry appears to result from the interaction between the vortex and a vertically shearing environmental wind. The convection on the east side is organized into the principal rainband, a squall-line structure that tends to maintain a fixed geographical orientation relative to the storm center. The principal band must therefore propagate against the mean swirling flow. It differs from an eye wall or convective ring in that its main inflow comes from its concave (inward) side. At mean swirling flows >35 m s^{-1}, principal bands are observed to encircle the center and to transform into convective rings.

Hurricane asymmetries are central to the track prediction problem as well as to the distribution of wind and convection in a moving vortex. It was found that a simple slab boundary layer model simulates the qualitative features of the wind field observed in Hurricane Frederic of 1979. The distribution of convection in Frederic and in Hurricane Allen of 1980, which was translating approximately twice as fast as Frederic, compared favorably with boundary layer convergence diagnosed from the model.

HURRICANE MODELING

Quasi-Spectral Model

A method called QSTING (quasi-spectral time integration on nested grids) combines the flexibility of grid-point representation, as in finite difference methods, with the accuracy of harmonic spectral methods. Toward the end of 1982, a two-dimensional QSTING model with six levels of nesting was used to simulate the boundary layer flow of a moving hurricane. Analysis of the results was continued in 1983. For the most part, the results confirmed the theoretical advantage of this new method.

12-Layer Nested-Grid Model

AOML

A hurricane landfall simulation with the 12-layer resolvable heating model was completed. Comparison of the track of the landfalling storm with that of an identical experiment without land (control) showed that the landfall storm was 15 min behind and 22 km to the left of the (control) at landfall. During the 10 h before landfall, the vortex executed a trochoidal oscillation of amplitude near 14 km, about twice that of similar oscillations that appear in the control experiment. Maximum low-level winds of 70 m s^{-1} were reduced to 34 m s^{-1} at 13 h and to 27 m s^{-1} at 24 h after landfall. During the 15 h before landfall, the convective activity of the control experiment decreased slowly and rainband activity was generally weak. In contrast, during the same time, convective activity for the landfall case increased substantially. This increased convection seems to be related to small increases of moist static-energy in the low troposphere that occur in convergence along the coast ahead of the storm. These increases were advected around to the rear of the inner nested grid where the increase of convective activity begins.

OBSERVATIONAL STUDIES OF THE SOUTH FLORIDA SEA BREEZE

Analyses of aircraft data have concentrated on comparing and contrasting the structure of the sea-breeze circulation on a day in 1980 and a day in 1981. The evolution of deep convection in the 1980 case was strongly influenced by a layer of very dry air between 850 and 700 mb. Deep convection occurred near the flight track, but rainfall did not begin until very late in the day. On the other hand, the 1981 case was characterized by profiles of temperature and moisture that were near the typical climatological values. The analyses of the two cases are aimed at understanding the role of the sea-breeze circulation in the timing of the deep convection.

A study of of peninsula-scale rainfall variations on sea-breeze days in south Florida was completed. Results show that the sea-breeze circulation accounts for approximately 35%-40% of the south Florida summer rainfall. Area-averaged rainfall and the time variations of peninsula-scale surface divergence and hourly rainfall on sea-breeze days are affected by changes in humidity, lapse rate, wind speed, and wind direction. Days with relatively high humidity and steep lapse rates typically have deep convective activity that tends to develop sooner and reach its peak earlier than normal. There are two sea-breeze regimes for low-level wind speeds ≥ 5 m s^{-1}. When the low-level wind blows parallel to the peninsula, the sea-breeze circulation is strong and area rainfall is greater than average. When the wind blows across the peninsula, the sea breeze is absent or weak and rainfall is below average.

Preliminary analyses of airborne Doppler radar data from two of the sea-breeze flights in 1982 were completed. These data were processed to yield maps of horizontal wind at heights from 0.5 to 12.0 km, which depict the airflow associated with a quasi-linear convective line that developed within the sea-breeze convergence zone along the southwest coast of Florida on 28 July 1982. The location and strength of convective-scale downdrafts are shown to be important factors in maintaining boundary layer outflow. The downdrafts apparently generated new convective growth ahead (westward) of the line and accounted for the westward propagation of the system.

Plans FY 1984

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

The analysis of past hurricane particle image data (Knollenberg data from $T < 0°C$) will be continued. Emphasis will be placed on describing a coherent picture of the microphysical structure of the storm clouds in relation to their location with respect to structural features of the storm.

A study of transitions in particle morphology and number density distributions through the melting layer will start; already available data will be used. Available data will also be used to initiate a study of precipitation drag, water loading, and water unloading in updrafts and downdrafts.

Convective and Mesoscale

The analysis of airborne Doppler radar data gathered in Hurricane Debby (1982) will be completed. Analysis of Doppler radar data from Hurricanes Alicia and Tico (1983) will begin.

Analyses of the convective and mesoscale features of Hurricane Frederic as revealed by land-based radar will be completed. Analysis of the data recorded on the Galveston NWS radar during the landfall of Hurricane Alicia (1983) will begin.

Synoptic Scale

Cooperative studies with NHC and NMC will continue to examine the effect of the ODW data on the operational hurricane track models. The influence of aircraft turns on the quality of ODW wind measurements will be determined. ODW data will be gathered for additional storms during the 1984 hurricane season.

Air-Sea Interaction

A new stepped-frequency microwave radiometer (SFMR) will be installed on an OAO (formerly RFC) aircraft. This instrument will become part of the instrumentation systems used for the hurricane air-sea interaction experiment planned for 1984. The NOAA Data Buoy Center has agreed to commit two drifting buoys to this experiment. Arrangements have been made with the Air Force to deploy these drifters ahead of the projected hurricane track.

HURRICANE TRACK PREDICTION

In preparation for the 1984 hurricane season, final operational packages of the Atlantic and eastern Pacific versions of the modified SANBAR system will be assembled and operationally implemented, and will probably replace the existing SANBAR package.

AOML

Archived twice-daily ATOLL (analysis of the tropical ocean lower layer) and 200-mb-wind objective analyses for the tropical Atlantic for June through November will be used to develop a climatology of quasi-steady and propagating disturbances for 1975 through 1983. The data for each year will be filtered to isolate particular frequency bands corresponding to 5-day waves. Complex empirical orthogonal functions (EOF's), which include phase information for propagation disturbances, will be used for the analysis.

Quantitative assessment of the combined time-space variability and the overall quality of ODW data is a prerequisite for the design of any objective analysis scheme for these data. ODW data will be compared with data from other sources (VAS, cloud vector winds, and ship reports). Comparison with the Bermuda rawinsonde data will aid estimation of purely local time variability due to passage of the storm and estimation of the quality of the ODW data in that region.

HURRICANE VORTEX DYNAMICS

Emphasis will be in three areas: continued experimentation with the prototype nonhydrostatic model; dynamic analysis and interpretation of the data from Hurricanes Alicia (1983) and Tico (1983); and numerical studies of the asymmetric structure of hurricanes including the interaction of the vortex with the large-scale environment.

Investigations with the nonhydrostatic model will include detailed analysis of the dynamic and microphysical budgets of completed experiments.

The quasi-spectral, nested-grid numerical model will be used in a barotropic, primitive equation form on a beta-plane, to investigate the effect of divergence on hurricane asymmetry and motion. Weak and hurricane-strength vortices will be used to investigate the effect of advective nonlinearities.

HURRICANE MODELING

Quasi-Spectral Model

A general logic for multiple mesh moving, which has already been developed, will be coded and used for basic tests.

Development of a spherical-Earth version of the quasi-spectral model (not necessarily covering the whole globe) will be started. Since the spherical model must run in two dimensions even for partial testing, the process of developing the model is likely to be slow.

12-Layer Nested-Grid Model

Simulation of a 13-day hurricane will be documented, with emphasis on comparison of model and atmospheric data.

OBSERVATIONAL STUDIES OF THE SOUTH FLORIDA SEA BREEZE

Analyses of the 1980 and 1981 case studies will be completed. Final testing of a numerical model to study the effects of differential horizontal advection on the growth of the mixed layer will be completed. The model will be initialized with data from the 1980 and 1981 sea-breeze flights. The Doppler radar observations of the development of deep convection in the sea-breeze convergence zones will be analyzed in detail.

PACIFIC MARINE ENVIRONMENTAL LABORATORY
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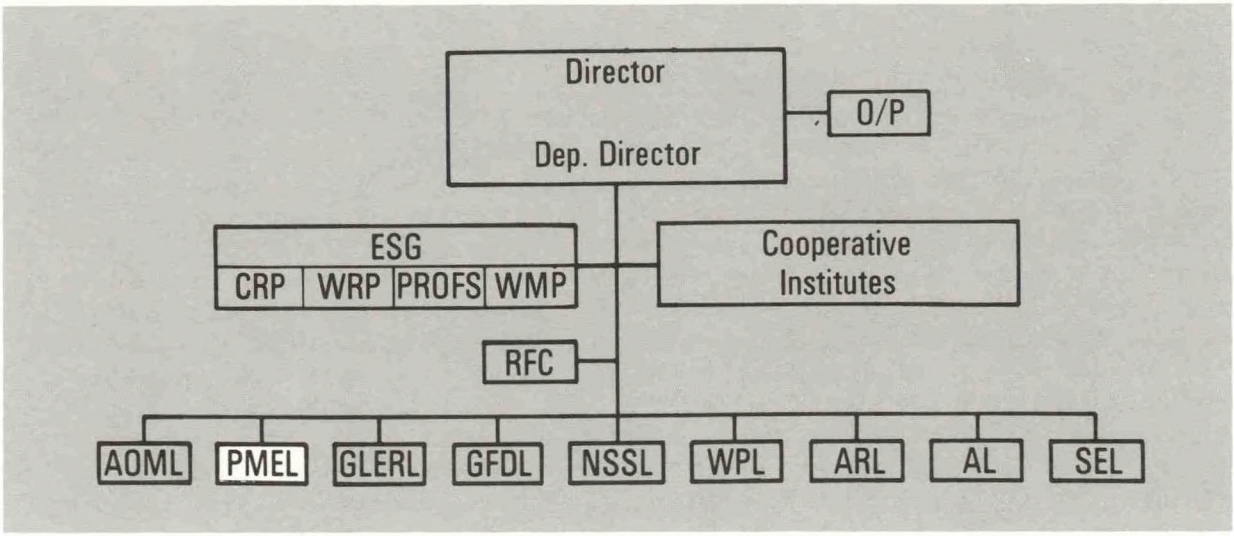


The Pacific Marine Environmental Laboratory (PMEL) carries out interdisciplinary scientific investigations directed toward understanding processes in coastal and open-ocean systems. The current oceanographic and meteorological research programs of PMEL focus on four general subjects: climate, marine environmental assessment, marine observation and prediction, and marine resources. Research results provide information necessary for effective management of marine resources and improved marine environmental forecasting. Two cooperative institutes, the Joint Institute for Study of the Atmosphere and Ocean (JISAO) and the Joint Institute for Marine and Atmospheric Research (JIMAR), established between NOAA and the Universities of Washington and Hawaii, respectively, provide a bridge between the academic community and PMEL scientists working in climate dynamics, estuarine processes, tsunamis, and environmental chemistry.

CLIMATE RESEARCH

PMEL climate research has three focuses: climate prediction, ocean climate dynamics, and the uptake of carbon dioxide by the oceans. Climate prediction studies include the development of season-ahead forecasts for the U.S. mainland and tools for assessing the validity of those forecasts. Ocean climate dynamics research is designed to develop an understanding of the large-scale, long-term interactions among major ocean currents, heat transport, and general atmospheric circulation. This research is proceeding with funding from Equatorial Pacific Ocean Climate Studies (EPOCS), Subtropical Atlantic Climate Studies (STACS), and the National Science Foundation (NSF). Carbon dioxide research is assessing the role of the oceans in removing excess carbon dioxide from the atmosphere. Climate research utilizes about 45% of PMEL's funding annually.

Accomplishments FY 1983

EPOCS

El Niño Studies

During the recent El Niño, PMEL conducted numerous measurements for the EPOCS program. One of the most interesting phenomena in the equatorial Pacific region is the Equatorial Undercurrent, a sub-surface, eastward-flowing current about 200 m thick and 400 km wide. Usually the maximum speed (1 m s^{-1}) is centered in the thermocline at depths of 50-150 m and occurs within 50 km of the Equator. Continuous measurement of the undercurrent in the eastern Pacific began in March 1980 when current and temperature data were recorded at 15-min intervals at up to seven depths (15, 50, 75, 100, 150, 200, 250 m) by means of vector-averaging current meters suspended beneath surface buoys tautly moored at 0°, 109°30'W from March 1980 to April 1982 and from October 1982 to April 1983, and at 0°, 108°W from April to October 1982. The 108°W data were used to extend the 109°30'W time series from April to October 1982. Previous current measurements recorded simultaneously at 0°, 109°30'W and 0°, 110°30'W for 100 days in 1979 have shown that there is little amplitude or phase difference in the currents for short zonal separations at these longitudes for frequencies less than 0.25 cycles per day.

Kelvin Wave Studies

A feature of the equatorial region that was described by theory before it was observed in nature is a class of free waves, trapped at the Equator, capable of rapidly propagating fluctuations from west to east. These waves, called equatorially trapped Kelvin waves, play an important role in our theoretical understanding of the response of tropical oceans to wind changes. In the Pacific Ocean, this wave response is an important component of models seeking to explain the response of the ocean during El Niño. Only recently, observational evidence centered around the work done at PMEL documented the existence of these waves. Investigators showed that the north-south structure of low-frequency sea-level fluctuations at the Galápagos Islands was consistent with a Kelvin wave. Others found a pulse in eastward transport in the upper 200 m that propagated nondispersively along the Equator from 153°W to 1000°W at the Kelvin wave phase speed. When these studies were extended in space and time, coherent sea level fluctuations were found to be propagating 10,000 km across the Pacific from the Gilbert Islands to the Galápagos Islands at the Kelvin wave phase speed. These independent studies of sea level and currents implied a relationship between the two parameters that was firmly established in the recently completed study of current measurements taken from moored buoys at 0°, 110°W and sea level at the Galápagos. These two series are highly correlated at a lag of 10.5 days (corresponding to a Kelvin wave phase speed), and their relative amplitudes are also specified by the Kelvin wave relationships. A single Kelvin wave model explains 70% of the Galápagos sea level in terms of the zonal transport per unit width at 0°, 110°W. This model does not account for the large, near-surface currents, which appear to be locally forced.

Remote El Niño Effects

Although maximum El Niño surface temperature anomalies occur at the Equator and much of the observational effort has been concentrated in the band of latitude where equatorial wave motions are trapped, the effects on surface temperature distribution extend off the Equator. The one hypothesis that has been proposed to explain the broader scale effects is that there are off-equatorial adjustments in the north-south slope of the thermocline and a resulting change in the strength of the zonal currents. Because of the large-scale temperature gradients, these anomalous currents will produce an anomalous heat transport. The ship-of-opportunity program to measure the temperature field in the Pacific yielded a data set that can be used to compute the transports of the zonal currents. If the temperature profiles are combined with historical data on the temperature-salinity relationship, the pressure gradients and resulting geostrophic flow can be computed. Data supplied by other institutions were used to compute the time series of surface transport through most of the El Niño event of 1982-83. In the central Pacific, the results may be compared with the data collected during 1979-80. This earlier time period may be considered to be representative of a "normal" period in the tropical Pacific. The maximum transport of the eastward North Equatorial Countercurrent (NECC) in the central Pacific was 50% higher in 1982-83 than in 1979-80, and the maximum appeared in September rather than at the end of the year. The data suggest that there were large changes in the eastward volume transport and that the high transports were associated with warming in the central Pacific. Further calculations of volume transport of currents in the western and eastern Pacific need to be carried out before the role of anomalous transports off the Equator, in changing the heat content, can be evaluated.

The 1982 El Niño event was also found to have significant effects at high northern latitudes in the Pacific. This was clearly evidenced by the significant rise in sea level and increase in temperature off the coasts of the Pacific Northwest and Alaska. The monthly anomaly of sea level increased by more than 7 cm from December 1982 to January 1983 in Sitka, Alaska, and Neah Bay, Wash. A few months earlier, a rise in sea level and major warming occurred at the Equator in the eastern Pacific, which suggests a 2- to 3-month transit time between the Equator and the high latitudes.

PMEL

The 1982-83 sea level anomalies from California to Alaska were compared with signatures from earlier events. The greatest similarity was with the 1957-58 El Niño. In addition, a significant signal as far north as Alaska was also evident following the 1941 event. For other El Niño events, sea level anomalies were not evident farther north than La Jolla, Calif. A possible explanation is that local effects, such as wind forcing, runoff, and coastalocean interactions, dominated the coastal water structure, and that the remote effects were masked.

Use of Historical Data in El Niño Research

Study of the El Niño phenomenon also proceeded through analysis of historical data sets. During the past few years, historical data sets of sea-surface temperature (SST), air temperature, sea-level pressure, winds, and cloudiness had been compiled. These data sets were examined for evidence of

large-scale, long-term climate changes during the last century. They were also used to study the changes of temperature and wind fields during El Niño events.

There are questions about the reliability of historical data sets, especially for the period before the 1950's and for regions of sparse data. There may be errors due to small or isolated sampling of fields having large temporal or spatial variability. Other errors arise from inaccurate or biased measurement techniques. The following question was posed: "How can we place error bars on the monthly anomalies so that we are 90% certain that the true value is contained within the specified range?" The answer was sought by mathematically simulating the compilation of the actual data sets. A multivariate autoregressive moving-average model was used to generate artificial, but realistic, time series of daily values for each region; monthly means derived from these daily values correctly reproduce the statistics of the actual data sets. The daily series were then sampled in various ways, and Monte Carlo techniques were used to construct probability distributions of the sampling errors as a function of month, location, and sampling rate. These distributions allow estimation of the error to be associated with each monthly anomaly obtained from the actual data set, and thus to estimate the reliability of historical data.

STACS

As part of the NOAA STACS program, a PMEL project is investigating the transport of the Florida Current, one of the major poleward transporters of excess heat accumulated near low latitudes. Observations of annual and interannual fluctuations of the current's transport are meager, and new long-term continuous measurements therefore are needed for ocean climate research. The electromagnetic method of measuring transport is based on the physical law stating that the motion of seawater, an electrolyte, through the Earth's magnetic field creates a voltage that generates electric charge separation and electric currents at right angles to the flow. The Florida Current creates a voltage difference across the Florida Straits. To measure this difference PMEL is using a submarine cable that makes seawater contact on Grand Bahama Island and on the Florida coast.

A major problem that has limited the use of cable voltage measurements is the large and rapid voltage fluctuation generated by ionospheric and magnetospheric disturbances. Fortunately most of this geomagnetic noise can now be removed by methods developed at PMEL. Preliminary estimates of transport, based on cable voltages (corrected for geomagnetic noise and tides), are in remarkably good agreement with the day-to-day fluctuations in transport estimated by velocity profiling devices. The estimated standard deviation between methods for 63 days is 0.66 10^6 m^3 s^{-1}, which is only 2% of the mean flow. This excellent agreement confirms that cable voltage measurements across the Florida Straits give an accurate estimate of the transport of the Florida Current.

The cable results show that there are changes in the transport of the Florida Current of up to 15 × 10^6 m^3 s^{-1} (50% of the mean flow) lasting as long as 40 days. These results are in sharp contrast to previous findings that the variations in the Florida Current transport are mainly confined to

periods shorter than 14 days and a small 10% annual variation. The transport of the Florida Current is so highly variable that continuous day-to-day recordings of transport are necessary for accurate measurement. Because of interannual changes many years of observation will be needed to determine the annual cycle.

CARBON DIOXIDE RESEARCH

Carbon dioxide (CO_2), generated by the combustion of fossil fuels, is increasing steadily in the Earth's atmosphere and affects both the radiation balance and the long-range global climate. The major repositories for fossil-fuel-derived CO_2 (excess CO_2) are the atmosphere and the oceans; each contains about 50% according to present estimates. The rate of CO_2 buildup in the atmosphere depends critically on the rate of oceanic CO_2 uptake, which is controlled by diffusion and convection, by the reaction of excess CO_2 with carbonate phases, and by air-sea exchange rates.

The CO_2 research programs at PMEL have three aims: to predict the oceanic CO_2 assimilation rate on the basis of the atmospheric source function; to determine the reactions of excess CO_2 with solid carbonate phases, which increase the ocean's capacity to assimilate CO_2; to evaluate the ocean's assimilation of CO_2.

In March and April 1983, PMEL occupied a meridional section in the central North Pacific to measure total CO_2, alkalinity, freons, bomb tritium and carbon-14, salinity, temperature, nutrients, and oxygen. These measurements completed our survey of the North Pacific Ocean.

Measurements in the western North Pacific indicate that the subtropical gyre is highly supersaturated (up to 400%) with aragonite ($CaCO_3$), and the colder surface waters of the subarctic gyre are nearing saturation. Our calculations suggest that continued atmospheric buildup of CO_2 will result in aragonite undersaturation in the surface waters of the North Pacific as early as the first half of the next century. Undersaturation of surface waters will continue to spread to lower latitudes as more CO_2 is released to the atmosphere.

Although we are approaching the time when amounts of excess CO_2 may be estimated directly, measuring the anthropogenic transients (e.g., ^{3}H, ^{14}C, freons) is now the only short-term procedure for evaluating the transport of excess CO_2 between the ocean's surface layers and thermocline. Our efforts in the North Pacific (i.e., north of 40°N) have focused on quantifying freon-11, tritium, and temperature so that transport of CO_2 can be evaluated. We have also improved the analyses of total CO_2, alkalinity, and pCO_2. Our aim is to improve estimates of excess CO_2 in the upper waters of the North Pacific.

Plans FY 1984

- A field program will be launched to study the processes affecting heat content of the upper layer of the ocean along the Equator, between 140°

and 110°W. This program will obtain deep-sea measurements of current and temperature, measurement of winds and air temperature, and profile measurements of temperature, salinity, and velocity. This EPOCS program is coordinated with the Tropic Heat Program sponsored by NSF.

- The measurements of current velocity and temperature from deep-sea moorings at 110°W and the sea-level measurements at the Galápagos Island, which were both begun in 1979, will be continued for the study of zonally propagating signals along the Equator (EPOCS).

- The best sampled region (Panama-Tahiti shipping lane) of the 100-year historical ocean/atmosphere climate data set will be analyzed to determine the sampling errors in estimating monthly and annual means. These errors will set quantitative bounds on the types of inferences that can be drawn about low-frequency climate change in the tropical Pacific.

- Satellite (NOAA) infrared sea-surface temperatures (corrected for aerosol contamination from El Chichón) in the eastern equatorial Pacific will be analyzed for 1981 and 1982. The development of the warming associated with the 1982-83 El Niño will be documented and related to EPOCS cruise data.

- Zonal current transport in the tropical Pacific for 1979-1983 will be calculated from the XBT data set. In particular, the changes in zonal transport and their effects on redistribution of heat during the 1982-83 El Niño will be examined. This work will be done jointly with French and Australian investigators.

- Voltage differences over the Florida Straits will be interpreted further by comparison with new data sets. In addition, the feasibility of utilizing the global network of active AT&T cables for oceanographic research will be assessed.

- Directly measured currents from the Emperor Seamounts region will be analyzed as a part of the study of the effect of the seamounts on the structure of the Kuroshio (Japan Current).

- Measurements will be obtained in the South Pacific to assess the uptake of CO_2 in the Antarctic Intermediate Waters and Western Boundary Current.

- Distributions of CO_2 components will be monitored at a station off the Washington coast for the purpose of examining secular changes.

- Assessment of the uptake of excess CO_2 in the waters of the North Pacific subarctic gyre will be completed.

MARINE ENVIRONMENTAL ASSESSMENT

Marine environmental assessment constitutes the research activity for about 40% of the PMEL staff. Emphasis is on understanding the complex physical and geochemical processes that determine the extent of human influence on the marine environment. Although the geographic focus of these studies has

been Pacific Northwest and Alaskan coastal and estuarine waters, the scientific knowledge acquired and methodologies developed are applicable to other marine systems. The two efforts at PMEL are studies of the long-range fate of chronic pollutants in marine waters and oceanic precursors to acid rain.

Accomplishments FY 1983

LONG-RANGE-EFFECTS RESEARCH

Studies in the Puget Sound-Strait of Juan de Fuca system, under way for several years, are leading to a better understanding of Puget Sound's ability to accommodate pollutant inputs. Many pollutants adhere to and move with particles, and ultimately are buried in the sound or transported out of the sound along with particles. The emphasis of much PMEL research, therefore, has been particle transport and fate. During FY 1983, long-range-effects research had five emphases.

A Demographic Model

The purpose of PMEL's Demographic/Pollutant Source model is to identify historical sources of pollutants and to make the quantitative measures available in a standardized format. These time series are then to be compared by suitable transformations with the pollutant deposition records that will result from the sediment core analyses. Three types of variates have been identified and all are now in the process of being loaded into a computer data base.

The first type consists of actual estimates of the mass rate of discharge of a pollutant into the environment. An example is lead. By a variety of means we have estimated the rate of consumption of lead additives in gasoline on a watershed-by-watershed basis from about 1930 to the present. Recent studies showed that the fraction of lead immobilized in the immediate vicinity of the roadway is determined by the local vegetative cover. The algorithm from this study will be applied to the historical consumption values to estimate the loadings of the surface runoff. Efforts are now under way to supplement these estimates with estimates of the input from lead pipes and marine repair and construction activities. The final product will be a time series of the mass rate of lead input on a watershed basis. This undertaking requires considerable data and previous analyses. These are available for only a few pollutants.

The second type of variate consists of ancillary data that pertain directly to transport processes or that bear a plausible but indirect linkage to pollutant loadings. An example of the former is the discharge of the Duwamish River. As a result of a long history of diversions, the Duwamish at present discharges only about one-fourth of its pre-1890 water volume. An example of the latter is the number of automobiles, by watershed. There is some likelihood that the mass deposition rates in a core may be related to such measures, and discovering such relationships would greatly simplify the search for a suitable predictor.

The third type consists of measures of economic activity expressed in dollars by "industrial sector." The region is specially blessed by the availability of a regional Input/Output model and a 20-year time series of sector activity values. The present model, based on 55 sectors, is far too detailed for our purposes, since collinearity between many of the variates would tend to obscure any attempt at correlating these time series with sediment core deposition rates. However, the sectors could probably be aggregated to form a much simplified system of six or seven sectors. Time series for these hybrids could then be constructed from existing data. In this case we would be searching for strong correlations between pollutant accumulation rates and variates such as "Defense Department purchases." If suitable correlations are discovered, prediction follows immediately from the routine projections that are made with the regional model.

Marine Sediment Analysis

At the present time, municipal and industrial waste effluents constitute the ninth largest input of freshwater to the Puget Sound region. Although these effluents are processed to conform to water quality standards, they still represent an important source of trace metals and organic toxicants, pollutants that may adversely affect fisheries. Local concern over wastewater standards is relatively new, and as recently as 20 years ago, before the opening of the West Point Sewage Treatment Plant in 1965, substantial quantities of untreated effluents were routinely discharged into Puget Sound. There are virtually no records of these discharges. In order to establish a budget for pollutants in the Puget Sound region (and thereby discern trends), we are using sediment cores to estimate the historical deposition of pollutants in the system.

Pollutants are delivered to the sediment by horizontal transport and vertical deposition. The rate at which pollutants are accumulated in sediments, however, is a complex function of both the sedimentation and bioturbation (mixing) rates. Sedimentation and bioturbation signals must be separated from measured sediment constituent profiles before particle and pollutant budgets and/or models can be formulated. Geochemists under contract to PMEL are determining the lead (^{210}Pb) and thorium (^{234}Th) geochronologies for box cores and Kasten cores collected from Puget Sound. Sediment inventories for several trace metal and organic pollutants from these cores have been established.

In FY 1983 PMEL scientists determined the distributions of two classes of organic pollutants as well as several trace metals, including manganese, iron, nickel, copper, zinc, and lead in sediments from Puget Sound. The organic pollutants are polycyclic aromatic hydrocarbons (PAH's) and normal and branched alkanes. Many of these compounds are mutagenic and carcinogenic and thus pose a significant threat in the marine environment.

The origins of these water-insoluble compounds are petroleum products and fossil fuel combustion, riverine input, and wastewater discharge. The distribution of PAH's in the sediments of Puget Sound reflects the increased industrialization and urbanization of the area since the early 1900's. PAH concentrations increase markedly in the sediments laid down between the turn of the century and the 1940's (and then decrease to present-day levels). The

concentration maximum in the 1940's is probably related to the change in home heating fuels from coal to oil, gas, and electricity. The branched alkanes and the normal alkanes both show maxima, although not as pronounced, near 1965, the time when Seattle terminated the dumping of raw sewage into the main basin of Puget Sound.

The distribution of stable lead at six core sites in Puget Sound illustrates the history of trace metal pollution in the Puget Sound region. The ^{210}Pb dates are provisional because they are being corrected for the effects of bioturbation. The stable lead profiles show an increase starting at about 1900, a maximum at about 1965-1975, and a slight decrease thereafter. The increases roughly correspond to the history of atmospheric lead contributions to the Puget Sound region, which suggests that the sediment is a historical record of input.

The sediment lead data were combined with other data on lead inputs and outputs for Puget Sound, to provide a preliminary lead budget for the region. This preliminary budget for lead indicates that the major lead input is anthropogenic and the major sink for lead is indeed the sediments, in which more than 85% of the lead input is deposited. Furthermore, the sources and sinks for lead roughly balance each other, which means we have accounted for most of the lead transport in Puget Sound. However, the data are still somewhat sparse and potentially significant errors exist for sedimentation, riverine input, and shoreline erosion. The lead inputs and outputs have been revised downward because of better analytical data for lead in Puget Sound and because we now have a much better understanding of the recirculation processes. The data for several of the other trace metals also indicate that the major sink is indeed the sediments. These preliminary results appear to indicate that contaminant concentrations in estuarine sediments can be predicted from their input rates.

Circulation and Particle Transport Studies

Studies of the transport of water and particles in the main basin of Puget Sound are important because they allow us to evaluate Puget Sound as a trap for dissolved pollutants as well as particle-borne pollutants and predict the distribution of particulate deposition Our present conceptual model of Puget Sound, based on extensive observations of water properties and currents, suggests that circulation is conducive to the accumulation of pollutants. These observations indicate that about two-thirds of the seaward-flowing surface water does not continue out of the sound but rather is mixed downward into the deep water at the Admiralty Inlet entrance sill. Such mixing is typical of fjord-like estuaries with sills, often found in the Northwest and Alaska. This downward mixing and retention of surface water contrasts sharply with the circulation typical of coastal-plain estuaries (e.g., Chesapeake Bay) where deep incoming water is mixed upward into the surface layer as the surface layer leaves the estuary.

PMEL

Direct measurements of water transport over Admiralty Inlet and within the main basin provide one method of quantifying this retention process. Current meter observations and model estimates indicate that wintertime transport landward across Admiralty Inlet is only one-half to two-thirds of the

landward transport within the main basin, thus supporting the refluxing concept. Transport differences in later summer appear to be much smaller, but data for this time period are sparse.

To help assess the consequences of the observed refluxing, we developed a quantitative mass transport model for Puget Sound. The model quantifies the transport in surface and bottom layers at various locations in Puget Sound on the basis of observations of salt and mass fluxes at a few locations. Transport calculations then allow predictions of the basin-wide distribution of dissolved, conservative substances based on the strength and location of the input. Preliminary results for dissolved copper show that the model, using measured input levels of natural and anthropogenic copper, predicts a concentration level close to the observed levels in Puget Sound.

Pollutant-Particle Studies

Because particles contain the largest portion of the pollutant load in estuaries, we undertook studies specifically addressing the transport pathways of the particles. Fine-grained particles are biologically or physically aggregated into larger particles that sink rapidly and provide an efficient vertical transport mechanism. This sinking thus provides a mechanism for retaining pollutants in Puget Sound in addition to that created by circulation refluxing.

Investigations using sediment traps indicate that removal of particles from surface waters is very rapid. Sediment trap data suggest that particles remain in the surface waters only about 10 days before removal by sedimentation. The rapidity of vertical transport is also illustrated by the basin-wide concentration of PAH's in sediment traps. Concentrations of PAH's are highest in the surface waters near Seattle, the principal source area. Little horizontal distribution of the particle-borne PAH's occurs before they are collected in the sediment traps.

Pollutant Transport and Burial Rates in the Bottom Boundary Layer

The bottom boundary layer, the region of the water column from the sediment surface to several tens of meters above, plays an important role in the vertical distributions and the horizontal transport of particles. Processes within the boundary layer help determine the areal extent and patterns of contaminants in the water and sediment column and the extent and duration of exposure of biota to contaminants.

Trace metal studies in boundary layers were conducted to learn more about the role of manganese and iron in removing trace metal contaminants from the water column. Much progress was made in substantiating the role of intrusions of oceanic water over the sill at Admiralty Inlet and in transporting particles down the main basin of Puget Sound. Density-driven currents tend to occur on a fortnightly basis. When superimposed on tidal currents, this southward-flowing water greatly enhances the down transport of particulates because stronger currents cause more erosion and provide larger transport distances before the particles resettle.

During recent years the combined contribution of intrusions and tidal currents on the erosion of fine sediment of the main basin has been resolved. Current and concentration time series have been used to infer an in-situ erosion rate, the first such result for marine sediments. One focus of modeling in the past year was turbulent diffusivity generated by the currents. Both the total loading and the vertical distribution of sediment is dependent on the diffusivity, and therefore its proper characterization is critical. Using a common closure model, we found that the diffusivity is a sensitive function of the mixing length parameter though the available data favor a particular value. This research led to a much more reliable estimate of the parameter (and diffusivity) than was previously possible.

The overall goal of the bottom boundary layer work is to quantify the patterns and redistribution process for contaminants. In the past year, an integration of previous work began with the development of a horizontal transport and deposition-pattern model. The early results show that channel width variations will be reflected in along-channel sediment deposition rates and suggest that the input of sediment to the main basin of Puget Sound from the side slopes is relatively large.

ACID RAIN RESEARCH

In recent years there has been increasing interest in the role of the oceans as a source of excess sulfur in the atmosphere. This interest has developed from concern over acid rain and the possible influence of marine and terrestrial organic sulfur on the chemistry of precipitation. A clear understanding of natural sources, both regional and global, is needed to assess the relative significance of anthropogenic emissions on the chemical composition of precipitation. During the past year PMEL continued measurements of oceanic acid rain precursors, the most abundant of which is the reduced sulfur compound, dimethylsulfide (DMS). DMS concentrations have been measured on cruises throughout the north Pacific Ocean in an effort to estimate the strength of the oceanic source of sulfur to the atmosphere. PMEL's observations in FY 1983 were the first DMS measurements ever made along the west coast of the United States. The coastal zone is biologically productive, especially during upwelling, and probably constitutes an intense source of organic sulfur compounds.

DMS concentrations in the north Pacific Ocean average 30 ng sulfur per liter. Higher concentrations (average 85 ng sulfur per liter) were found in the more productive eastern equatorial waters. These concentrations, however, were lower than those found last year (spring 1982) in the western equatorial Pacific (average 100 ng sulfur per liter). The decrease is a result of the El Niño, which caused a significant decrease in biological productivity in 1983. In the absence of an El Niño we would expect higher biological productivity and thus higher concentrations of DMS in the east than in the west Pacific. DMS concentrations along the U.S. west coast averaged 50 ng sulfur per liter during this same period, probably a low value due to the El Niño. These measurements were used to calculate the flux of DMS to the atmosphere along the west coast extending 1,000 km offshore. This flux is approximately equal to the sulfur emmissions from Mount St. Helens during 1981, and four times the annual emission of the Tacoma copper smelter, the major source of anthropogenic copper in the Northwest.

Plans FY 1984

LONG-RANGE-EFFECTS RESEARCH

- Complete pollutant source computer data base.
- Complete input model algorithms for region.
- Make input predictions based on Puget Sound Council of Governments demographic projections.
- Continue to study the sediment histories of pollutants in Puget Sound by expanding our use of geochronometers to include long-lived isotopes ($^{239,240}Pu$) to delineate deep-mixing processes. Data obtained will be combined with sediment pollutant inventories to provide an adequate data base for relating pollutant source strengths to time histories in sediments.
- Make initial estimates of the processes that control the flux of water across the entrance sill and along the main basin of Puget Sound.
- Develop a numerical tidal model for Puget Sound and interface it to a model of sediment erosion and deposition in the bottom boundary layer.
- Refine and extend the Puget Sound mass transport model to evaluate the distribution of nonconservative substances.
- Evaluate the efficiency characteristics of sediment traps under varying current flow conditions.
- Quantify source and sink terms for PAH's in Puget Sound.
- Extend boundary layer and transport models. Specifically, build second-order closure flow models for time-dependent and shallow water regimes. Develop models for describing the progression of intrusions down the main basin of Puget Sound. Develop and explore steady and time-dependent transport models of the horizontal transport of particulates.
- Examine the seasonal cycles of water properties and currents along the main basin using the recently acquired 16-month time series records.

ACID RAIN RESEARCH

- Conduct a cruise off the West Coast to Hawaii, to obtain additional concentration data.
- Conduct laboratory measurements of DMS solubility and diffusivity to enable us to make better flux estimates.

MARINE OBSERVATION AND PREDICTION

Marine observation and prediction research is directed toward understanding and improving the prediction of phenomena related to marine warning and forecasting services. PMEL scientists work closely with colleagues from NWS to define research needs and assure that research products are made available to operational elements of NOAA. Research subjects include near-shore winds and waves, Arctic ice dynamics, and tsunami propagation and run-up. Approximately 20% of PMEL personnel and resources are involved in this research.

Accomplishments FY 1983

SEA ICE RESEARCH

The most thorough field study of the Bering Sea marginal ice zone (MIZ) attempted to date was conducted during February 1983. This study was part of a larger program addressing processes that control interactions among the atmosphere, ice, and oceans in the Northern Hemisphere MIZ's. The program was conducted in the vicinity of St. Matthew Island and employed the following research platforms: (1) the NOAA Ship Discoverer, (2) the U.S. Coast Guard ice breaker Westwind, (3) the NOAA P-3 research aircraft, and (4) the NASA CV-990 Airborne Laboratory.

PMEL researchers were active in obtaining meteorological and CTD (conductivity, temperature, and depth) measurements from both ships, deploying drifting satellite stations on the sea ice, and directing measurements from the P-3 aircraft. They also deployed a set of eight satellite-tracked buoys, two of which were equipped with an anemometer, current meter, and air and water thermistors; measurements were recovered through the GOES satellite. Comparison of the drift data with winds adjusted to 10 m shows that the ice floes initially drifted 3.5% of the wind speed, increasing to 7% of the wind speed within 30 km of the ice edge. At approximately the same time, the ice began to diverge, at first generally dispersed and then organized into bands in the outer marginal ice zone.

The meteorological observation program focused on boundary layer processes associated with passage of cold air from the ice cover to open water and on vertical fluxes of heat, moisture, and momentum over ice and water. Study of the meteorological measurements in the boundary layer in terms of a theory previously proposed by researchers at PMEL suggested that the initial acceleration and divergence of the ice floes are caused by the acceleration of the wind from the ice to open water. That acceleration is due to the change in the surface, from rough ice to smooth water, and due to the difference between boundary layer air temperatures over cold ice and over warm water. Combined wind, ice, and water motion observations should also be adequate to test previous drag coefficient values that relate wind speed to ice drift. **PMEL**

A model to forecast sea ice extent in the Bering Sea was put in place at the National Meteorological Center (NMC) of the National Weather Service. The model is driven by winds and air temperatures derived from the NMC spectral atmospheric forecast model. Sea-surface temperatures are taken from the

Bering Sea regional analysis. The model balances ice advection and thermodynamic processes to determine a new ice edge location; initial ice extent and conditions will be hand-digitized by the Navy/NOAA Joint Ice Center analysts. The model will provide 3-day forecasts, three times a week, and 6-day forecasts to Anchorage and Seattle Ocean Service Centers. Final verification and documentation of the model is being accomplished by researchers from the Marine Services Research Division at PMEL and the Marine Products Branch of NMC, using 1983 winter forecast products. The results of model runs will be compared with ARGOS buoy drifts and satellite-derived ice extents from the February MIZEX-WEST experiment. The model should be viewed as the first step toward improved polar services based on research from PMEL.

HAZARDOUS WAVES

An improved forecast procedure for predicting waveheights was developed for the Columbia River Bar, a region of intense wave-tide-current interactions. The theory on which the new algorithm is based accounts for wave shoaling, bathymetric refraction, and momentum transfer from currents to waves. The wave height at the bar (i.e., at the entrance to the river) is a function of surface current strength at the bar, and the offshore wave period and direction. Nomograms were developed for estimating wave heights at the bar from heights of offshore waves that propagate from various directions. Each curve in the nomogram corresponds to a different ebb tidal current speed, and its intersection with a vertical line corresponding to a particular offshore wave period provides the estimate of wave height amplification (i.e., percentage increase as the waves propagate from offshore onto the bar). It is important to consider swell and local wind wave events separately, since the behavior at the bar is quite different in each case. When tested against wave observations for 3 weeks at the Columbia River, the model accounted for 70% of the observed variance in significant waveheight at peak ebb, a 15% improvement over previous methods.

FISHERY OCEANOGRAPHY

PMEL and the Northwest and Alaska Fishery Center (NWAFC) jointly initiated a program in fishery oceanography. The ultimate goal of the program is to relate variations in abundance of fish and shellfish stocks of the Alaskan continental shelf to variations in the physical environment. Understanding such relations could improve resource use and management. The program developed simultaneously along three paths: (1) increased communication between scientists at PMEL and other institutions, e.g., NWAFC, University of Washington's College of Ocean and Fishery Sciences, University of Alaska's Institute of Marine Sciences, the International Pacific Halibut Commission; (2) synthesis of existing knowledge of the region's physical environment; and (3) development of a computer system that can easily access an ever-expanding data base. In this multidisciplinary program, a key to successful communications among specialists has been the NWAFC's Ecosystem Working Group. This group's membership was expanded to include PMEL. Gaps in data and/or understanding have been identified as objectives for future studies, and preliminary hypotheses that relate variations in year-class abundance to variations in the physical environment have been established. To refine such hypotheses, all relevant environmental data have to be made accessible so that long-term mean

conditions and anomalies about the mean can be computed and used to form indices. These can then be related to indices of abundance of various animals. To attain this goal, a Fishery Oceanography Cooperative Users System (FOCUS) was developed, and is being used to examine historical data.

TSUNAMI RESEARCH

From April 1982 to November 1983, two pressure gages were deployed near the Galápagos to measure pressure fluctuations at 3,571-m, and 15-m depths. During this period, three small tsunamis, long waves generated by Hurricane Fabio (July 1982), and very-long-period changes associated with planetary waves were observed. This successful experiment demonstrated that tsunamis could be measured in the deep-ocean environment.

Plans FY 1984

- Cooperative evaluation between PMEL and operational units of the NOAA Bering Sea Ice Edge Forecast Model.
- Cooperative evaluation between PMEL and operational units of the Columbia River Bar nomogram.
- Use of the fisheries oceanography data base to test two hypotheses relating fishery indicators to interannual variation in physical oceanographic processes.
- Development and dissemination of an improved algorithm to predict superstructure icing of vessels in northern waters.
- Deployment of a triangular array of three deep pressure transducers in the equatorial Pacific to track the passage of a tsunami in the deep ocean. The experiment will last 6 months, long enough to detect the passage of a planetary wave. By locating these pressure gages close to moored current meters, the dynamics of a wide spectrum of waves may be better understood.

PMEL

MARINE RESOURCES

Current studies of sea floor spreading centers on the Gorda and Juan de Fuca ridges have built on capabilities first developed for the Deep Ocean Mining Environmental Study (DOMES). PMEL is researching the physical and geochemical processes involved in the formation of massive sulfide deposits and the deposition patterns of hydrothermal plume-borne metalliferous particulates.

Accomplishments FY 1983

Six years ago the first direct observation of hydrothermal venting was made at the Galápagos Spreading Center. This event and several others over the next three years initiated the quest for a detailed understanding of the geochemistry of hydrothermal venting processes that we just began. Central to this geochemical inquiry are determinations of the relationships of venting processes to (1) the formation of massive sulfide deposits, (2) the depositional patterns of hydrothermal-plume-borne metalliferous particulates, and (3) the global distributions and inventories of the hydrothermally associated elements.

Since 1980 PMEL researchers have conducted hydrothermal research on the Gorda and Juan de Fuca Ridges which are located all or partially within the Exclusive Economic Zone off the coasts of Washington and Oregon. Our studies have focused on the distributions of hydrothermal plumes (as identified by elevated concentrations of helium, methane, manganese, iron, zinc, lead, and arsenic) and the processes that are occurring within them (e.g., dissolved-to-particulate phase changes, scavenging of metals from vent or sea water, and settling processes). Hydrothermal plumes were observed and sampled over both ridges. Highly elevated Fe and Mn values observed at several sites on the Juan de Fuca Ridge during an interdisciplinary cruise in June 1983 suggest that some samples were collected very close (possibly within 1 km) to "hot" vents. Information about vent end-member concentrations is needed to understand plume distributions and processes and can be obtained only by sampling from a submersible. In 1984 we will have our first opportunity to capture fluids and gases from within a vent as we coordinate our studies with those of other NOAA investigators in the use of the research submersible Alvin on the Juan de Fuca Ridge.

Plans FY 1984

- Continue to refine our near-field hydrothermal vent-site studies on the southern Juan de Fuca Ridge. Extend our sampling grid to encompass the distant-field hydrothermal plume and initiate water column investigations in the Blanco Trough, a deep and partially enclosed hydrothermal system in which we anticipate geochemical behavior strongly contrasting to that observed on the relatively exposed (to circulation) Juan de Fuca Ridge Crest Spreading Center.

- Participate in a NOAA-wide cooperative study of the Juan de Fuca Ridge using the research submersible Alvin. Collect hydrothermal fluids from several venting sites along the ridge to define "end-member" hydrothermal plume constituent values.

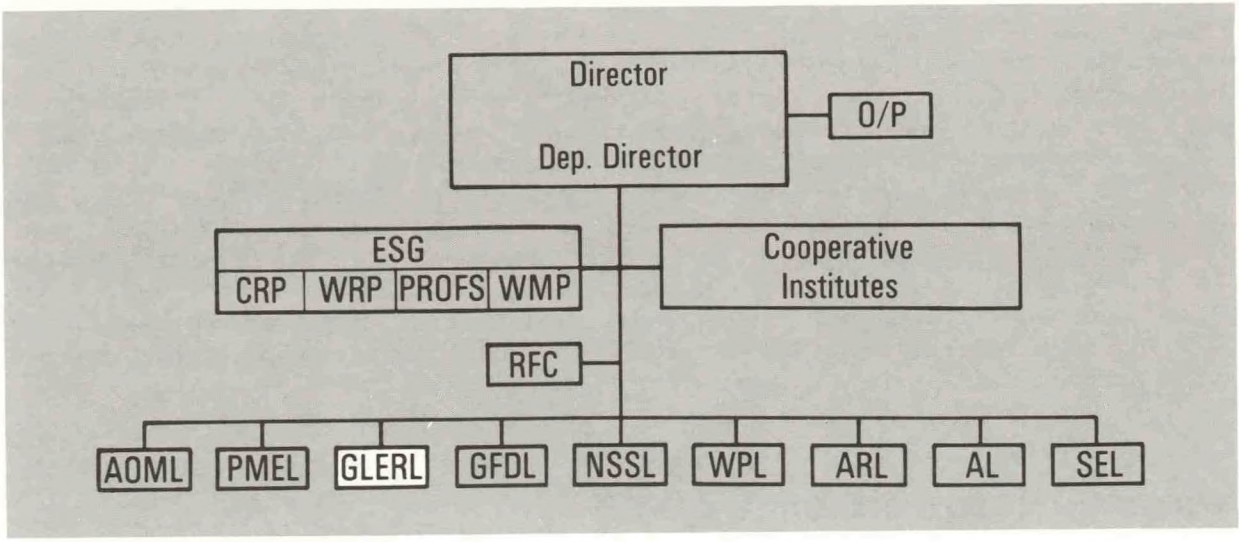
- Initiate studies to determine the net circulation over the southern Juan de Fuca Ridge. Moored current meters and nephelometers will be in place for a year.

- Enhance our at-sea capabilities to measure hydrothermal plume signals by adding a methane-analyzing system, ultra-high-sensitivity nephelometers, and a PMEL-designed thermistor chain. These will be supported by our

energy dispersive X-ray fluorescence system, which can measure both dissolved and particulate hydrothermal species and which was extremely useful in guiding our FY 1983 near-field sampling operations.

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
Ann Arbor, Michigan

Eugene J. Aubert
Director



The Great Lakes Environmental Research Laboratory (GLERL) conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters, with special emphasis on the Great Lakes. It performs field, analytical, and laboratory investigations to improve understanding and prediction of coastal and estuarine processes and interdependencies with the atmosphere, land, and sediments; places special emphasis on a systems approach in problem-oriented research to develop environmental service tools; and provides assistance to resource managers and others in obtaining and applying the information and services developed. The environmental information is provided to government and private organizations to facilitate planning and decision making in water resource management. The GLERL program includes both basic and applied studies and combines experimental, theoretical, and empirical approaches.

Research is carried out through four groups: Synthetic Organic and Particle Dynamics, Ecosystem and Nutrient Dynamics, Lake Hydrology, and Physical Limnology and Meteorology. Disciplines and activities include aquatic chemistry and biology, applied mathematics, meteorology, geology, hydrology, physical oceanography, ecology, computer systems applications, instrument design and development, and experimental design and analysis.

GLERL's multidisciplinary program reflects needs for specific information about the Great Lakes. Studies of selected chemical and biological properties are needed to understand the ecological status and trends in the lakes and to manage waste, water supplies, and fisheries. Models to show the transport and fate of contaminants as a function of human input to the lakes are needed for wastewater management and regulation policies. Information on lake water levels, connecting channel flows, and ice distribution is useful to those concerned with erosion control, transportation, recreation, and power generation. Lake circulation studies are pertinent to the transport and dispersion of pollutants. Surface waves, seiches, and surges affect shipping activities, recreation, shoreline flooding, and erosion.

OCEAN AND GREAT LAKES RESEARCH AND ASSESSMENT

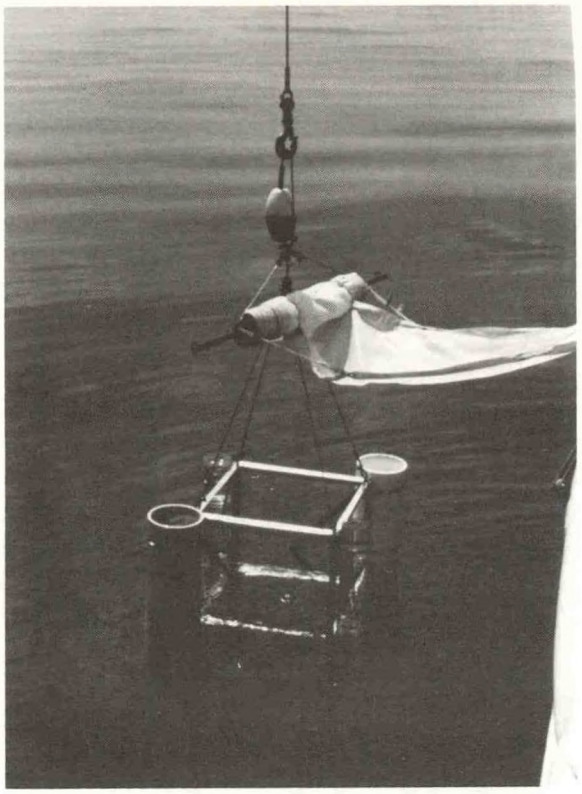
Ocean and Great Lakes Research and Assessment activities at GLERL are directed toward (1) improving understanding and prediction of natural marine ecosystems, physical phenomena, and the impact of human-induced stresses on the ecosystem, and (2) developing a sound scientific basis for management decisions pertinent to marine resources, marine pollution, and environmentally sensitive marine activities. Activities in support of this program include investigation of the short- and long-term effects of human, agricultural, and industrial wastes on aquatic life and water quality, particularly in the near-shore zone which is the area of maximum use and conflict; measurement, analysis, and prediction of physical phenomena such as currents, lake levels, river flows, and sea-air-sediment interactions; and participation as representatives of NOAA and the Department of Commerce in regional, national, and international organizations addressing problems of the Great Lakes.

Accomplishments FY 1983

A free-drifting, satellite-tracked drogue was used to conduct a major Lagrangian ecosystem experiment in Lake Michigan. Specific objectives of the study were to describe, understand, and eventually simulate temporal changes in dissolved and particulate nutrients, phytoplankton, and zooplankton. The Lagrangian approach was used to minimize the complicating influence of physical transport on the interpretation of biological and chemical measurements. During several 5-day periods data were collected to characterize the vertical structure of mixed-layer nutrient chemistry and phytoplankton and zooplankton composition (see GLERL Fig. 1). Analysis of the data began recently.

A major problem in testing the predictive effectiveness of ecosystem models is the limited amount of comprehensive long-term field data available for aquatic ecosystems. Physical, chemical, and biological data collected continuously from Lake Washington over the last 30 years are being used to test a generalized ecosystem model for natural waters, including the Great Lakes. The long-term goal of this work is to develop and test a "next-generation" ecological model of lakes. A temperature diffusion model was calibrated for the 20-year data set, and estimates of vertical diffusion coefficients were summarized. Current efforts test those values by simulating total alkalinity. Initial results indicate the existence of previously undocumented sources of total alkalinity in the Lake Washington environment.

Research continued to address the potential importance of microscale heterogeneity in controlling phytoplankton species composition. Experiments were performed on three species to test the effects of nutrient patchiness on pure culture populations of algae. The following effect was clear and common among the species: Cultures exposed to a patchy nutrient regime grew on less average phosphorus per cell than did cultures grown at the same rate on homogeneous supply. Nutrient patchiness also appeared to produce smaller cells (reason unclear at this time). The effects of nutrient patchiness on natural assemblages of algae were tested in laboratory experiments. Preliminary results suggest that the heterogeneous supply produced a final species assemblage unlike the one produced under homogeneous nutrient supply.



GLERL Figure 1.--Sediment traps used in the Lagrangian ecosystem experiment to determine the downward flux of particulate matter.

Zooplankton feeding processes and rates need to be understood and quantified to predict the role of these invertebrates in cycling nutrients and controlling phytoplankton successional patterns in the lakes. In a cooperative study with the Skidaway Institute of Oceanography high-speed microcinematography was used to examine the feeding process of a Great Lakes copepod with three different-sized foods (diatoms). In contrast to marine species previously examined, the copepod used both active and passive feeding modes simultaneously, allowing capture of small particles at all times.

Work continued on the impact of food supply on nutrient regeneration by pelagic zooplankters, Biological regeneration of nutrients is a major source of nutrients to phytoplankton in the Great Lakes. Animal excretion is particularly relevant to recycling of nutrients in lakes because the nutrients released are directly available to phytoplankton. Our research has continued to elucidate important mechanisms of nutrient cycling and regeneration from organic sources in the pelagic and benthic zones. Ammonium excretion by Daphnia feeding in bottles containing suspensions of heat-killed algae was measured and directly compared with NH_3 excretion determined by a previously described flow-cell method. These experiments supported the usefulness of the heat-killed cells and showed that the flow-cell method approximates, but may

slightly underestimate, ammonium excretion by Daphnia magna. This underestimation probably occurs because the animals do not display their full ammonium excretion potential unless feeding on suspensions of algae.

Regeneration from sediments appears to be an important source of nutrients to phytoplankton in nearshore zones of the Great Lakes. Although phosphorus is not as readily released from aerobic sediments (like those in the Great Lakes) as from anoxic ones, recent work implies that phosphorus is indeed supplied to overlying waters from lake sediments. Benthic macroinvertebrates contribute to this process by mineralization (metabolic conversion of detritus into dissolved inorganic nutrients) and bioturbation (mechanical mixing) of the sediments to enhance nutrient release into overlying waters.

The importance of benthic invertebrates, compared with microbes, to the mineralization process (conversion of organic nutrients to inorganic forms) in lake sediments was evaluated using new techniques developed at GLERL. Our results imply that benthic invertebrate excretion may supply at least half of the nutrients mineralized in the near-surface sediments,

Perhaps no other biological group of organisms is a better indicator of water quality than the benthic fauna. Communities respond to and reflect environmental changes over long periods of time. Research continues to evaluate present-day distributions of benthic invertebrates. By comparing present numbers and kinds of organisms with those found 17-50 years ago, insight is gained into the lake's changing trophic state.

The 1978 Water Quality Agreement between the United States and Canada included language designed to minimize future toxic pollutant loads and mitigate the impact of existing contaminants. It is necessary to improve our understanding of how such chemicals move through a large aquatic ecosystem so that regulation and management of trace contaminants can be effective. Therefore, an in-house modeling team, consisting of chemical, toxicological, ecological, and physical scientists, was established. At first, research was conducted either in-house or at the University of Michigan; the program has now been expanded to include several other research groups, an arrangement that allows maximum flexibility.

During the past year, a preliminary design was completed of a toxic cycling model that includes the effect of sediment resuspension and reequilibration of sediments with the water column. Initial calibration runs for this model were made, and results of a simulation were compared with resuspension rates estimated from sediment traps. The model appears relatively insensitive to 50% changes in resuspension. Recent field work indicates that the monthly resuspension can change seasonally by an order of magnitude and may have significant impact on the model. Current results indicate that resuspension is acting as a scrubbing mechanism.

Many of the major synthetic organic pollutants of concern in the Great Lakes have a high affinity to sediments. One probable mode of entry of these contaminants into the food chain is ingestion of sediments by benthic organisms, which remobilize the compounds. Benthic organisms may play an additional role in the fate of pollutants through xenobiotic biotransformation, resulting in a direct decrease in the pool of potentially toxic compounds.

Studies continue to examine the kinetics of uptake, depuration, and biotransformation of selected polycyclic aromatic hydrocarbons (PAH's) by selected benthic organisms. During the past year, studies continued on the uptake of sediment-sorbed PAH. The uptake rate constant in Pontoporeia hoyi for benzo(a)pyrene (BaP) was small but reasonably reproducible. These rate constraints were used in conjunction with the uptake rate constant from water and the depuration rate constant to predict steady-state body burdens of phenanthrene and BaP for three different depths in Lake Michigan. The steadystate body burdens for the predicted and measured values compared well. The sediment-associated BaP is predicted to contribute 8%-35%; the sediment-associated phenanthrene is predicted to contribute 8%-88% of the steady-state body burden. A kinetics model for the bioaccumulation of PAH in Pontoporeia hoyi was developed to incorporate the uptake from water and sediment. The rate constants were allowed to vary with season, as had been determined for BaP, and with temperature. The seasonal variation with temperature was taken from a relationship determined for whole-lake data for Lake Ontario. This model predicted that the body burden of PAH for the P. hoyi would vary with the season, the highest concentrations occurring in winter and spring and the lowest in fall.

The association of synthetic organic contaminants with particles in an aquatic system plays an important role in determining the compounds' behavior and fate. Recent work indicates that PAH and other hydrophobic compounds can be bound up in a complex with natural organic matter. This phenomenon has important implications both to the sorption behavior of compounds and to their bioavailability. A reverse phase separation technique was used to determine the binding of carbon-14-radiolabeled organic pollutants to humic materials in aqueous solution. Initial laboratory results indicate that the bioavailability of the complexed contaminant to a selected amphipod is significantly lower than the bioavailability of the "free" compound.

Sediment traps were deployed at 12 stations in Lake Michigan, and samples were collected for the total summer period of stratification and for the total unstratified period. Particle fluxes indicate strong near-bottom resuspension throughout the year, and an intense injection of resuspended matter into the surface waters during winter. These large winter fluxes, when incorporated into our models, play an important role in determining water column concentrations and residence times for hydrophobic contaminants. Major field experiments are under way to improve our understanding of this process.

GLERL

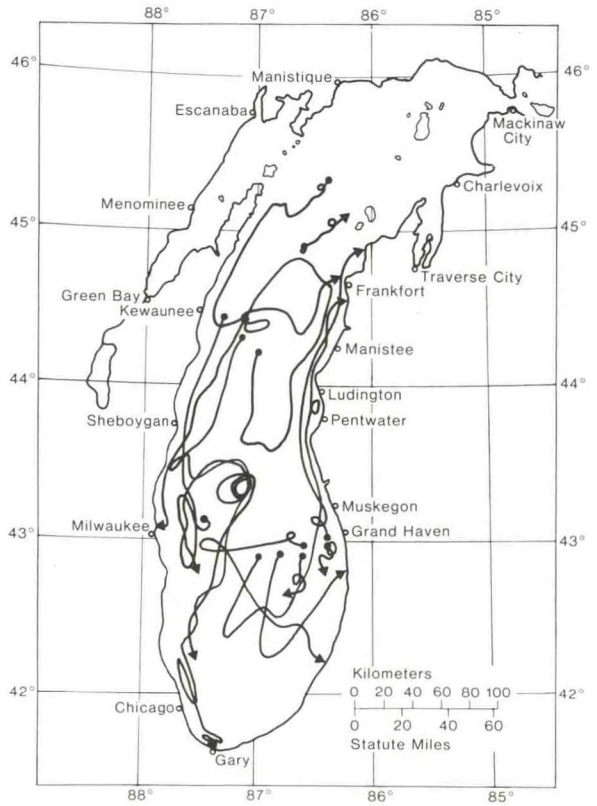
As part of the study of the long-term behavior and fate of toxic organic compounds in the Great Lakes, GLERL scientists collected box and gravity cores from locations of maximum sediment accumulation in the four lower lakes. The aims of this study are (1) to build an optimally self-consistent description of sedimentation, bioturbation, diffusion, and reaction for contaminants (inorganics, organics, and radionuclides) in each of the Great Lakes to aid development of long-term modeling efforts, and (2) to use historical records of contaminant fluxes reconstructed from self-consistent diagenetic models as a form of ground truth for models describing the behavior of contaminants in the water column. At the same time, cores were collected a few kilometers away, where accumulation was significantly slower, to test the assumption that the distribution of compounds reaching these locations would be similar.

A comparison of theoretical and experimental rotational mode structures in the southern basin of Lake Michigan shows that observed currents agreed with currents computed with a rigid-lid, vertically integrated model only in the frequency range corresponding to the maximum energy in the meteorological forcing, approximately 0.125-0.3 cycles per day. In this range, spectral peaks occur at identical frequencies for the wind, observed currents, and modeled currents. At lower and higher frequencies, the model underestimates kinetic energy observed in the currents.

After a year of charting the progress of satellite-tracked current drifters in Lake Michigan, a data base for drifter trajectories totaling more than 5,000 km was compiled (see GLERL Fig. 2). Data analysis to date reveals a persistent oscillation at 17 hours due to inertial motion and another in the 3-5 day range due to periodic overlake wind changes.

A two-dimensional, vertically integrated model and a three-dimensional, thermally stratified model are being used to simulate Lake Michigan currents. These simulated currents drive a water quality model that advects, diffuses, settles, and resuspends particles and dissolved toxic materials. To accomplish this, a general computer program was developed to calculate advective motion, settling, and resuspension,

Analyses of water temperature and current data collected in Lake Erie during 1979-80 were completed. These data document the process of central basin stratification and provide current flows during the existence of a thin hypolimnion layer.



GLERL Figure 2.--Drifter tracks for 8 months. The median speed was 17 cm s^{-1}; 99% of the speeds were less than 55 cm s^{-1}.

Current and water temperature data recorded in Green Bay were analyzed. Data from meters moored in.the bay mouth showed persistent high-speed flow out of the bay in the upper levels and flow of cold hypolimnetic water (below the thermocline) far into the bay. This circulation shows that bay flushing rates are significantly higher than previous estimates made with vertically averaged flow.

The longshore momentum balance in the inner and outer regions (relative to the breakers) of the coastal boundary layer was determined for four storm episodes on Lake Erie. Analysis of wind, wave, and current measurements revealed the relative importance of acceleration, pressure gradient, bottom stress, wave radiation stress, and wind stress in the two regions.

Work continued to develop mathematical models to simulate and predict basin runoff into each of the Great Lakes. Runoff predictions are needed to forecast water supply and lake levels. The models will also contribute to understanding of the response of watersheds to natural forces. The rainfall-runoff models will be incorporated into the GLERL model that represents the hydrologic water balance of the Great Lakes system. The GLERL Large Basin Runoff Model was applied to Lake Superior data and grouped for 22 subbasins around the lake. Both lumped- and distributed-parameter approaches were used to apply the model. Subbasins and the entire basin were modeled at daily, weekly, and monthly mass balance computation intervals by using daily data for the daily and weekly models and monthly data for the monthly model.

The first series of experiments for the Unsteady Overland Sedimentation Project was completed last year to test an existing theory of soil erosion. GLERL provided the theoretical formulations for experiments conducted by the U.S. Department of Agriculture. Refinement to the theory included specification of flow-dependent geometry, which allows for fluid flow equilibrium times to exceed sediment concentration equilibrium times.

The study of the winter flow regimes of the St. Clair and Detroit Rivers continued with completion of the second field season of continuous current measurements in the St. Clair River at Port Huron. Preliminary arrangements were also made for simultaneous measurements in the Detroit River.

Plans FY 1984

GLERL

A numerical model will be developed to describe the effect of the wave radiation stress on nearshore currents and the modification of waves by refraction, shoaling, and bottom friction. The model will be tested against the coastal boundary layer and surf zone data set obtained in Lake Erie in 1981.

Preliminary analysis of data from current meters deployed in Lake Michigan during summer 1982 and recovered in summer 1983 shows a high percentage of data return. The data will be analyzed and applied to study the low-frequency rotational modes of the lake and to test models for computing these modes. Since many of the drifter buoy tracks pass near the moorings, we will compare data from these two current measurement techniques.

Lake Erie circulation studies will conclude with publication of a synopsis report that will relate the biological and chemical lake characteristics to the underlying physics, Planned as a sequel to the Project Hypo summary of 1970 field work, the new report will be an environmental update of conditions one decade, and billions of sewage treatment dollars, later.

Particulate matter from sediment traps will be analyzed to estimate the extent of summer and winter sediment resuspension.

Radiochemical analysis of sediment cores collected from regions of high sediment accumulation in all five Great lakes will be completed. Results will be used to calibrate improved sediment-mixing models.

Uptake, depuration, and biotransformation rates of PAH's by major lake invertebrates will be measured. Results should indicate why benthic organisms have such high concentrations of organic contaminants.

Monthly measurements of water column concentration of cesium-137 and beryllium-7 will be completed. Results will be used to calibrate particle dynamics models.

The GLERL Large Basin Runoff Model will be used to forecast basin runoff and net basin supply for Lake Superior, and the forecast potential for the Great Lakes will be developed. A near-real-time hydrometeorological data acquisition and reduction system will be designed to support forecasts for the Lake Superior basin.

The experimental study of the St. Clair River winter flow regime using remotely monitored electromagnetic current meters will be continued following laboratory testing and reevaluation of the meters.

Data collected for the Lake Michigan Lagrangian Ecosystem Pilot Study will be analyzed, and the second year's field effort on species-specific ecological changes will be carried out.

The relative importance of benthic invertebrates, compared with microbes, in nutrient mineralization and regeneration will be quantified for selected sediment sites,

The quantitative importance of subsurface phytoplankton populations relative to surface populations will be determined for Lake Superior and Lake Michigan.

Mechanisms of zooplankton feeding determined from high-speed motion picture films will be combined with results of traditional feeding experiments to develop a model of zooplankton feeding.

A data set giving species composition, abundance, and biomass estimates of Lake Michigan benthic fauna will be completed, and analysis of long-term trends will begin,

A new statistical approach to analyze the kinetics of substrate-dependent phosphate uptake by algae will be completed and applied to evaluating the effects of phosphate and silicate limitation on phytoplankton growth in Lake Michigan.

OCEAN AND GREAT LAKES SERVICES RESEARCH

Ocean and Great Lakes services research activities have focused on better understanding leading to improved prediction of phenomena involved with marine warning and forecasting services. GLERL research includes field and analytic investigations of waves, flooding, water level oscillations, storm surges, overwater winds, and lake ice formation, growth, transport, and decay. Researchers in these areas work closely with colleagues at such agencies as the National Weather Service to assure that GLERL products meet the needs of operational forecasters. Followup on forecast accuracy and fine tuning of forecast procedures, in collaboration with these operational forecasters, are often included. GLERL scientists participate as representatives of NOAA and the Department of Commerce in regional, national, and international organizations addressing Great Lakes services research problems.

Accomplishments FY 1983

A parametric dynamical wave prediction model developed in Canada has been adapted, modified, and compared with extensive measurements of wave height and direction. The model, after being tested in ideal lake geometry, was modified to take account of the influence of cross-wind gradients of wave height on wave direction. The results corresponded closely to the analytical solutions for both wave direction and wave height. The model was applied to the Lake Erie directional wave measurements at the GLERL tower and to measurements made by the NOAA NOMAD (Navy Oceanographic Meteorological Automatic Device) buoy in western Lake Erie during the same time period. The results showed that, with locally measured wind data as input, the model provides remarkably accurate estimates of the general wave characteristics.

An improved spill model was completed and is now being tested. Improvements over the old version include increased resolution, multiple spill capability, zoom, and conformance to the GLERL modeling system standards.

A study was completed on the effect of mean wind stress on water level gage elevations with respect to chart datum. It was found that mean setup can have a significant influence on the gage-transfer method, particularly on Lake Erie. Correction factors for gage elevations on Lake Erie were determined and submitted for consideration to the International Joint Commission committee on the new Great Lakes water level datum. **GLERL**

A study of the effects of ice cover on river flow in the St. Lawrence River was completed. The final result is a hydraulic transient model for the upper St. Lawrence River, which can be used to simulate the flow conditions throughout a season of ice cover, The model combines the computational algorithm developed in the GLERL upper St. Lawrence River ice model and a new formulation for the ice cover effects developed in this study.

A revised Great Lakes Ice Atlas is in press. The document contains three major sections: (1) maps for half-month periods illustrating the areal distribution characteristics of the Great Lakes ice cover, (2) graphs and tables of winter severity during the 20 years of the ice cover climatology (1960-79) and

the 60 years prior to that climatology (1898-1959), based on accumulated freezing degree-days, and (3) ice thicknesses at near-shore locations.

Lake Superior temperature data were analyzed to identify the general characteristics of the seasonal decline in temperature during autumn and winter.

Work continued in interpreting the large collection of nearshore ice thickness data for 30 stations around the Great Lakes. Results suggest the significance of very localized processes in producing a given ice cover stratigraphy.

Despite extremely mild conditions in the 1982-83 winter, sufficient ice cover was available to test a method of measuring spectral reflectance under clear skies. Measurements of incident and reflected shortwave radiation were taken by mounting 3-in integrating spheres on the spectroradiometers.

Ice thermodynamic modeling was advanced during the past year by comparing two methods of simulating heat transfer through the ice sheet. Tests at five sites along the St. Lawrence River showed that the model accurately simulates rates of growth and the influence of snow cover if the time interval is 24 hours or longer. If the time interval is much shorter than 24 hours, the model must simulate heat transfer along a nonlinear temperature gradient.

GLERL provided more than 3,050 research products in both Ocean and Great Lakes Research and Assessment and Ocean and Great Lakes Services Research activities in response to almost 2,000 documented requests. This was in addition to regular mailings to those interested in receiving lists of publications (every 6 months) and any of the five types of GLERL publications.

Plans FY 1984

The wave forecast model developed and tested in 1983 will be further tested for possible operational application. Some improvements in the analytical formulation of the model will also be tested.

Data from NOAA Data Buoy Center (NDBC) NOMAD buoys deployed in the Great Lakes since 1977 will be statistically analyzed to examine individual, joint, and multivariate long-term distributions of the parameters and to develop statistical models for representation and prediction.

One satellite-reporting wave buoy will be acquired. The buoy will be used in support of wave-modeling efforts and for independent comparison tests with NDBC NOMAD buoy measurements of wave characteristics.

Drifter data will be collected in Lake Erie's western basin and in the Lake Ontario-Niagara River plume to further improve the spill model.

Drifter buoys will be implanted in the Lake Erie ice cover and tracked by satellite. The location data will be used to determine the speed and direction of ice cover movement at a number of locations.

Additional spectral reflectance measurements over snow and ice surfaces will be gathered with a field system modified for use under clear skies.

The feasibility of using digital data gathered by the NOAA-7 satellite for analysis of lake-wide shortwave radiation reflectance from the ice cover will be investigated.

A new field system for measuring thermal and radiation profiles within an ice cover will be developed,

The one-dimensional reduced version of the Great Lakes ice dynamics simulation model (an ice transport model applicable to the Great Lakes) will be extended to two dimensions.

The autumn and winter temperature decline characteristics of discrete areas of Lake Superior will be investigated; Results of this study will provide information useful for modeling temperature decline and initial ice formation for specific areas of Lake Superior.

Investigation of the variability of Great Lakes ice cover, using the digital ice concentration data base developed for the Ice Atlas, will continue.

FACILITIES

Measurements of trace synthetic organic materials and nutrients continued in the chemistry laboratories. In the biology laboratories, subjects of experiments include particle size selection, zooplankton grazing on natural lake algae and seston, nutrient uptake, growth rates, competition by algae for nutrients, cycling rates of selected algal nutrients, and investigations of the physiology and feeding rates of planktonic and benthic organisms.

The computer systems group supports the work of GLERL scientists by designing, coding, debugging, and testing systems and applications programs. The facility was greatly enhanced this year by the acquisition of a VAX 11/780 computer system, This system is expected to satisfy the small-to-moderate computing needs of GLERL scientists. General scientific computing is done on a CDC Cyber 170/750 located in Boulder, Colo., and accessed by means of a remote-job-entry station and about 25 interactive terminals located throughout the laboratory.

The GLERL library supports laboratory activities by maintaining a tailored research collection and offering special retrieval services when the collection cannot meet the documentation or information needs of the researchers.

The 65-ft research vessel Shenehon participated in several studies involving sediment trap mooring, collecting large-volume water samples, sediment coring, nutrient cycling, and benthic, planktonic, and bacterial experiments.

As before, current meter and sediment trap mooring, maintenance, and deployment constituted a significant portion of the workload of the Marine

Instrumentation Laboratory. Electromagnetic current meters were deployed in the St. Clair River during the winter and continue to operate without interruption. Acoustic and electromagnetic current meters were extensively tested and evaluated. Satellite track drogue buoys, originally intended for ocean use and considered disposable, were modified to allow recycling and extended usage. A radio direction finder to locate the buoys was also developed. Various sampling, extraction, and incubation devices were built or modified for work in marine pollution studies.

INTERNATIONAL AND INTERAGENCY ACTIVITIES

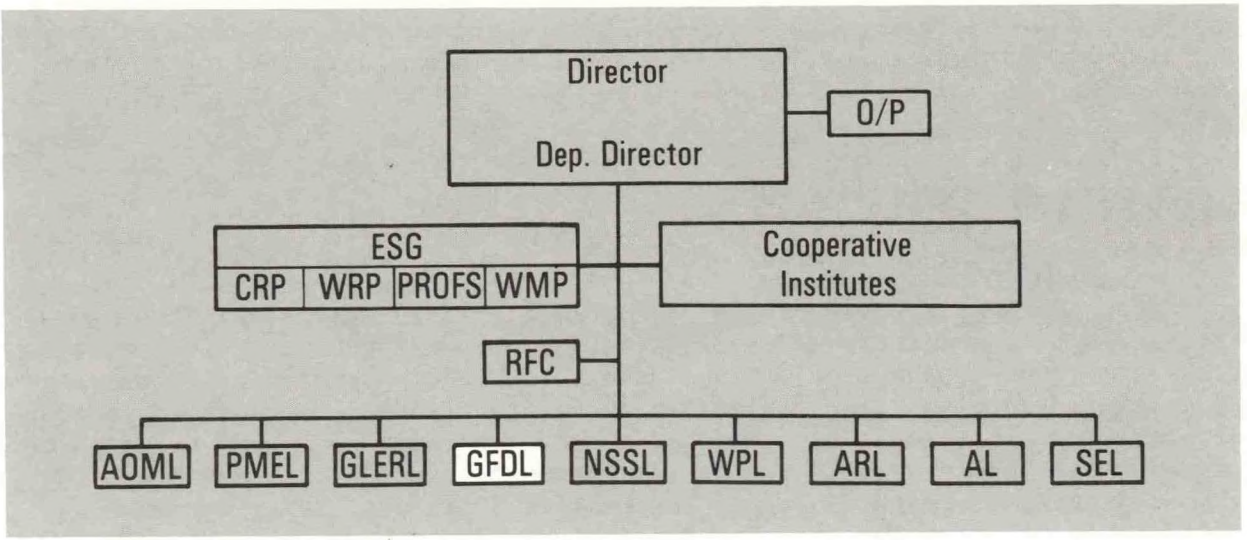
GLERL staff members were active in several International Joint Commission boards and committees, including the Levels and Flows Advisory Board, Information Network Board, Diversions Working Committee, Lake Michigan Task Force for Surveillance, Science Issue Panel, Aquatic Ecosystem Objective Committee, and Task Force on Modeling,

A GLERL staff member serves on the Natural Resources Management Committee (Subcommittee on Land and Air; Subcommittee on Water) of the Great Lakes Commission.

GLERL participated in the activities of the International Coordinating Committee on Great Lakes Hydraulic and Hydrologic Data, the Regional Response Team for Oil and Hazardous Substance Spills, Joint United States-Canadian Ice Information Working Group, the International Association for Great Lakes Research (Vice President, Board Member, Secretary), Science Education Administration of the U.S. Department of Agriculture, NOAA-U.S. Geological Survey Coordinating Committee for Hydrologic Research, International Association for Hydrologic Research, the Interagency Hydromet Steering Committee, the National Research Council Panel on Niagara River Ice Boom Investigations, the International Society for the Study of the Sea-Water Interface, the Governor's Problem Solving Institute, and the EPA/Corps of Engineers dredging study.

GEOPHYSICAL FLUID DYNAMICS LABORATORY
Princeton, New Jersey

Isidoro Orlanski
Acting Director



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

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

GFDL

The scientific work of the Laboratory encompasses a variety of disciplines: meteorology, oceanography, hydrology, classical physics, fluid dynamics, chemistry, applied mathematics, and numerical analysis. Research is facilitated by the Geophysical Fluid Dynamics Program, which is conducted collaboratively with Princeton University. Regular Princeton faculty, visiting 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.

Visiting scientists may also be involved in GFDL research through institutional or international agreements, or through temporary Civil Service appointments.

The following sections describe GFDL's contributions in five major research areas that correspond to NOAA's missions in oceanography and meteorology.

WEATHER SERVICE

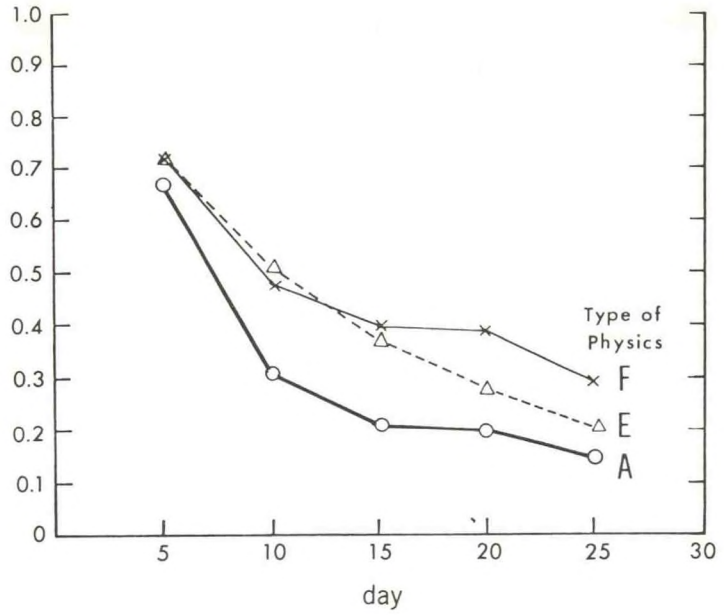
During the past two decades synoptic-scale weather forecasts have improved considerably because of the development of highly sophisticated numerical models that include more realistic description of the physical processes of the atmosphere, have high spatial resolution, and parameterize turbulent processes accurately. Creditable forecasts for periods up to a few days are now possible. The limits of atmospheric predictability have been extended to several weeks, but still the forecasts of some meteorological variables, such as precipitation, remain elusive. For small 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.

This success in the extension of atmospheric predictability encourages us to pose more challenging questions. Can the weather be predicted on time scales of months? Are mesoscale weather systems and regional-scale precipitation patterns predictable and, if they are, is such prediction dependent on predicting 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, mesoscale convective systems, severe storms, and tropospheric blocking.

Accomplishments FY 1983

For the past several years, GFDL has been engaged in the production of a Level III-b gridded analysis of data from the First GARP Global Experiment (FGGE). The analysis was performed using an experimental continuous data assimilation system. In FY 1983, GFDL completed the operational production of the analyzed data sets, which were transmitted to two World Data Centers for archiving and dissemination.

Monthly forecast experiments with general circulation models (GCM) were conducted for four winter cases, and skill in the 10-day and 20-day mean height prognoses was demonstrated. These experiments revealed that GCM quality and validity of the initial conditions are crucial for a successful simulation of planetary-scale circulation patterns and blocking phenomena. This implies that, in the development of models for use in forecasting on the monthly time scale, internal dynamics must be treated carefully before the effects of the anomaly components of external forcing can be included. GFDL Figure 1 shows that improving the internal dynamics improves the forecast.



GFDL Figure 1.--The effect of a GCM's internal dynamics (i.e., model physics) on its forecasting skill is shown as a function of the forecasting range (in days). Forecasting skill is represented by the correlation coefficient between the observed and forecast 500-mb geopotential height anomaly for 10-day mean conditions averaged over four winter monthly forecast experiments. A finite difference GCM uses three different versions of model physics--A, E, and F. A physics is an early version (1965 after Manabe), E physics is a mid-1970's version, and F physics is the latest and most advanced version (1978 after Miyakoda). The F version differs from the E version by incorporating a sophisticated cumulus parameterization. The results show clearly the importance of internal dynamics in improving extended range (e.g., monthly) forecasts.

The importance of subgrid-scale processes on GCM performance has emerged clearly in recent prediction studies. By using a sophisticated cumulus parameterization, the simulation of tropical precipitation was improved. In addition, the condensational heating from precipitation processes then exerts an appreciable effect on the formation of middle-latitude planetary waves. Since mountain peaks also exhibit appreciable effect on the large-scale flow, a theory characterizing the extent to which a mountain acts as a barrier to the oncoming flow was developed and has important implications concerning the representation of mountains in GCM's. **GFDL**

Several cases of blocking were successfully simulated by a GCM. In parallel, a new theory was developed in which blocking appears as a nonlinearly amplified response to a weak localized forcing.

Analysis of a 15-year series of observed geopotential height maps has revealed that the zonal winds averaged over certain longitude ranges have distinct meridional profiles associated with an existing classification of

teleconnection patterns. The patterns were reproduced to a considerable extent when the appropriate zonal wind profiles were used in a linear barotropic model. Thus, the zonal wind profile emerges as a key factor in determining the character of the teleconnection pattern.

The structure and dynamics of convection associated with fronts was clarified using numerical simulations and stability analyses. The simulation of an observed moist cold-front system produced a squall line that shows a dual-updraft structure very similar to that commonly observed. A linear, two-layer, dry model without microphysics was able to reproduce this dual-updraft structure for certain low-level wind intensities. Also, a stability analysis of narrow cold-frontal rainbands revealed a barotropic mechanism by which horizontal shear can organize the rainband convection into the regularly spaced cellular structure observed by radar.

Results from a limited-area model nested in a global spectral model suggest that the positions and strength of mesoscale (as well as synoptic) features within the limited-area model are more sensitive to uncertainties in the lateral boundary conditions than to uncertainties in the initial conditions after only a few hours of simulation.

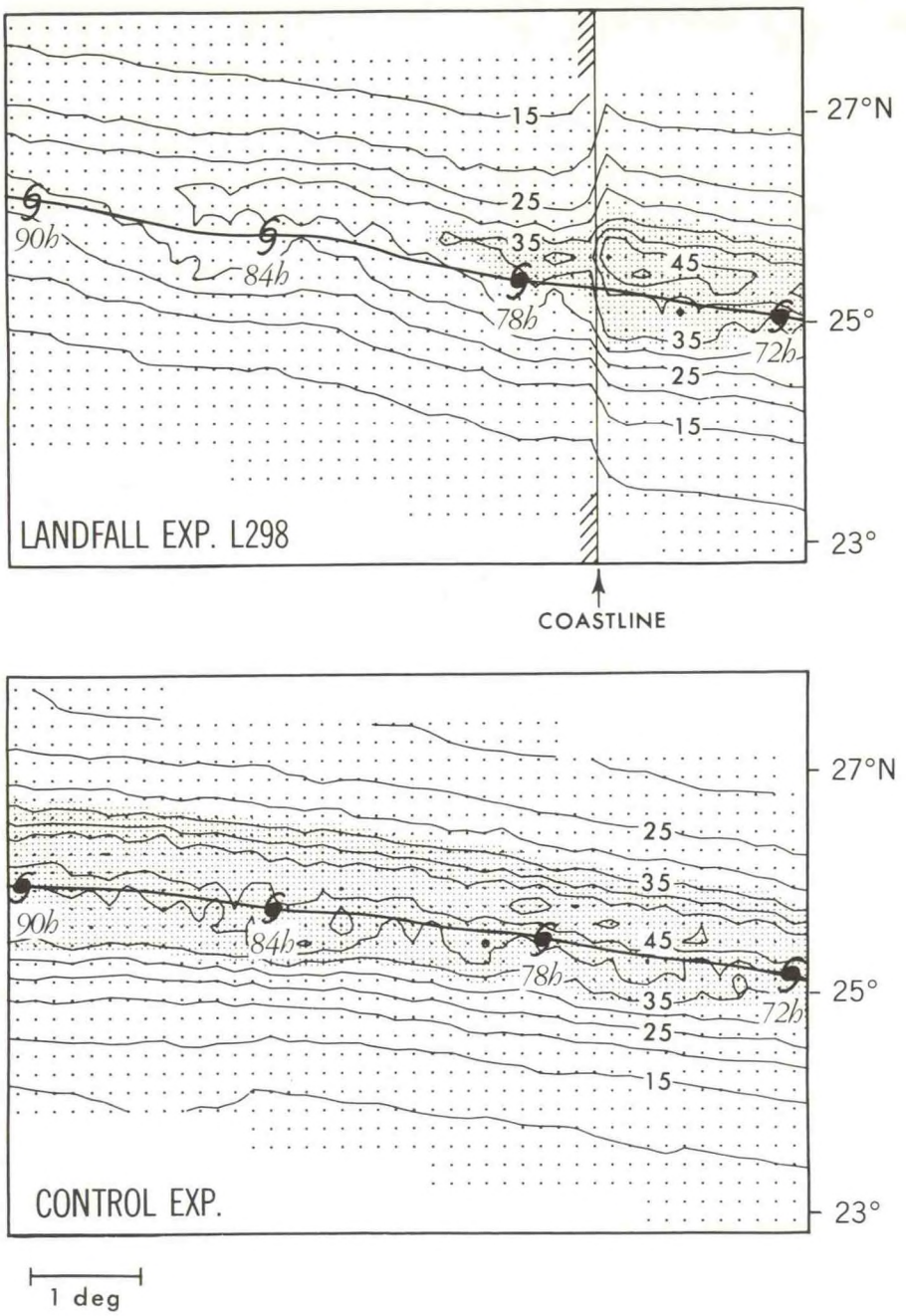
A meso-beta simulation of the severe-storm outbreak of 10-11 April 1979 (SESAME Day I) over Oklahoma and Texas, which used initial and boundary data from a dense network of observations, shows good agreement with the observed precipitation patterns as well as the mesoscale environment in which severe storms first developed.

Cloud simulations under continental conditions obtained some realistic results including a maximum vertical velocity slightly larger than 20 m s^{-1} at 7.5 km and a maximum disturbance potential temperature of 5.5°C near 8.5 km. At the surface 1.5 cm of rain fell in one-half hour, and the downdraft outflow was cooler than its environment by 6°C.

The landfall and subsequent decay processes of tropical cyclones were simulated using a triply nested numerical model (see GFDL Fig. 2). A major cause for decay was found to be the reduction of water vapor supply to a storm system after landfall. The lower surface temperature over land also made a large contribution to decay through the suppression of evaporation, the alteration of the boundary layer winds, and the reduction in conditional instability.

The mechanism of comma vortex formation in the tropical cyclone model was studied. The tail of the comma pattern tends to develop at the high-wind side of disturbances. The beta effect retards the development of a comma vortex when basic flow is easterly and enhances it when flow is westerly. The air-sea interaction is necessary for formation of the distinct comma vortex.

A numerical study on the transformation of a tropical easterly wave revealed that a heating effect is required for the growth of the wave. The nonlinearity effect, if and only if it is combined with the heating effect, accounts for the formation of a distinct vortex at a trough region of a wave.



GFDL

GFDL Figure 2.--A numerical simulation demonstrates the effect of landfall on hurricane winds. The horizontal distribution of the maximum low-level winds for a landfalling hurricane is shown in the top panel (land surface temperature = 298 K); the control case of a hurricane proceeding only over the ocean is given in the bottom panel (ocean temperature = 302 K). The shaded areas indicate hurricane force winds above 33 m s^{-1}. Over the ocean, hurricane force winds continue throughout the 90-h period of simulation, but after landfall (top panel) they are sharply curtailed by major decay mechanisms, such as reduced water supply and lower surface temperatures over land.

Plans FY 1984

Plans in extended range forecasting are to complete the monthly forecast experiments for the four winter cases, to make a comparative study of different model physics (versions A, E, and F), to construct a higher resolution spectral model (R42L18) with F physics, and to undertake monthly forecast experiments for the historically anomalous 1982-83 winter case.

The generation of transients in local baroclinic zones, the distribution of the consequent eddy fluxes, and the effects of the fluxes on blocking will be investigated.

In mesoscale dynamics we shall investigate further the impact of initial and boundary data on the simulation of mesoscale convective systems, simulate the Pacific comma cloud and the Midwest summer mesoscale convective complex, and complete research on the development of cellular structure in frontal rainbands.

Further plans are to investigate the value of an explicit formulation of moist convection as a means of representing convective processes in a meso-beta-scale model, to nest a cloud model within a meso-beta-scale solution, and to examine the vertical momentum transfer and kinetic energy transformation associated with the interaction of vertical wind shear and deep moist convection.

Plans in hurricane research are to simulate hurricane landfall with a new model to investigate further the effect of topography on landfall, and to complete research on the comma vortex formation in hurricanes and on the transformation of easterly waves.

CLIMATE

The purpose of climate-related research at GFDL is twofold: to describe, explain, and simulate climate variability on time scales from seasons to millenia; and to evaluate the impact on climate of such human activities as the release of CO_2 and other gases into the atmosphere. The phenomena that are studied include large-scale wave disturbances with periods of a few weeks, and their role in the general circulation of the atmosphere; the seasonal cycle, which must be known before departures from it (interannual variability) can be appreciated; interannual variability associated with phenomena such as the El Niño/Southern Oscillation; very-long-term variability, which includes the ice ages for example; and the dynamics of planetary atmospheres, the study of which enhances our perspective on terrestrial meteorology and climate. To achieve these goals, both observational and theoretical studies are necessary; available observations are analyzed to determine the physical processes by which the circulations of the oceans and atmospheres are maintained; and mathematical models are constructed to study and simulate the ocean, the atmosphere, the coupled ocean-atmosphere-cryosphere system, and various planetary atmospheres.

Accomplishments FY 1983

The CO_2-induced change in hydrology was the subject of continued investigation by use of an atmosphere-mixed-layer ocean model. It was found that, in winter, soil moisture in the subtropical steppe belt tends to decrease with increased CO_2 concentration, owing to the poleward shift of the middle-latitude rainbelt.

The transient response of climate to an increase of the atmospheric concentration of CO_2 was investigated by use of a coupled ocean-atmosphere general circulation model with idealized geography. It was found that the zonal mean of surface air temperature over continents responds more quickly to an increase in CO_2 levels than does the corresponding surface temperature of the oceans, which have large thermal inertia.

The results from a model experiment indicate that a large-scale soil moisture anomaly in the middle-latitude rainbelt tends to persist longer than a similar anomaly in the subtropics from which moisture is exported to the neighboring rainbelts.

Simulation of the climatic effect of massive continental ice sheets occurring in an ice age indicated a significant reduction of soil moisture in a zone south of the ice sheets in North America and Eurasia. This is consistent with some geological evidence from the last glacial maximum.

A linear, baroclinic stationary wave model reproduced very accurately the stationary eddies in the wintertime upper troposphere of a general circulation model. The linear simulation allows one to dissect the stationary wave field into parts resulting from different features in the mean diabatic heating field and in the surface topography.

The theoretical justification for barotropic models of planetary-scale stationary eddies forced by topography was clarified by studying the extent to which the stationary eddy field is dominated by external Rossby waves and by the design of a barotropic model that satisfactorily captures the external Rossby wave part of the solution.

The effects of wave-wave interactions on middle-latitude transient ultra-long waves were examined by eliminating some selected wavenumber components from a GCM.

GFDL

The GFDL troposphere-stratosphere-mesosphere GCM (SKYHI) simulated the equatorial semiannual oscillation (SAO) in good agreement with observations. The westerly acceleration phase of the SAO is driven by absorption of dissipating Kelvin waves. The easterly acceleration phase on the summer hemisphere side of the Equator is provided by advection of easterly angular momentum by the cross-equatorial mean meridional acceleration. On the winter hemisphere side, the easterly acceleration is provided by absorption of winter planetary waves propagating into low latitudes.

A detailed space-time spectral analysis of the SKYHI GCM achieved some remarkable new results on the structure of equatorial Kelvin waves. All classes of identified Kelvin waves have zonal wavenumber 1-2, an eastward phase velocity, and an upward flux of eastward momentum. In addition to the

"traditional" Kelvin wave (period, 10-30 days; vertical wavelength Lz, 10 km), there have been identified "fast" Kelvin waves (period, 5-7 days; Lz, 20 km), and "ultra-fast" Kelvin waves (period, 3-4 days; Lz, 40 km). These simulated waves agree well with recently discovered observational counterparts.

A coupled ocean-atmosphere model that simulates the amplification of modest initial perturbations during El Niño/Southern Oscillation events was developed. The model reproduces the simultaneous growth of perturbations in the atmosphere and ocean.

Global atmospheric circulation statistics for May 1958 through April 1973 were published as a NOAA Professional Paper. The volume includes more than 8,000 maps and cross sections on microfiche. The mean climate and its year-to-year variability are shown for the monthly, seasonal, and annual time scales.

The global cycles of angular momentum, energy, and water substance in the atmosphere-ocean-solid earth system and some of the regional variations were documented and published.

A high correlation was discovered between the monthly-mean hemispheric temperature averaged over the entire troposphere and the sea surface temperature in the eastern equatorial Pacific Ocean. Increased convection in the tropics during El Niño conditions (warm episodes) apparently leads to an overall warm atmosphere with a lag of about 6 months.

Observed transient eddy heat and vorticity fluxes tend to destroy zonal asymmetries in the time-mean circulation. Disturbances with time scales longer than 10 days dominate this process.

Middle-latitude disturbances accompanying cold air outbreaks over eastern Asia show a typical life cycle with baroclinic growth during the polar outbreaks followed by a decay dominated by barotropic processes.

A model of Jupiter's Great Red Spot and Large Ovals, based on intermediate-geostrophic (IG) dynamics, provided an explanation of the structure, the longevity, and possibly the origin of these solitary and isolated forms of vortex. IG motions occur on scales greater than those of quasi-geostrophic ones. The longevity of some planetary-scale patterns in the Earth's atmosphere may be due to the stability of IG-scale motion, as suggested by the theory.

Plans FY 1984

Plans for CO_2-climate sensitivity studies include constructing a global ocean-atmosphere model with realistic geography by combining a spectral model of the atmosphere with a finite difference model of the oceans and then studying the transient and equilibrium responses of climate to a CO_2 increase.

Ice age studies will examine the response of an idealized nine-level atmospheric GCM to successive decreases in the solar constant, Q, to see if sensitivity increases monotonically as Q is lowered, as predicted by simple

energy balance models, or if the sensitivity has the more complex dependence on Q found with a two-level primitive equations model.

Research on wave dynamics and climate will include theoretical and numerical studies of the effects of transient eddies on the mean zonal flow and the comparison of linear stationary-wave models with GCM's. The comparison will extend the analysis of the wintertime stationary waves to the seasonal variation of the stationary waves, and will examine the extent to which monthly or seasonal mean anomalies from the mean GCM climate can be understood as being due to anomalies in the forcing of stationary waves.

Plans for troposphere-stratosphere-mesosphere modeling are to complete the analysis of equatorial Kelvin wave structure and to continue the analysis of seasonal integrations of the SKYHI model.

Studies on unstable air-sea interaction will be continued with inclusion of CISK (Convective Instability of the Second Kind) processes.

ATMOSPHERIC QUALITY

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

Ongoing research involves studies of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Capability is being developed to solve for a number of trace constituents simultaneously. Interdependent experiments using this capability will involve ozone and its precursors, partitioned components of total reactive nitrogen, carbon monoxide, and other trace species. Also, a dynamically active ozone photochemistry is being developed for inclusion in the GFDL troposphere-stratosphere-mesosphere GCM.

Accomplishments FY 1983

GFDL

Comparison of analysis results from the 3-D "classical ozone" model of the troposphere against available observations and against a comprehensive ozone photochemical model led to some surprising, but tentative, conclusions. The classical ozone theory, which assumes that ozone is produced in the stratosphere, migrates through the troposphere, and is destroyed at the surface, agrees quite well with observations. However, to produce the observed summertime behavior of ozone in the Northern Hemisphere, net photochemical destruction of ozone may be required in high latitudes, and net production may be necessary in middle latitudes. These conclusions are quite sensitive to assumptions about the highly uncertain NO_x amounts in the troposphere.

Preliminary modeling experiments were carried out to examine the mixing of a passive tracer due to deep moist convection. The initial tracer is confined to a surface layer 1,750 m deep. After the mixing associated with a 1-h convective shower cloud, the horizontally averaged tracer concentration has a bimodal distribution in the vertical. The primary maximum is in the boundary layer, and the secondary maximum is in the layer of convective outflow at 10 km. A well-defined minimum in tracer concentration is found at middle levels. These results illustrate the well-known nonlocal character of moist convective mixing.

Plans FY 1984

Plans include continued studies on the convective mixing of a passive tracer to examine the downward advection of tracer from the upper atmosphere as well as from the boundary layer source treated previously. Studies will include the effect of water solubility. In the tropospheric "Combustion Nitrogen" and "Maximum Insight" series, final steps in the atmospheric N_2O and "Classical Ozone" model experiments will be completed and compared with observations.

Model development will continue on a self-consistent two-dimensional tracer transport model.

MARINE QUALITY

GFDL research related to the quality of the marine environment has as its objective the simulation of ocean conditions in coastal zones and in estuaries, and the modeling of the dispersion of geochemical tracers (e.g., tritium, radon) in the world oceans. Over the next few years, two- and three-dimensional models of estuaries such as the Hudson-Raritan and Delaware Estuaries will be 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.

Accomplishments FY 1983

The marine geochemistry group began to consider how to model nutrient cycling in the ocean. This is the major first step in predicting the role of the oceans in determining atmospheric CO_2. Preliminary box model calculations suggest a mechanism for predicting the levels for the partial pressure of CO_2 observed in glacial waters, which are lower than those in the lower-latitude oceans. This mechanism requires more efficient nutrient uptake by organisms in high-latitude waters and/or less efficient mixing of nutrients into the mixed layer.

Plans FY 1984

Plans include the testing of nutrient cycling parameterizations in a coarse-resolution sector model, and then in the North Atlantic model, completing the analysis of Cs-137/Sr-90 Weathership and other observations, and analyzing data from the Transient Tracers in the Oceans program in the North Atlantic.

OCEAN SERVICES

Models for predicting ocean conditions are being developed at GFDL. The simpler models can predict relatively few parameters. For example, one-dimensional models of the turbulent surface layer of the ocean predict the sea-surface temperature and heat content of the upper ocean. More complex three-dimensional models are being developed to study phenomena such as the time-dependent development of Gulf Stream meanders and rings, the generation of Somali Current after the 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 El Niño/Southern Oscillation phenomena. Much of the ocean dynamics work cited under Climate is also relevant to Ocean Services.

Accomplishments FY 1983

A three-dimensional ocean circulation calculation with high vertical resolution was carried out on the CYBER-205 to provide a detailed check on analytic theories of the thermocline. The model was successful in showing how convection and wind stress act together to inject low-potential-vorticity water along density surfaces. Of particular interest is the simulation of subtropical mode water near the western boundary.

"A Climatological Atlas of the World Ocean" describing the annual mean and seasonal structure of the oceans was published as a NOAA Professional Paper. The basic analyses are already widely used in the United States and abroad.

Plans FY 1984

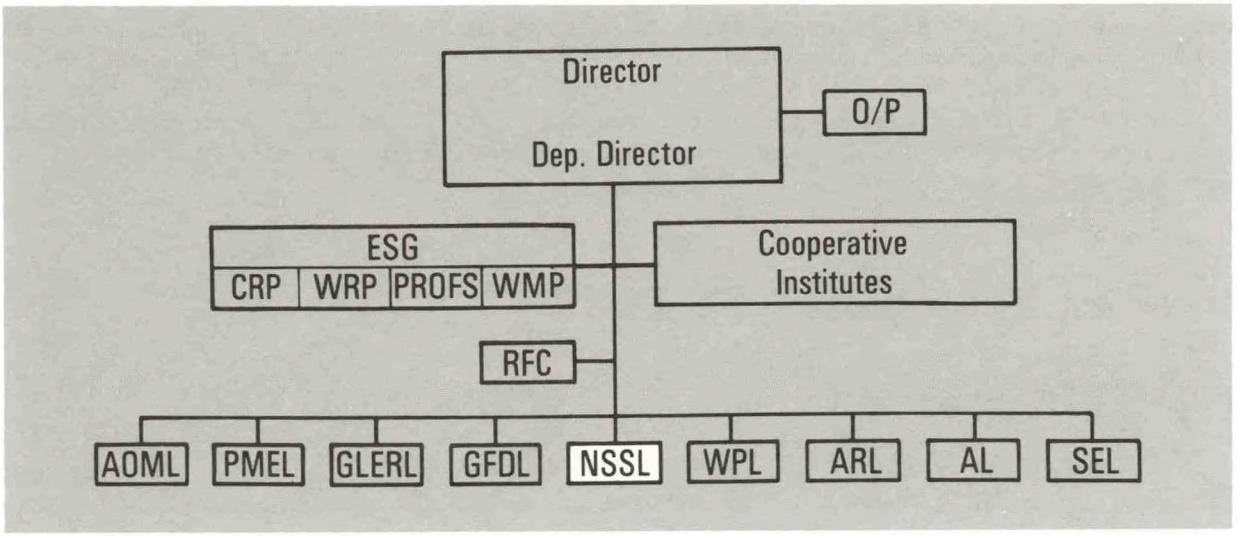
Plans in ocean dynamics are to develop a high-resolution model of the tropical Pacific Ocean to study the seasonal and interannual variability, including simulation of the El Niño phenomenon, and to extend eddy-resolving models to a more realistic geometry, in order to assess the role of eddies in the transport of water mass properties.

The coupled ice pack/ocean model with higher resolution will be used to identify the areas of maximum ice growth and to examine the effect on the heat and salinity budget of the Arctic Ocean.

Observational studies will investigate further the heat and sweetwater balances over individual oceans and the year-to-year variability in subsurface heat storage over data-rich areas in the North Atlantic Ocean.

NATIONAL SEVERE STORMS LABORATORY
Norman, Oklahoma

Edwin Kessler
Director



The National Severe Storms Laboratory (NSSL) supports NOAA's weather observing and forecasting missions through studies of storm processes, numerical and conceptual modeling of storm phenomena, and development of improved means for observation. The NSSL mission has changed little over the years, but approaches have changed considerably in response to new technological developments, new scientific discoveries, and new requirements. Recent emphasis has been on Doppler radar applications and studies of storm electricity.

The Laboratory has a 50-station capability for digital recording of surface meteorological parameters, and maintains instrumentation on the tallest tower in the United States that is equipped for recording boundary layer parameters. Two 10-cm Doppler radars on a 41-km baseline provide unique capabilities for recording atmospheric circulations both in precipitating weather systems and in the optically clear boundary layer. A comprehensive range of instrumentation for recording electrical parameters has been brought to a high peak of refinement so that distributions of wind, water substance, and lightning can be recorded contemporaneously, and their interaction examined.

Through numerous relationships with other government agencies and universities, NSSL constitutes a resource for severe-storm data examined by researchers around the country and overseas. The Laboratory, with its collaborators, has nearly completed analyzing data collected during the interagency field program SESAME 1979 (Severe Environmental Storms And Mesoscale Experiment), and is applying the results to improve understanding and prediction of severe storms and to improve the use of observing tools. The Laboratory is working closely with the Joint System Program Office (JSPO) of the Next-generation Radar (NEXRAD) program to help develop an effective national weather radar network for the late 1980's and beyond.

METEOROLOGICAL RESEARCH

The Meteorological Research Group seeks to improve thunderstorm forecast and warning capabilities by developing conceptual, numerical, and laboratory models of major thunderstorm phenomena and of the prestorm atmosphere. Observation, analysis, and interpretation of storm flow fields and hydrometeor distributions expand our understanding of external and internal forcing, processes that contribute to intense thunderstorms and their attendant phenomena. Theoretical and observational studies are organized within two projects: Modeling and Dynamics, and Storm Evolution and Analysis.

Accomplishments FY 1983

THEORETICAL STUDIES

Powerful predictive tools may result from an understanding of the origins of storm rotation. Most tornadic storms rotate cyclonically, but a few rotate anticyclonically. An application of linear inviscid convection theory indicates that the difference is tightly related to the vertical shear of ambient winds relative to the motion vector of a storm; when the vertical shear of the environmental wind is large and the storm-relative winds veer with height, then updrafts rotate cyclonically and downdrafts anticyclonically. The theory leads to a technique for forecasting mesocyclone formation, given a sounding and an observed storm motion.

Doppler radars in observing programs should be deployed for economy and best satisfaction of experimental objectives. Possible networks of two to nine radars have been examined for maximization of the quantity Areal Coverage/Error. The network of all radars operating simultaneously is superior to that obtained by combining optimum smaller networks. The method provides adaptability to varied requirements; for example, a network can be designed to be optimum for a specified probability of occurrence of an event and with resolution to identify a phenomenon of specified scale.

Doppler radar data indicate distributions of air velocities. New diagnostic methods, being refined at NSSL, lead from the velocity distributions and sounding data to estimates of temperature, water vapor, hydrometeor fields, and microphysical processes within the observed storms. Because the methods involve some working backward as well as forward with equations incorporating dynamical and/or microphysical processes, they are described as "retrievals" of state parameters and processes. The methods are proving to be powerful aids to understanding of storm processes.

A retrieval scheme for microphysical processes and parameters was substantially improved at NSSL, to include different forms of ice, with expanded descriptions of cloud- and raindrop distributions and the physics of warm-cloud processes. In a study of hail growth in an Oklahoma multicell storm with this improved model, injection of hail embryos in the main updraft led to most of the large hail that formed. Trajectories and growth of hailstones calculated in the model are in excellent agreement with the location of hailstones sampled beneath the storm, and with the hailstone fine structure.

A numerical model and Doppler radar data were also used to investigate hail growth characteristics in two other observed severe storms. One storm, although tornadic, was not a major hail producer; the other, a prolific producer of destructive large hail, did not harbor significant tornadoes. The study demonstrates that a broad region of moderate updraft (20-40 m s^{-1}) is critical for hail production because hail does not remain long enough in stronger updrafts to grow substantially. Therefore, convective instability in the troposphere beyond a certain threshold does not seem as important as factors (which remain uncertain) that determine shape and size of the updraft.

A control of microphysical processes on hailstone production is demonstrated in a model of low-density growth (riming with immediate freezing on contact of liquid water). Low-density hailstones ascend more quickly in the updraft by virtue of their smaller fallspeed relative to the air, and their trajectories are markedly different from model hailstones of density 0.9 g cm^{-3}.

Dynamical parameters in a tornadic storm that occurred on 20 May 1977 were retrieved to obtain a better understanding of the transition from pretornadic to tornadic stages. In the pretornadic stage, horizontal pressure gradients near the updraft maximum and near the characterizing couplet of high and low pressure were found to be oriented at each altitude parallel to the environmental wind shear vector there. This finding agrees with a recent analysis based on linear theory. The vorticity maximum is coincident with a strong pressure gradient in the pretornadic phase, and with minimum pressure in the tornadic stage.

OBSERVATIONAL STUDIES

Mesoscale Observations

Subjective interpretation of data from meteorological satellites has provided better diagnoses of major weather systems and improved warnings of severe weather, but there is a substantial unrealized potential in objective analysis of satellite data. Radiance data provided by the most technologically advanced satellites are descriptors of temperature distributions. Detail in thermal fields is enhanced by matching the shape of analyzed gradients to the shape of satellite-observed radiance gradients, while constraining the pattern to fit widely spaced radiosonde data. When analyzed fields were tested with a quasi-geostrophic numerical model, upward motion defined by the model correlated 35%-100% better with cloud locations when satellite and rawinsonde data were both used, than when rawinsonde data alone were used. Additional development of the method at NSSL leads to objective analysis of temperature through the whole atmosphere, given radiance distributions in four- to six-wavelength channels.

NSSL

A second effort in the mesoscale area seeks to have an on-site mesoscale numerical model for general research purposes, including tests of model initialization with satellite data as discussed above. The Anthes-Warner (Penn State) mesoscale model is being adapted for use on the CDC-750 computer at Boulder.

Severe Storms

Statistical analyses of severe-storm parameters, prepared from NSSL mesonetwork data, include these findings: The surface parameters associated with both isolated storms and squall lines are statistically nonstationary and nonhomogeneous; the greatest variance in squall line parameters lies ahead of the line, and the greatest variance in isolated storms lies beneath the storms. These and other statistical data contribute to optimal design of networks for storm observation.

The NEXRAD program contemplates a network of Doppler radars over most of the United States. It is accordingly important to know how to interpret the patterns of radial velocity that will be depicted by these radars. To this end, an atlas of the signatures of various wind regimes as seen by single Doppler radar was prepared at NSSL.

A study of the thermodynamic properties of tornadic thunderstorms showed that mesocyclone intensification during tornadogenesis reduces the normal upward pressure gradient force and probably facilitates formation of the concentrated rear flank downdrafts that are often associated with tornadic storms. The study indicates that rear downdrafts respond to mesocyclone intensification, rather than being a cause of mesocyclones as has been frequently assumed.

Cloud and precipitation forms in ascending saturated air, and data on air motions in association with precipitation particle sizes are critical to understanding of precipitation development. Doppler velocity spectra collected at vertical incidence are a potential source of high-resolution information, but accuracy in estimates of particle sizes has been poor owing to computational intertwining of sizes, the fall speed of the particles, and the vertical air speed. However, a new dual-wavelength technique allows determination of vertical air motion independent of drop size distribution. Comparative tests of this and other methods highlight the high accuracy of the new method, but also indicate its extreme sensitivity to errors in the data.

A NOAA P-3 aircraft equipped with Doppler radar participated in the Oklahoma observational program during May. Flights on three days with severe storms demonstrated that the area in which storms can be effectively studied is substantially enlarged when ground-based and airborne Doppler radars are used in combination.

Plans FY 1984

We expect to complete a diagnostic model to examine the dynamics of vortex formation. Velocity and thermodynamic fields from both observational and numerical modeling studies will be used as input data.

Theoretical and observational investigations into the formation of mesocyclones will continue. A technique for predicting mesocyclones, given a sounding and observed storm motion, will be evaluated.

We will be developing and testing signature recognition techniques and the use of mathematical algorithms with Doppler radar data to distinguish and identify thunderstorms and their various severe manifestations.

Air bubble and crystalline structures of modeled hailstones and samples collected at the ground will be compared. The field phase of a cooperative project to use in situ measurements, surface hail collections, multi-Doppler radar, and numerical models is planned for spring 1984. A major activity of the study is to initialize and check model results with observed hailstones both in-cloud and on the ground.

Documentation of a microphysical and thermodynamic retrieval model will be completed. The model will be applied to storm data for four case studies.

Documentation will be completed on dynamic retrieval experiments for the 20 May 1977 tornadic storm case and on observational and modeling studies of the 19 May 1977 squall line.

DOPPLER RADAR AND STORM ELECTRICITY RESEARCH

The NSSL facility to observe electrical and kinematical processes contemporaneously with precipitation phenomena has no parallel. The major objectives of Doppler Radar and Storm Electricity Research (DRASER) include (1) determining relationships between processes of lightning discharge, thermodynamics, and precipitation in thunderstorms in order to develop improved indicators of thunderstorm severity and hazards; (2) developing and refining remote-sensing techniques for locating, tracking, and predicting thunderstorms and their attendant hazards; (3) defining lightning and kinematic characteristics of storms for inputs into engineering criteria for hazards to aircraft and ground facilities, and into models used in environmental studies; (4) providing ground truth and supportive data for development of new instrumentation and refinement of observational techniques.

These objectives are addressed through both theoretical and observational studies. The Doppler Radar Group focuses its efforts on interpretation of prestorm and stormy weather phenomena, using Doppler radar data for both. In FY 1983, the Storm Electricity Group concentrated its analyses on data simultaneously obtained from our many storm electricity sensors. The following discussion also includes a section on research in DRASER that is particularly relevant to the NEXRAD program or to flight safety.

Accomplishments FY 1983

DOPPLER RADAR

Wind Estimation by Doppler Radar - Theoretical Studies

Since Doppler weather radar has some capability to measure winds in the clear air, we have sought to apply prestorm Doppler radar data to thunderstorm forecasting. Clear-air radar echoes are several orders of magnitude weaker than echoes from storms, and special care in data processing, editing, and analysis is required; hence much effort is expended on developing techniques for accurate representation of the wind fields.

We formulated a unifying statistical theory to explain the scattering properties of turbulently mixed clear air observed with VHF Doppler radar wind profilers. The theoretically derived angular dependence of echo power shows that anisotropic scatter can explain an important class of observations.

The developed theory embraces several echoing mechanisms and extends the existing formulations for the case where the Fresnel zone radius is comparable with or smaller than the correlation length. Conditions are specified under which Fraunhofer and Fresnel scatter from turbulent air can be distinguished, and it is demonstrated that the spectral sampling function is independent of the resolution volume locations.

We compared three techniques used to retrieve the three wind components from measurements of radial velocity made with single Doppler radar: triple fixed beams, velocity-azimuth display (VAD), and velocity-elevation display (VED). We examined the errors in the retrieved wind field components when each of these techniques was applied, and derived equations for the bias and variance of the uniform wind components under the assumption of spatial linearity time invariance, and a specified radial velocity variance. In our comparison test each method used the same number of data samples to estimate wind at a constant height; all methods produced the best estimate at an elevation angle θ_e near 55°. Although estimate variance can be reduced by averaging, bias errors cannot. Furthermore, selection of an elevation angle can require a compromise based on the accuracy of the measurement, because bias errors of horizontal wind decrease with θ_e whereas errors of vertical wind increase.

Wind-Profiling Experiments

An experiment was designed to verify the hypothesis that UHF Doppler weather radars with a 10-dB edge over the present NSSL radars should be capable of measuring winds to about 12 km when eddy dissipation rates exceed 10^{-3} m^2 s^{-3}. NSSL's Engineering Support Group developed and successfully tested a data recorder interface for attachment to NASA's ultrasensitive UHF radars (which do not have Doppler processors) at Wallops Island, Va., to record analog video for later playback through NSSL's Doppler processor and color display. Coherent and continuous echoes to about 7 km height were observed from the clear air on one day of tests at Wallops Island.

A related experiment with NSSL's radar indicated that the effective structure constant in prestorm midday convection has values near 10^{-13} $m^{-2/3}$ at 0.5 km and decreases to about 10^{-14} $m^{-2/3}$ at 2.5 km AGL, above which echoes were not detected. Height dependences of measured reflectivity were compared with those theoretically predicted from the height decrease of insect densities measured elsewhere by other investigators. The comparison showed remarkable agreement in the decrease of reflectivity with height.

Storm Initiation

Analysis of Doppler radar and rawinsonde data revealed some interesting aspects of the evolution of boundary laver winds and stability just prior to the development of tornadic thunderstorms. In contrast to another case, widespread vertical motion was not the cause of destabilization observed just

prior to thunderstorm formation near NSSL on 17 May 1981. In fact, VAD analysis of Doppler radar data reveals mesoscale subsidence up to within a half-hour of subsequent storm development. Satellite photos show a corresponding dissipation of widespread cumulus east of the dry line during this period.

A computer program was developed to evaluate the stability of air parcels lifted from the lower atmosphere; initial conditions were defined by rawinsonde data. The analysis suggests that the first air to become freely buoyant on 17 May 1981 originated about 1.5 km above the ground, rather than at the surface. The destabilization of this layer was a result of the rapid vertical mixing of heat and moisture that occurred within 1 h of storm formation near the dry line zone.

Mapping Wind Fields and Divergence in the Convective Boundary Layer

Refinements to a linear wind algorithm improved the accuracy of divergence estimates based on single-Doppler radar data.

The feasibility of applying linear and time-invariant regression theory to Doppler velocity data at a constant height was studied. A constant-height technique is appealing because horizontal divergence can be derived without the knowledge of vertical gradients needed with the present technique known as velocity-volume processing. A multivariate data-editing technique to retrieve radial velocities in the presence of ground clutter, anomalous targets, and noise was studied and appears to give good results. This editing technique and a uniform wind analysis were applied to data obtained during a low-level jet occurrence. Early results look excellent.

Reflectivity and/or velocity perturbations provide tracers of larger scale motion. A method of estimating large-scale wind fields for a clear-air boundary layer case was examined, and perturbations in velocity were shown to have longer lifetimes than those in reflectivity.

NSSL cooperated in boundary layer field experiments with a group from the University of Wisconsin, with the radiometer group of WPL, and with personnel of NCAR and the Argonne National Laboratory. Experiments involved measurements of clear-air radar reflectivity and velocity data, refractive index, sensible and latent heat fluxes, boundary layer height, and total precipitable water.

Airborne Doppler Lidar and NSSL Doppler Radar Intercomparison

Airborne lidar can greatly enlarge the area over which wind observations can be made, and tests of lidar aboard aircraft may point the way toward satellite-borne lidar for global wind mapping. As part of an interagency effort to develop lidar capabilities, clear-air boundary layer wind data were collected on 29 June 1981 by NASA's airborne Doppler lidar, NSSL's two Doppler radars, an instrumented tower, and a rawinsonde. Vertical profiles of horizontal wind speed and direction measured by the two remote-sensing systems were constructed by interpolating data to common grid volumes at different heights throughout the boundary layer. Data from these diverse instruments agreed within 1 m s^{-1} after the lidar data were corrected for a Schuler resonance in the aircraft's inertial navigation system.

Velocity variance spectra of the the wind field components were computed from the lidar and radar data. Wavelengths between 1 and 16 km were resolvable. Averaged spectra from lidar and radar compared well; peaks in both spectra were near the 4-km wavelength predicted by theory.

STORM ELECTRICITY

Positive Cloud-to-Ground Lightning

Flashes that lower positive charge to ground, as opposed to the more frequent flashes lowering negative charge, are receiving increasing attention because of the relatively large hazard they apparently pose both at the ground and in the air. A high percentage of positive cloud-to-ground (+CG) flashes appear to have continuing current, i.e., sustained current flow of several hundred amperes for tenths of seconds. Most +CG flashes have been confirmed to propagate downward; they are therefore initiated within the cloud and are not simply triggered by tall structures as is often assumed.

To measure the reliability of extremely-low-frequency (ELF) observations for detection of all CG flashes and identification of +CG flashes, more than 100 ELF waveforms were compared in terms of electric field change and lightning strike location, and by use of very-high-frequency (VHF) maps and strip-film 35-mm photographic data. Theoretical studies are relating channel characteristics to electromagnetic radiation fields, and +CG flash occurrences are being examined in relation to storm severity and evolution. This year we observed for the first time a few isolated storms in which almost all ground flashes lowered positive charge. Such anomalous cases represent significant study areas and are receiving much of our attention.

Storm Structure and Lightning Discharge Locations

In a tornadic storm, 2½ h of single Doppler radar and lightning ground strike data showed that the number of strokes per flash increased significantly after the tornadic stage of the storm ended. Within 10 km of the mesocyclone center, the ground flash rates were also lower before and during tornadoes than afterward. An inverse relationship was found between trends in lightning ground strike rates and mesocyclone strength as measured by cyclonic shear.

We are also relating mapped lightning structure, determined from NSSL's VHF mapping system, to the precipitation and winds of severe storms, synthesized from Doppler radar data. The VHF sources of all major lightning flashes in one important case tended to be concentrated in high reflectivity regions and at low altitudes. On the other hand, although VHF sources from all minor flashes in a storm covered a much larger area and were principally confined to high altitudes, their distribution was very patchy. Furthermore, the VHF sources along the channels of individual minor flashes were localized in a relatively small volume, but produced a near continuum of lightning activity, centered at 11-13 km altitude, that had no apparent temporal association with the major flashes sporadically occurring at lower altitudes.

The NASA Wallops Island 70- and 10-cm wavelength radars were used to sense lightning channels and precipitation simultaneously, to determine whether reliable relationships exist between storm structure and lightning echo properties. A theoretical study to estimate the lightning channel radar cross section was completed.

Interaction Between Electric Fields and Precipitation

Doppler velocity spectra, reflectivity, and electric field change data are being analyzed for 75 lightning flashes that propagated through the beam of the vertically looking Doppler radar at Norman. In addition to continuing earlier work on the use of lightning as a tracer of updraft velocity, we are also searching the data for possible interaction between the lightning and precipitation within the radar beam. We have already documented changes in the Doppler spectra at higher altitudes at the time of flash occurrence.

The presence of a lightning channel within the radar's resolution volume provides a better estimate there of average vertical air motion $\bar{w}$ when the channel echo spectrum is resolved within the Doppler spectrum of precipitation. When $\bar{w}$ is accurately estimated, the drop size distribution N(D) is also better defined. In one case, the speed of the updraft was estimated to be 11 m s^{-1}, the presence of hail was deduced, and the number density per unit particle size, versus particle size, was calculated to span 13 orders of magnitude! The probable number of hailstones between 9.5 and 10.5 mm was 10^{-4} m^{-3}, and there were on the average 10^4 such stones in the resolution volume of 108 m^3.

Electric Fields

In cooperation with a NOAA Postdoctoral Fellow at the University of Mississippi, we installed instruments in a trailer for reception of data from balloon-borne electric field meters. Analysis of a sounding through the downshear anvil of a severe storm shows electric fields of about 100,000 V/m at distances 60 km and more from the 50-dBZ precipitation core of the storm. This is 100 times larger than fields previously measured in plumes from smaller storms elsewhere and is comparable with most values previously found within and near precipitation cores. These initial results raise intriguing questions with regard to the formation and distribution of charge and the production of lightning in severe storms, and about hazards to aircraft.

NSSL

Mobile Laboratory

Analysis of unique data from the University of Mississippi/NSSL mobile laboratory on CG flashes will help provide information needed in the design of a satellite lightning mapper for use in the detection and study of severe storms. To date our analysis has yielded data on about 500 flashes that were observed simultaneously from the ground and from a U-2 aircraft above a large isolated storm.

Equipment Improvements

The NSSL system for locating lightning ground strikes was improved to provide more convenient and reliable operation of the central processor and to display data in real time. For the VHF system, circuit design was completed for new logic units with full hemisphere coverage to replace the "sector-limited" units in the present system. When these new units are fabricated and installed, each site will be capable of measuring lightning signal source directions to 0.5° accuracy throughout the hemisphere at rates to 64,000 per second, which is four times the present rate. With less operator interaction than the present system, the new system will provide three-dimensional locations of VHF sources along lightning channels within a nominal range of 80 km.

NEXRAD AND AVIATION-RELATED RESEARCH

Squall Lines and Gust Fronts

In support of NEXRAD development we studied gust fronts associated with strong squalls in Oklahoma, and downdrafts behind these fronts. It was found that peak reflectivity of the gust front (outside of precipitation) is between 2 and 11 dBZ. A detailed analysis of one "solitary gust" demonstrates that refractive index fluctuations can account for a good portion of the observed reflectivity profile.

Along and behind the gust front of a strong squall line, strong shears are produced by the constantly evolving and interacting cells that generate short-lived up/down drafts. We found that the difference among outflow velocities produced by these downdrafts depends little on the downdraft size, and the maximum measured shear (velocity difference divided by distance) is associated with smallest size. Mesocyclone-like signatures may develop at low altitudes along the advancing gust, indicating the evolution of whirlwinds near the surface. Such circulations may produce a large decrease in headwind component of an aircraft and thus present a hazard.

A study of solitary waves, in collaboration with a visiting scientist from the People's Republic of China, used observations from NSSL's instrumented tall tower, Doppler radar, and surface-based instruments. Solitary waves have recently been implicated in numerous incidents in which aircraft have encountered dangerous levels of shear during takeoff and landing.

Thunderstorm Turbulence

Doppler measurements are characterizing turbulence important to aircraft. In the storm of 17 May 1981, we found that the energy density of turbulence was about constant but the total turbulent energy increased as the storm grew. The locations of the maxima of energy density (deduced from spectra of mean Doppler velocity) coincided with maxima in eddy dissipation rates (calculated from Doppler spectra width data). This suggests that the large-scale turbulent eddies fragmented into scales small compared with the radar's resolution volume until the energy of microscale turbulence was tranformed into heat in accordance with predictions by Kolmogorov.

The NASA B-57 aircraft and Gust Gradient Program personnel from Marshall and Arnold Space Flight Centers obtained data on turbulence and gusts in the vicinity of large organized storms during five flights.

Real-Time Weather Data Processing

An algorithm that processes Doppler radar data to provide profiles of wind and an indication of turbulence throughout the boundary layer was specialized for real-time use in the 1983 Spring Program. During 70 days of uninterrupted afternoon operation, there were only three days when echoes were too weak for the wind to be measured with the Doppler radar in the clear air. On evenings when a low-level jet was present, wind profiles to 3 km altitude were provided regularly. The height of observations also increased when clouds were present. Furthermore, indications of turbulence from deviations of local radial velocity from the uniform wind model generally agreed with turbulence experienced by nearby aircraft.

NSSL staff refined and tested algorithms to present the distribution of estimated three-dimensional winds from single-Doppler radar data (velocity volume processing), to measure divergence, and to detect mesocyclones, all in real time. The algorithms work well and are significant contributions to development of NEXRAD and to the effective use of the NEXRAD radar.

Plans FY 1984

- Analyze case studies of storm data (Doppler radar and electricity) collected during 1981, 1982, and 1983 to determine relationships among electricity precipitation, and kinematics in storms.

- Complete, upgrade, and test the VHF mapping system to make an all-hemispheric lightning mapper.

- Analyze the occurrence of positive cloud-to-ground (+CG) flashes and continue efforts to define their existence relative to storm severity, and assist in the transfer and interpretation of CG flash data to NWS in Oklahoma City for use in storm forecasting and warning.

- Make mobile and fixed-base electrical measurements in cooperation with NASA/MSFC and others to assist in the development of a lightning-observing satellite, to assess lightning hazards to aircraft and measures for lightning protection, and to extend our general knowledge of the electrical structure of the stormy atmosphere. **NSSL**

- Continue to be the NOAA representative to the National Interagency Coordinating Group of the Atmospheric Electricity Hazards Protection Program to coordinate research on lightning hazards to aircraft.

- Continue in-depth examinations of the prestorm radar data with other data sources and theory, in order to develop improved operational capabilities for forecasting the locations where storms develop and then intensify.

- Continue a study of the evolution and origin of gust fronts and downdrafts as a prelude to determining the predictability of such events.

- Conduct studies of advanced techniques for reduction of velocity and range ambiguities in Doppler radar.

- Implement a polarization capability on one of NSSL's two Doppler radars, examine appropriate signal-processing techniques, and investigate alternate schemes for estimating differential reflectivity.

COMPUTER AND ENGINEERING SUPPORT AND RESEARCH

This group develops techniques and equipment, maintains the NSSL observational facilities, and supports the observational programs associated with the meteorological research. The NSSL base facilities consist of two 10-cm meteorological Doppler radars, a WSR-57 (surveillance radar), a tall (444 m) tower, a 52-station (maximum) surface network, an air traffic control facility, and equipment for measuring electrical phenomena in the atmosphere. The group also provides engineering support for the NEXRAD JSPO/Interim Operational Test Facility of NWS.

Accomplishments FY 1983

COMPUTING AND DATA PROCESSING

NSSL's Perkin-Elmer 3242 data processor, on line with the Doppler radar at Norman, has been upgraded with a second nine-track tape drive, a seven-track tape drive, and a 300-megabyte disk drive. In support of quality control, data from our Doppler radars, lightning sensors, surface networks, and tower are now read and processed on the Perkin-Elmer.

Archiving of NSSL Doppler radar data for 1977-83 is now possible on the CDC-750 at Boulder. The 1979 SESAME SAM data set was rebuilt to correct errors and was redistributed to users; all necessary programs from the decommissioned SEL-8600 have now been converted for use on the CDC-750.

Doppler radar research data were collected at Norman and Cimarron from 17 May through 10 June. More than 560 magnetic tapes were written and subsequently copied and indexed at Boulder.

NSSL supplied data sets to these users:

Finnish Meteorological Institute, Helsinki	(R. King)
Florida State University, Tallahassee, Fla.	(J. Stephens)
McGill University, Montreal	(M.K. Yan)
NASA, Greenbelt, Md.	(J. Heymsfield)

NASA, Huntsville, Ala.	(S. Goodman)
NWS, Silver Spring, Md.	(K. Shreeve)
NWS, Columbus, Ohio	(C. Simpson)
NWS Training Center, Kansas City, Mo.	(D. Lowden)
Rice University, Houston, Tex.	(G. Byne)
Servicio Meteorologica Nacional, Buenos Aires	(J. Nuñez)
Sperry, Southhampton, Pa.	(L. Lemon)
University of Washington, Seattle, Wash.	(P. Dodge, B. Smull)
Weather Research Program, ERL, Boulder, Colo.	(I. Watson, J. Cunning)

FACILITIES ENGINEERING

Much of the group effort centers around support of the Spring Program both in terms of engineering and computer development and in operation support and data handling.

The first six weeks of the 1983 Spring Program of the NSSL, beginning on 4 April, was devoted to support of the NEXRAD Operational Tests. Then on 16 May, for a 4-week period, the research experiments for NSSL and outside investigators were conducted. On 13 June, support was returned to NEXRAD and continued until about mid-July. As usual, all NSSL facilities were utilized in the data acquisition program.

Coherent Ground Clutter Canceller

Design and fabrication of a ground clutter canceller for use with Doppler radars was completed with installation of some modifications suggested by initial tests.

WSR-57 Air Traffic Control Terminal

Hardware development was completed with modifications to the computer terminal equipment and interface components to improve acquisition of aircraft position data and capabilities for data processing. Software was developed to utilize the system routinely to collect, display, and store color images of WSR-57 video in a Plan Position Indicator (PPI) format. During the spring program, WSR-57 color display data were selectively recorded for rapid playback, data screening, and case study selection. This system was operated through the end of FY 1983 in support of a program to evaluate storm sensors aboard a B-52 aircraft.

KTVY Tower Data Collection System

A second-generation computer-based data collection and recording system was designed. Hardware components are assembled, software is being developed and debugged, and operational status is targeted for the spring 1984 operational season.

Nine-Track Tape Drive for Norman Doppler

Two nine-track tape recorders were acquired from the decommissioned SEL-2600 computer. An interface was designed, fabricated, and put on line to allow the new drives to record and play back radar data at the Doppler data collection and control facility in Norman. This system was operational during the spring 1983 storm season.

Plans FY 1984

COMPUTING AND DATA PROCESSING

If approval is received from procurement authorities, a VAX11/780 computer system will be installed in late FY 1984 at NSSL. This system will give an opportunity for more timely examinations of data collected in the spring and will provide more rapid editing and playback of Doppler data.

FACILITIES ENGINEERING

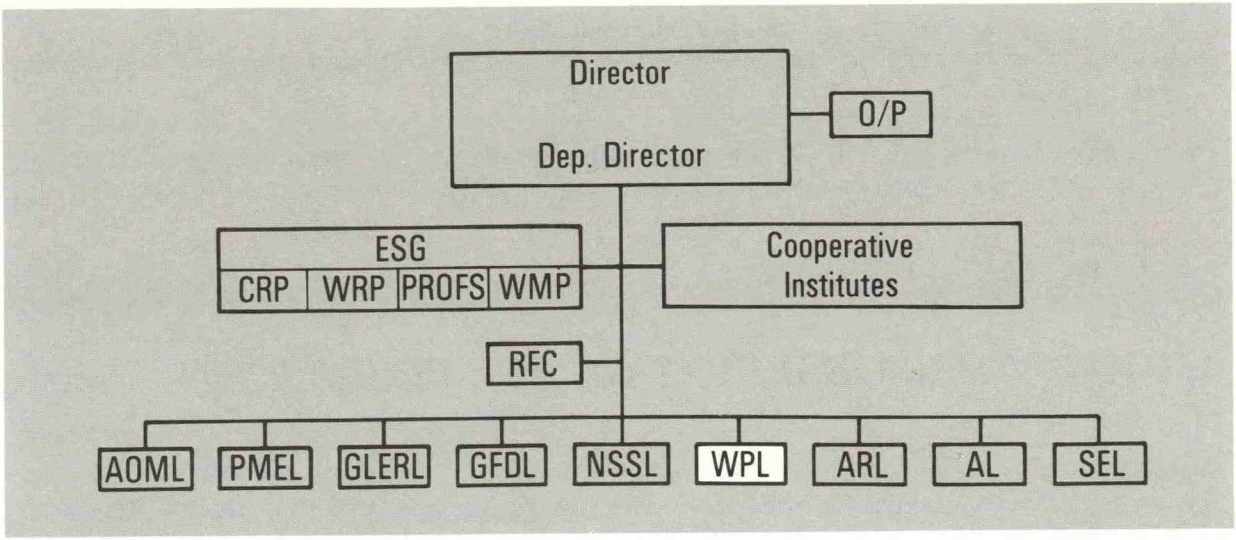
During the spring of 1984 the NSSL Doppler radar at Norman will be configured to support quasi-real-time transfer of Doppler radar data from Norman to the NWS Forecast Office at Will Rogers Airport. Lightning data will be superimposed on the radar data and transferred also. NWS will have a radar meteorologist at the Norman site for data selection and coordination.

The spring research program will include participation by a number of instrumented aircraft. The WSR Air Traffic Control Terminal for display of aircraft targets at NSSL will be expanded.

A major engineering program for FY 1984 will be development of a capability for switching at the pulse repetition frequency between vertical and horizontal polarizations with one of NSSL's Doppler radars. This capability is expected to provide improved methods for identifying hail, estimating rainfall rate, and studying physical processes attending electrification and hydrometeor formation. It is planned to have a system capable of providing differential reflectivity measurements at 16 range locations by April 1984.

WAVE PROPAGATION LABORATORY
Boulder, Colorado

C. Gordon Little
Director



NOAA's core mission of atmospheric and oceanic forecasts and warnings requires that it observe the present states of the atmosphere and ocean in order to be able to predict their future states. Since both media are three-dimensional, the observations must also be three-dimensional; moreover, the data sets must adequately resolve spatial or temporal structures at least as small as those to be forecast.

In general, the denser the observational data set in space and time, the more complete and accurate the services can be. Experience has shown that in situ measurement methods, which require a sensor at each measurement location, are too expensive to be practical for anything but the largest scale phenomena. In 1967, the Wave Propagation Laboratory (WPL) was set up to explore the possibility that remote sensors might provide the several-orders-of magnitude improvement in space/time density of observations required to predict or warn of smaller scale phenomena.

The WPL mission is, therefore, to improve the Nation's geophysical research and services, through the development and application of cost-effective remote measurement systems. To achieve this goal, it must successfully perform the following functions:

- 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 and telecommunication purposes.

- Development and experimental evaluation of new geophysical remote-sensing concepts.

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

- Improvement of the Nation's monitoring, forecasting, warning, and research services, through transfer of remote-sensing technology to others.

Because observational capability underlies essentially all geophysical research and services, WPL's research has broad impact and already contributes to four of OAR's nine programs.

The following presentations give a brief rationale for the research and explicit statements on the FY-1983 programs and FY-1984 plans. Where appropriate, the research tasks within each program are grouped according to meteorological scale.

WEATHER OBSERVATION AND PREDICTION

WPL's contributions to weather observation and prediction support NOAA's largest and most important single service, namely, weather forecasts and warnings. This service is required on many space and time scales. Thus, it is important to recognize that WPL's remote-sensing R&D program includes contributions on all scales from the micrometeorological to the global.

MICROMETEOROLOGICAL AND BOUNDARY LAYER R&D

Research on micrometeorological processes in the atmospheric boundary layer is important because these processes include the turbulent fluxes of heat, moisture, and momentum that change the dynamic and thermodynamic properties of air masses. Remote sensors contribute uniquely to the research by providing the resolution and continuity in both space and time that are required to observe, monitor, understand, and predict these important boundary layer processes. WPL has long led in the development and application of such sensors.

Accomplishments FY 1983

BOUNDARY LAYER SENSOR DEVELOPMENT

Boulder Atmospheric Observatory

The Boulder Atmospheric Observatory (BAO), with its remote sensors and fully instrumented, 300-m-high meteorological tower, is a unique facility for study of the atmospheric boundary layer (including the propagation of acoustic and electromagnetic waves in it) and for the evaluation, intercomparison, and calibration of in situ and remote sensors. It was utilized throughout the year in a number of significant studies.

Measurements on the tower showed that, under stable conditions, turbulent flows can occur with inner scales of turbulence considerably larger

than 5 cm. This important new result means that 10-cm radars operate at too short a wavelength to permit routine profiling of winds in the stable (as opposed to convective) troposphere.

Tests at the BAO confirmed the ability of the FM-CW radar to measure height profiles of C_n^2, the structure parameter of radio frequency refractive index fluctuations in the inertial subrange. Calculations of eddy dissipation rates, observed simultaneously by the FM-CW radar and the adjacent BAO tower, sometimes were found to agree well, but on other occasions disagreed markedly. The reason for this behavior is not yet known, and is under study.

The optical C_n^2 profile is important to the design of many optical systems. A lidar technique had been proposed to measure it remotely; theoretical and experimental studies confirmed that the method is not useful, because it requires excessive measurement precision.

Acoustic echosounders often reveal extraordinarily complex boundary layer structure. An echosounder was operated for 6 months alongside the fully instrumented tower to acquire data under diverse, well-monitored meteorological conditions, for use in the automated interpretation of acoustic soundings.

WPL completed the analysis of the Environmental Protection Agency (EPA) Instrument Intercomparison Experiment, conducted at the BAO during September 1982. This experiment evaluated the ability of several different versions of acoustic echosounders and in situ sensors to measure turbulence intensity. The second and final stage of the EPA Convective Plume Diffusion Experiment was conducted successfully at the BAO during September 1983, making use of tower, radar, and lidar measurements of turbulence and plume diffusion. Meteorological tower data support were provided to the Air Chemistry experiment of the National Center for Atmospheric Research (NCAR) at the BAO.

Scintillation Techniques

The small-scale temperature and humidity eddies produced by boundary layer turbulence cause optical signals propagating in the lower atmosphere to twinkle, or scintillate. Understanding these eddies, and the scintillations they cause, permits the design of remote sensors that monitor the nature and intensity of meteorologically important turbulent exchange processes occurring in the boundary layer. WPL made new advances in understanding the details of the scintillation process during FY 1983.

WPL

In general, the refractive index of moist air at a given pressure is a function of both temperature and humidity. The correlation between small-scale temperature and humidity eddies is therefore important. An experimental study demonstrated that the correlation and spectral coherence between temperature and humidity eddies was very high, up to the Nyquist limit of 50 Hz. This has important implications to electromagnetic and acoustic wave propagation.

Earlier WPL theoretical work indicated that the path-averaged inner scale of turbulence (a measure of the size of the smallest eddies present) could be derived from optical scintillation studies. This prediction has now

been confirmed over a 250-m path--a result of considerable importance, since the inner scale of turbulence is a measure of momentum flux. It also opens the possibility that scintillation measurements can be used to derive path-averaged heat and water vapor fluxes.

The sensitivity of the atmospheric refractive index to fluctuations in temperature, pressure, and humidity is a function of electromagnetic frequency. A new algorithm was developed that computes these sensitivities in the millimeter part of the spectrum, where water vapor terms are very strong.

A major study of millimeter wave propagation was initiated with U.S. Army Research Office funds. The experimental program was designed and is now under way, in cooperation with the Georgia Institute of Technology, at a new field site in Flatville, Ill. The propagation path is fully instrumented, and major efforts will be devoted to relating the observed propagation effects to meteorological conditions.

Differential Absorption

A path-averaging humidity sensor, based on differential absorption between two frequencies in the near infrared, was tested over a 1-km path. The observations agreed to within 10% with those from conventional in situ sensors.

BOUNDARY LAYER RESEARCH

A report was published on the structure of nocturnal stable layers and the role of gravity waves in producing counter-gradient heat fluxes.

A computer model that uses surface measurements of heat flux and routine rawinsonde data to predict the growth of the convective boundary layer depth was developed. The model also predicts turbulence parameters at stack height. A second model was developed that simulates the effect of entrainment at the top of the boundary layer.

Surface data from the JAWS (Joint Airport Weather Studies) project were analyzed, resulting in a data set describing the properties of convective storm "microbursts"--localized downbursts that can produce wind shear hazardous to planes landing or taking off.

Plans FY 1984

SENSOR DEVELOPMENT

Additional observations of millimeter-wave propagation will be made at the Flatville site, and a report prepared.

The results of studies to measure the inner scale of turbulence optically will be prepared for publication.

The report on the 1983 Acoustic Doppler Sounder Intercomparison Experiment will be completed.

BOUNDARY LAYER AND MICROMETEOROLOGICAL RESEARCH

A report on Project Aeolus, providing detailed analyses of several front-range meteorological events, will be completed.

The data from the convective plume diffusion experiment in September 1983 will be analyzed.

Project Phoenix-II, a major convective boundary layer study, will be performed in cooperation with the University of Oklahoma. It will be conducted at the BAO, and will utilize tower, aircraft, and multistation Doppler radar data.

R&D ON MESO-BETA AND -GAMMA SCALES

A single ground-based radar or lidar system can remotely monitor atmospheric processes on the meso-gamma (2 to 20 km) and perhaps the meso-beta (20 to 200 km) scales. Such data sets are required for an extraordinarily wide range of atmospheric research problems, as well as for short-term local weather nowcasts and forecasts. WPL progress in this area assigned to the Weather Observing and Prediction program is divided into two main categories, mesoscale sensor development and mesoscale research. (Specific applications of WPL's mesoscale remote sensors are discussed in the sections on Air Quality and Climate.)

Accomplishments FY 1983

MESOSCALE SENSOR DEVELOPMENT

Infrared Doppler Lidar

The capabilities of the 10.6-μm-wavelength lidar were further improved by the addition of a real-time spectral processor and color display. The elevation angle drive was converted from manual to electrical control, and will shortly be computer controlled. The lidar was calibrated; the accuracy of its velocity measurements was determined, by comparison with calibrated anemometers on the BAO tower, to be better than 0.34 m s^{-1}. **WPL**

Millimeter Wave Radar

The 8.6-mm-wavelength radar was upgraded with rapid (4-Hz) polarization switching under microprocessor control. The new system was tested successfully in the MAYPOL precipitation polarization experiment, jointly with NCAR.

Dual-Channel Microwave Radiometry

The accuracy of global positions, determined by the global positioning satellite system, is currently limited by path length uncertainties introduced primarily by the unknown amount of water vapor along the satellite-to-ground paths. The ability to determine these corrections was demonstrated in a joint experiment with the National Geodetic Survey, using WPL's steerable dual-channel microwave radiometer for measuring vapor and liquid water.

The distribution of liquid water in clouds is not readily determined. A new method, based on scanning the cloud in coordinated planes using two spaced dual-channel microwave radiometers, has been proposed, and is being tested jointly with NCAR. Computer simulations of the method (a radiometric analog of tomographic X-ray scans) indicate good prospects of success.

Critical to the accuracy of microwave radiometric measurements of water vapor and liquid water is a knowledge of the absorption coefficients under relevant conditions. The absorption coefficients for the vapor are very small--typically on the order of 0.1 dB per kilometer. A new empirical equation, based on recent WPL measurements, has been developed to take into account discovery of a much stronger dependence on total atmospheric pressure than had been predicted by earlier theories.

MESOSCALE RESEARCH

The FY-1982 JAWS data were successfully analyzed on the NCAR Research Data Support System (RDSS), and resulted in the first wind fields derived from two-station Doppler lidar observations.

The downward progression of high wind speeds was observed during a chinook wind event in Boulder in February 1983. The event was first observed as a large-amplitude wave at 10 km altitude, 6 hours before onset of high winds at the surface.

The amount of 10-μm radiation backscattered by atmospheric particles is of both meteorological and technological interest, since it occurs in a radiatively important window region of the spectrum. Profiles of atmospheric backscatter were obtained throughout the year, using the 10-μm Doppler lidar. Temporal changes in the stratospheric particle loading from the El Chichón, Mexico, volcano were studied to heights as great at 30 km, and compared with similar observations obtained by the visible wavelength lidar. The El Chichón dust layer was also used to measure the infrared opacity of cirrus clouds.

The two steerable dual-channel radiometers participated in six major field experiments and several smaller observational projects. These included support of Bureau of Reclamation weather modification experiments in California and western Colorado, using the radiometers' unique ability to monitor cloud liquid water remotely. Similar support was also provided to the State of Utah's winter seeding program. Horizontal variations in water vapor were monitored in California in support of the U.S. Air Force; the radiometer also participated (in combination with radars) in cloud precipitation research experiments in Oklahoma (with NSSL) and in Colorado (with NCAR).

Dual-polarization Doppler data were obtained successfully with the 8.6-mm-wavelength radars during the MAYPOL orographic precipitation experiment. An unusual behavior of the bright band relevant to precipitation at the surface was observed; analysis is continuing.

Plans FY 1984

MESOSCALE SENSOR DEVELOPMENT

IR Doppler Lidar

Full computer control of the scanning of the Doppler lidar will be developed, including standard PPI, VAD, and RHI scans.

Subject to availability of funds, the procurement of the new laser with 2 joules per pulse and 50-Hz repetition rate will be completed. A 50-fold increase in average transmitted power is anticipated.

The technology of coherent profiling of water vapor, using differential absorption lidar (DIAL) techniques, will continue to be explored.

Dual-Channel Radiometry

The ability of two spaced radiometers to develop maps of the distribution of liquid water will be tested. The ability to estimate water vapor profiles will be added, through the combination of existing humidity profile statistics, surface weather parameters, and the radiometric data.

FM-CW Radar

Appropriate software will be completed to permit use of an array processor (instead of a spectrum analyzer) in the processing of the FM-CW radar data. This will increase the flexibility of use of the radar.

8.6-mm Radar

The capabilities of the 8.6-mm dual-polarization Doppler radar will be enhanced by the design and procurement of a real-time data processing and display system, for use with the radar in the field. **WPL**

MESOSCALE RESEARCH

IR Doppler Lidar Studies

Funding permitting, the 10.6-μm lidar will be mounted aboard the Discoverer, and will obtain new data on the latitudinal variation of aerosol backscatter profiles during a 3-month cruise to 55° S.

Observing-system simulation studies of the potential impact of a wind-profiling satellite will be continued in cooperation with the National Meteorological Center (NMC), the European Center for Medium-Range Weather Forecasting (ECMWF), and NASA/Goddard Space Flight Center.

The Doppler lidar will participate in the Defense Nuclear Agency (DNA) Direct Course experiment. In addition, meteorological targets of opportunity, such as downslope winds, fronts, lenticular and other clouds, and air pollution events will be studied.

Radar Studies

Critical studies of echo-intensity versus height and time will be made at Stapleton Airport, using the 10-cm-wavelength FM-CW radar, and the 33-cm-wavelength wind-profiling radar. These studies should throw new light upon the inner scale of atmospheric turbulence.

A warm-cloud experiment will be planned, involving the simultaneous use in Hawaii of WPL's 8.6-mm dual-polarization Doppler radar, steerable dual-channel radiometer, and in situ sensors.

The 8.6-mm radar will participate in the DNA Direct Course experiment.

A 3-cm Doppler radar will take part in an electrified cloud experiment at Socorro, N. Mex.

R&D ON SYNOPTIC AND MESO-ALPHA SCALES

Although individual ground-based remote sensors are limited by Earth curvature to meso-beta-scale applications, arrays of such sensors can be used to study atmospheric processes up to continental scale. WPL's planned contribution to this scale is the Profiler, a combined radar-radiometric system for the continuous measurement of profiles of wind, temperature, and humidity. A suitable array of such systems could continuously provide the three-dimensional fields of these parameters on the meso-alpha (200 to 2,000 km) and synoptic (2,000 to 10,000 km) scales for numerical weather prediction (NWP). Such a system would have major impact on NWP since the observation data could be (1) time-averaged to remove aliasing of high-frequency components, (2) entered more frequently into the NWP algorithms, and (3) inserted in the form of time derivatives as well as time averages. It is also believed that the wind field data (which are critical to mesoscale NWP) would be considerably more accurate and representative than those available from radiosondes.

Accomplishments FY 1983

PROFILER DEVELOPMENT

The UHF wind-profiling radar at Stapleton Airport, Denver, was brought on line, providing improved height resolution (100 m, 300 m, and 900 m vs. 2.4 km) and improved minimum height (300 m vs. 2.4 km AGL) relative to the Platteville radar. New wind profiles were provided every 20 minutes by telephone to Boulder.

The three outlying 50-MHz wind-profiling radars were installed in northeastern Colorado (Fleming, near Sterling), northwestern Colorado (Lay Creek, near Craig), and southwestern Colorado (Cahone, near Cortez). Wind profiles were reported automatically over telephone lines each hour to the Profiler hub computer in Denver, and thence to Boulder.

The Cahone wind Profiler was moved temporarily to Glen Falls, N.Y., in August, to participate in the Cross-Appalachian Tracer Experiment (CAPTEX) acid rain experiment, for a 3-month period.

The six-channel microwave radiometer was operated continuously at Stapleton Airport during FY 1983. This permitted a three-way comparison of more than 450 Profiler soundings with simultaneous (or quasi-simultaneous) rawinsonde and TIROS 6/7 polar-orbiting operational soundings. This study showed that pressure heights measured by the Profiler are more accurate than those from the rawinsonde to about 500 mb (and much more accurate than those measured by the satellites). On the other hand, above about 300 mb, upper-air temperatures measured by satellites were more accurate than those measured by the Profiler. Pressure heights measured by combining the Profiler and satellite soundings are more accurate than those measured by either system alone, and more accurate than those from radiosondes up to about 400 mb. The addition of radar data on the height of the tropopause and other temperature inversions should lead to significant further improvements in the remotely sensed pressure-vs.-height profiles.

A 405-MHz wind-profiling radar was designed that combines the cost advantages of the 50-MHz VHF radar with the improved height resolution and lower minimum height of the 915-MHz radar. Components are on order.

MESOSCALE ATMOSPHERIC RESEARCH

WPL

The mesoscale severe-weather event of 12-13 June 1983 was analyzed; data from the five Colorado Profiler sites, and observations from NWS radiosondes, the PROFS mesonet, and the BAO tower were used.

Profiler data were used by PROFS scientists in an analysis of the severe blizzard that occurred Christmas Eve, 1982, in Colorado, immobilizing Denver with up to 3 ft of snow.

The height resolution of the wind Profilers is considerably better than that of the radiometrically determined temperature and humidity profiles. Since the wind and mass fields are linked dynamically, the possibility exists

that the high-vertical-resolution wind field data can be used to improve the temperature field. A computer simulation experiment successfully demonstrated how high-resolution wind profiles could be used to restore frontal temperature inversion detail missing in the radiometrically smoothed temperature field.

The NOAA P-3 was used to observe stratospheric-tropospheric exchange events during the AGASP experiment. These events documented the presence of El Chichón volcanic debris in the polar vortex.

Plans FY 1984

PROFILER DEVELOPMENT

The 405-MHz wind-profiling radar will be assembled and tested. Tests will also be performed of the satellite data collection capability as an alternative Profiler network communication link.

Depending upon funding availability, the combining of Profiler radiometric data with NOAA satellite soundings will be extended to geostationary VAS data. If possible, a real-time system for combining VAS and Profiler temperatures and humidity soundings will be developed. Algorithms will also be developed to combine radar velocity and echo-intensity profiles with radiometric data to obtain improved temperature profiles.

A central Profiler data collection system will be designed to accommodate larger networks, and perform in real time the quality control, archiving, and data distribution functions.

R&D ON THE GLOBAL SCALE

Weather forecasts for periods more than a few days ahead require global observations of winds, temperature, and water vapor. The current global weather-observing system relies heavily on the international radiosonde network over populated land areas, supplemented by satellite observations over the oceans and polar regions. This observational system has two main weaknesses. First, and most important, the present methods for measuring wind from satellites rely on displacements of the cloud and water vapor fields; the resultant velocity fields have severe limitations in spatial coverage, height resolution, and accuracy. Second, the accuracies of the derived temperature and humidity profiles are poorest near the ground, limiting the accuracy of the derived pressure heights and thicknesses. WPL's WINDSAT (a laser radar, satellite-borne sensing system) and Profiler programs are designed to remove, or greatly reduce, these limitations.

Accomplishments FY 1983

Before global weather-observing systems are implemented, it is important to evaluate the potential impact of the new data sets on weather forecasting. WPL is, therefore, working with the NWS National Meteorological Center (NMC) to conduct such studies. Observing-system simulation experiments can be conducted at various levels of sophistication (and reliability); WPL participated in a numerical weather prediction simulation workshop organized by NMC. Accuracy estimates for WINDSAT, based on the WPL WINDSAT simulation model, were provided to the workshop participants.

Profiles of the infrared backscattering coefficient, β, were measured throughout the year. Analyses of 250 independent profiles are providing information on air mass trajectories.

Studies by RCA, sponsored by NOAA, have shown that the Advanced TIROS-N satellite bus would be capable of supporting a 2-year WINDSAT global wind field mission.

Plans FY 1984

If funds become available, the 10.6-μm Doppler lidar will undertake a 3-month cruise to 55° S. on board the Discoverer, to acquire critically needed additional β measurements in Pacific Ocean areas.

Cooperation with NMC, NASA/Goddard, and ECMWF will continue in support of their WINDSAT simulation studies. In particular, WPL will supply simulated WINDSAT data that include the effects of clouds.

WPL will continue to stimulate interagency cooperation between NOAA, DOD, and NASA in the area of WINDSAT studies and planning.

AIR QUALITY

NOAA's weather service mission includes the provision of meteorological information and understanding relevant to air quality. WPL contributes to this program through the application of its remote sensors to the measurement of the three-dimensional fields of wind, turbulence, and aerosol in experiments relating to air pollution.

Accomplishments FY 1983

Plume data obtained by optical lidar and 3-cm radar systems during the FY 1982 EPA convective plume dispersion experiment were analyzed and compared. Good agreement was found between the two sets of observations, and with laboratory tank experiments and numerical models.

A major report on the use of acoustic sounders in the FY 1979-1982 ASCOT (Atmospheric Studies in Complex Terrain) experiments is in preparation, and will be presented at the November 1983 ASCOT Analyses Workshop. WPL was host for the meeting to plan the next ASCOT experiment, now scheduled for western Colorado in FY 1984.

WPL scientists participated in the EPA Small Hill Plume Impaction field program near Farmington, N. Mex., with lidar, Doppler and monostatic acoustic sounders, tethersonde, sonic anemometers, and optical transverse wind sensors. The remotely sensed data showed flow separation and reversals that greatly influenced pollution dispersion.

Plans FY 1984

Data obtained during the FY-1983 EPA convective plume dispersion experiment will be analyzed and reported. The same will be done with data from the Farmington, N. Mex., ridge experiment.

WPL will participate in the first phase of the EPA full-scale plume impaction studies at the Tracy power plant in Nevada.

Planning will continue for WPL participation with remote and special in situ sensors in the FY-1984 DOE ASCOT study in western Colorado, and the second phase of the EPA impaction studies in Nevada.

CLIMATE

The United States has a major program to understand the processes that determine climate. Fundamental to the studies is the role of the ocean, which acts like a flywheel, storing and releasing vast quantities of heat. WPL is developing and applying remote sensors to ocean climate studies.

Accomplishments FY 1983

CODAR (Coastal Ocean Dynamics Applications Radar) was operated on the east coast of Florida to map surface currents during the July 1983 STACS (SubTropical Atlantic Climate Studies) program. Two systems provided surface-current maps showing the spatial structure and temporal variability of the Florida current, which carries almost all the northward oceanic heat flow in the North Atlantic.

Plans FY 1984

WPL plans to operate the same two CODAR systems in support of STACS from mid-November 1983 to mid-January 1984.

A major uncertainty in predicting climate change resulting from fossil-fuel burning involves CO_2 uptake by the oceans, particularly in polar regions, where uptake is enhanced by the cold water, and where downwelling carries the CO_2 directly to the deep ocean. As part of the Arctic Cyclone Study (described in more detail in the section Marine Observation and Prediction) to be carried out in January-February 1984, WPL will work with other ERL staff and university researchers to measure vertical atmospheric CO_2 fluxes near the marginal ice zone.

MARINE OBSERVATION AND PREDICTION

The difficulty and expense of obtaining in situ observations of ocean parameters make remote-sensing methods highly desirable. WPL is, therefore, active in the development, testing, and use of remote sensors for ocean parameters.

Accomplishments FY 1983

A new method was developed for processing CODAR echoes. It retains the objectivity of least-squares techniques, while maintaining the speed of earlier linearized methods.

The use of CODAR to measure currents from the Doppler shift of buoy-mounted transponders was demonstrated, paving the way for new diffusion and search-and-rescue applications. The ability to use a network of CODARs was also demonstrated, and should lead to more economical field operation in the future.

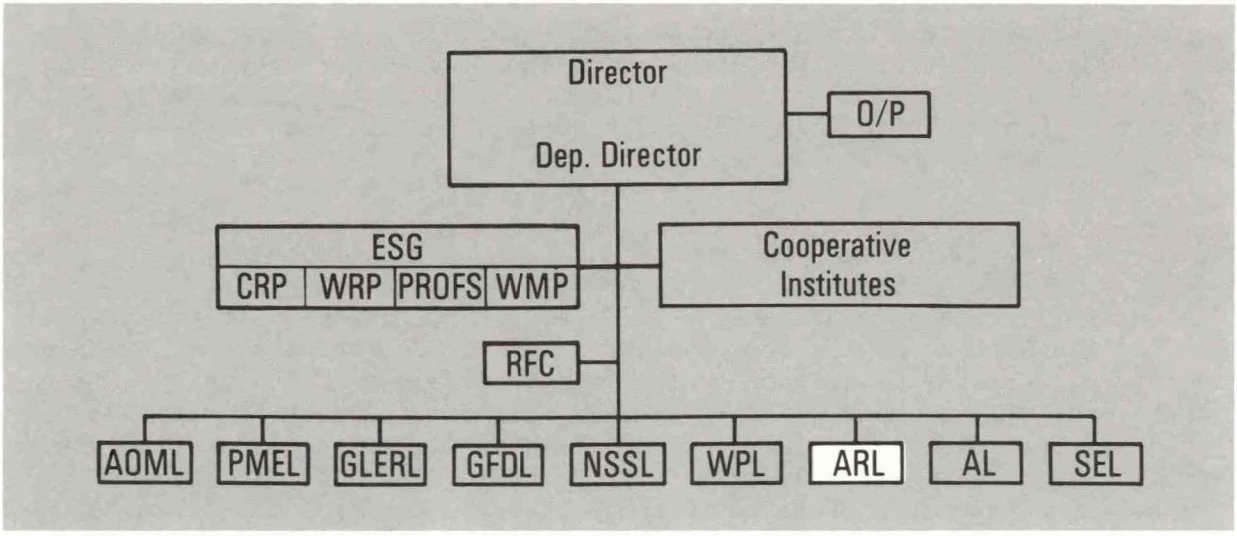
Detailed documentation on CODAR was almost completed. Planning began for FY-1984 CODAR support of National Ocean Service (NOS) surveys of circulation in Delaware Bay.

A unified theory of electromagnetic wave scatter from the sea surface, valid for roughness of arbitrary scale, was published. The theory (and some experimental confirmation) of the use of synthetic-aperture radar to measure ocean surface currents was published. Two scientific papers dealing with satellite remote sensing were published, one dealing with the measurement of sea-surface conditions, the other dealing with studies of sea ice.

Plans FY 1984

The two WPL CODAR units will be installed in operationally hardened vans to facilitate transport and use of the systems in field experiments. Preparation of real-time display and diagnostics will provide major flexibility for the evaluation of system performance and experiment design in the field. If funds are made available, the new system will be given the first field tests during the NOS survey of Delaware Bay.

In January and February 1984, WPL will lead a multi-agency, multi-nation Arctic Cyclone Study, using the NOAA P-3 research aircraft to (1) measure CO_2 exchanges between the air and sea in the polar oceans, as described under the climate heading above, (2) develop and evaluate remote-sensing techniques for monitoring sea state and ice, and (3) study the meteorology of the Arctic, with emphasis on the Greenland lee wave, the Icelandic low, and polar lows. NASA, the U.S. Navy, and Norwegian and British agencies will also participate in the study, in some cases with research aircraft of their own.



The Air Resources Laboratory (ARL) includes a headquarters group in Rockville, Md.; the Field Research Division in Idaho Falls, Idaho; the Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, Tenn.; the Meteorology Division in Research Triangle Park, N.C.; the Solar Radiation Facility, the Sun-Climate Staff, the Air Quality Division, and the Geophysical Monitoring for Climatic Change Division (GMCC) in Boulder, Colo.; and GMCC observatories at Mauna Loa (Hawaii), Barrow (Alaska), the South Pole, and American Samoa.

ARL research is geared to needs of users, who are frequently other Federal agencies with related missions. Funding and guidance derive from this association through interagency agreements. In some cases, the ARL unit under contract to another agency acts as its meteorological arm, to provide meteorological guidance. Most ARL research deals with the use of meteorology to understand and predict human influence on the environment, especially with regard to the atmospheric transport and diffusion of toxic effluents. General areas of study include turbulence and diffusion in the atmosphere, atmospheric trajectories from microscales to global scales, meteorology of air pollution, CO_2 and climate, acid rain, and monitoring of atmospheric constituents for climatic change. Following general descriptions of the work of the various ARL groups, ARL research activities are described here under two main headings, Air Quality and Climate.

HEADQUARTERS GROUP

The ARL headquarters research group in Rockville develops models that simulate local, regional, and global transport and diffusion of pollutants injected into the atmosphere. Mesoscale and regional-scale versions of these models are being used extensively by the Department of Energy (DOE) to evaluate the environmental effects of various means of energy production. Air-

sampling programs and other field experiments are conducted to provide data for model verification. Major funding for this work is provided by the DOE Office of Health and Environmental Research (OHER) and the Environmental Protection Agency (EPA). Research on total ozone and ozone profile data and on the sources, transport, and deposition of acid precipitation is also being carried out. In addition to these air quality studies, climate studies include research on the sources and sinks of CO_2 in the atmosphere, on global temperature and humidity changes, and on sunshine duration and cloudiness over the contiguous United States.

FIELD RESEARCH DIVISION

Most of the research of ARL's Field Research Division in Idaho is sponsored by the Nuclear Regulatory Commission (NRC), DOE, and EPA. It is directed toward current and anticipated environmental problems associated with the release to the atmosphere of toxic and undesirable effluents by our industrialized society. These problems include the quantification of downwind atmospheric dispersion contributed by the meander of plumes under light wind and inversion conditions, the effect of the land-sea interface, the effect of surface roughness and complex mountainous terrain, the measurement of the vertical as well as the horizontal profile of plume concentration, and the measurement of air trajectories. Tracer gas techniques and radar-tracked, constant-level balloon trajectories as well as standard meteorological profiles of wind and temperature are used in full-scale field experiments to address these problems and provide the necessary data for transport and diffusion model verification.

ATMOSPHERIC TURBULENCE & DIFFUSION DIVISION

The Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, Tenn., is generally concerned with air quality and consists of research on the physics of the lower atmosphere, with emphasis on the processes contributing to atmospheric transport, dispersion, and deposition, and on the development of numerical models using the results of this research. The Division works closely with the Oak Ridge National Laboratory (ORNL) and with atmospheric science units at other national laboratories, universities, and Federal agencies. The largest single funding source is the DOE Pollutant Characterization and Safety Research Division. Additional sources include NOAA, EPA, the Dept. of Defense (DOD) and the U.S. Geological Survey (USGS). The program is organized in four major areas: plume transport and diffusion in the planetary boundary layer, complex topography, atmosphere-canopy interactions, and dry deposition.

METEOROLOGY DIVISION

Meteorology Division support and services to EPA include theoretical and experimental studies of the physical processes affecting transport, diffusion, transformation, and deposition of air pollutants; development, evaluation, modification, and dissemination of air quality simulation models for inert and reactive pollutants' effects on weather and climate; and studies to define the relationships between air quality and meteorological parameters.

The Meteorology Division provides operational support to various EPA groups in their abatement and compliance activities. This includes technical advice; applications of air quality simulation models; evaluation of the meteorological portions of state implementation plans, environmental impact statements, and requests for variances; expert testimony at public hearings and judicial proceedings; emergency field services; and preparation of technical staff reports and documents.

SUN-CLIMATE STAFF

The Sun-Climate Staff conducts fundamental research on the causes and mechanisms of climatic change, on time scales of months to decades, including solar variability as a possible cause. The application is directed toward, but not limited to, climatic change in the United States. The general approach is to develop understanding of climatic processes through analytical studies using climatic, oceanographic, solar radiation, ozone, and other data, principally those representative of the current century. Fundamental research on solar UV radiation is done through analysis and modeling of its secular variation and intensity and through direct measurement of ultraviolet (UV) flux.

Progress is monitored on a grant to the University of Arizona that began in FY 1980. The grant's purposes are (1) to develop and deploy a highly accurate spectrometer and associated calibration device for ground-based measurement of the secular characteristics of solar spectral changes in the UV, visible, and near-infrared portions of the electromagnetic spectrum; and (2) to study the effects on surface-based measurements of atmospheric attenuation in these regions of the electromagnetic spectrum.

AIR QUALITY DIVISION

Air Quality Division research is directed, within the mesoscale in the lower troposphere, to (1) improving the understanding of the mechanisms of formation, residence times, and sinks of natural and anthropogenic cloud and ice nuclei; (2) elucidating the effects of those nuclei, other aerosols, and trace gases on the formation, colloidal stability, optical properties, and chemical composition of clouds; (3) determining the effects of pollutants on the radiation budget, visibility, and atmospheric electrical phenomena.

SOLAR RADIATION FACILITY

The Solar Radiation Facility has the following functions: to maintain standard instruments for solar radiation measurements, to calibrate pyranometers and pyrheliometers, to test specimen solar radiation instruments, and to make radiation measurements and establish their interrelationships. The Facility also serves as a World Meteorological Organization (WMO) regional radiation center.

GEOPHYSICAL MONITORING FOR CLIMATIC CHANGE DIVISION

Measurements of atmospheric trace gases and aerosols are made at NOAA's four baseline observatories by the Geophysical Monitoring for Climatic Change (GMCC) Division. These measurements are made to detect and document long-term global trends of trace constituents in the atmosphere. Assessments determine what sources and sinks control the long-term trend of a trace constituent and what climatic impact can be expected from such a trend.

AIR QUALITY

ATMOSPHERIC TRANSPORT

Accomplishments FY 1983

A major atmospheric transport and dispersion study, the Cross-Appalachian Tracer Experiment (CAPTEX) began in September 1983. The DOE, EPA, the Electric Power Research Institute, the National Weather Service, the Atmospheric Environment Service of Canada and the Ministries of the Environment of Ontario and Quebec all participated in CAPTEX '83 under the direction of ARL. There were five releases of a perfluorocarbon tracer gas at Dayton, Ohio, and two releases at Sudbury, Ontario. Tracer concentrations were measured in thousands of air samples collected at 80 sites in the United States and Canada as far as 1,100 km away. The release locations were chosen, in part, because the Ohio Valley and the Sudbury smelter plant are considered to be significant pollutant sources affecting air quality and causing acid rain in the New England states and southeastern Canada. Seven sampling aircraft were used to determine the vertical distribution of the tracer. The density and frequency of upper-air soundings were greatly increased over the experimental area, and a wind profiler was utilized. The CAPTEX experiments are providing a unique data base to test, evaluate, and improve the transport and dispersion modules of long-range pollution models.

Another tracer experiment was carried out in collaboration with the DOE Savannah River Laboratory to provide long-term, regional-scale transport and diffusion data for evaluating air pollution models. Krypton-85 emitted routinely from the Savannah River plant, S.C., was sampled twice daily at five stations from 300 to 1,000 km to the northeast over an 18-month period. These data will be used along with CAPTEX data for extensive testing of ARL transport and dispersion models.

Plans FY 1984

The CAPTEX '84 atmospheric dispersion experiments will be concluded in October 1983, and planning will begin for CAPTEX '85. These experiments will provide information on mechanisms affecting long-range dispersion and extensive data for evaluating air pollution models. Data will be compiled in a convenient form for use by the atmospheric science community.

ARL's year-long Metropolitan Tracer Experiment (METREX) in the Washington, D.C., area is scheduled to start in November 1983. The objectives are to obtain data to evaluate dispersion models in an urban setting and to develop and compare dispersion climatologies over adjacent urban and rural areas. Perfluorocarbon tracers will be released at two different sites every 36 hours. Average monthly tracer concentrations will be measured at about 80 sites and continuous 8-h samples will be collected at three sites to provide more detailed data on individual plumes.

ARL will also participate in the DOE Atmospheric Studies in Complex Terrain (ASCOT) dispersion experiments scheduled for fall 1984 in Colorado. The perfluorocarbon tracers will play a key role in delineating valley flows and their interaction with larger scale flows.

ACID DEPOSITION

Accomplishments FY 1983

Acid rain or atmospheric deposition of acidic materials has become one of the most discussed environmental problems, both nationally and internationally. Public awareness and concern about acid rain and its possible effects are at a high level. In response to this interest, ARL, along with other ERL labs, has provided the best scientific description and advice for possible mitigation of the problem. ARL scientists have made major contributions in the international area, such as planning the global precipitation chemistry network in conjunction with the World Meteorological Organization, cooperating with the European effort in long-range transport of acidic substances, and producing scientific documents to be used in the Canadian-U.S. bilateral negotiations. In the national effort, ARL participation has included taking an active leadership role in the Federal acid rain program--the National Atmospheric Deposition Assessment Program (NADAP).

To fulfill NOAA's research responsibilities under NADAP, ARL performed or supported a wide range of activities in FY 1983. Projects included the following:

- Studies of acidic and alkaline materials that have natural origin and contribute to the chemistry of precipitation were completed.

- The ARL back-trajectory program was used extensively to evaluate the chemistry of a given area and its relation to possible sources.

- A considerable effort was spent in analyzing data from the Global Research Network. Results show the importance of organic acids in contributing to the acidity of rain in remote areas.

- Special studies were conducted in the Northeast that demonstrated the importance of long-range transport of acid-forming sulfur compounds.

- The project to look at atmospheric transport off North America began in FY 1983. Initial results lead to the conclusion that at least a third

of anthropogenic sulfur and nitrogen compounds are transported to the eastern Atlantic and beyond.

- All three special research sites sponsored by NOAA were established and are conducting acid rain studies.

Plans FY 1984

Ongoing activities will be supplemented by two new activities (pending new support) in FY 1984:

- A special study to evaluate the possible inflow of natural acid-forming materials from the Gulf of Mexico region will begin.

- Increased research in the development and implementation of a dry-deposition research network will begin.

ATMOSPHERIC TRACER STUDIES

Accomplishments FY 1983

A month-long transport and diffusion study was conducted during October in the Four Corners area of New Mexico around the Hogback Ridge. Eleven intensive measurement periods of 12 hours each were completed. Dual gaseous tracer releasings, samplings, and gas chromatograph analyses were accomplished. Concurrent plumes of oil fog were released and photographed. About 150 hours of 1-s meteorological samplings were collected from more than 80 sensors mounted on 4 towers. Preliminary data analyses have been completed and initial results supplied to the sponsor, EPA.

A three-volume report was completed for the Idaho Field Experiment. Listings of data, descriptions of the measurement systems, and comparisons of the data and model estimates were described. A data archive on magnetic tapes was formulated. NRC and DOE sponsored this research.

Gaseous tracers, SF6 and Freon 13B1, were released, sampled, and analyzed as part of the Convective Diffusion Study conducted near Boulder, Colo., during September. Sequential 10-min tracer samples were collected at 30 locations during nine 2-h test periods. The field experiment was sponsored by EPA.

Perfluorocarbon tracer releases began in support of the CAPTEX experiment during September. These releases will continue into FY 1984. DOE sponsors this research.

A new transponder and airborne tracking capability was developed, and the prototype was demonstrated for EPA. The transponder provides a Loran-C positioning and is flown on a 1 m^3 tetroon. Releases and tracking of these tetroons began in late September in conjunction with CAPTEX, and will continue into FY 1984.

Plans FY 1984

A preliminary full-scale plume study will be conducted near Reno, Nev., for 2 weeks in November. Measurement techniques will be similar to those used for the Hogback Ridge field experiment, but fewer. Preparations for the FY 1985 comprehensive full-scale plume study will begin. EPA sponsors this research as part of its Complex Terrain Dispersion Model program.

The data measurements from the Shoreline Environment Atmospheric Dispersion Experiment field program, along the western shore of Lake Michigan, will be processed, summarized, and reported. NRC and DOE jointly sponsored the measurement program. NRC sponsors the analyses and report preparations.

Gaseous tracer support will be provided during the ASCOT field measurements in late FY 1984. Other support activities await completion of the final experimental design. DOE sponsors this research near Rifle, Colo.

Analyses and reporting of the Convective Diffusion Study will be completed in CY 1983 for EPA.

Final analyses and reporting of quality assurance information will be completed for the Hogback Ridge data measurements. Data archive tapes will be prepared and provided to EPA.

PLUME TRANSPORT & DISPERSION

Accomplishments FY 1983

The program to document the growth of the morning mixed layer was modified to provide information on mixed-layer structure near noon. Field data were obtained in the first week of every month at a site in Oak Ridge. Computer models of planetary boundary layer (PBL) evolution are now being tested with data obtained in the routine measurement program.

An automatic video digitization facility was developed. Tests of the special video recording and playback equipment and of the computerized plume analysis system have continued, using field photographs of plume releases as well as those obtained in wind tunnel experiments.

Further work on developing a numerical model of dispersion from low-level nuclear waste disposal sites began under NRC funding. The new model will apply modern micrometeorological similarity theory to assess dispersion from surface area sources. **ARL**

Revised procedures for estimating PBL dispersion statistics from external meteorological and surface variables were further evaluated, and revised recommendations were produced in a program partly supported by NRC. This work examines the way in which surface boundary layer relationships can be applied to extend surface-based, height-dependent dispersion relationships into the mixed layer. A major goal of the program has been to identify areas

in which misleading results can be obtained as a consequence of inappropriate normalization of variables.

Logistic and technical support was provided for the Electric Power Research Institute Plume Model Validation Study, conducted in Oak Ridge during FY 1983. This study was a large, multilaboratory effort focused on the transport and dispersion of emissions from TVA's Bull Run steam plant near Oak Ridge.

Plans FY 1984

A break was introduced in the routine PBL sounding program at Oak Ridge. Morning data for two years were obtained and will be analyzed during FY 1984. The outcome of this analysis will be used to help direct future activities in PBL sounding. It appears likely that a routine sounding program monitoring the onset and early growth of the nocturnal inversion will begin during FY 1984.

The use of natural tracers as indicators of intermittent turbulence during periods of strong PBL stratification is being investigated. Depending on the results of these preliminary considerations, a field study of nocturnal turbulence will be initiated during 1984 using an acoustic sounder, fast-response wind and temperature instruments, and a fast-response ozone monitor.

Video records made at the Farmington, N. Mex., plume impaction study during FY 1983 will be analyzed. Dispersion in the vicinity of forest canopies will be addressed both experimentally and theoretically, in collaboration with the ATDD program on atmosphere-canopy interaction.

COMPLEX TOPOGRAPHY

Accomplishments FY 1983

A two-dimensional drainage flow model of pure katabatic flow was improved as a result of comparisons with data from physical modeling studies and analytical models. The model is being modified to include the effects of a dense forest canopy and an ambient wind field.

Analysis of data obtained in the 1982 exploratory study of flow regimes in the Piceance Basin in western Colorado continued. Reports summarizing ATDD contributions to the ASCOT program were completed.

Plans FY 1984

The DOE ASCOT program will renew its experimental efforts in the vicinity of the Piceance Basin in western Colorado. Several ARL units are to take an active role in the development of experimental plans and will be strong

participants in the field studies tentatively scheduled for September and October 1984.

Simpler case studies are also being discussed, including a series of experiments aimed at extending perfect-site flux-measuring capabilities into real-world situations, such as those of major interest to the ASCOT program.

Wind and turbulence data from within and above the deciduous forest will be analyzed to determine the effects of differing upwind topographies upon turbulence structure and upon turbulent exchange processes.

ATMOSPHERE-CANOPY INTERACTION (FOREST METEOROLOGY)

Accomplishments FY 1983

Field facilities at the Walker Branch Watershed in Tennessee were improved by the addition of a small laboratory to provide facilities for visitors and for testing and repair of equipment used in intensive case studies. Several micrometeorological experiments were conducted. These showed the diurnal variability of the distribution of heat sources in the canopy; theoretical investigations of the consequences of this variability are now in progress. Studies of the eddy fluxes of heat, moisture, and momentum demonstrated that single-point micrometeorological methods are capable of producing representative surface fluxes over nonsimple surfaces. The requirements of a surface heat energy balance have been satisfied to the accuracy necessary to evaluate heat storage in the canopy. A program to measure eddy fluxes of carbon dioxide above the canopy commenced, and preliminary data are now being analyzed.

Climatological monitoring and data reduction continued. Monitoring work expanded to allow determination of bulk canopy radiative properties on a continuing basis, as required for energy budget analyses. Canopy solar radiation models are being tested.

Plans FY 1984

Periodic measurements of above-canopy vertical turbulent exchange of momentum, sensible. and latent heat, and mass (CO_2, SO_x, O_3, and particles) will be made using variance and covariance flux measurement techniques. The periods of study will be selected to obtain turbulent exchange data during major seasons of the year and phenological phases of the forest, under a variety of meteorological conditions. In addition to providing information about effects of physiological resistances to turbulent exchange between forests and the atmosphere, these measurements will provide data basic to the determination of pollutant deposition velocities at the ATDD research site, as required for inferring dry deposition rates from atmospheric concentration and meteorological monitoring data. **ARL**

Efforts will continue to devise a measurement protocol for studies of subcanopy wind and turbulence. Techniques that will allow quantification of the roles of horizontal pressure gradient terms, vertical momentum gradients, turbulent gust penetration through canopy gaps, and gravity flow in producing observed subcanopy flow phenomena are under investigation. A long-term objective of this effort will be to include such effects in higher order closure models of canopy flow.

Periodic measurements of forest canopy radiant temperature distributions will be made at the Walker Branch site under terms of a contract with the U.S. Army, using a new automatic-scanning infrared thermometer.

Periodic determinations of spatial distributions of diffuse to direct photosynthetically active radiation will continue, for use as a technique for assessing canopy structure indirectly.

Comparison of predictions of phytoactinometric models with observed canopy radiation distributions will be completed under a contract with the U.S. Army Research Office. Extant radiation distribution data sets will be further analyzed and interpreted.

ATDD will be co-host of a Forest Environmental Measurements Conference in Oak Ridge, Tenn. This conference has attracted an outstanding international group of participants, and should affect the direction of forest meteorology research efforts, including those at ATDD, for many years to come.

Climatological monitoring at the Walker Branch site will continue. A new data acquisition system with on-line data reduction and summarization capabilities will streamline climatological data handling and manipulation procedures.

DRY DEPOSITION STUDIES

Accomplishments FY 1983

Experimental work on dry deposition expanded on two distinct levels. First, a series of intensive case studies commenced during 1983 in Pennsylvania (February), Tennessee (May), and Illinois (July). These studies combine experimental capabilities of NOAA with those of the EPA Environmental Science Research Laboratory, Argonne National Laboratory, and Pennsylvania State University. Measurements were made of the eddy fluxes of sulfur dioxide, sulfate particles, nitrogen dioxide, nitric acid vapor, ozone, and aerosol particles in several size ranges. Second, work commenced on setting up a prototype dry deposition monitoring program for the National Acid Precipitation Assessment Program (NAPAP). The program is based on the measurement of atmospheric concentrations of important trace gases and aerosol chemical species, and on the determination of site-specific deposition velocities appropriate for each constituent.

Considerable input was given to both the EPA volume of Critical Assessment Review Papers on acid deposition, and the related National Academy of Sciences document.

Plans FY 1984

Six prototype dry-deposition monitoring stations will be set up in a cooperative venture with EPA and USGS. Meteorological data obtained at these stations will be reduced during the initial phase of the program, and dry deposition fluxes will be estimated from the concentration data produced by EPA collaborators.

An integrated observational program of air chemistry, atmospheric particle, and micrometeorological measurements will be carried out in collaboration with Pennsylvania State University (State College, Pa.) and the Argonne National Laboratory (Argonne, Ill.). The field studies are designed to improve existing techniques and develop new methods for evaluating dry deposition rates of selected atmospheric pollutants, particularly acidic contaminants. The measurement program will provide, as a minimum, (1) data on sulfur and nitrogen oxides, ozone, and time-dependent particulate size distribution function; and (2) a comprehensive set of micrometeorological observations sufficient for evaluating momentum, evaluating heat and moisture fluxes, and determining deposition velocities of selected atmospheric pollutants.

The formulations necessary for evaluating appropriate deposition velocities from recorded meteorological data will be developed using the results of intensive field studies as guidance. These field studies will employ covariance and gradient methods at carefully selected field sites, especially at the Walker Branch Watershed experimental site jointly operated by ATDD and ORNL.

VERIFICATION OF AIR QUALITY MODELS

Accomplishments FY 1983

The major emphasis continued to be the development, evaluation, and verification of air quality simulation and meteorological models, including the collection of critical data bases. Work on the problem of pollutant dispersion in complex terrain included (1) performance of the Small Hill Impaction Study #2 at Hogback Ridge near Farmington, N. Mex., to expand the applicability of the complex-terrain dispersion models developed for Cinder Cone Butte to the case of a two-dimensional ridge; (2) statistical testing of the VALLEY, COMPLEX I, COMPLEX II, and the newly-developed Complex Terrain Dispersion Model using the entire data base from Cinder Cone Butte and part of the data base from Hogback Ridge; and (3) documentation of initial versions of the VALMET (valley) and MELSAR (mesoscale) air quality models, part of the Green River Ambient Model Assessment project to analyze the impacts of the oil industry over pristine wilderness areas. **ARL**

ENAMAP-2 (Eastern North American Model Air Pollution), a Lagrangian model for predicting the regional deposition of SO_x and NO_x, was developed and documented. Data preprocessors were developed to prepare the monthly meteorological data required to exercise the model for any year.

Eight tracer experiments were conducted at the Boulder Atmospheric Observatory to study diffusion characteristics under convective conditions.

A mathematical model of two-pollutant ambient air effects, which can be applied to either acute or chronic ambient exposures, was developed, published, and applied to soybeans exposed simultaneously to ozone and sulfur dioxide near power plants.

Version 5 of UNAMAP (User's Network for Applied Modeling of Air Pollution), containing 31 air quality simulation models and test data, became available on magnetic tape from NTIS in August. Several documents were published covering work performed on (1) the preparation of users' guides for air quality models, (2) a comparison of sigma schemes for estimating plume dispersion, and (3) preparation of meteorological data for use in routine dispersion calculations.

Progress continued on the development and evaluation of the Regional Oxidant Model (ROM), including (1) implementation of a Biogenic Emissions System for generating hourly gridded biogenic emissions compatible with ROM, (2) conversion of the Canadian emissions data to generate gridded hourly emissions, (3) implementation of a network of 20 processors that supply the spatially and temporally resolved input data, and (4) installation and optimization of a preliminary version of ROM on a CRAY-1 computer.

A mathematical-physical model simulating transport, diffusion, and chemical reactions of pollutants on and immediately downwind of roadways was released for use through the UNAMAP system. The model (a supplement to the earlier HIWAY model) is based upon a vehicle-wake theory, which was tested and modified as a result of tests conducted in a specially constructed wind tunnel.

A laboratory study was conducted of the stratified flow over triangular-shaped ridges of various cross-wind aspect ratios to obtain information on lee-wave structure, interactions between the lee-waves and the near-wake recirculating region, and the height of the dividing streamline (below which all fluid moved around, rather than over the body). The study demonstrated that wave amplitudes can be maximized by "tuning" the hill shape to the lee-wave field, that steady wave breaking can occur and multiple rotors can exist on the surface downstream of the ridges, that vortex shedding in horizontal planes is possible at low Froude numbers, and that the effect of the ratio of the cross-stream width of the ridge to its height on the dividing-streamline height is negligible.

A laboratory study examined concentration distributions on a hill surface resulting from plumes impinging from upwind sources under neutral and very stable flow conditions. The study demonstrated that (1) when the source is below the dividing-streamline height, plumes impact on the front surface of the hill and yield surface concentrations nearly the same as would be observed at the plume centerline in the absence of the hill; (2) when the source is above the dividing-streamline height H_D, the plume surmounts the hill top; if it is only slightly above H_D, maximum surface concentrations can again essentially equal those observed at the plume centerline in the absence of the hill; further increases in source height result in very rapid decreases in maximum surface concentration; (3) the location and value of the maximum

surface concentrations are found to be extremely sensitive to slight displacements of the source from the stagnation streamline when the source is below H_D; and (4) potential-flow models provide reasonable estimates of surface concentrations on three-dimensional hills.

A series of experiments was conducted to test the feasibility of towing-tank simulations of strongly stable atmospheric flows over very long (two-dimensional) ridges. The study showed that steady-state conditions are not established in a finite-length towing tank and, hence, casts doubt upon the validity of previous laboratory studies.

Plans FY 1984

Direct meteorological research support to EPA will continue. Research will continue on developing and evaluating air quality simulation models for inert and reactive pollutants and the associated meteorological models, on all temporal and spatial scales. Major emphasis will be on model development, evaluations, and verification using available data bases; use of the data base obtained during the North East Regional Oxidation Study (NEROS) field program to evaluate and modify a regional photochemical oxidant model; a feasibility study in preparation for a major field study in the western United States to establish a data base for the development of air quality dispersion models for areas of complex terrain; development of long-range transport models; development of boundary layer models; study and modeling of atmospheric processes affecting acid deposition; and attention to the problems of model uncertainty. Work will continue in the Fluid Modeling Facility, using the wind tunnels and water channel/towing tank, on the study of plume dispersion in complex terrain, in the wake of automobiles, and around buildings.

AIR QUALITY MEASUREMENTS

Accomplishments FY 1983

Measurements in the summers of 1981, 1982, and 1983 have shown repeatedly that the V. Schaefer Obervatory at Whiteface Mountain, N.Y., at 1512 m MSL, 73°54'W, 44°22'N, is within the area affected by pollutants transported from large source regions (e.g., the Great Lakes Basin and the Ohio Valley) and is subject to acid precursor input varying with changes in wind directions; air masses moving to the site from western Canada generally bring pristine air while those coming from the industrialized eastern United States are typically associated with high pollution levels. Polluted air, for example, shows an increase, relative to nonpolluted air, in the small-particle mode of an aerosol size distribution at 0.1 m particle radius. Total aerosol number concentration increases from 268 to 1,810 cm^{-3}, total mass loadings from 1.5 to 33 g m^{-3}, and sulfur-containing aerosols from 94 to 1,100 cm^{-3}.

ARL

At sufficiently high humidities, cloud drops nucleate on the submicrometer sulfur particles. Nucleation scavenging, therefore, is an important

mechanism by which sulfate concentrations are enhanced in polluted clouds, yielding measured concentrations 11 times as high as those in continental background clouds, and 36 times as high as those in maritime clouds.

Identification of the mechanism by which pollutants are captured by clouds is important for the design of control strategies. Under the premise that SO_2 is the precursor of the submicrometer sulfur particles that act as cloud condensation nuclei, reductions of SO_2 could result in a significant lessening of the sulfate content of clouds and precipitation. Analyses of pairs of water samples, collected simultaneously, showed that concentrations of sulfate were higher in mist and raindrops than in cloud droplets; the difference was about 30%.

The Whiteface Mountain data indicate that the measured inorganic anion and cation balance is often inadequate to account for the measured pH, the H^+ concentration being greater than that inferred by inorganic analysis. This suggests that some of the acidity of both polluted and unpolluted clouds may be associated with natural anions, possibly organic, for which analysis is not usually done. Analysis of cloud- and rainwater samples collected during the Summer 1982 field project showed that the oxalate anion was present. As was the case with the sulfate and nitrate ions, the concentration of oxalate in cloud water was greatest at the onset of a cloud episode, when the air mass has passed over industrialized, hence polluted, areas. Measured oxalate concentrations in cloudwater from a polluted air mass were 0.5-0.7 ppm; concentrations in cloudwater-rainwater samples from a clean, continental airmass were 0.03 to 0.14 ppm. The presence of other organic anions was indicated, but was not determined quantitatively.

The main conclusion to be drawn from this data set is that both maritime and continental background aerosols contain some unknown anions that contribute to the natural acidity of cloud water. This natural acidity level has to be precisely known in order to assess the effects of anthropogenic pollutants on clouds and precipitation.

Radiative-optical properties of polluted and nonpolluted clouds were calculated by applying the matrix-operator method to measure cloud-drop spectra. Results show that the polluted clouds scatter more sunlight in the forward direction than do nonpolluted clouds. Consequently, at equal optical depths, the polluted cloud has a lower solar albedo than does the nonpolluted cloud. For partially absorbing clouds, caused by dissolved cloud condensation nuclei of radius 0.4 μm and refractive index 1.5-0.04, this is still true at small optical depths. At larger optical depths, however, increased absorption by a larger number of small drops causes the albedo to fall below that of polluted clouds. The infrared (10-μm) emissivity of polluted clouds is significantly greater than that of nonpolluted clouds at geometric depths from several hundred meters to 2 kilometers. These results show that changes of the physical and chemical properties of clouds by anthropogenic pollutants inadvertently change the radiative-optical properties of clouds. This could affect the climatological-mean surface temperature in regions where temperature inversions are frequent and persistent.

Plans FY 1984

Research will concentrate on a quantification of the differences between chemical and physical characteristics of natural and of polluted clouds. This will be done by determining pertinent properties of maritime clouds offshore, and their modifications as they travel inland. The Gulf coastal region, Southern Atlantic states coastal region, and the Pacific Northwest coastal region are climatological inflow boundaries for air masses that traverse large areas of the continental United States.

A twin-engined aircraft, equipped for trace gas analysis, cloud- and rain-water collection, aerosol size distribution measurements, and turbulent flux measurements, will be operated during appropriate seasons, primarily spring and summer. Flights will be conducted at altitudes both within and above the boundary layer, along traverses parallel to the Gulf coast shoreline at locations 30-50 km offshore, near shore, and at various distances inland, as required to identify contributions from marine, marsh or estuarine, and inland rural areas. Sample collection and in situ analyses will be done both in clear air and in clouds. In situ measurements of sulfate, trace sulfur-containing gases (such as H_2S, SO_2, CS_2, OCS, and $(CH_3)_2S$), nitrate, NO, and NO_2 will be made on a real-time basis where possible. Both horizontal and vertical atmospheric transport parameters will be measured on the aircraft or estimated from sounding networks. The flux of acids and acid precursors into the midwestern and eastern United States will be estimated and compared with network deposition measurements. The contribution of the natural wetland/marine and continental (natural and anthropogenic) sources of acid precursors will thus be assessed.

OZONE

Accomplishments FY 1983

Total-ozone and ozone-profile data for the world were updated through the autumn of 1982. In 1982 the total ozone was 2.0% above average in north temperate latitudes but 0.4% below average for the world as a whole, the latter deviation being insignificant. There is still no evidence of a long-term reduction in global total ozone. In the 32- to 48-km layer sensitive to anthropogenic effects, the ozone amount in north temperate latitudes was 2.6% below average in 1982, following a downward trend of 2.3% between 1970 and 1981. There is thus evidence for a slight reduction in ozone in the high stratosphere, but the cause of this reduction is unknown. In the tropospheric 2- to 8-km layer of north temperate latitudes the ozone amount was 15% above average in 1982 following an upward trend of 12% between 1970 and 1981. There is thus evidence of a tropospheric increase in ozone. It would appear that the near invariance of total ozone during the past several years is due to a balancing of tropospheric ozone increase and stratospheric ozone decrease.

Plans FY 1984

The total-ozone and ozone-profile data will continue to be updated with emphasis on detecting any further ozone decrease in the high stratosphere and ozone increase in the troposphere.

CLIMATE

SUN-CLIMATE RELATIONSHIP

Accomplishments FY 1983

Studies continued of the association of U.S. climatic anomalies with meteorological and oceanographic conditions in the tropical Pacific. The results indicate that during years when temperatures were below normal in the eastern tropical Pacific, winter temperatures tended to remain below normal in the southeastern United States and winter precipitation was above normal in the southeastern and northwestern United States. But in the years with warmer-than-normal temperatures in the eastern tropical Pacific, much of the eastern two-thirds of the country tended to have winters that were colder and wetter than normal. The studies also show the cause of these climatic anomalies to be Northern Hemisphere tropospheric circulation anomalies, which vary with temperature conditions in the eastern tropical Pacific.

Specification models, based on temperature conditions in the tropical Pacific, were used as a basis for preparing experimental U.S. temperature and precipitation outlooks for 1 to 12 months. Since February 1983, the outlooks have been issued quarterly and made available to the National Climate Program Office (NCPO) and the Climate Analysis Center (CAC) of the National Weather Service, which issues the official monthly and seasonal U.S. climate outlooks.

The Sun-Climate Staff completed analysis of solar UV radiation (160-400 nm) observations for 1 year from Nimbus-7. The UV variation over 30-day periods was typically >3% at wavelengths <208 nm and about 1% at 208-265 nm. The solar UV variations were quasi-periodic; periods varied from about 25 to 28 days and changed after several months. Occasionally, dominant periods of about 13 days were observed. The standard indices of sunspot number and solar radio flux failed to show predominant periodic behavior at 13 days. This suggests that the latter indices have a different dependence on the position of the solar active regions compared with the proximity of the central meridian of the Sun than is the case for UV emissions from solar plages. Solar UV models have been extended to include 200-300 nm, Lyman-alpha, and the full-disc Ca-K flux. The Sun-Climate Staff completed construction of the UV monochrometers for rocket-flight measurements of the solar UV spectral irradiance.

The University of Arizona, under a NOAA grant, continued the development of a ground-based solar spectrometer. Preliminary observations with a secondary spectrometer are continuing on Mt. Lemon near Tucson, Ariz.

Plans FY 1984

Basic research will continue on the identification of climatic variability with solar and other time periods and of causes and mechanisms for these climatic changes. A question to be investigated is whether persistence of either U.S. climatic anomalies or global circulation anomalies is related to solar activity. The application of specification models to experimental forecasts of U.S. climate on periods 1-18 months will continue. Issuance, quarterly, of experimental U.S. temperature and precipitation outlooks for the NCPO and CAC, based on temperature conditions in the eastern tropical Pacific, will continue.

Basic research on analysis and development of models of UV and ozone variability will continue. A rocket-flight UV spectroradiometer will be calibrated and tested.

The University of Arizona will continue development of the ground-based solar spectrometer and will continue its observational program from Mt. Lemon. A meeting will be held in early 1984 to recommend a mountain observatory site suitable for conducting the observational program with the University of Arizona solar spectrometer.

SOLAR RADIATION NETWORK

Accomplishments FY 1983

All 38 pyranometers that were returned from the network stations in FY 1982 and 1983 were run regularly in a calibration array, and curves have now been obtained that show the hourly, daily, and yearly variability of the individual instruments with the NOAA standard pyranometer. These data should allow corrections to be made to network measurements to approach a ±1%-2% absolute measurement of daily totals of solar radiation.

Regular transfer calibrations of the working standard and control pyranometers by the absolute cavity radiometer verified a steady drop in sensitivity of about 0.5% year in one type of pyranometer. This finding strengthens the case for regular and frequent recalibration of field instruments.

Analysis of the Boulder direct radiation measurements showed a maximum depletion near noon of 20% in December 1983 caused by the dust cloud from the eruption of the El Chichón volcano in Mexico in May 1983. Effects of the dust cloud are still evident in the Boulder direct radiation data, amounting to about 5% through the 1983 summer.

Sunphotometers for the measurement of atmospheric turbidity were built, calibrated, and delivered to nine NWS stations. This measurement will be used to help verify the direct radiation measurements made at each station and also to provide a climatology of turbidity as part of the WMO BAPMoN (Background Air Pollution Monitoring Network) program.

Plans FY 1984

Pyranometers will be replaced at all 38 network stations, and pyrheliometers will be replaced at as many stations as time and instruments permit. In a special study, the old-style pyranometers in use at 10 stations will be returned, recalibrated, and tested.

The Sixth New River Intercomparison is scheduled for November 1983 at the DSET (Desert Sunshine Exposure Test) Laboratories in Phoenix. This will also be a WMO regional comparison of both pyrheliometers and pyranometers. The NOAA reference instruments will serve as the standards for the comparisons.

Data from 10 network stations of radiation measured simultaneously with old- and new-style pyranometers will be analyzed in cooperation with the Solar Energy Research Institute (SERI) to relate old (before 1977) and new network data.

Intercomparisons of field and laboratory experiments will be carried out in cooperation with SERI in a continuing study for the International Energy Agency of the characteristics of various types of pyranometers that are used to test solar energy collectors.

Work will continue in writing national (ASTM) and international (ANSI) standards for solar radiation measurements.

Depending on the degree of cooperation available from the National Weather Service, sunphotometers will be sent to all network solar radiation stations that are not already taking this measurement.

HUMIDITY

Accomplishments FY 1983

Tropospheric humidity was examined for the interval 1958-1980 at Brownsville, Tex., and Great Falls, Mont. Changes in instrumentation and measurement procedures have necessitated adjustments to the raw data. In general, changes in relative humidity, mixing ratio, and precipitable water at the two stations have paralleled changes in Northern Hemisphere surface temperature, that is, decreased from 1958 to about 1970, and increased thereafter. At both stations the relative humidity has varied inversely with temperature on a seasonal and yearly time scale, and the mixing ratio directly with temperature on this scale, but over the longer term these relations do not always hold. Precipitable water appears the most representative of the humidity elements.

Plans FY 1984

Relative humidity, mixing ratio, and precipitable water will be monitored at the same 63 radiosonde stations used for temperature monitoring.

TEMPERATURE

Accomplishments FY 1983

Global temperatures obtained from the 63-station radiosonde network have been updated through the summer of 1983. In the tropics the stratospheric warming due to the eruption of El Chichón (Mexico) in the spring of 1982 was 3°-4°C, comparable with the stratospheric warming due to the eruption of Agung (Indonesia) in 1963; because of the higher altitude of the El Chichón dust cloud, the related warming occurred higher in the stratosphere. In both cases the maximum warmth was observed two seasons after the eruption. In the Northern Hemisphere and the world, and particularly in north temperate latitudes, there was cooling at the surface and in the troposphere before the eruption of El Chichón, and warming after the eruption. Surface temperatures in north temperate latitudes were very warm during the winter of 1982-83, and spring and summer temperatures also set many records for warmth in these latitudes, as well as in the hemisphere and the world. On the basis of the first three seasons, 1983 will be a very warm year despite the El Chichón eruption in 1982. This warmth is believed to be associated in part with the very warm sea-surface temperatures in the equatorial eastern Pacific (El Niño) in late 1982.

Plans FY 1984

The temperature data in troposphere and stratosphere will continue to be updated with emphasis on detection of tropospheric cooling due to the El Chichón eruption.

SUNSHINE DURATION AND CLOUDINESS

Accomplishments FY 1983

Sunshine duration and cloudiness over the contiguous United States were compared for the interval 1950-1981. During this period the cloudiness increased about 3% and the sunshine duration decreased about 1%. On the basis of yearly data there is a correlation of -0.81 between these two quantities, the correlation being greatest in autumn (-0.95) and least in spring (-0.78). Year-average correlations exceed -0.9 in south central and northeastern United States, and are less than -0.7 in northwestern and southwestern United States.

ARL

Plans FY 1984

Sunshine duration and cloudiness data will be updated through 1982. Emphasis will be on detection of some effect on either quantity from the El Chichón volcanic eruption in the spring of 1982.

CARBON DIOXIDE

Accomplishments FY 1983

Background measurements of atmospheric CO_2 have been made continuously since 1958 at Mauna Loa and since 1974 at the other three baseline observatories. Since 1979, the baseline observatory measurements of CO_2 have been complemented by a 20-station flask-sampling network to provide a more detailed global coverage.

Predictions of future concentrations of atmospheric CO_2 are based on estimates of future emissions of CO_2 by the burning of fossil fuels, etc., which are inserted into models of the carbon cycle. During FY 1983 a sensitivity study of sources of error in the predictions of future atmospheric CO_2 was conducted. The study showed that if the broad aspects of the model were even approximately correct, the details of the model characteristics (e.g., the exchange of CO_2 between reservoirs) contributed much smaller errors to the final prediction than do reasonable uncertainties in the predicted future emissions.

The GMCC CO_2 record is now archived annually with WMO in Geneva, Switzerland. In 1983 both flask and continuous CO_2 values were archived with the CO_2 Information Center (DOE Oak Ridge National Laboratory) as well. The flask and continuous measurements of CO_2 were reduced to a final atmospheric concentration value based on a Scripps Institution of Oceanography (SIO) X-81 scale and identified for background atmospheric conditions. CO_2 measurements by NOAA and by SIO made at the GMCC baseline observatories were compared in detail and found to be in general agreement at the 0.1% (0.3 ppm) level or better.

The GMCC CO_2 data are being analyzed to obtain the long-term status of the globally averaged latitudinal variation and the annual growth rate and seasonal variations of the atmospheric CO_2. The global mean growth of atmospheric CO_2 from 1976 to 1982 has been $\simeq$1.5 ppm yr^{-1}. This resolves to a loading of an airborne fraction of 0.54 of the total CO_2 released to the atmosphere from fossil fuel burning. Analyses are also being done to describe interannual variabilities in the CO_2 growth rate, and short-term variabilities due to short-term natural variabilities in ocean/atmospheric circulation changes (El Niño).

An observed secular increase in the CO_2 seasonal amplitude at all latitudes suggests that during the last decade the mean seasonal exchanges of CO_2 between the atmosphere, ocean, and biosphere have undergone a significant change. The seasonal amplitudes at Barrow and Mauna Loa increased 1% to 2% yr^{-1} during 1976-1982.

Data from the four baseline observatories, the 20-station flask-sampling network, and supplemental shipboard measurements were synthesized to create a zonally averaged global atmospheric CO_2 distribution as a function of latitude and time which show clearly the latitudinal and seasonal (summer) drawdown in the Northern Hemisphere and the near absence of a seasonal variation in the Southern Hemisphere. Analysis of recent measurements of isotopic ^{13}C in flask samples (USGS cooperative program with GMCC) showed, in a global

model of CO_2 atmospheric concentrations, the dominance of land vegetation in the Northern Hemisphere seasonality and the dominance of the oceans in the high southern latitudes' lack of seasonality.

Preliminary test sampling, when possible, from the flask network air samples previously analyzed for CO_2 began to yield global distribution of carbon monoxide and methane. These two gases are critical in models of tropospheric chemistry and global climate change.

High levels of CO_2 in the Arctic in late winter/early spring were documented by CO_2 sampling at Barrow, Alaska; Mould Bay, Canada; and Weather Ship M, near Iceland.

Plans FY 1984

Final background flask-sample values for the period 1968-1982 will be archived by December 1983 with the DOE CO_2 Information Center and with WMO. The full record of CO_2 measurements at the Barrow, Mauna Loa, Samoa, and South Pole observatories will be corrected, edited, and converted to the SIO X-81 scale. Preliminary selection of background monthly means will be archived with the DOE CO_2 Information Center, and the provisional daily values (for 1982) will be archived with WMO. Provisional selection of background daily values for all stations and all years will be archived with DOE and WMO by February 1984.

The perturbation of global atmospheric CO_2 by the 1982/83 El Niño/ Southern Oscillation event will be studied.

The continuous CO_2 measurements at Barrow, Mauna Loa, Samoa, and the South Pole will continue. First field tests at Mauna Loa will evaluate an alternative CO_2 continuous measurement system employing gas chromatography evaluation with respect to the standard nondispersive infrared technology used until now.

The flask network will expand to improve latitude coverage, especially in a critical equatorial upwelling zone (Christmas/Fanning Island, cooperatively with Scripps Institution of Oceanography) and at midsouthern latitude (Easter Island, Chile, and cooperatively with Australian CSIRO [Commonwealth Scientific and Industrial Research Organization] at its clean-air site at Cape Grim, Tasmania). The first year's in situ vs. total column CO_2 and CH_4 measurements at Kitt Peak Observatory will be evaluated in a cooperative program with Battelle Laboratories in order to assess Fourier transform infrared spectroscopy as a monitoring technique for radiatively important trace gases linked to climate change. **ARL**

A test program with CSIRO and the Oregon Graduate Center will use the GMCC CO_2 flask network samples to analyze for CH_4 and CO concentrations. An attempt to identify space and time variations of these species will be made.

A Mauna Loa field comparison of GMCC and SIO continuous CO_2 analyzers, as part of DOE-supported evaluation of the GMCC vs. Scripps CO_2 records at Mauna Loa since 1974, will be completed in 1984.

Possible oceanographic expeditions in 1984 include the PMEL Marine CO_2 expedition in the North and South Pacific and a coordinated aircraft/shipboard program in spring 1984 to assess the equatorial Pacific Ocean source of atmospheric CO_2 by eddy correlation and flux gradient measurements. The U.S./U.S.S.R. collaboration in environmental science will continue with U.S. participation in the U.S.S.R. Pacific oceanographic expedition making continuous gas chromatographic measurements of CO_2 in air and surface seawater from 40°N to 40°S in the central Pacific.

OZONE

Accomplishments FY 1983

After the eruption of the El Chichón volcano in April 1982, a specially calibrated Dobson spectrophotometer was used at Mauna Loa Observatory to make simultaneous observations of ozone and SO_2. (SO_2 possesses absorption spectra at the Dobson instrument wavelengths, and can interfere with the ozone measurements.) Preliminary analysis of the data indicated that the residence time of SO_2 in the stratosphere was short following the eruption, so that SO_2 interference caused no significant (greater than +1%) errors in measured total ozone amounts.

Dobson instrument Umkehr observations initiated at Mauna Loa Observatory in May 1982, following the eruption of El Chichón, showed severe biasing of conventional Umkehr data at 45-km altitude by stratospheric aerosols. Negative ozone amounts were initially computed for this region of the atmosphere. As the stratospheric layer gradually cleared, the ozone values became increasingly positive, returning to nearly normal values in December 1982. Ozone profiles derived from processing of the data by a new, short Umkehr method did not show as severe an interference by the aerosols. The derived profiles, however, exhibited unrealistically low altitudes for the stratospheric ozone maximum.

The weekly program of ECC (electrochemical concentration cell) ozonesonde releases, begun in September 1982 at Hilo, Hawaii, continued through FY 1983. Balloon ascents to altitudes of 39 km were routinely attained. The data have been processed but have been withheld from publication pending determination of corrections to data above 6 mb. Between 6- and 2-mb altitude, the dropoff in measured ozone appears to be too rapid, for reasons not yet determined.

Tests in Boulder on high-altitude (to 40 km) ECC ozonesondes continued throughout the year. Soundings were made at a frequency of one per month. ECC sondes were compared with other types of ozone-measuring instrumentation in July 1983 at Palestine, Tex., during a NASA-sponsored balloon ozone instrument campaign. This campaign was only partially successful, owing to balloon burst at relatively low altitude. Successful intercomparisons to 40 km were obtained in July, however, with a Dasibi-type UV photometer in Palestine, Tex., and with several other kinds of instruments during September at a European balloon ozone campaign conducted in Aire Sur L'Adour, France.

A balloon-borne SO_2 sonde was developed for SO_2 measurements in the troposphere and the stratosphere. The sensor employed is a modified ECC ozone sensor. Measurement sensitivity in the low troposphere is about 0.5 parts per billion by volume (ppbv) SO_2. A maximum of 72 ppbv SO_2 was measured at 1.4-km altitude, the source being a local power plant. The SO_2 concentration decreased to zero at about 4.0 km--the base of a stratus cloud layer.

An earlier version of the ECC SO_2 sonde was flown from Hilo, Hawaii, in late September 1982. A reactive gas above the tropopause was detected which is now believed to have been H_2S. Definitive tests have yet to be made to determine the sensitivity of the SO_2 sonde to H_2S. Improved versions of the instrument were flown from Boulder, Colo., in January 1983 and from Pittsburg, Pa., in February 1983. No significant amounts of reductant gases were found at that time in the troposphere or the stratosphere.

Total ozone observations with Dobson ozone spectrophotometers were continued at Bismarck, N. Dak.; Caribou, Maine; Tutuila Island, Samoa; Mauna Loa, Hawaii; Wallops Island, Va.; Nashville, Tenn.; Boulder, Colo.; Tallahassee, Fla.; Huancayo, Peru; and Amundsen-Scott, Antarctica. Observations at Point Barrow, Alaska, were terminated early in the new year in anticipation of transferring the observing site to Poker Flat, Alaska. Efforts made to re-establish total ozone observations at or near White Sands, N. Mex., were unsuccessful. Observations at White Sands by the U.S. Department of the Army were terminated in January 1982. A new total ozone measurement station was established at Fresno, Calif., and became operational in June 1983.

A program established in 1982 to check on the calibration status of Dobson spectrophotometers throughout the world by means of traveling standard lamps has been highly successful. By the end of FY 1983, 76 instruments had been tested. Of these, 20 were identified as requiring recalibration.

In related work, Dobson instrument no. 90 was transported from Bangkok to Boulder in August 1983 for modernization, optical alignment, and recalibration. A visiting technician from Bangkok was trained in maintenance and calibration of the instrument.

Work begun in June of 1982 to automate six Dobson spectrophotometers for Umkehr observations continued during FY 1983. The bulk of the work on the instruments and their Ash dome shelters was completed. The first of these instruments was installed in Haute Provence, France, in late August 1983. The station became operational 1 September 1983. This project has been funded by the EPA, the Chemical Manufacturers Association, NOAA, and WMO. Ozone measurements from GMCC observatories are also being used as ground truth to satellite measurements.

Plans FY 1984

Automation of Dobson instruments for Umkehr observations and their establishment at field stations is expected to be complete by June 1984. Observatory sites have not all been finally selected, but they are expected to be

Poker Flat, Alaska; Mauna Loa, Hawaii; Pretoria, South Africa; Huancayo, Peru; and Perth, Australia.

Another intercomparison of ozone-measuring instrumentation, including ECC sondes, will be conducted at Palestine, Tex., early in FY 1984 under sponsorship of NASA. Monthly ozone soundings will be continued in Boulder.

Work continues on establishing a six-station global network of automated Dobson instruments to measure ozone profiles in order to detect any downward trends in stratospheric ozone and to provide satellite ground truth.

AEROSOLS AND RADIATION

Accomplishments FY 1983

An Arctic Gas and Aerosol Sampling Program (AGASP) using the NOAA P-3 aircraft was conducted in the spring of 1983 over the Arctic. NOAA participants in this major effort were GMCC, the Research Facilities Center, WPL, and CIRES. Also participating were the Office of Naval Research, National Center for Atmospheric Research, DOE, NASA, Lawrence Livermore and Berkeley Laboratories, research groups from Canada and Norway, State University of New York at Albany, Georgia Institute of Technology, Colorado State University, and the Universities of Rhode Island, Maryland, Alaska, California at Davis, Washington, and Stockholm.

In the AGASP program, aircraft observations confirmed the earlier measurements made at Barrow of a winter/early-spring influx of anthropogenic aerosols and gases over the Arctic that has come to be known as the Arctic Haze. Measurements of radiatively active, anthropogenic gases and aerosols during AGASP showed that trace species levels are far above background over the Arctic in the winter and early spring. The principal sources have been identified as Siberia and northeastern Europe.

GMCC's second major effort undertaken in FY 1983 involved measurements of the El Chichón stratospheric cloud. El Chichón volcano erupted in Mexico in April 1983 and ejected huge quantities of gases and aerosols into the stratosphere. GMCC scientists participated in two special NASA-990 flights to gather information on the meridional variation of the optical properties of the El Chichón stratospheric dust cloud. Contributions consisted of measurements of the (diffuse-sky)/(direct-Sun) ratio for determining the cloud's optical absorption and scattering properties, and narrowband optical depth measurements at six wavelengths spanning the visible solar spectrum. Special instrumentation was developed for these measurement flights.

The El Chichón cloud was first detected at the Mauna Loa Observatory. Lidar measurements permitted description of the height, depth, and evolution of the volcanic debris cloud over the Pacific region. In October 1982 a series of special radiation measurements of the El Chichón cloud was made at the Observatory. The measurements consisted of spectral (diffuse-sky)/(direct Sun) hemispheric flux and zenith-sky intensity, and narrowband optical depth. Radiation-measuring instrumentation in the new solar dome was used

extensively for these measurements. Decreases in solar radiation and increases in atmospheric turbidity were detected at the surface at Barrow, Mauna Loa, and South Pole that were directly related to the global spread of the volcanic debris in the stratosphere originating from the eruption of El Chichón. The Mauna Loa observations showed as much as a 7% decrease in total incoming solar radiation, and solar irradiances that had not returned to normal in August 1983. The El Chichón effort is a good example of GMCC's continuing role in detecting stratospheric loadings and assessing their longevity as screens of incoming solar energy.

A high-precision narrowband sunphotometer, to be used as a reference for calibrating instruments in the U.S. turbidity network, was constructed and tested at Boulder and Mauna Loa. The short-term (on the order of a week) variability of the Langley calibration was determined to be on the order of +0.6% for the short wavelengths and +0.2% for the long wavelengths. These values are well within the WMO precision requirements for baseline turbidity measurements.

Measurements of light scattering and condensation nuclei, made in the summer of 1982 at Whiteface Mountain, N.Y., were compared with computed trajectories of air flow to determine source direction or high particle concentrations. High concentrations were found to correlate with trajectories having a strong component from the west. A 1983 set of measurements (that included size distribution as well) was made at Whiteface Mountain to provide information on year-to-year variability. The summer weather of 1982 and of 1983 differed considerably so we expect to see interesting differences in measurements.

Plans FY 1984

GMCC has organized and will be host for an intercomparison of narrowband sunphotometers used in the United States, Canada, and Thailand. These sunphotometers vary greatly in sophistication, ranging from complete automation to handheld, dial readout. The purpose of the intercomparison is to standardize the measurements made by these instruments. An immediate problem is the disagreement between observations of the El Chichón dust cloud. It is expected that the findings of the workshop will be used to explain the differences and provide a measure of the uncertainties associated with the different instruments. Should WMO sponsor the first international sunphotometer intercomparison during the latter part of March 1984, GMCC will participate.

Concurrent measurements of El Chichón stratospheric dust and Umkehr ozone profiles will be analyzed for an empirical relationship between stratospheric dust and errors to the Umkehr measurement. The results will be compared with theoretically predicted error relationships to stratospheric dust and the empirically derived relationship determined from the statistical analysis of the historical Umkehr data set that was performed in 1983. **ARL**

Short and standard Umkehr measurements will be compared with concurrent SBUV (solar backscatter ultraviolet) flyover measurements of vertical ozone profiles to determine the degree to which they correspond. This comparison is expected to provide vital information on the value of the Umkehr as a ground truth system for validating SBUV observations of vertical ozone profiles.

Surface and aircraft radiation measurements of the El Chichón dust cloud will be analyzed to determine optical scattering and absorption features. This analysis will require theoretical calculations to interpret the measurements. In addition, Mauna Loa lidar measurements will be analyzed to produce a time-dependent model of the vertical dust profile changes.

South Pole infrared and visible radiation measurements will be evaluated for possible application to heat budget studies. The measurements are being continued for a second year to provide further information on the seasonal variability of the infrared measurements.

TRACE GASES

Accomplishments FY 1983

Atmospheric baseline measurements of chlorofluorocarbons (CFC-11, CFC-12) and N_2O continued at Mauna Loa Observatory; Pt. Barrow, Alaska; Niwot Ridge, Colo.; American Samoa, South Pacific; and South Pole, Antarctica.

Stratospheric water vapor soundings with balloon-borne frost point hygrometers were continued in Boulder at a frequency of one flight per month. Stratospheric water vapor measurement intercomparison tests were conducted with the Aeronomy Laboratory at Laramie, Wyo., in February 1983, and with the National Environmental Satellite, Data, and Information Service satellite water-vapor-measuring instrumentation at Palestine, Tex., in April 1983.

Plans FY 1984

Atmospheric baseline measurements of chlorofluorocarbons and N_2O will be continued at the GMCC observatories. Stratospheric water vapor soundings will be continued in Boulder.

Monthly water vapor soundings will be continued in Boulder. GMCC will participate in another round of water vapor instrument intercomparisons at Palestine, Tex., in October 1983. Exploratory water vapor soundings are planned for Samoa, in anticipation of participation during 1985-1987 in a NASA-sponsored Tropospheric/Stratospheric Exchange experiment.

The halocarbon N_2O program in the past has required baseline station personnel to fill flasks with local air, then ship them to the Boulder laboratory for gas chromatographic analyses. For many years, South Pole samples have shown inordinate variability and greater susceptibility to pressure loss and contamination because of longer storage times and extreme temperature fluctuations during shipping. Action is being taken to install a portable gas chromatograph at the South Pole station for more reliable gas measurements. This instrument will be hand operated initially. Collection of air samples will continue at the South Pole for analyses in Boulder to provide overlap data.

In expanding research in radiatively important trace gas species, steps have been taken to procure a gas chromatograph, gas standards, and associated equipment to begin automated measurements of CFC-11, CFC-12, CCl_4, CH_3CCl_3 and N_2O at Mauna Loa Observatory. Work during FY 1984 will involve testing the equipment and data-processing methods, as well as establishing initial baseline records for CCl_4 and $CHCCl_3$.

DATA ACQUISITION

Accomplishments FY 1983

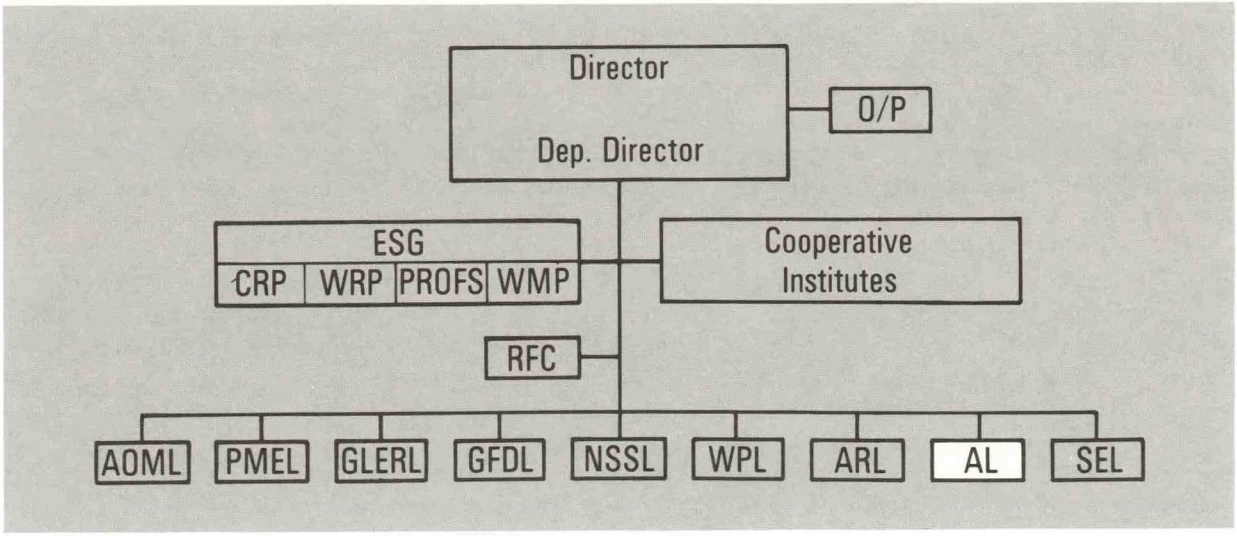
Since the beginning of GMCC measurements, a central computer-based recording and instrument control system has been used at each observatory. In FY 1983 a replacement "control and monitoring system" (CAMS) was developed for installation at the GMCC observatories. The CAMS uses integrated electronics and a Z80 microprocessor, and interfaces internally with a standard S70 bus.

Plans FY 1984

The original central system at each observatory will be replaced with three of the smaller stand-alone CAMS boxes. Testing will continue in FY 1984, and installation is scheduled toward the end of FY 1984.

AERONOMY LABORATORY
Boulder, Colorado

Eldon E. Ferguson
Director



The Aeronomy Laboratory conducts research on chemical and physical processes of the Earth's atmosphere to advance the capability to monitor, predict, and control the quality of the atmosphere. The research concentrates on the stratosphere and troposphere but also involves the ionosphere and the atmospheres of other planets.

Research methods involve both in situ and remote measurement of critical atmospheric parameters, including chemical composition and dynamic properties such as wind velocities, turbulence, and wave motions. 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 research of the Laboratory is accomplished by six interactive programs: Atmospheric Chemical Kinetics, Atmospheric Dynamics, Atmospheric Sampling, Atmospheric Waves and Turbulence, Optical Aeronomy, and Theoretical Aeronomy.

ATMOSPHERIC CHEMICAL KINETICS

AL

The primary activity of the Atmospheric Chemical Kinetics program is the experimental investigation of chemical reactions that are important in the atmosphere. Neutral reactions involving atoms and free radicals dominate the chemistry of the lower atmospheric regions, the stratosphere, and the troposphere.

The chemistry of the stratosphere is of great interest because of the potential for humans to alter the ozone layer inadvertently, with disastrous consequences. First, the possibility of an ozone reduction from exhaust chemicals released in stratospheric flights of supersonic aircraft transports was considered. This brought worldwide attention to the potential for a global problem: an increase in biologically harmful UV radiation at the Earth's surface, caused by the reduction in stratospheric ozone. Later, chlorine-containing halocarbons and nitrogen fertilizers were identified as potential threats to stratospheric ozone. In addition to the effects of increased UV radiation on biological systems, changes in the chemical composition of the atmosphere may also produce climatic changes.

Two major environmental problems are associated with the chemistry of the troposphere: photochemical air pollution and acid precipitation. Photochemical air pollution or smog is generally limited to urban and near-urban areas. It involves the formation of chemicals such as ozone and peroxy compounds, which damage or irritate plants and animals. These chemicals are generated in air by a complex reaction scheme involving nitrogen oxides, oxygen, hydrocarbons, carbon monoxide, and sunlight. Usually the reactant chemicals are transformed into their toxic products in the vicinity of the source. In acid precipitation, sulfur and nitrogen source compounds may travel over large distances before they are deposited as strong acids in remote rural locations. A hazard of these compounds is the fact that they can dissolve toxic metal compounds and the metals then damage plants and wildlife.

Most chemical reactions that take place in the troposphere and stratosphere involve free radicals. These are atoms or molecules characterized by a high reactivity, which often results from having one or more unpaired electrons. These reactions define the formation and destruction of atmospheric ozone, the oxidation of natural and anthropogenic chemicals released into the atmosphere, and formation of acid rain. The Atmospheric Chemical Kinetics program emphasizes quantitative studies of the rates and mechanisms of the important gas phase reactions of atoms and radicals. Studies are made over a wide range of temperatures and pressures to simulate conditions in the atmosphere.

Accomplishments FY 1983

The temperature dependence of the disproportionation reaction of HO_2 radicals was studied at low pressures using laser magnetic resonance detection with a flow tube kinetic system. The rate constant for

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

was measured at temperatures between 253 and 390 K. The reaction is found to have a large negative temperature dependence, similar to what has been observed in other studies of radical-radical reactions. This reaction is very important in the atmosphere because it is the source of gaseous hydrogen peroxide. Hydrogen peroxide is thought to be taken up by water droplets and aerosol particles and then to oxidize SO_2 to sulfuric acid.

NO_3 radicals were detected by both absorption and laser-induced fluorescence techniques. At low pressures the latter can detect smaller quantities and will therefore be tested as a detection method for NO_3 kinetic studies. A study of the NO_3 reactions with NO and NO_2 started.

A flowing-afterglow apparatus was modified for use as a chemical ionization detector of atmospheric free radicals. A small glass flow tube reactor in which neutral radical reactions will be carried out was installed on the side of the flowing-afterglow flow tube. All the gas from the radical reactor flows into the ion reactor. The method is to detect radicals by converting them to ions and observing the ion product using the ion detection section of the flowing afterglow. The ionization process is efficient because reactions between neutrals and ions tend to be very rapid and because radicals form very stable ions. Preliminary results show that stable radicals such as NO and NO_2 are detectable in the range 109 to 1,010 molecules cm^{-3} by chemical ionization and Penning ionization methods.

Some preliminary results were obtained on the kinetics of atomic sodium (Na). A flow system having two movable inlets and a resonant fluorescence detection system for Na was constructed. One inlet is attached to a Na oven by means of a heated tube, which delivers Na vapor to the flow tube. The second inlet provides a movable source of O_3 reactant. Two types of measurements have been made: (1) With the O_3 off, moving the Na source permits measurement of the diffusion coefficient of Na in the carrier gas; (2) with the Na source fixed and O_3 added through the reactant inlet, it is possible to measure the rate coefficient for the reaction

$$Na + O_3 \rightarrow NaO + O_2 \ .$$

The measurement of Na kinetics is aimed at clarifying the role of Na in stratospheric ozone chemistry.

The deactivation of vibrationally excited O_2^+ ions was investigated in a selected ion flow-drift apparatus. Ions in the 1, 2, and >2 vibrational levels (v) were selectively detected by their enhanced reactions with Xe, SO_2, and H_2O, respectively. Rate coefficients for relaxation of O_2^+ ($v > 0$) by Ne, Ar, Kr, H_2, D_2, N_2, CO, CO_2, H_2O, CH_4, SO_2, SF_6, and O_2 were measured. The quenching rate coefficients for $v = 2$ were found to be about a factor of 2 larger than for $v = 1$. The rate coefficients were found to be correlated with the energy of the ion-quenching neutral bond energy. The dependence of some of the rate coefficients on collision energy was also investigated. A major conclusion of this study is that the relaxation occurs through the formation of a collision complex in which the vibrational excitation is transferred into the weak bond between the ion and neutral, resulting in dissociation analogous to vibrational predissociation in van der Waals complexes. Results of this study have important applications to the relaxation processes in ionized environments such as the Earth's upper atmosphere and in electrical discharges.

AL

Plans FY 1984

Development of the chemical ionization detection method for free radicals will continue. The results obtained so far indicate that positive-ion, negative-ion, and Penning ionization by argon metastables are all very promising. Current work is pursuing negative-ion chemical-ionization detection of the $HOSO_2$ radical, which is very important in the acid rain problem. The major obstacle is the need for a suitable negative-ion species that can be used to ionize the $HOSO_2$ radicals. This problem results from the lack of thermochemical data on the $HOSO_2$ radical and its ion, and the presence of electronegative compounds such as SO_2 and NO_2 in the gas mixture containing $HOSO_2$.

An experiment is being developed to test some new methods for generating atmospheric radicals using hot metal surfaces. Research in other laboratories has produced evidence that some metal surfaces will generate radicals when certain gases are passed over them. For example, hot platinum wires have been used to generate OH radicals from water vapor. New methods of generating H, O, Cl, and Br will also be tested. The development of these new radical sources is very important to kinetic studies because the present methods of generating radicals are indirect or introduce reactive impurities.

Current projects on NO_3 and Na kinetics will be continued. NO_3 reactions with NO and NO_2, which are very important in the atmosphere, will be studied. The reaction of Na with O_3 will be completed, and some other reactions of Na will be studied. The temperature and pressure effects in the reactions of both NO_3 and Na will also be investigated.

The recently purchased Fourier Transform spectrometer will be put into operation, for experiments with two unstable atmospheric molecules. One experiment concerns HO_2NO_2, peroxynitric acid. High-resolution infrared spectra of HO_2NO_2 will be obtained. They will be used by scientists in other laboratories to evaluate high-resolution spectra obtained in the atmosphere, to determine if detectable amounts of HO_2NO_2 are present. This evaluation will be a valuable test of atmospheric chemistry models. Another experiment will study the HO_2NO (peroxynitrous acid) molecule. This molecule has never been detected in a gas phase system. It is proposed that HO_2NO may be formed in the reaction

$$OH + NO_2 + M \rightarrow HONO_2 + M \qquad (a)$$

$$\rightarrow HOONO + M \qquad (b)$$

by way of (b). If this is found to be true it may have a very important effect on our understanding of the chemistry of nitrogen oxides in the atmosphere. At present this reaction is the main removal mechanism for nitrogen oxides and the major source of atmospheric nitric acid.

Studies of the kinetics of vibrationally excited ions will be continued. Further measurements of the rate constants for deactivation of atmospheric ions will be made using the Selected Ion Flow Tube - Drift Tube Apparatus. Data on the vibrational relaxation of ions by neutrals will be analyzed with the objective of developing a comprehensive theory to describe the quenching process. Such a theory would be very useful for predicting the relaxation rates for ions for which no laboratory measurements are available.

ATMOSPHERIC DYNAMICS

The Atmospheric Dynamics program studies the atmosphere by analyzing Doppler radar echoes from irregularities in the atmosphere. Doppler radars measure wind profiles, including the vertical components, and profiles of certain parameters of turbulence. Because of their rapid cadence of measurement and great altitude range, Doppler radars are well suited for studying phenomena that vary rapidly in time, such as buoyancy (internal gravity) waves and turbulence. They are useful, also, for studying slowly varying phenomena such as planetary waves and tides. The Doppler radar technique used for such studies is generally called the MST (Mesosphere-Stratosphere-Troposphere) radar technique. (Radars that are sensitive enough only to observe in the lower stratosphere and the troposphere are called ST radars.) MST measurements are valuable for studying zonal and meridional tidal variations throughout the atmosphere; energy coupling processes between the troposphere, stratosphere, and mesosphere; generation and propagation of atmospheric waves; Sun-weather relationships; atmospheric turbulence; atmospheric stability, etc.

To exploit the capabilities of the MST radar technique, the program has followed several lines of experimental research. In 1973 we started construction of the Sunset VHF pulsed-Doppler ST radar near Boulder, the first VHF radar designed and constructed specifically for MST radar studies. In 1976 we began exploring the limits of the MST technique by using a variety of radars with a wide range of frequencies, geographical locations (from near the Equator to the Arctic), sensitivities, and configurations. These studies demonstrated that the MST technique works from 40 to 1,300 MHz at all locations, and that, with a sufficiently powerful radar operating below ~70 MHz, measurements can be made at all heights from near the ground up to about 100 km. On the basis of these studies, during FY 1979 construction (funded by NSF) began on a large MST radar at Poker Flat, Alaska, and was essentially completed in 1982. Because of its unique design, however, the radar has operated almost continuously, with gradually increasing sensitivity, since construction began in February 1979.

Accomplishments FY 1983

In June 1983 profiles of the turbulence structure constant C_n^2 were measured simultaneously by the Sunset ST radar and by an optical stellar scintillometer developed at the University of Nice, France. Preliminary comparisons show excellent agreement between the two experiments at most heights and times.

In an investigation of the climatology of C_n^2, using the large body of data from the Poker Flat MST radar, significant variability was found, both seasonal and day to day.

Careful measurements of the reflectivity in the vertical as a function of range gate length were made by both the Sunset ST and the Poker Flat MST radars, in an effort to settle the controversy over the range-gate dependence of Fresnel (partial specular) reflectivity. The result was that in most

cases the reflectivity was linearly proportional to the length of range gate, as predicted by simple theory, but that occasionally the reflectivity varied as a larger power (up to 2).

We showed that the refractivity structure that gives rise to the Fresnel reflectivity could be due to oblique displacements by low-frequency buoyancy (internal gravity) waves acting on the background gradient of refractive index.

We were the first group to use three-station arrays of ST radars to measure the phase velocity and wavelength of buoyancy waves. During FY 1983 we analyzed the data from the first experiment, in southern France in April and May 1982. The principal result to date is that the power spectrum of vertical velocity has the shape predicted by buoyancy wave theory on days with light winds, but is quite different on days with high winds. During July and August 1983 we used an array of ST radars in a 60-km triangle in Colorado (in cooperation with PROFS and WPL) to study further the buoyancy waves associated with thunderstorms.

In June 1983 the Air Force Geophysical Laboratory launched a series of rockets concurrently with Poker Flat MST radar observations in order to examine the fine-scale mesospheric structure responsible for the strong summer radar echoes.

The long-term variability of the horizontal and vertical winds at Poker Flat were analyzed. The mean horizontal flow is consistent with models, but the mean vertical motion is almost an order of magnitude larger and in the opposite sense to the models.

Experiments were initiated to measure the vertical flux of horizontal momentum in the mesosphere.

Plans FY 1984

Our research on turbulence has two objectives: to describe the statistics of occurrence of turbulence and to develop physical understanding of the processes that cause turbulence in the free atmosphere. Accomplishment of the latter objective should permit further development of our model for the occurrence of turbulence in the free atmosphere.

The dependence of the occurrence of turbulence on geographical location (including latitude and topography), season, time of day, synoptic weather, thunderstorm activity, buoyancy wave activity, etc., will continue to be studied with our existing radar systems.

Simultaneous measurements of C_n^2 made during June 1983 by the Sunset ST radar and the French stellar scintillometer will be repeated during October and November 1983. The new measurements will be optimized on the basis of the June 1983 experiments.

Our model for the generation of the refractivity structure that gives rise to Fresnel reflectivity will be tested by critical experiments.

Buoyancy waves play an important role in atmospheric dynamics: They efficiently transport energy and momentum, both vertically and horizontally, and their breakdown into turbulence at small vertical scales results in a major energy sink in the free atmosphere and is the major source of turbulence. Three-radar array data will be further analyzed to study the generation and propagation of buoyancy waves. A four-station microbarograph array will be installed in the Boulder area. Power spectra of wind fluctuations versus period, vertical wavenumber, and horizontal wavenumber will be computed under as wide a variety of conditions as possible in order to study the degree of universality of the spectral shape and amplitude. The relation between the buoyancy wave spectrum and our model for the occurrence of turbulence will be further refined.

The continuous data set obtained from the Poker Flat MST radar over the past 4-1/2 years is proving to be invaluable in studying a variety of atmospheric phenomena: Zonal and meridional tidal variations, energy coupling between the lower atmosphere and the mesosphere, the generation and propagation of atmospheric waves, atmospheric turbulence, etc. The data will serve as a base for cooperative studies with the University of Alaska, Boston College, UCLA, the University of Colorado, Cornell University, the University of Illinois, the University of Washington, the Air Force Geophysical Laboratory, and ERL's Geophysical Fluid Dynamics Laboratory.

The June 1983 simultaneous rocket-Poker Flat MST radar data will be analyzed. Similar high-spatial-resolution data will be gathered during the winter, when the causal mechanism for the observed turbulence is thought to be different.

There is currently a great deal of interest in the dynamics of the tropical atmosphere from two different points of view. First, it is thought that atmospheric equatorial waves may play an important role in the control of climate, even in middle latitudes. Second, it is thought that the trace species and pollutants in the stratosphere enter through the tropical tropopause. Because of the unique capabilities of the MST radar technique for studying atmospheric dynamics, we are investigating the possibility of installing one or two ST radars in the tropical Pacific during FY 1984 and 1985. These radars would also support the Aeronomy Laboratory involvement in the TOGA (Tropical Oceans and Global Atmosphere) experiment.

ATMOSPHERIC SAMPLING

The origins of the present Atmospheric Sampling program lie in the recognition that human activities may inadvertently pose a threat to the Earth's stratospheric ozone layer, which serves as a shield against harmful solar radiation. The Atmospheric Sampling group was formed to address this critical problem. Research efforts of the group led to the first successful measurements of chlorofluoromethanes at the altitudes in the stratosphere where these compounds are significantly photodissociated. The findings supported the predictions from theoretical models concerning the photochemistry of these compounds and, hence, the predictions of the potential adverse consequences to stratospheric ozone. Since that time, the scientific efforts of

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the group have followed the approach used in these stratospheric chlorofluoromethane measurements. Problems are selected that combine significant new scientific research with important national or global atmospheric environmental questions. The instruments and techniques required in the studies are generally conceived, designed, and developed within the group and are subjected to rigorous laboratory and field validations. The subsequent field application of these instruments and techniques employs a variety of platforms: balloons, stratospheric and tropospheric aircraft, ships, vans, and semipermanent ground stations.

The experience, skills, and interests of the group have expanded considerably since the initial stratospheric chlorofluoromethane studies and now encompass a broad range of topics in atmospheric chemistry including the following:

The natural emissions that contribute to atmospheric acidity and alkalinity.

The transport, transformation, and deposition processes involved in acid deposition.

The tropospheric/stratospheric exchange processes that are a factor in regulating stratospheric and tropospheric chemistry and climate.

The tropospheric and stratospheric photochemical cycles responsible for the production and destruction of global ozone.

Relative to potential inadvertent deleterious alterations of the Earth's atmosphere, several key environmental issues are being addressed: stratospheric ozone depletion, acid deposition, tropospheric ozone production, and climate.

Accomplishments FY 1983

WATER VAPOR MEASUREMENTS

With the goal of using H_2O as a window into stratospheric photochemical and transport processes, a balloon-borne, fast-response, self-calibrating instrument for the in situ measurement of stratospheric H_2O was designed, developed, and tested in flight several years ago. Since 1978, there have been numerous successful measurement flights from Wyoming, Texas and Brazil, the results of which have already contributed significantly toward the understanding of stratospheric photochemistry. In almost all the data, the stratospheric H_2O concentrations have a minimum just above the tropopause and increase with increasing altitude. A recent comparison of the Wyoming flight data with the Brazil flight data suggests that stratospheric H_2O increases meridionally from the tropics to middle latitudes. The observed vertical and meridional increases are consistent with the existence of a stratospheric source of H_2O, such as the oxidation of methane. The fast response of the instrument has revealed a rich structure in the H_2O profile, which is re-

produced from ascent to descent. This indicates that the structure is relatively long lived in both time and space.

NO AND NO_2 MEASUREMENTS

The first simultaneous measurements of stratospheric nitrogen oxide (NO) and nitrogen dioxide (NO_2) were made in collaboration with the National Center for Atmospheric Research (NCAR), using a balloon instrument that employs chemiluminescent/photolytic detection of NO and NO_2. Simultaneous measurements of ozone concentrations from the same gondola used a UV-absorption instrument. NO and NO_2 mixing ratios were measured during four flights--from Palestine, Tex. (November 1981; July 1982), and Gimli, Manitoba, Canada (August 1982; December 1982). The NO and NO_2 mixing ratios agree reasonably well, given normal atmospheric variability, with previous determinations of NO (in situ) and NO_2 (long-path) in the stratosphere. In addition, the measured [NO_2/NO]-ratio altitude profiles for the Palestine (November 1981) and Gimli (August 1982) flights agree with theoretical predictions. However, the measured [NO_2/NO]-ratio altitude profile from Palestine (July 1982) is smaller than theoretical predictions above 30 km and larger than theory below 21 km, an effect that may be related to the El Chichón eruption. Finally, in the fourth flight, the NO mixing-ratio profile measured from Gimli (December 1982) indicated that the NO mixing ratio increased sharply between 25 and 30 km. This observation supports the Solomon-Garcia model for the NO_2 "cliff" that predicts such strong photochemistry and transport-induced gradients of the concentrations of NO and NO_2 in northern latitudes at these altitudes during the winter.

NIWOT RIDGE RESEARCH SITE

The Atmospheric Sampling group maintains and operates a permanent field station at a remote site at the 10,000-ft level on Niwot Ridge, near the Continental Divide, in a biopreserve administered by the Institute of Arctic and Alpine Research of the University of Colorado. The location has the valuable feature that, depending on wind direction, the site can be used to examine the photochemistry of clean continental air or to study the chemistry of relatively polluted air. Because of the unique facilities and location of the Niwot Ridge site, it has been designated by the National Acid Precipitation Assessment Program as one of its three sites where research is conducted on measurement methodologies and special regional and local acid rain problems. The goals of the group, for the Niwot Ridge site, are (1) to determine the likely origins of the acidity observed in the rainfall in the remote mountain areas of the Colorado Front Range, a point of current controversy; (2) to identify and quantify the significant contributions to the acidity in precipitation at Niwot Ridge and their gas-phase precursors; (3) to establish the diurnal and seasonal variations of the above constituents; and (4) to maintain a field-laboratory site, accessible year-round, that is sufficiently equipped and supplied for instrument and technique development as required and other special monitoring research. Several of the tropospheric studies and instrument developments described below employed the Niwot Ridge research site.

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TROPOSPHERIC OZONE STUDIES

The seasonal and diurnal variations of ozone mixing ratios were measured at Niwot Ridge. These data have been correlated with the NO_x ($NO + NO_2$) mixing ratios measured concurrently at the site. The seasonal and diurnal variations in O_3 can be reasonably well understood by considering photochemistry and transport. The correlations observed between O_3 and NO_x are interpreted to represent in situ or in-transit photochemical production of ozone from precursors that are transported to the site. Calculations that use a simple clean-tropospheric chemical model are consistent with the NO_x-related trend observed for the daytime ozone mixing ratio.

SYSTEMATICS OF AROMATIC HYDROCARBON CONCENTRATIONS

Measurements of the aromatic hydrocarbons--benzene, toluene, ethylbenzene and ortho-xylene--at Niwot Ridge showed distinct correlations between the ratios of the concentrations of these compounds and the degree of direct urban influence, as indicated by NO_x ($NO + NO_2$) concentration. The major homogeneous atmospheric removal mechanism of aromatic hydrocarbons is reaction with the hydroxyl radical, OH. Thus, the decrease in the ratios of aromatic hydrocarbon concentrations (which are independent of dilution) can be related to the transport time and average OH number density of an air mass. Measured ratios of aromatic compounds at this site, along with ratios reported for several cities in the western United States and estimates of transport times from these cities, were used to calculate temporally and spatially averaged OH number densities. Hydroxyl radical number density estimates yield diurnally averaged values of about 10^6 molecules cm^{-3} for this important atmospheric species, which has not been directly measured.

OXALATE OBSERVATIONS

Precipitation samples and aerosols collected with filters at the Niwot Ridge site were examined for acids other than sulfate and nitrate. The existence of oxalate, $(COO)_2^{=}$, in both types of samples was demonstrated using ion chromatography. Mixing ratios were observed up to 50 pptv in air samples and 0.3 ppm in precipitation. This is apparently the first identification of tropospheric oxalate. Correlation of airborne oxalate with airborne nitrate suggests a pollution source.

GLOBAL NITRATE DEPOSITION FROM LIGHTNING

Lightning has long been recognized as a natural source of NO_x. The Atmospheric Sampling group assessed predictions of lightning/nitrogen models in the following way. The nitrate deposition fluxes predicted by the lightning model were compared with measurements of (a) the current nitrate deposition occurring in remote areas and (b) the preindustrial nitrate deposition. The remote-area data include those measured at Samoa, deduced from Hawaii and Amsterdam Island precipitation, obtained from South Pole ice cores, and inferred from our own South Pacific studies. The preindustrial data are from pre-1900 levels in South Pole and Greenland ice cores. The observed global

distribution of nitrate fluxes agrees well with that predicted by the lightning model. Furthermore, the observed seasonal variations are consistent with the maximum lightning occurrence in the summer. This agreement points to lightning as the probable major source of nitrate in remote areas and permits a meaningful estimate of the lightning contribution to nitrate deposition over North America: 5% to 10% of the anthropogenic NO_x emissions, with an uncertainty factor of 3.

AIRCRAFT NITROGEN OXIDE INSTRUMENT

A new-generation chemiluminescence NO instrument is being developed in collaboration with NCAR. Recently, the instrument was intercompared, at Wallops Island, Va., with another chemiluminescence instrument and one using a laser-induced-fluorescence technique. In this rigorous, triple-blind intercomparison, sponsored by NASA, NO concentrations measured with the three instruments agreed within ±20% over a wide range of concentrations. The excellent agreement between the laser-induced-fluorescence and the chemiluminescence methods strongly suggests that the markedly different methods are free from artifacts and/or interferences.

TOTAL ODD-NITROGEN DETECTOR

A new technique was developed for the real-time, quantitative conversion of the sum of the atmospheric odd-nitrogen species, NO_y, to NO. The technique uses the reduction of these compounds by CO at a heated gold catalyst to yield NO. The NO is then detected by the sensitive chemiluminescence detectors developed in this Laboratory. The capability to detect a variety of NO_y compounds (NO_2, HNO_3, N_2O_5, NO_3, and peroxyacetyl nitrate) in this way opens up attractive prospects for determining tropospheric and stratospheric odd-nitrogen budgets and provides an additional tool to investigate tropospheric/stratospheric exchange mechanisms.

STRATOSPHERIC OZONE INSTRUMENT

A new dual-beam UV-absorption instrument for balloon-borne measurements of atmospheric ozone was developed. It has two identical absorption chambers, each alternating between reference mode (ozone-free) and sample mode by means of a four-port valve and ozone scrubber. The ratio of the absorption signals, along with the known lengths and ozone absorption cross section, yields the ozone concentration. The absorption measurement requires no calibration. The instrument has been flown six times, accompanying the group's H_2O and NO/NO_2 experiments, and considerable ozone structure has been revealed. In addition to providing ozone data to use in these stratospheric photochemistry and dynamics experiments, the profiles give a good indication of the instrument's very rapid response time. This response time allows covariation studies to be done in concert with other fast-response instruments to examine atmospheric dynamics.

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QUANTIFICATION OF HNO_3 MEASUREMENTS

A small, portable HNO_3 calibration system utilizing a nitric acid permeation tube was built, and with it we field-tested the nylon filter used to collect gas-phase acids. The tests indicated that there are no major analytical problems with the collection, extraction, and analysis procedure we use to measure HNO_3 and that our measurements are a true indication of the HNO_3 loading.

Plans FY 1984

INSTRUMENT INTERCOMPARISONS

H_2O

NASA will sponsor the second intercomparison of stratospheric H_2O instruments in October 1983, at the National Scientific Balloon Facility (NSBF) in Palestine, Tex. The Atmospheric Sampling program's balloon-borne and U-2 aircraft instruments will take part. The agreement among water-vapor measurement techniques on the first flight series in May 1981 was within ±30%, but the systematics of the differences prompted Laboratory reevaluation of many aspects of the instruments. The group's Lyman-alpha photofragment fluorescence instrument had used a published cross section in its analysis. As part of the intercomparison, this cross section was measured. The new value is similar to the earlier determination, but the precision and accuracy is better, thereby improving the data of the instrument.

N_2O, $CFCl_3$, and CF_2Cl_2

NASA will also sponsor an intercomparison of four techniques for measuring stratospheric N_2O, $CFCl_3$, and CF_2Cl_2 concentrations. Balloon-borne instruments will be launched simultaneously from the NSBF in spring of 1984. The group's grab sampler will be one of the instruments involved.

Ultraviolet Ozone

The group's UV ozone instrument was part of the NASA-sponsored Balloon Ozone Intercomparison in the summer of 1983. The data obtained are being assessed as indications of instrument performance. The second flight of this series is scheduled for October 1983.

INSTRUMENT DEVELOPMENT

Gas-Chromatographic System

A cryogenic-trapping/flame-ionization gas-chromatographic system is being developed for detecting atmospheric sulfur compounds. The laboratory tests are complete and the first field trials are under way at the Niwot Ridge site. The initial aim of this study is to assess the clean-air and

polluted levels of gas-phase sulfur in relation to the amount in precipitation in the mountain area. Intercomparison of calibration standards is under way with the University of Idaho.

Diode-Array Spectrometer

A state-of-the-art diode-array spectrometer was incorporated into a spectrometer/computer absorption spectroscopy apparatus. The device has been used to obtain spectra of stratospheric NO_2 of heretofore unobtainable quality. A key part of the procedure is a least-squares data reduction procedure that employs standard spectral relative intensities obtained from laboratory measurements. The system obtained total-column NO_2 data when it accompanied the stratospheric NO/NO_2 experiment into the field. Now, the system is at Fritz Peak Observatory and will use long-path (approximately 10 km) absorption techniques to examine the photochemistry of several tropospheric species.

Hydrogen Peroxide Detector

An ultraviolet excimer laser is being explored as a detection scheme for hydrogen peroxide, using photofragment fluorescence. Hydrogen peroxide is thought to be a major oxidant of SO_2. Currently, there is no way to detect H_2O_2 reliably in the gas phase.

Tungsten Acid Denuder Tube

Work is in progress to evaluate and develop the tungstic acid denuder tube method as a fast-response technique for measuring nitric acid (HNO_3) and ammonia (NH_3).

NITROGEN OXIDE FLUX MEASUREMENTS

The sensitive chemiluminescence detectors for NO available in this Laboratory will be used to develop accurate methods to determine the concentrations and fluxes of natural nitrogen compounds and, thereby, to provide the data necessary to estimate contributions of natural sources to the NO/NO_2 budgets.

ATMOSPHERIC WAVES AND TURBULENCE

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

Wave and turbulence fluctuations are present in vast regions of the atmosphere because the natural state of the atmosphere is often locally unstable. Such fluctuations have a striking effect on transport of pollutants and were intensively observed as long as two decades ago. However, because

of mathematical and conceptual difficulties, no theories of turbulence and nonlinear wave interactions were available for determining the strength of these fluctuations and how they influence pollution dispersal and meteorology. The development of such theories has become a principal concern of this program during the past decade.

Accomplishments FY 1983

The Atmospheric Waves and Turbulence program (1) calculated the mean field contribution to the pressure-velocity correlations needed for boundary layer modeling, corrected the Launder terms, and programed the theoretical terms into a test model for the Navy; (2) determined the heat flux and cooling caused by gravity waves; (3) derived formulas that predict the intensity (kinetic energy density) and thickness of CAT (clear-air turbulence) in terms of measurable mean shear and Brunt-Vaisala frequency; (4) calculated a global average of the eddy diffusivity caused by gravity waves in the mesosphere, and showed that gravity wave transport is significant in the stratosphere; (5) developed a theory that predicts the puzzlingly slow decay of turbulence observed in oceans, atmosphere, and laboratory; (6) proved that a simple relationship exists between friction (momentum flux deposition), heat flux, and eddy diffusivity caused by gravity waves in the middle atmosphere.

Plans FY 1984

The following studies of turbulence in the atmosphere are planned:

- Continue to develop a reliable turbulence model of the planetary boundary layer by applying contemporary turbulence theory from first principles. This year's goal is to calculate the influence of stable stratification on the pressure fluctuation terms, to show why the fundamental hypothesis of return to isotropy cannot be applied to atmospheric turbulence modeling, and to calculate the realistic deviations from isotropy.

- Apply MST radar data to determine the seasonal variation of diffusivity in the mesosphere.

- Explain theoretically, and calculate, the apparently universal spectrum observed for vertical scales of fluctuations in oceans and the atmosphere.

- Develop a theory for temperature fluctuations in oceans and atmosphere.

- Apply theory to the boundary layer model currently used by the Naval Environmental Prediction Research Facility (NEPRF). The NEPRF facilities will be used to test and expand the theory. A liaison has been set up with NEPRF for this purpose.

Planned studies of gravity waves include continuation of the modeling of eddy diffusion and friction from 20 to 100 km altitude, coupling of the tropo-

sphere to the mesosphere, the influence of gravity waves on the mean flow, the role of tidal waves in atmospheric diffusion, and the interaction of gravity waves with airglow and minor atmospheric constituents. In addition, recent new insights into the importance of gravity wave heat flux and Rayleigh friction in the middle atmosphere will be further developed. The heat flux studies will be in collaboration with the Optical Aeronomy program.

OPTICAL AERONOMY

The Optical Aeronomy program uses optical measurements of the atmosphere as a tool for studying fundamental processes such as energy balance, composition, and dynamics. Major attention is now given to measurements bearing on the composition and dynamics of the lower atmosphere, principally the troposphere and stratosphere, although important problems in the upper atmosphere continue to receive some attention.

Accomplishments FY 1983

The eruption of the Mexican volcano, El Chichón, produced a stratospheric cloud of dust and sulfur-containing molecules. Near the poleward edge of the cloud we found a very large decrease in stratospheric NO_2 accompanied by a small increase in total stratospheric ozone. The increase is somewhat greater than predicted as resulting from NO_x chemistry alone. The causes of these changes, particularly in NO_2, remain obscure.

We completed a long series of measurements of stratospheric NO_3, an important tracer of NO_x chemistry. Its temporal and latitudinal behavior conflicts with theoretical expectations but exhibits some interesting correlations with large-scale dynamical flow patterns in the stratosphere. There is a suggestion that the behavior of NO_3 is influenced by an unknown scavenging species manufactured at high latitude and transported to middle latitude.

The Solar Mesosphere Explorer (SME) satellite yielded a rich and detailed extension of the global picture of stratospheric NO_2; it confirms many of our earlier findings from ground-based observations. Stratospheric OH also showed an increase which appears to be associated with the El Chichón eruption. The satellite was also used to measure NO_2 in the troposphere, both in urban pollution and over tropical lightning storms.

The behavior of tropospheric NO_3 and NO_2 was studied in exceptionally clear Pacific air; even here we find evidence that NO_3 is rapidly removed by an unknown scavenger. To aid tropospheric studies we installed an improved long-path absorption facility at Fritz Peak, which incorporates the new spectrometer developed in the Atmospheric Sampling group.

Vertical winds in the thermosphere were studied using the new TESS (twin etalon scanning spectrometer) interferometer, thus opening up a new area of investigation. The extension of measurements to higher latitude has brought

out the dependence of thermospheric winds upon local heat sources at high latitude. An unexpected semiannual variation in thermospheric temperature was discovered.

Plans FY 1984

A principal goal is to use the new long-path absorption facility to study NO_2 and NO_3 in the troposphere in clean air, in an attempt to understand more about removal of nitrogen oxides from the troposphere.

Analysis of the NO_2 measurements from SME will continue, particularly those of NO_2 in the troposphere, which allow pollution to be monitored from space.

The high-resolution spectroscopic studies in the stratosphere, mesosphere, and thermosphere will be pursued with particular attention to a greater coverage in latitude.

THEORETICAL AERONOMY

The objective of the Theoretical Aeronomy program is to undertake theoretical studies of important atmospheric problems, to construct and utilize computer models of the chemistry and dynamics of the atmosphere, and to analyze atmospheric data collected within the Laboratory or by collaborative experiments. The ultimate goal of the program is to attain an understanding of the composition, dynamics, and energy budget of the atmosphere that is sufficiently detailed to permit accurate predictions of trends. In recent years the principal concern has been with problems related to the minor-constituent composition of the stratosphere and mesosphere (the middle atmosphere), deriving largely from the widespread practical concern with stratospheric ozone and its potential depletion by artificial pollutants. More recently, however, the activities of the group have expanded to investigate problems of tropospheric chemistry and tropical atmospheric dynamics. These newer areas are expected to grow, in parallel with corresponding growth and shifts of emphasis in the experimental programs of the Laboratory. Most of the program's projects are developed and carried out in close collaboration with the Laboratory's experimental programs, or with other atmospheric research groups outside the Laboratory, including at present those at GFDL, NCAR, and the University of Colorado. These outside links are essential to the objectives of the program, and will be maintained and strengthened where possible in future years.

In addition to its own projects, the group has the important function of assisting other Laboratory programs on problems that require advanced computer programing techniques. This direct service function provides further coupling between this program and the more experimental side of the Laboratory.

Accomplishments FY 1983

Research in tropospheric photochemistry centers around acid deposition and tropospheric ozone. Acid deposition is a serious problem in the northeastern United States and eastern Canada. Precipitation with pH in the range of 4.0 to 4.5 is quite common in these areas downwind of midwestern industry. Most of the anions contributing to the high acidity are $SO_4^=$ and NO_3^-. The precursors of $SO_4^=$ and NO_3^- are SO_2 and NO_x ($NO + NO_2$). Tropospheric ozone plays a central role in the photochemistry that controls the abundance and interaction of SO_2, NO_x, and other important atmospheric trace gases (e.g., CO, CH_4, and H_2S). The photochemistry and transport of acid material and ozone are closely related. There is increasing evidence that tropospheric ozone may have been perturbed by anthropogenic emissions of hydrocarbons and NO_x ($NO + NO_2$). Perturbation of tropospheric ozone may cause a chain reaction that could change the distribution of trace gases. Since ozone and some of the trace gases absorb IR radiation in the window of CO_2 and H_2O absorption, the radiation budget in the troposphere, and thus the climate, may be altered. In addition, surface ozone may damage plants and may be a health hazard.

The Theoretical Aeronomy program is involved in several topics of research in the areas of tropospheric ozone and acid deposition:

- Collaboration with the Atmospheric Sampling Program on planning and interpreting measurements of NO_x, O_3, HNO_3, SO_2, and particulate NO_3^- and $SO_4^=$, with emphasis on measurements made at Niwot Ridge, Colo.
- Collaboration with scientists at GFDL on modeling the tropospheric ozone and NO_x distributions with a three-dimensional general circulation model.
- Studies of the detailed photochemistry of O_3, NO_x, OH, and hydrocarbons in a one-dimensional model.
- Collaboration with scientists at NCAR on developing a mesoscale air quality model for the Colorado Front Range.
- Development of a combined liquid-phase and gas-phase photochemical model to study the oxidation of NO_x and SO_2.
- Model studies of the distribution of NO_x and SO_2 that are produced from natural sources.

Investigation of the gas-phase oxidation mechanism of SO_2 in the atmosphere showed that the SO_2 injected in the stratosphere by the El Chichón volcanic eruptions was oxidized by OH through a mechanism that recycles atmospheric OH rather than consuming it. The result predicted by our model calculation was substantiated by the observed lifetime (about 1.5 months) of SO_2 in the stratosphere and by the observed increase in atmospheric-column OH concentration following the arrival of volcanic clouds at Fritz Peak, Colo. Verification of such an SO_2 oxidation scheme may have important implications for the linearity problem of the "source-receptor" relationship of acid deposition, since the gas-phase oxidation rate would decrease with increase in SO_2 emission if OH were consumed by SO_2. Our results show that the gas-phase oxidation rate of SO_2 is linearly proportional to SO_2 emission rate.

Most previous research on vertical transport of trace gases and air pollutants has been restricted to the planetary boundary layer (PBL). Exchange between the boundary layer and the free troposphere has been neglected by air quality models that concentrate on the local- and urban-scale air pollution problem. Recent studies of long-range transport (more than 1,000 km) of air pollutants such as acid deposition and studies of global tropospheric photochemistry have shown that long-range transport of air pollutants above the PBL may be more important than transport within the PBL. In order to quantify the vertical transport, we analyzed the vertical distribution of radioactive tracer ^{222}Rn over the continents and derived vertical eddy diffusion coefficients for various seasons. Because the radioactive decay time (3.8 days) of ^{222}Rn is similar to the atmospheric residence time of many air pollutants such as HNO_3, NO_3^-, SO_4^-, and some hydrocarbons, the amount of ^{222}Rn transported above the boundary layer can be used to estimate transport of these pollutants. Scientists at GFDL are making a model study of the ^{222}Rn distribution and the related transport processes.

The oxidation of NO_2 was studied by investigating the ratios of NO_2 to benzene and toluene to benzene at Niwot Ridge as measured by scientists of AL's Atmospheric Sampling program. We have shown that NO_2 is oxidized primarily by OH in the atmosphere and that an upper limit for the concentration of OH can be derived from the aromatic hydrocarbon measurement. This is consistent with our model calculations that satisfactorily predict the photochemical production and diurnal variation of O_3. Production of ozone is not observed when NO_x is less than 0.5 ppb. This is consistent with the result obtained by a three-dimensional general circulation model simulation of tropospheric ozone in a collaborative effort with scientists at GFDL.

Chemical-dynamical model studies of the middle atmosphere continued, with an increased focus on the photochemistry of ozone and NO_2 in the stratosphere. These studies, performed in collaboration with NCAR, use a two-dimensional residual Eulerian model that extends from 16 to 116 km altitude, from pole to pole. The advantage of the residual Eulerian framework can be summarized as follows: it can be shown that when the classical Eulerian mean and eddy transports are computed self-consistently, a large cancellation occurs such that the remaining net transport in the stratosphere is a small residual. Problems arise in many photochemical models because neither of the two terms is computed at all; rather, the eddy transports are parameterized by eddy diffusion coefficients, and the mean circulation is taken from a dynamical model study. Thus the eddy coefficients may not be consistent with the adopted mean circulation. Recent dynamical studies have shown that many of these problems can be avoided by using the residual Eulerian circulation, which represents the desired net residual directly. Although certain assumptions are inherent in the residual Eulerian approach as well, at least the correct qualitative sense of the transport should result from such a formulation.

NO_2 is a stratospheric species that is strongly influenced by transport processes. We found that the use of the residual Eulerian circulation has important effects on the computed NO_2 distribution. We also employed new temperature-dependent absorption cross sections for N_2O_5. Results from the present study are in good agreement with many of the observed features of the behavior of stratospheric NO_2. During winter at high latitude, extremely sharp gradients in the total column of NO_2 are sometimes observed; this phe-

nomenon, sometimes referred to as a "cliff", was first observed in the Optical Aeronomy program in 1977. A theoretical study showed that it is probably due in large part to the conversion of NO_2 to N_2O_5 in the polar night region. In particular, we showed that the complete dynamical-history of the air parcels under observation must be considered, especially in high-latitude winter where the presence of planetary waves leads to unusually rapid meridional flow, which transports air parcels out of the polar night, where NO_2 has been converted to N_2O_5, to lower latitudes. The observed and calculated abundance of NO_2 in such parcels is then found to be unusually low.

Using the same model, we also conducted a study of the 11-year solar cycle. We considered likely variations in auroral particle precipitation, extreme ultraviolet, middle ultraviolet, and visible radiation, and then we examined the photochemical and dynamical responses to these perturbations. A most interesting result of this study is that the increased auroral particle and extreme ultraviolet flux changes led to greatly enhanced thermospheric NO densities. In the polar night region, NO was found to flow down to the upper stratosphere, resulting in a decrease in high-latitude upper stratospheric ozone abundances in the theoretical model, particularly at solar maximum. The available satellite ozone data exhibit several features that support this finding, suggesting that coupling between the thermosphere and stratosphere may have interesting consequences for stratospheric ozone at high latitudes.

Collaborative work with scientists at the University of Colorado on the Solar Mesosphere Explorer (SME) satellite continued. A comparative study of the calculated and observed ozone abundances in the mesosphere during quiet conditions was performed. On 13 July 1982, an extremely intense solar proton event occurred. Such events are expected to produce large amounts of odd hydrogen in the mesosphere, a species that catalytically destroys ozone there. Therefore, significant ozone changes are expected to occur in the mesosphere under these conditions. Observations of these changes provide an important test of the present understanding of ozone photochemistry, in both the mesosphere and the stratosphere.

Work on the interannual variability of the height of the tropopause in the western equatorial Pacific Ocean continued, using a data base of radiosonde profiles obtained from the National Climatic Data Center. This work is carried out jointly with the Atmospheric Dynamics program. The main emphasis has been on examining the global nature of the interannual variation by comparing the western Pacific data with data from other tropical locations and on searching for significant periodicities. Three stations with long data bases were used--Yap (10°N, 138°E), Curacao (12°N, 69°W), and Ascension (8°S, 14°W). The principal findings are these:

(1) The tropopause over Yap is almost always higher and colder than that over the other stations.

(2) The interannual variations are extremely well correlated over the entire period examined (29 years at Yap, 27 years at Curacao, 13 years at Ascension).

(3) The principal periods are close to 2 and 4 years.

The significance of each of these results is as follows:

(1) The adiabatic ascent of upper tropospheric and lower stratospheric air forming the rising branch of the Hadley cell is more intense in the western Pacific than in the eastern or western tropical Atlantic. This probably reflects warmer sea-surface temperatures and enhanced convective activity.

(2) The correlation of interannual variations is a manifestation of a truly global phenomenon. Yap and Ascension are separated by 23,000 km, and are in separate oceans and different hemispheres.

(3) The periods are close to those of the stratospheric quasi-biennial oscillation and the tropospheric Southern Oscillation, respectively. This suggests a physical link between these two mysterious features of the tropical atmosphere.

A separate study has been made of the response of the tropical Pacific tropopause to the injection of stratospheric aerosols by the El Chichón volcanic explosion in spring 1982. Preliminary results have indicated that the increase in temperature in the lower stratosphere caused by the absorption of solar radiation by the volcanic material was largely compensated for by increased adiabatic cooling due to the enhanced tropospheric convective activity associated with the great oceanic warming event (El Niño) of 1982-83.

Plans FY 1984

Tropospheric ozone and its possible perturbation by human activities will continue to be major subjects of research. Important problems are the photochemical production and destruction of O_3, transport of O_3, distribution of tropospheric NO_x, OH, and RO_2 radicals, and effects of nonmethane hydrocarbons. We will continue to study these problems by working closely with the Atmospheric Sampling program and the Atmospheric Chemical Kinetics program. Collaboration with scientists at GFDL on three-dimensional modeling will be strengthened in both stratospheric and tropospheric modeling.

Studies of the acid deposition problem will be expanded. Emphasis will be on atmospheric transformations of SO_2 and NO_x, heterogeneous processes, and natural emissions of sulfur and nitrogen compounds. Developing a regional acid deposition model for the Colorado Front Range, in collaboration with NCAR, is a long-range goal. The model will consist of a mesoscale meteorological model and a photochemical model. It will be useful for interpreting the data at Niwot Ridge and for designing other measurement strategies, and such a model can be readily applied to study regional oxidant problems such as that of rural O_3.

The interaction of dynamics and chemistry in the middle atmosphere represents an important part of our understanding of aeronomy, particularly under the influence of chlorofluorocarbons or other external perturbations. We plan to continue to develop our dynamical-chemical model in order to study both the natural and the perturbed stratosphere. Chlorocarbon chemistry is being incorporated into the model, and we are also studying the effects of

turbulence produced by breaking planetary and gravity waves. The continued refinement of these and other aspects of the physics and chemistry of the model is expected to lead to a more detailed understanding of the stratosphere and mesosphere.

Cooperative work with the Atmospheric Dynamics program on the variability of the tropical tropopause will continue, with emphasis on some aspects that have not been adequately considered. These include the relationship between the height of the tropical tropopause and the global angular momentum of the atmosphere, an analysis of the physical mechanisms underlying tropopause formation, and a study of the implications of a varying tropopause height and temperature for stratospheric composition and for the Earth's radiation budget.

AL

SPACE ENVIRONMENT LABORATORY
Boulder, Colorado

Harold Leinbach
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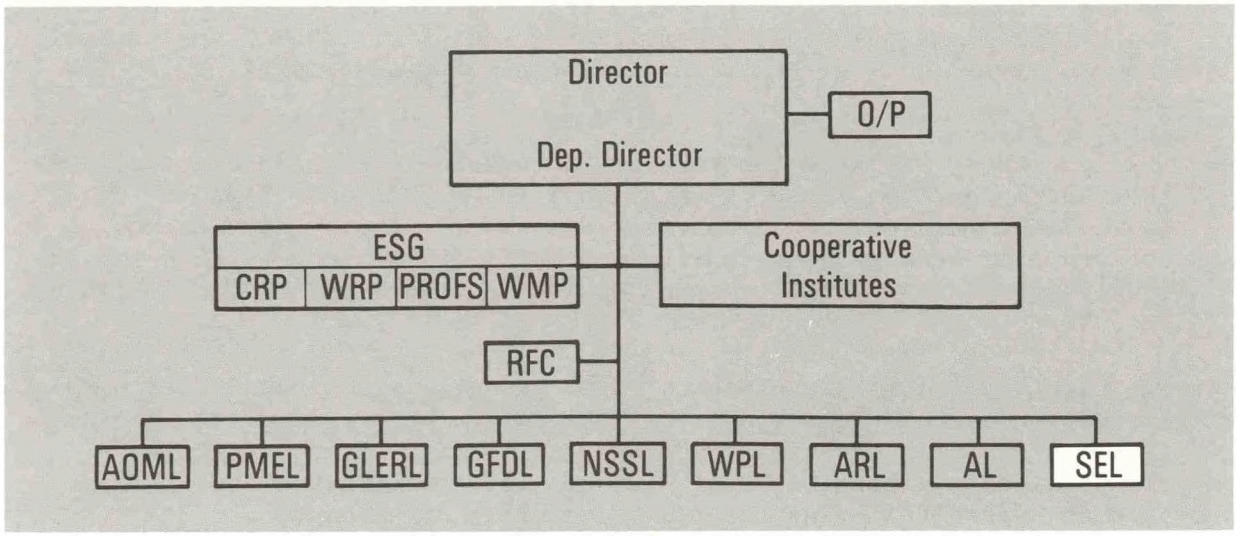


The Space Environment Laboratory (SEL) provides real-time space environment monitoring and forecasting services, develops techniques for forecasting solar disturbances and subsequent effects on the Earth's environment, and conducts research in solar-terrestrial physics in support of its service mission. SEL is composed of three Divisions: the Space Environment Services Division, the Research Division, and the Systems Support Division.

The Space Environment Services Division serves a growing national and international community of users concerned with the effects of solar activity on the Earth's environment. The Space Environment Services Center (SESC) and the Real-Time Data Services (RTDS) jointly constitute the major activity of the United States in solar-terrestrial monitoring, forecasting, and real-time data collection and dissemination. Many of the services are joint activities of NOAA and the U.S. Air Force (USAF).

The Research Division conducts long-term research into the phenomena that affect the solar-terrestrial environment and develops new analysis techniques and indices for SESC products. This involves understanding emission of radiation from the Sun, the propagation of matter and energy through the solar wind, and the interactions between the solar wind and the Earth's magnetosphere, ionosphere, and upper neutral atmosphere.

The Systems Support Division assists all Laboratory projects in using computers for acquiring and analyzing data through the Analysis Branch, and in developing instrument hardware, engineering software, and data systems design. The division develops satellite and ground-based instrumentation for SESC data collection and analysis, and supports research projects.

Highlights of laboratory activities during FY 1983 include the following:

- A computer system was purchased for the SEL Data Acquisition and Display System (SELDADS). It will be delivered to the Laboratory in June 1984 and will replace the present obsolescent real-time data system in 1985. The new system will greatly enhance the quality and timeliness of SESC services.

- The Laboratory assisted the Federal Coordinator for Meteorological Services and Supporting Research in preparing the "National Plan for Space Environment Services and Supporting Research." This report documents the scope of Federal space environment activities and describes the integrated 5-year program for space environment services and supporting research.

- Long-lasting (days) disturbances in the very-low-frequency (VLF) Omega navigation system, following some solar disturbances, degrade the navigational position determination of aircraft and ships. An ongoing study suggests a possible basis for providing warnings of such long-lasting events following the causative solar disturbances.

- Provision of solar-terrestrial data and warnings to customers by satellite data relay was successfully demonstrated. This technique promises to supplant the use of telephone data links for this purpose.

- The report "Solar X-Ray Imager Feasibility Demonstration" described an instrument proposed for use on a future GOES satellite to provide spatial information on solar coronal holes and active region structures, which promises to enhance the existing capability for predicting magnetic storms that adversely affect military and civilian systems.

SPACE ENVIRONMENT SERVICES DIVISION

Solar activity forecasts, geomagnetic forecasts, and warnings of events in progress as measured by real-time observations, are valuable to a great variety of users. For example, the NASA Space Shuttle program uses this information in orbital planning and planning for astronaut radiation safety. Ionospheric communications, including low-frequency navigation systems (Omega), are perturbed during strong flares, proton events, and geomagnetic storms; the space environment forecasts and warnings aid users in coping with the ionospheric disturbances. The orbits of navigational satellites may be modified by increased density of the heated upper atmosphere during magnetic storms. Satellite ephemerides are based on the forecast or observed level of magnetic activity. Closer to the ground, the same magnetic activity can induce strong voltage and current transients in electric power distribution lines, leading to possible system outages. In long pipelines, the induced currents may upset cathodic corrosion protection systems. In both situations, customers utilize the geomagnetic forecasts and warnings to minimize adverse effects on systems. Geophysical prospecting companies using airborne magnetometers avoid flights during magnetically disturbed conditions.

Accomplishments FY 1983

SPACE ENVIRONMENT SERVICES CENTER

SESC, a joint operation of NOAA and the USAF Air Weather Service (AWS), provided forecasts, alerts, and data for a variety of users who have systems that are affected by disturbances in the space environment or who are conducting scientific experiments to improve understanding of the environment. Customers using the services included NASA, the Departments of Defense, Transportation and Energy, universities, research foundations, and industrial and commercial users.

SESC had a major role in producing the "National Plan for Space Environment Services and Supporting Research," issued by the Office of the Federal Coordinator for Meteorological Services and Supporting Research. The report describes the coordinated national program and a centralized forecast center that provides a basic set of Earth-space environment services to meet common needs of government and non-government agencies.

SESC demonstrated the feasibility of using low-cost satellite broadcasts to distribute its Earth-space environment products. The broadcasts will be continued on an operational basis, effecting a major improvement in distribution to customers.

REAL-TIME DATA SERVICES

RTDS operates systems that provide data from various solar and geophysical sensors for supporting SESC operations. RTDS has three operational components: SELDADS at Boulder, Colo.; the Table Mountain Observatory 12 miles north of Boulder; and the High Latitude Monitoring Station at Anchorage, Alaska. Systems at the three sites were operated 24 hours per day, 7 days per week.

A contractor was selected to provide a replacement system for the existing SELDADS. The new system (SELDADS II), consisting of a main processor and a group of microcomputer preprocessors, will improve quality and timeliness of SESC services.

SELDADS consists of facilities to acquire, process, and display a wide range of solar geophysical data for use by SESC forecasters. SELDADS operated on a round-the-clock basis. Data were provided over dedicated lines to the USAF AWS at Offutt Air Force Base, Nebr., and to the Naval Ocean Systems Laboratory, San Diego. The data were also used by a number of industrial, governmental, and scientific groups who dial up the system from their own terminals. The following systems provided data to SELDADS during the year.

- Networks operated by the Defense Communications Agency provided worldwide data from the International Ursigram and World Days Service network and from regional Warning Centers operated by major countries in Europe, Asia, and Australia.

- The Table Mountain Observatory north of Boulder received data from the space environment monitors (SEM) on the Geostationary Operational Environmental Satellite (GOES) for processing and relaying to SELDADS where they were displayed and archived.

- The National Environmental Satellite, Data, and Information Service (NESDIS) supplied data from NOAA-6 and -7 polar-orbiting satellites. The data are stored, archived, and sent to the Global Weather Central (GWC) at Offutt Air Force Base.

- Data were received by way of the GOES data relay from the Real-Time Geophysical Observing Network, a chain of magnetometers operated by the U.S. Geological Survey, the University of California at Los Angeles, and the State University of New York.

- The High Latitude Monitoring Station at Anchorage, Alaska, received geophysical data collected at local and remote ground-based sensors located across Alaska and at Thule, Greenland. The site is jointly operated by RTDS and AWS. Local high-frequency radio propagation and magnetic forecasts are prepared along with special products for AWS. Data summaries are sent out every 15 minutes on the Astrogeophysical Teletype Network.

- The Astrogeophysical Teletype Network, operated by AWS, supplied data from observatories around the world, including the High Latitude Monitoring Station in Anchorage and the USAF Solar Observing Optical Network (SOON). These data are decoded in SELDADS and stored for retrieval and display.

Plans FY 1984

As new prediction and analysis routines become available, the services program will be improved to meet national needs. Distribution of service products by satellite broadcast will commence on a regular basis. New formats for use in geomagnetic forecasting will be completed. Work will continue on the use of shear indices in flare forecasting. To prepare for the use of SELDADS II, data base definition, the design of user software for the forecasters, and a system of documentation of the hardware and software will continue. An SESC forecaster will assist the NASA Solar Maximum Mission at the Goddard Space Flight Center on a reimbursable basis.

A 5-year plan for handling solar images in the forecast operation will be completed. New equipment will be procured to assist in the collection of solar data in real time from cooperating observatories. These interim improvements will maintain image collection capabilities until an initiative can be developed for FY 1986.

A revised and updated description of the data necessary to carry out current and projected services will be developed. The requirements will include solar images and radiation measurements, near-Earth and upper-atmosphere satellite detectors, and ground-based geomagnetic and ionospheric sensors.

RTDS will continue routine operation of its three components on a round-the-clock basis. The microcomputer preprocessors for SELDADS II will be brought on line, as the software required to access and process the real-time incoming data streams is developed. Work will begin on interface to the SELDADS II computer after its delivery in the summer of 1984. This work will also involve the gradual phaseout of the original SELDADS, so as not to disrupt the continuity of data flow and processing.

RESEARCH DIVISION

Projects of the Research Division were Solar Physics, Interplanetary Physics, Magnetospheric Physics, and Atmosphere-Ionosphere-Magnetosphere (A-I-M) Interactions.

Accomplishments FY 1983

SOLAR PHYSICS

Work in solar physics concentrated on solar magnetic fields and solar X-ray emissions. This included (a) the calibration and formatting of raw data, and software and communications development for reception of data in real time; (b) observational studies of evolutionary patterns on the Sun; and (c) theoretical modeling of the solar corona.

Techniques were developed to replace labor-intensive, hand-drawn daily maps with maps plotted by computer routines. Software and communications were developed for daily transmission of solar magnetic field maps from Stanford University to SEL. These maps were used to evaluate the effect, at the Earth, of solar sector boundaries. Digital data are used to construct the threedimensional forms of large-scale fields at heights above the solar surface where these fields may couple directly to the interplanetary magnetic fields along which disturbances tend to travel. The data base of H-alpha synoptic charts (global maps of the Sun for each complete 27-day solar rotation) was maintained and prepared for archiving.

Solar data show a close relation between large-scale solar magnetic fields and the locations of coronal holes; they also show a relationship between large-scale patterns of solar magnetic fields and the locations of strong and persistent sunspot and flare activity. A relationship was established between localized shear within sunspot groups and the location, size, and time of large solar flares. A catalog of outstanding active regions, in terms of their X-ray flare production, is being compiled. In-flight calibrations of solar X-ray detectors on the GOES operational satellites were carried out. The empirical work was complemented by theoretical work on the nature of polar coronal holes.

INTERPLANETARY PHYSICS

The principal activity had a twofold objective: (a) developing multi-dimensional, time-dependent models of the solar corona, solar wind, and interplanetary magnetic field and (b) contributing to physical knowledge of the interplanetary medium. The short-term goal was to verify the 2½-dimensional computer models using available real-time solar data of occurrence, severity, and duration of geomagnetic disturbances. Verification was carried out for a particular epoch (August 1979) during which there was substantial solar activity (solar flares, high-speed streams from coronal holes, erupting prominences) and geomagnetic activity. Tests of a three-dimensional, time-dependent magneto-hydrodynamic (MHD) model were conducted.

Studies were conducted to incorporate into the models non-Maxwellian distribution functions of various ions.

A simplified version of the nonplanar (2½-dimensional) MHD model was tested with solar wind shock velocities resulting from 62 solar flares. The test consisted of the complementary input of solar optical and GOES soft X-ray data, and the output is the predicted time of arrival of the shock at the Earth. This approximate model takes into account only the flare-generated shock wave and its propagation under the piston-driven and subsequent blast wave approximations. A plan was prepared to incorporate this version into operational forecasting procedures using real-time shock velocity input.

The project continued participation in two NASA programs, Solar Maximum Mission and Pioneer-Venus-Orbiter, which are concerned with solar activity in the low corona associated with solar flares and the ionospheric consequences of transients, respectively.

MAGNETOSPHERIC PHYSICS

The objectives of research in magnetospheric physics include the experimental and theoretical study of the geomagnetic field and the several particle populations within it, and the dynamics of the complex electromagnetic processes through which these fields and particles interact. Emphasis is on the use of data obtained from instruments aboard the GOES and NOAA/TIROS (Television and Infrared Observation Satellite) operational satellites, whose data constitute a principal input to the resources of SESC.

A major objective of the project's research is an understanding of those processes by which energy is transferred to the magnetosphere, stored therein, and ultimately dissipated in the Earth's upper atmosphere and ionosphere. Further effort was applied to the acceleration of auroral particles in the magnetospheric tail by the cross-tail electric fields observed there. The model produced predictions in excellent agreement with in situ observations of auroral particle fluxes. This acceleration mechanism may represent an important source for the development and maintenance of the Earth's quiet-time ring current. Together, the auroral and ring current systems represent the principal sources of ground geomagnetic disturbance.

In response to concerns about the Omega navigation system, the project undertook an examination of the polar radiation environment during periods of long-delayed (days) after-effects on VLF radio signals. The delayed recovery of the ionization level, following a polar cap absorption (PCA) disturbance results either from an additional particle ionization source, or from ionospheric chemical processes. The relatively complete description of the polar particle radiation environment provided by the NOAA/TIROS and GOES instruments should allow us to identify one of these as the cause. Comprehensive observations were assembled of protons, alpha particles, and electrons precipitating into the polar ionosphere during and after five PCA events in 1982, along with corresponding observations of Omega phase advances. The ionospheric responses are being evaluated for comparison with those Omega records. Preliminary results suggest an unexpected approximate relationship between GOES low-energy particle measurements and the Omega phase advance. These findings may provide a basis for improved warnings of delayed after-effects.

An atlas of ion distributions throughout the magnetospheric trapping regions was produced from data obtained from the International Sun-Earth Explorer (ISEE) satellite.

ATMOSPHERE-IONOSPHERE-MAGNETOSPHERE INTERACTIONS

The primary objective of this research is to understand the transfer of electrical and mechanical energy from the Earth's magnetosphere into the upper atmosphere and to characterize the consequences of that energy input on the ionosphere, the upper atmosphere, and sea level environment.

Studies were conducted to establish a real-time index of high-latitude activity, based on data from the Real-Time Geophysical Observing Network. A major effort continued in the analyses of observations from the Total Energy Detector on board the NOAA/TIROS series of polar-orbiting spacecraft. This detector regularly measures the energy carried into the polar atmosphere by auroral particles (both electrons and protons) with energies up to 20 keV. A second complement of charged particle detectors monitors the particle population with energies from 30 keV to solar protons with energies >1,000 MeV. These measurements provide an excellent guide to the level of geophysical activity affecting a variety of operations. The measurements are important scientifically since auroral particles are a major source of energy into the upper atmosphere above 90 km and, therefore, dominate the dynamics of the polar upper atmosphere. Measurements of the energy input to the atmosphere may be a better indicator of atmospheric heating (and, therefore, of satellite drag) than the conventional geomagnetic K and A indices. Localized measurements of energy input can now be extrapolated to estimate the total rate of energy input over an entire polar hemisphere, which is about 2 gigawatts for quiet times and more than 300 gigawatts for an active period.

SEL

Plans FY 1984

SOLAR PHYSICS

- Complete software for routine solar mapping.
- Use large-scale patterns of solar magnetic fields for 27-day (and longer) solar-terrestrial forecasts.
- Develop real-time models of coronal magnetic fields for operational use.
- Extend coronal modeling to solar maximum.
- Develop data bases for long-range solar activity predictions.
- Correlate solar X-ray and 10-cm radio emissions to improve forecasts of daily indices at both wavelengths.

INTERPLANETARY PHYSICS

- Test validity of the nonplanar MHD model by input of August 1979 coronal data.
- Develop a fully three-dimensional, time-dependent computer model of the interplanetary "transmission line."
- Compare predicted shock arrival times (from real-time solar radio, optical, and X-ray data) with in situ spacecraft observations of shocks, recorded times of geomagnetic storm sudden commencements, and sudden impulses at ground-based magnetometer stations.
- Distribute an operational users' guide to all USAF observatories where solar radio spectral data are obtained from sweep frequency interferometers.

MAGNETOSPHERIC PHYSICS

- Conclude Omega study with comparison between the recovery of particle-induced ionospheric ionization and the recovery of delayed Omega VLF phase advance.
- Continue study of tail acceleration mechanism to investigate effects of multiple traversals of the tail acceleration region by mirroring particles.
- Continue exploitation of NOAA/TIROS data by comparing enhancement of medium-energy particle precipitation over the polar caps with the occurrence of interplanetary disturbances and geomagnetic activity.

ATMOSPHERE-IONOSPHERE-MAGNETOSPHERE INTERACTIONS

- Develop a practical, useful, and fully automatic method of characterizing geomagnetic activity using real-time data sources such as the GOES satellite and Real-Time Geophysical Observing Network.
- Utilize the NOAA/TIROS particle observations (late 1978-present) to develop maps of ionospheric conductivity as functions of magnetic local time, magnetic latitude, and activity as parameterized by the hemispheric power input.
- Explore the feasibility of monitoring upper-atmosphere density and composition by inference of energy input from NOAA/TIROS observations.

SYSTEMS SUPPORT DIVISION

Accomplishments FY 1983

ANALYSIS

The Analysis group provides computer-programing support to the Laboratory. Members of the group combine experience and training in physics, engineering, and mathematics with expertise in the use of computer systems.

The Analysis group completed its support of the solar flux and ultraviolet radiation projects (now based in ARL). Access was provided to NASA tapes of Nimbus-4 and -7 data, and assistance with statistical analysis was given. The archive production of the NOAA GOES soft-burst X-ray project was substantially completed for SMS-2 and GOES-2. When a decision was made to deemphasize this work, the documentation was revised and completed so that the program can be used again in the future.

The standard archive tape for data from the operational SEM instruments was completed for GOES-2 through May 1983. At that date a change in SEL real-time processing occurred, which necessitates a restructuring of the standard archive processing.

A major effort was started to reconfigure and expand the general operational spacecraft off-line data processing to accommodate the changes that have occurred in the spacecraft telemetry from GOES-5 and the changes that have occurred in SELDADS processing. We plan to incorporate the maximum amount of automatic data quality checking and to permit a major portion of the off-line processing, including archive tape production, to be carried out by SELDADS II.

ISEE-2 tape processing was completed through 1982 day 046, and the Interplanetary Monitoring Probe (IMP) production was completed for all tapes received from NASA. This work has now been transferred to the Applied Physics Laboratory of Johns Hopkins University as planned.

Documentation of the Phase-2 software for the SEL high-frequency radar was completed as planned. Some additional improvements were incorporated with support from Los Alamos National Laboratory, and final versions were prepared for distribution.

The ERL computer initiative was supported with further benchmark generation and testing until it was supplanted by an initiative for a Department of Commerce Scientific Computer Center.

The benchmark program was extended and has been applied to a range of systems in an effort to evaluate the actual performance of the new "super micro" 16/32-bit systems. SEL plans to use these systems as scientific workstations supporting interactive graphical presentation of research data.

Procurement of the SELDADS II main processor system was supported by participation in the Technical Advisory Committee, which completed technical

specifications for the Request for Proposal. The group also participated in the analysis, design, and preliminary programing of the SELDADS II systems.

INSTRUMENT DEVELOPMENT

The Instrument Development group provides general support to the Laboratory with instrument hardware, engineering software, and data system design. Support throughout the lifetime of a Laboratory program often begins with system conceptual development and proposal writing, and continues through design, fabrication, and test phases. Support of field deployment or launch operations often involves continuing evaluation and consultation during data reduction and analysis. Program management and technical supervision of contractors are provided for larger programs.

Operational Space Environment Monitors

Work on the High Energy Proton and Alpha Detector (HEPAD) for the GOES program progressed satisfactorily, and no difficulty is anticipated in meeting the delivery requirement. Several repairs were carried out on TIROS SEM sensors, and studies of a HEPAD failure on GOES-5 were completed.

Support was provided to NASA for ongoing NASA contracts for fabricating GOES-G and -H and the associated SEM instruments. Specifications were reviewed for the proposed redesigned GOES (GOES NEXT).

Solar X-Ray Imager

SEL established an operational extreme ultraviolet and X-ray imager as its first priority for enhancement of the present SEM system on the NOAA GOES spacecraft. Because of the constraints of the present spacecraft design this addition can be made only during a major redesign of the spacecraft. Such a redesign, known as GOES NEXT, has been under study by NOAA and NASA for several years. In preparation for an operational sensor, SEL in collaboration with NASA Marshall Space Flight Center (MSFC) carried out a study of the major system components that would be required (i.e., the X-ray optics and the solid state imaging detector). It was concluded that the technology exists for the realization of a suitable flight instrument. In addition, SEL studied in greater detail the operational use of the imager data and the specific improvements in services that would become possible.

We expect a Request for Proposal for the GOES NEXT system to be issued by NASA on behalf of NOAA in the first quarter of 1984. In collaboration with MSFC, the Laboratory has prepared performance and interface specifications for an operational imager. The contractor will be required to accommodate an X-ray imager as part of the SEM. However, budgeting constraints may delay construction of an actual instrument.

Solar UV Spectroradiometer

The design study carried out for ARL on this project was expanded and a decision made to build the prototype electronics in-house. Detailed design is substantially complete, and about 30% of the circuitry has been completed.

Microprocessor Support System

Fifteen general-purpose microprocessor systems were procured to provide SEL staff with generally available word processing and small-scale scientific computing. Software was written to automate the preparation of purchase and travel requisitions, provide local accounting of other-objects expenses, and support laboratory personnel and overall budget preparations.

Plans FY 1984

ANALYSIS

The major efforts of the Analysis group will be directed toward design completion and partial implementation of both the SELDADS II preprocessor software and the general operational satellite off-line data-processing system.

The characterization of "super micro" systems will continue, and specifications will be prepared for a procurement.

INSTRUMENT DEVELOPMENT

Operational Space Environment Monitors

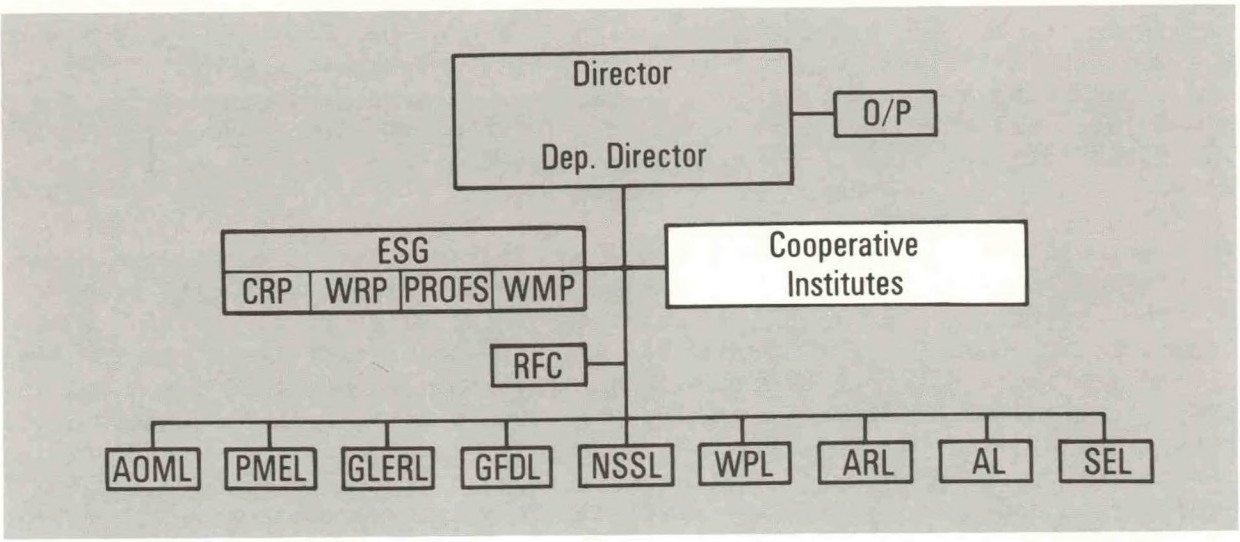
The HEPAD instrument fabrication and test will be completed and the two HEPADs delivered for the GOES programs. Operational instruments in storage will be maintained as required, and support to the GOES NEXT program will continue.

Solar UV Spectroradiometer

The electronic system for the ARL experiment will be delivered and the overall calibration of the system supported.

Microprocessor Support System

The 15 separate units will be converted into a local area network and provided with a more capable central printer for technical document preparation.



Several Environmental Research Laboratories interact with the university community through cooperative institutes. These institutes provide a mechanism for research collaboration and training in areas of mutual interest to NOAA and the academic community. There are six of these institutes at universities in Colorado, Washington, Hawaii, Oklahoma, and Florida; each is closely associated with one or more of NOAA's Environmental Research Laboratories.

CIMAS

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is a joint effort between the National Oceanic and Atmospheric Administration (NOAA) and the University of Miami's Rosentiel School of Marine and Atmospheric Science (RSMAS), with the objective of enhancing research collaboration between the institutions. The two research themes of CIMAS are "Ocean-Related Aspects of Climate" and "Ecosystem Dynamics". Research under both themes focuses on the tropical environment and uses satellite remote-sensing technology and mathematical modeling techniques to study oceanic processes affecting climate and fish stock variability.

The CIMAS staff includes eleven Fellows who are appointed from RSMAS faculty and NOAA's laboratories in Miami and who conduct collaborative research. Also included in FY 1983 were two Visiting Fellows, two Members, three Associate Scientists, eight Research Associates, one Postdoctoral Associate, and two graduate students. Members of the staff are stationed variously at the CIMAS building, the RSMAS campus, and NOAA laboratories. CIMAS further supports NOAA activities through the visiting scientist program, and by conducting conferences and workshops.

Accomplishments FY 1983

Ocean-climate research of CIMAS scientists focused on ocean circulation patterns using data from drifting buoys, continuous temperature-density (CTD) recorders, expendable bathythermograph (XBT) and airborne expendable bathythermograph (AXBT) profiles, an acoustic Doppler backscatter profiler, and the radioactive hydrogen isotope tritium, plus mathematical modeling of the mixed layer and of the origins of relatively warm and saline oceanic bottom water. Additional climate studies concentrated on the sea breeze of the Florida west coast and on hurricane motion.

Research in conjunction with the Equatorial Pacific Ocean Climate Studies (EPOCS) has continued to be a primary effort. Analysis of data from previous years resulted in the preparation of two manuscripts concerning the dynamics and energetics of the "30-day waves", which were first seen in satellite sea surface temperature data. A composite mean of all drifter data prior to the 1982-83 El Niño is being compiled to serve as a baseline for future analysis of the event. Corrections are being developed to account for drogue loss. The problem of drifter calibration has been a concern for several years, and present efforts indicate that a statistical approach can be used to determine the relation between data collected from drogued and undrogued buoys.

A concerted cooperative effort with the coastal South and Central American countries was made to enhance the collection of XBT and other data from the eastern tropical Pacific. The XBT program collected approximately 1300 XBT profiles and more than 400 AXBT profiles from aircraft missions in January, July, and September. Processing and collection of these data are continuing.

A new acoustic Doppler backscatter current profiler was installed on the R/V Researcher in late 1982. Comparisons of data from this profiler and from conventional current profiling techniques indicated that velocity profiles good to a couple of centimeters per second can be obtained with the new system to depths of 270 m almost continuously. Three studies of circulation patterns in the eastern Pacific were completed. One describes the normal seasonal variations along 110°W from 6°N to 7°S; another documents the changes that took place in sea level, currents, and temperature structure when the 1982-83 El Niño began; the third describes the near-surface circulation patterns that are produced by meridional winds along 85°W.

Research on the transient spreading of the tracer tritium, based on sampling undertaken during EPOCS, the North Pacific Experiment (NORPAX), and the Pacific Equatorial Ocean Dynamics (PEQUOD) programs, continued. It was demonstrated that there was a net southward, cross-equatorial tracer flux in the upper layers of the Pacific Ocean during the last decade. Continuing assistance was provided in the production of an atlas and data report on tritium collected under the aegis of EPOCS, NORPAX, AND PEQUOD. A major new effort was undertaken to study synergisms between the wind-driven and thermohaline circulations on ocean gyres by using numerical model experiments. Experimentation with existing models led to the discovery of an unexpectedly strong influence of the middle-depth thermohaline forcing on the separation of the western boundary current and on associated eddy dynamics.

A model of the ocean's coupled carbon, oxygen, and phosphorus (COP) system was developed jointly with faculty of the RSMAS Marine Geology and Geophysics Division. The COP model is a first step in understanding the interaction among the chemical, biological, and physical transport processes and the imprint these processes leave on the sedimentary record. The model represents a first-order theory of ocean-wide anoxia, with emphasis on the deposition of organic carbon; this work has been reported in two publications. Progress of this research is fundamental to CIMAS's study of the ocean's climatically important role as a reservoir of carbon dioxide.

A multi-dimensional mathematical model of the mixed layer was developed in order to understand the layer's dynamics, particularly the effects of advection on the evolution of the ocean's density structure. It was found that vertical shear in the velocity distribution of the mixed layer combined with a horizontal density gradient can result in a considerable production or absorption of mechanical energy. As a consequence, the characteristics of the deepening of a mixed layer with a sheared velocity profile are different from those of a slab type layer. An important conclusion is that velocity shear can substantially enhance the speed with which density anomalies are propagated horizontally. In a related study, a physical mechanism has been isolated that can be responsible for the generation of thermal fronts at the ocean's surface. It is related to the fact that, under steady winds, the uniformity of the available mixing energy requires that a cold layer be shallow (large buoyancy flux over a small depth) and that a warm layer be deep. The consequent variation in mixed-layer depth leads to convergence or divergence of the Ekman velocity, and associated frontogenesis or frontolysis.

Atlantic Ocean circulation was the subject of considerable research within CIMAS during FY 1983. Applications of marine geodesy to studies of the heat flux of the Florida Current are being developed. In addition, two studies were completed on a subthermocline lens observed during the Local Dynamics Experiment subprogram of the combined Polygon and Mid-Ocean Dynamics Experiments (POLYMODE) that provided unique descriptions of this previously unknown phenomenon. A third study led to the discovery of a strong correlation between the annual cycle of the wind stress curl over the western Caribbean, and the annual cycle of the transport at the Florida Straits. Identification of the forcing mechanism of the annual variation in the transport at the Florida Straits has been an issue of some contention in the physical oceanographic community. Many theoretical mechanisms have been proposed, but none has been substantiated by field data. The strong correlation discovered suggests a local forcing mechanism which, if actual, may require a re-thinking of many of the scientific community's ideas about the importance of the seasonal transport of heat and mass through the Florida Straits and its impact on the annual cycle of the heat budget of the North Atlantic.

In conjunction with scientists at NCAR and CIRES, the interannual variability of North Atlantic heat storage was investigated. The data set for the North Atlantic was set up, and preliminary efforts focused on a section sampled in 1968-1974 from the east coast of the United States across to the Mediterranean. The seasonal cycle of the vertically averaged temperature of the upper 400 m has been resolved; its amplitude (1°C) is larger in the west than in the east (0.5°C), and there is an apparent phase shift such that variation in the east lags that in the west. Additionally, a year-to-year variation is clearly present. In the western basin there was a period of

depronounced cooling beginning in late 1968, and its effect remained through 1972. This result is consistent with observations made at Bermuda.

A study of the interaction between the South Atlantic and Indian Oceans through the Agulhas Current system was completed. The relation to climate is that the Agulhas is a relatively warm current that meets and interacts strongly with the cold west wind drift. It was shown that the amount of "leakage" of Agulhas water into the cool South Atlantic is mainly dependent on the large-scale conditions over the Indian Ocean. A portion of this Southern Ocean study was done in collaboration with faculty from the RSMAS Division of Meteorology and Physical Oceanography.

During the summer months of 1980, 1981, and 1982, NOAA P-3 aircraft were used to gather data for an observational study of the Florida west coast sea breeze. CIMAS participated in the analysis and in the development of an informal research report for two cases. The study demonstrated the following:

(1) How the strength of the large-scale flow determines the onset time of the sea breeze circulation.

(2) How the availability of moisture (on the mesoscale) determines the onset time of deep convection, and the effects the deep convection have on the mixed layer.

(3) That the peninsula-scale divergence appears to have little or no effect on the evolution of the sea breeze.

(4) The effect the magnitude of the sea breeze forcing (land-sea temperature differences) has on accelerating the sea breeze circulation.

(5) That the cloud base height from the airborne movie cameras compared well with the mixed layer heights from soundings.

Airborne Doppler data for a third flight were analyzed, and a comprehensive description of the mixed layer height and its interaction with the sea breeze circulation is now being prepared. A mixed-layer model was completed and will be used to study the effect of the sea breeze advection on the development of the mixed layer.

CIMAS participated in hurricane motion studies that tested AOML's Quasi-Spectral Time Integration on Nested Grids (QSTING) model. Most, if not all, of FY 1983 was spent in implementing and testing certain filtering procedures needed to control noise generated when signals propagate from a fine-resolution mesh to one of coarser resolution and also to minimize the oscillations due to Gibbs phenomenon, which occur in spectral models using nested grids. This testing is nearing completion.

Ecosystem dynamics research in CIMAS was conducted on satellite applications to fishery oceanography and on the effects of predator pressure on coral reef systems. CIMAS collaborated with faculty of the RSMAS Biology and Living Resources Division to determine the ocean-related variability of aggregations and vulnerability of bluefin tuna in the Gulf of Mexico from satellite and fishery data.

CIMAS's reef fish research concentrated on coral reef ecology, specifically examining microhabitat distributions, population changes, inter-reef variation, and the resiliency of reef fish populations to reduced harvesting pressure. A major resource survey of Looe Key National Marine Sanctuary began in FY 1983; the field work was completed, and the data are under analysis. NOAA's assessment of king mackerel stocks in the Gulf of Mexico and South Atlantic bight was conducted jointly with CIMAS personnel; recruitment variability is high and perhaps in a declining trend in the Gulf of Mexico.

CIMAS conducted a major international workshop, Fish Ecology III. The workshop, attended by 40 scientists from government and academic institutions, was the third of a series designed to develop the direction of research on fish population variability problems. Large-scale studies of the past have failed to allow a significant advance in understanding the nature and magnitude of variations exhibited by fish populations. Therefore, research needs to focus on micro- and fine-scale phenomena of the physical, chemical, and biological ocean environment. Recent advances in technology and the understanding of fish larvae survival mechanisms allow the micro- and fine-scale research focus. General plans for experiments were developed at the workshop and were published by CIMAS in FY 1983 along with contributed papers in the workshop's report.

CIMAS was organizer and host of the 18th Meeting of the Association of Island Marine Laboratories of the Caribbean; more than 100 scientists from 12 countries participated. CIMAS also organized and chaired the Management Options Session at the first Western Atlantic Turtle Symposium held in Costa Rica; sea turtles are endangered or threatened species throughout their range in the Western Atlantic. This conference brought together scientists and resource managers from 38 countries.

Plans FY 1984

Research under the ocean-climate theme will continue in support of NOAA's EPOCS, STACS, and hurricane-forecasting programs. Data obtained from drifting buoys, XBT's, and AXBT's in the eastern tropical Pacific Ocean during the past year will be analyzed; several manuscripts are planned that will characterize the ocean circulation aspects of the 1982-83 El Niño event. Summaries of tritium data collected by EPOCS, NORPAX, and PEQUOD will be completed as will manuscripts on an estimate of the depth of the equatorial upwelling using tritium and on a study of the tritium distribution on isopycnal surfaces in the equatorial Pacific Ocean. We plan to extend the analysis of interannual variability in North Atlantic heat storage by increasing the time series of measurements through the early 1980's; additional North Atlantic sections will be examined to determine if adequate sampling has occurred. A new Postdoctoral Associate will join CIMAS in February 1984 to increase research efforts on the heat budget of the central tropical Atlantic. CIMAS will support efforts to improve the QSTING hurricane forecast model by participating in the introduction and testing of moving meshes of the nested grids; this modification will allow the principal signal (i.e., the moving vortex) to remain with the highest resolution meshes throughout the numerical prediction of its motion.

Research will be expanded on the ocean aspects of the carbon dioxide (CO_2) atmospheric loading problem. Further development of the COP mathematical model is planned in order to understand the ocean's role as a CO_2 reservoir. Based on the preliminary model, a study of marine chemical cycles and their impact on the geological record is in progress. It involves the construction of a hierarchy of models that will include, in addition to the COP model, models of time dependence, sulfate reduction, and bottom water formation by buoyant plumes. The results of these models can be used to interpret the geological record, for example, the worldwide Cretaceous anoxic events and the Miocene anoxia occurrences in the eastern Mediterranean Sea. The model results will describe modern day analogs such as the Black Sea and the Cariaco Trench. The time-dependent models will allow the estimation of time scales for the establishment and duration of anoxic events and will constrain variability of ocean chemistry on glacial-interglacial time scales. The observed intra-annual variability of atmospheric CO_2 is greatest over the marginal ice zone in the Northern Hemisphere; therefore, a cyclesonde laboratory supported by the Office of Naval Research has been set up in CIMAS to develop measurement technology and to analyze cyclesonde and ship data that characterize the physical variability of the ocean at the marginal ice zone.

New efforts are being planned to support United States involvement in the international Tropical Oceans and Global Atmosphere (TOGA) program. A proposal is in preparation for the study of global scale interactions between oceanic and atmospheric heat transport using heavily parameterized models.

Ecosystem dynamics research will continue to focus on reef fish ecology and oceanic and biological processes contributing to fish stock and sea turtle variability. An analysis of data collected during the FY 1983 survey of the Looe Key National Marine Sanctuary will be completed. Monitoring of the changes in reef fish populations along Florida's coral reef tracts will continue as a long-term project. Mathematical modeling of the protogynic life history of groupers will be initiated to determine the effects of exogenous mortality sources on population productivity and to determine the efficacy of state-of-the-art stock assessment techniques. Simulation modeling of fishery management institutional structures will be undertaken to determine the efficacy of existing institutional structures with regard to tropical fishery resources.

A new Postdoctoral Associate will join CIMAS in January of 1984 to enhance research on the effects of oceanic processes on the survival of larval fishes. Initial research will focus on oceanic mechanisms affecting the pelagic phase of fishes that recruit among island reef tracts of the Caribbean and those mechanisms affecting tuna population size variability that appear also to be related to climate variability. Additional research along this line will address the fine-scale vertical distribution of plankton in the Gulf Stream, using state-of-the-art instrumentation such as in situ camera and acoustic systems, to quantify the relationships between plankton distributions and physical parameters such as the thermocline and pycnocline; the objective is to make more accurate observations to improve our understanding of the factors that regulate plankton distributions and migrations, as a means of understanding the nature of plankton patchiness and ultimately fish stock variability.

A new research theme entitled "Ocean - Sea Floor Hydrothermal Interactions" is under development. Following initial approval in FY 1983 to pursue this theme, funding was obtained by the two principal investigators and they led an interdisciplinary effort to prepare a proposal involving interactions among ocean biology, chemistry, geology, and physics associated with the hydrothermal activity of sea floor movements. This effort represents a unique attempt at a systems approach to this interesting and important ocean process.

CIMAS will be host to a number of conferences. Ten visiting scientists scheduled in FY 1984 will provide 20 or more lectures in their fields while consulting with CIMAS scientists.

CIMMS

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) is a joint venture of the University of Oklahoma (OU) and ERL through the National Severe Storms Laboratory. CIMMS received first funding in late FY 1978 and began major efforts during FY 1979. The program objectives and activities of CIMMS complement and supplement those of NSSL and the University through research conducted by Visiting Fellows, NOAA and University staff, and student appointees. The present council of Fellows, which helps formulate policy, includes two members from NSSL, both of whom hold adjunct professorial appointments at OU, and two members from OU. The Advisory Council, which includes representatives from OU, NOAA, and outside organizations, meets annually.

During 1983 CIMMS continued to expand. CIMMS was host to researchers from China, India, Japan, and England who undertook studies in Doppler radar meteorology, and meteorological data analysis for periods of 1 to 3 months; principal financial support came from their universities or governments. A CIMMS research scientist represented CIMMS in the Alpine Experiment (ALPEX) field program by attending "Mediterranean Cyclogenesis and ALPEX," sponsored by the International School of Meteorology of the Mediterranean, the World Meteorological Organization, the National Science Foundation, and the Italian Ministry of Science and Technology Research. The same scientist attended the IUGG/IAMAP conference held in Hamburg in August 1983. Another CIMMS scientist conducted research under Navy contract on an operational global satellite data assimilation scheme which was implemented and tested upon the Navy Operational Global Atmospheric Prediction System (NOGAPS) at Fleet Numerical Oceanography Center, Monterey, Calif., and also conducted research on the development of a mesoscale variational temperature analysis scheme under a NASA contract. The CIMMS mesoscale model is being used to test this scheme. A Postdoctoral Fellow from Israel did some investigations of mesoscale dynamics and sea-breeze. Approximately 10 students employed by CIMMS are engaged in research studies toward advanced degrees; 5 are undergraduate students. Most CIMMS student employees are associated with both NSSL and the OU School of Meteorology. A CIMMS Research Associate works in the NEXRAD (next-generation radar) program. Four Postdoctoral Fellows on multiyear appointments work in boundary layer dynamics, mesoscale modeling, mesoscale dynamics and stability convection, and variational methods.

CIMMS selected 15 new Fellows and 1 Senior Fellow from related disciplines. All have outstanding qualifications which enable them to interact with CIMMS on interests in research and science.

CIMMS personnel were authors or co-authors of approximately 17 reports and publications during FY 1983.

The First Conference on Mesoscale Meteorology, co-sponsored by CIMMS and the American Meteorological Society, was held 31 May-3 June 1983; approximately 130 attended this conference in Norman, Okla.

Although OU has suffered some financial setbacks, construction of new facilities for CIMMS and the School of Meteorology in the College of Geosciences began in July 1983.

Prominent in CIMMS plans (1985) is the "Symposium on Variational Methods in Geosciences" to be held at Norman and jointly sponsored by CIMMS and the University of Clermont, France.

CIRA

The Cooperative Institute for Research in the Atmosphere (CIRA), established September 1980, is jointly sponsored by Colorado State University (CSU) and NOAA and has close relationships with ERL in Boulder and NESDIS in Suitland, Md.

The Institute's research has concentrated on global climate dynamics, local-area weather forecasting, severe storms, and the application to climate studies of satellite observations. In addition, the Institute and the National Park Service cooperate in air quality research. CIRA is playing a major role in the NOAA-coordinated U.S. participation in the International Satellite Cloud Climatology Project (part of the Climate Research Program), and we plan increased involvement in studies of the El Niño/Southern Oscillation phenomenon and other climate research and applications projects. In the planning stage is formal cooperation with the World Meteorological Organization and the United Nations Environmental Program to assist the Indian Meteorological Department in developing a sector processing center for its INSAT (Indian Satellite) ground station.

Five NESDIS scientists in residence at CSU constitute the Regional and Mesoscale Meteorology Branch of the NESDIS Development Laboratory. They lead the CIRA collaboration with ERL in the area of short-range weather forecasting research.

The CSU departments currently engaged in CIRA research are Atmospheric Science, Statistics, Psychology, Civil Engineering, Electrical Engineering, and Recreation Resources. Currently 23 separate research projects have been funded through CIRA, including an IPA (Intergovernmental Personnel Act) with the National Weather Service. CIRA personnel consist of 12 Fellows, 1 Postdoctoral Fellow, 3 Visiting Fellows, 8 Research Associates, 3 Visiting Scientists, and a Director. During FY 1983, five Graduate Research Assistants received degrees--three M.S. and two Ph.D. Each year the Visiting Fellows

Program provides the opportunity for independent research at CSU in collaboration with NOAA scientists. A "co-op" program allows CSU graduate students to work in residence at NOAA Laboratories. A workshop entitled "Research on Weather and Climate Applications at Colorado State University" was held at the Pingree Park Campus in September 1983.

Plans include continued collaboration of NOAA and CSU scientists and students in research related to NOAA's mission within the special themes of CIRA, expansion of the Visiting Fellows Program, and continued development of research involving NOAA and CSU scientists with other agencies.

CIRES

The Cooperative Institute for Research in Environmental Sciences (CIRES) is jointly sponsored by the University of Colorado and NOAA and receives a roughly equivalent amount of support from other public and private sources. CIRES Fellows have academic affiliations with eight departments at the University of Colorado: Chemistry, Chemical Engineering, Physics, Geography, Geological Sciences, Electrical Engineering, Mechanical Engineering, and Astrophysical, Planetary, and Atmospheric Sciences. Current research in CIRES is in four broad areas: Environmental Chemistry, Climate Dynamics, Atmospheric Dynamics, and Solid Earth Geophysics. CIRES research on these subjects was reported in approximately 65 publications in 1983.

ENVIRONMENTAL CHEMISTRY

There are particularly strong links and collaborative research programs between scientists in CIRES and in the Aeronomy Laboratory and the Geophysical Monitoring for Climatic Change Division of the Air Resources Laboratory. Major joint field and laboratory studies were completed during 1983.

The areas of research include environmental analysis, reaction, kinetics, molecular biology, surface science, and analytical instrumentation. Environmental applications include such diverse subjects as acid rain, air and water pollution associated with oil shale and other energy source development, climate change resulting from carbon dioxide emissions from fossil fuel burning and other pollutants, stratospheric ozone depletion, improvements in catalyst technology, fuel additives to improve efficiency of combustion and decrease pollutant emissions, photochemical oxidant formation in the troposphere, use of microorganisms to detoxify chemical waste, earthquake hazard evaluation based on gaseous emissions from the ground, protection of crops against frost, marine measurements of chlorofluoromethanes as transient tracers of ocean circulation and global uptake of pollutants by the sea, and evaluation of the atmospheric consequences of nuclear warfare.

Underlying environmental chemistry research is the need for ultrasensitive means of detecting, identifying, and quantifying specific chemical species in the atmosphere, in the ground, in water, in living organisms, on surfaces of catalysts and atmospheric particulates, and in flow tubes that simulate reactions occurring in the atmosphere. As a necessary part of their research program, several CIRES chemists are actively involved in developing

entirely new methods of chemical analysis. This includes improving the physical methods themselves, and designing and synthesizing molecules to serve as selective reagents or to aid in the separation of particular species from complex matrices. This basic research concerns both physics and chemistry, and is expected to lead to greatly improved capabilities to elucidate and measure such geophysical processes as acid rain, oxidant formation, stratospheric ozone destruction, and alterations causing climate change.

CLIMATE DYNAMICS

The CIRES climate dynamics program is concerned broadly with achieving a better understanding of the Earth's climate system, its physical basis, and the sources of its variability. Quantitative description of the system involves the use of surface, airborne, and satellite observations. Present efforts are concentrated principally on the oceans and ice and snow cover, on synoptic (short-term, regional) as well as global paleoclimatic scales.

The emphases of the climate program reflect the global modeling of climate strongly represented at the National Center for Atmospheric Research (NCAR) and certain aspects of climate monitoring in the NOAA-ERL Global Monitoring for Climatic Change Program. However, the CIRES program as a whole has several distinctive features:

- Orientation toward the real world rather than one created by models.
- Concentration on the more slowly acting/responding components of the climate system (ocean, ice, land/sea distribution).
- Interest in short-lived events and processes forcing and interacting with those components.

The program at present has six distinct elements:

Historical Data Set Construction

The aim is to combine all available digitized surface data since 1854 for the world ocean (more than 100 million observations) into a quality-controlled Comprehensive Ocean/Atmosphere Data Set (COADS). When completed in another year or so, the COADS, together with the existing records for the continents, will provide the international research community with its first global picture of surface climatic variations over the last 130 years. This work is being accomplished in cooperation with NOAA's National Climatic Data Center and NCAR.

Climate Analysis

The aim is to understand the structure and dynamics of global climate variations on the seasonal, interannual, and decadal time scales. Several closely related projects are contributing to the construction of a climatic reality for models to simulate, and for the testing of model results. The projects follow this research strategy:

(a) Delineate the dynamic behavior of the climate system as clearly as is possible from existing data by diagnostic analysis. Major emphasis is placed on the surface geophysical fields for the period since 1854.

(b) Formulate conceptual models to explain the climate behavior delineated by the diagnostic analysis.

(c) Test and refine the conceptual models by diagnostic analysis, mathematical simulation models, and observational studies.

CIRES collaborates with AOML, PMEL, and ARL in field observational studies such as Equatorial Pacific Ocean Climate Studies and Subtropical Atlantic Climate Studies. The CIRES work emphasizes data set processing and diagnostic analysis for the global ocean and atmosphere.

Ice Sheet Modeling

Ice sheet modeling simulates the dynamics of large sheets in order to evaluate their natural variability and their potential responses to anthropogenic changes in the environment.

In cooperation with Australian glaciologists of the University of Melbourne and the cryosphere-climate group in CIRES, the ice-sheet group has prepared a detailed physical description of the Greenland ice sheet and plans to refine the existing description of Antarctica. The dynamic state of major ice streams in Greenland and Antarctica is being investigated with alternative assumptions for a key mechanism--the sliding of the ice on bedrock covered by a pressurized water layer.

This research finds its greatest scope in paleoclimatic reconstruction, but also derives timeliness and urgency from the widespread concern that a substantial and irreversible rise in sea level could result from CO_2-induced polar warming. The work has become part of the continuing international exploration of the polar ice sheets and involves intensive participation in national and international committees and working groups.

Cryosphere-Climate Interaction

This project has long-term objectives of evaluating the role of the global snow and ice cover (the cryosphere) and its variability in the climate system, and determining the response of the snow and ice to climate variations. A current project, funded by NSF and NASA, involves the study of surface-atmosphere interactions in the Arctic using satellite data on sea ice and cloudiness conditions. A DOE project is assessing the variability in lake freeze-up/break-up in relation to climatic factors, as a guide to possible CO_2-induced warming effects. Other cooperative projects involve reconstructions of Northern Hemisphere climate for 1851-1900 (with the University of Massachusetts and the University of East Anglia) and an analysis of alpine climate data for Niwot Ridge, Colo. (as part of the University of Colorado's Long-Term Ecological Research Program).

In another project, CIRES operates the World Data Center-A (WDC-A) for Glaciology (Snow and Ice) and the associated National Snow and Ice Data Center. Scientific guidance is provided by the Committee on Glaciology of the Polar Research Board (National Academy of Sciences) and an ad hoc Panel on Glaciological Data of the Polar Research Board and the Committee on Geophysical Data. Base funding is provided by the National Environmental Satellite, Data, and Information Service, NOAA; NOAA, NASA, DOE, and ONR provide additional contractual support. WDC-A maintains data archives on snow cover, sea ice, ice cores, ice sheet radio-echo soundings, and Great Lakes ice. It also has large collections of global satellite imagery, glacier photographs, and glaciological literature.

Air-Sea Interaction

The aim of this project is to expand understanding of certain aspects of the ocean role in global climatic variability by modeling the physics of large-scale atmosphere-ocean interaction processes.

The El Niño/Southern Oscillation sequence, including its dynamic and energetic causes, has become a major focus of effort. We are studying the effect of clouds in the atmospheric boundary layer on the heat storage in the upper ocean in the tropics and subtropics, and also the role of air-sea interaction in the formation and propagation of sea-surface temperature anomalies and in the transport of moisture toward the Equator. Model simulations have begun in cooperation with NCAR scientists. A secondary focus is provided by ongoing studies of heat transport and storage variations in the North Atlantic, using historical XBT data.

Paleoclimatology-Paleoceanography

The aim is to understand how past global climate has changed, and in particular to investigate how changes in continental runoff may have affected oceanographic conditions, especially vertical mixing and organic carbon sedimentation. Continental paleotopography is being reconstructed, and atmospheric circulation for different hypothetical continent configurations is being modeled with the Community Climate Model in collaboration with NCAR scientists.

ATMOSPHERIC DYNAMICS

Most of the CIRES atmospheric dynamics studies have been concentrated on atmospheric gravity wave motions and turbulence.

Flow and Transport in Complex Geometry

Research activities in one CIRES group have three main focuses: (1) small-scale atmospheric flows and transport over complex terrain, (2) computer-aided analysis of viscous flows and/or transport problems in engineering science, and (3) flow and stability problems associated with space manufacturing experiments. The first two are intimately connected and, in fact, the second is a spinoff from the first since the atmospheric flow models are non-hydrostatic;

the third has evolved through a collaboration with American and French groups in designing experiments to fly on the Shuttle.

The first study focuses on the development of a nonhydrostatic, Boussinesq algorithm for the numerical simulation of small-scale atmospheric flows over complex terrain, for environmental and energy-related studies ranging from pollutant transport and dispersal to siting studies for potential wind power applications. Galerkin finite-element techniques have been used to generate a robust algorithm capable of implementing non-uniform meshes and complicated boundary conditions.

The purpose of the second research activity is to improve current numerical algorithms and develop new algorithms for numerical simulation of incompressible flow in computer-aided design. These new algorithms are being applied to the study of physical instabilities; the study of free and/or moving surface problems that arise in film coating, electroplating, and many other industrial applications; and the study of the flow of stratified fluids in complex geometries.

The third research topic is a quantitative characterization of two effects that are related to the overall problem of space manufacturing: (1) the migration of a bubble, or drop, along a temperature and/or concentration gradient by means of gradients in interfacial tension; (2) the stability of cylindrical layers of fluid heated from below when Soret effects are large. This research is being coordinated with scientists at NASA Lewis Laboratory who are designing a bubble migration experiment for a Shuttle flight and with scientists in Lyon, France, who are designing a materials science experiment to measure Soret coefficients on a Shuttle flight.

Wave Dynamics

The modeling of the transport of atmospheric minor constituents is important to the understanding of chemical and dynamical changes that occur in the atmosphere. The coupling between chemistry and dynamics is crucial in transport studies. Therefore, a coupled model is being developed in collaboration with the NOAA Aeronomy Laboratory and NCAR. The model incorporates interactions between large-scale planetary waves, the mean atmospheric circulation, and atmospheric chemistry.

In a second study with the Aeronomy Laboratory, gravity wave and tidal momentum fluxes are being determined from data provided by the NOAA-operated high-powered Doppler radar at Poker Flat, Alaska. The calculations are important in determining the frictional drag in the upper atmosphere as well as in determining the origin of atmospheric turbulence.

The third wave dynamics study is an investigation of the feasibility of using a new signal processing technique (singular value decomposition) instead of the Fast Fourier Transform for determining the Doppler frequency of a return echo signal. Theoretically, the new technique is more accurate and can be implemented inexpensively on a microprocessor. Additionally, singular value decomposition is being used to extract tidal harmonics from a time series of wind data that covers only a fraction of a day. The important role of these new radars in dynamical studies and in operational forecasting is now being recognized.

SOLID EARTH GEOPHYSICS

Solid-earth geophysics continues to be one of the principal themes of CIRES research, although support for the program, is obtained predominantly from outside NOAA/ERL (USGS, NSF, NASA, DOD, etc.). Some of the CIRES research on geodesy is now supported by the National Geodetic Survey. The NOAA National Geophysical Data Center also provides support and an important point of interaction between CIRES and NOAA scientists.

The current program concerns theoretical studies, observational seismology, geodynamics (crustal deformation using modern geodetic techniques), and laboratory studies of rock failure and rock properties under high stresses. Observational seismology is directed to the investigation of dynamic Earth processes and Earth structure on the basis of the data from seismograms of earthquakes or other seismic sources.

Earthquake prediction research has provided a focus for much of the work in observational seismology in recent years; seismotectonic studies have offered a closely related second focus. In the search for approaches to earthquake prediction we have studied seismicity patterns, focal mechanisms, seismic wave velocities, crustal deformations, average magnitudes of earthquake sets, stress drops, magnetic field variations, wave attenuation, and the chemistry of soil gas. We have shown that some of these observables have changed before past major earthquakes.

The geodynamics program has used a variety of modern techniques to investigate local and regional deformation of the the crust. Recently, the National Geodetic Survey (NGS) entered into a cooperative agreement with CIRES, under which geodynamics research through modern geodetic techniques should flourish. The NGS agreed to share the funding of a faculty position through the Physics Department and CIRES, and that faculty member was hired and began work in 1983. Current CIRES research topics of importance to NGS include two- and three-color laser electronic distance measurement instruments, and Earth rotation parameters, including nutations, body and ocean tides, and changes in the length of the day.

Research directed to understanding local and regional crustal deformation is based on high-precision measurements of the changes in the length of lines several kilometers long; temporal changes in the Earth's gravity field; analysis of satellite-derived geoid anomalies, especially that of the Indian Ocean, and their implications for crust and upper mantle dynamics and properties; monitoring of tilts of the crust; and the development and use of NASA-sponsored extraterrestrial geodetic techniques, based on laser ranging to satellites and radio interferometric observations of natural or artificial radio sources in space. Other work in geodynamics includes studies of tectonic processes by monitoring random and magnetotelluric signals.

The present efforts of the rock physics group are directed toward gaining better understanding of the dependence of rock deformation and fracture on time and ambient conditions. This work is motivated by the desire to elucidate such diverse phenomena as the evolution of planetary crusts, earthquake mechanisms and precursors, and problems associated with the disposal of hazardous waste materials.

JIMAR

The Joint Institute for Marine and Atmospheric Research (JIMAR) is located at the University of Hawaii. JIMAR was formed in FY 1978 in association with the University and PMEL. The principal research interests of JIMAR are climate, equatorial oceanography, and tsunamis.

Accomplishments FY 1983

CLIMATE RESEARCH

Studies to develop a climatology of cirrus surge duration were expanded to include the period 1976-1981. The finding that most surges were apparently triggered by passing 500-mb troughs links cirrus surges and mainland tornadic outbreaks.

Regression analysis demonstrated that Hawaiian winter rainfall appears to be related to the Southern Oscillation Index in January and February but not in December. This is probably because the large-scale upper tropospheric circulation over Asia and the Pacific undergoes a seasonal change between early and late winter. Thus the model of Horel and Wallace might be applicable only in late winter.

Analysis of SAWINs (satellite winds) and the climatic shear-derived surface winds continued, and the various associated trade wind indices were maintained. The averaging period was shortened (from one month to one-half month) and the space resolution (from 5° to 2½°) was improved. By merging mean resultant ship winds in the western Pacific with the SAWIN fields, the analyses were extended across the whole tropical Pacific.

Historical sea-surface temperature and pressure data for the area east of the Phillipines (10°-20°N; 130°-150°E) were analyzed. The existence of a 1.3°C spurious diurnal temperature rise stemming from local ship heating was confirmed. It was found that in the deep tropics cold, relatively dry downdrafts do not significantly enhance sensible and latent heat losses from the ocean surface.

The convergence zone over the central and eastern Pacific during the FGGE (First GARP Global Experiment) was described. After satellite pictures were used to stratify the convergence zone by intensity, the climatological structure along meridional and vertical axes was defined using omegasonde data. Standard deviations within each class were surprisingly small.

EQUATORIAL OCEANOGRAPHY

On 11 July 1983 R/V Machias returned to Honolulu, marking the end of the data collection phase of the Line Islands Profiling component of PEQUOD (Pacific Equatorial Ocean Dynamics). Machias had been away from Honolulu since 19 February 1982 and in that time had made 21 cruises from Fanning Island, collecting 529 profiles of velocity and temperature from ocean surface to bottom.

The strong and unusual El Niño event that began in summer 1982 and continued throughout the project greatly increased the value of the data. This is the first time that currents in the equatorial band have been measured regularly during the onset and maturity of an El Niño.

Pacific sea level data were used to study the annual and interannual variability of the energy levels of equatorial 30-day wave oscillations. The energy level of the 30-day oscillations in the central Pacific seems to be strongly correlated with the Southern Oscillation Index. The FGGE Tahiti Shuttle data were used to estimate the absolute and potential vorticity distributions for the Undercurrent.

PEQUOD data were used to begin studying the 1982-1983 El Niño event. Sea level and sea-surface temperature (SST) measurements at Jarvis Island, along with meteorological and SST observations from the Machias, give some insight into the evolution of El Niño. SST at Jarvis began to rise at the rate of 5°C per year in January 1982. This increase in SST extended at least over the latitude band from 3 degrees south to 3 degrees north. The rise in sea level at Jarvis associated with the El Niño did not occur until July 1982. Anomalous winds and convective activity in the Line Islands were not observed until September 1982. This sequence of events clearly indicates that remote forcing plays a major role during the onset of El Niño.

Studies of equatorial Kelvin wave beams continued, and a study of the structure of dispersive Rossby waves was initiated. Data analyses were pursued to assess the role of Kelvin waves in the advection of SST anomalies, and to determine how well Kelvin waves can be detected in island and coastal sea level data.

TSUNAMI RESEARCH

Hurricane Iwa was used as a realistic opportunity to exercise our post-event monitoring capability. Navy and Civil Air Patrol aircraft made photo reconnaissance flights over the areas of Oahu and Kauai that were most affected by storm waves. Data were also obtained by questionnaire and interviews, and used as input to several reports on the hurricane. Evidence of an unusual storm surge, akin to a tsunami in several respects, was found on the west coast of Oahu.

An infrared photography capability was added to the survey procedure. Results of several trial exercises involving both aircraft and ground photo-observers were generally satisfactory. An additional monitoring site was established on Hawaii.

The large (6-in outer diameter) digital tsunami gage suitable for testing in a wave tank was nearly completed. This version has oversized batteries and plug-in circuit boards for ready experimentation. It incorporates both hydraulic and electronic low pass filters, and can be operated at 1- or 8-s sampling rates. A smaller (3-in) field test prototype is 80% complete. This model is intended to be deployed near shore. It will fast-sample to sense swell, or slow-sample to measure the tide, as examples of a wave analogous to a tsunami. Wave data from both gages are recorded on strip charts and may also be analyzed directly on a computer.

Plans FY 1984

CLIMATE RESEARCH

Investigations of the structure of the eastern Pacific near-equatorial convergence zone and of tropical Pacific cirrus surges will be combined to study meteorological interactions between tropical and middle latitudes. It is hoped, thereby, to determine whether deep-amplitude middle-latitude troughs trigger surges, whether an active convergence zone is a necessary condition for surge generation, and whether the tropics initiate poleward energy flux or merely constitute a passive reservoir responding to extratropical forcing.

The relationships of wintertime monthly rainfall over Hawaii to 200-mb heights and to the Southern Oscillation Index undergo a seasonal variation. Explanations will be sought in the context of teleconnections and the Southern Oscillation. Secular changes in the relationships for the period 1950-1972 will also be investigated.

Investigations of the expanded marine data deck will focus on the problems associated with surface heat exchange and atmospheric circulation in trying to identify small areas with unequivocal climate change signals.

The PEQUOD and NORPAX (North Pacific Experiment) Shuttle data will be compared in detail. Special attention will be given to the structure and evolution of deep equatorial jets. This should be especially interesting because the 1982-83 El Niño event was so clearly evident in the PEQUOD data.

The detection of Kelvin waves by sea level data will be further examined as will the role of Kelvin waves in the advection of SST anomalies.

The effect of coastal geometry on equatorial waves in the Indian Ocean will be studied.

A model of interannual variability of the tropical Atlantic will be developed.

TSUNAMI RESEARCH

We will continue to maintain and upgrade JIMAR's tsunami-monitoring capability. The prototype tsunami gage will be completed and tested. An initial production of 12 gages will begin. A strategy for deploying these gages in case of a pending tsunami will be developed. We will also cooperate in developing the new THRUST (Tsunami Hazard Reduction Utilizing System Technology) program of NOAA and the Agency for International Development.

A model for local tsunami effects in the Hawaiian Island chain will be developed. We hope that the same model will be useful for studying local storm surges of the type generated by Hurricane Iwa. We will also continue to be involved in the University of Hawaii Natural Hazards Group, which was started last year.

JISAO

The Joint Institute for Study of the Atmosphere and Ocean (JISAO) was formed in FY 1977 with the University of Washington. The main areas of emphasis within JISAO continue to be climate dynamics, estuarine processes, and environmental chemistry.

Accomplishments FY 1983

Research in climate dynamics involved a variety of activities and topics: descriptive studies of the remarkable 1982-83 El Niño event; participation in the FOCAL (Français Océan et Climat dans l'Atlantique équatoriaL) and SEQUAL (Seasonal Equatorial Atlantic experiment) programs designed to study the seasonal variability of subsurface temperature, currents, and heat content in the equatorial Atlantic; theory of the vertical propagation of equatorially trapped waves forced by low-frequency fluctuations in surface wind stress; the design of observing networks for monitoring currents and thermal structure in the upper layers of the ocean; analysis of data on finestructure within the equatorial thermocline in relation to the vertical exchange of heat and momentum; and experiments with a simple numerical model designed to simulate recurrent atmospheric circulation regimes.

JISAO sponsored, fully or in part, visits by 41 scientists, 15 of whom were from foreign countries. Seminars included 26 on climate-related topics, 13 on environmental chemistry and 1 on estuaries. In addition, three long-term visiting scientists carried out research on climate-related topics.

Plans FY 1984

JISAO scientists will be actively involved in the analysis of an extensive set of marine surface observations, which has been reformatted by scientists at ERL's Cooperative Institute for Research in Environmental Sciences (CIRES) in Boulder. Emphasis will be placed upon the record of past El Niño events and upon interdecadal climatic trends observed during the past century. Present oceanographic research will continue, and another project on atmospheric dynamics will begin with the arrival of a new Postdoctoral Fellow in January. The environmental chemistry project on the absorption of metals and metalloids onto oxides in natural systems is expected to begin. Active visitor programs are planned in both climate dynamics and environmental chemistry.

APPENDIX: Acronyms and Abbreviations

ACURATE	Atlantic Coastal Unique Regional Atmospheric Tracer Experiment
AFOS	Automated Field Observing System
AGASP	Arctic Gas and Aerosol Sampling Program
AGL	above ground level
AL	Aeronomy Laboratory (ERL)
ALERT	Automated Local Evaluation in Real Time
ALPEX	Alpine Experiment
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
ARL	Air Resources Laboratory (ERL)
ASASP	Active Scattering Aerosol Spectrometer Probe
ASCOT	Atmospheric Studies in Complex Terrain (DOE)
ASDL	Aircraft to Satellite Data Link
ATDD	Atmospheric Turbulence and Diffusion Division (ARL)
ATOLL	Analysis of the Tropical Ocean Lower Layer
AWDS	Automated Weather Distribution System (NWS)
AWIPS-90	Advanced Weather Interactive Processing System for the 1990's.
AWS	Air Weather Service (USAF)
AXBT	airborne expendable bathythermograph
BAO	Boulder Atmospheric Observatory (ERL)
BaP	benzo(a)pyrene
BAPMoN	Background Air Pollution Monitoring Network
BL	boundary layer
CAC	Climate Analysis Center (NMC)
CAMS	control and monitoring system
CAPTEX	Cross-Appalachian Tracer Experiment
CARCAH	Chief, Aerial Reconnaissance Coordination, All Hurricanes
CAT	clear-air turbulence
CDD	cooling degree days
CG	cloud to ground
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CISK	Convective Instability of the Second Kind
COADS	Comprehensive Ocean/Atmosphere Data Set
CODAR	Coastal Ocean Dynamics Applications Radar
COP	carbon, oxygen, phosphorus
cpd	cycles per day
CRP	Climate Research Project (ERL/ESG)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSU	Colorado State University
CTD	conductivity, temperature, depth
DIAL	differential absorption lidar
DMS	dimethyl sulfide
DNA	Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
DRASER	Doppler Radar And Storm Electricity Research (NSSL)
DSET	Desert Sunshine Exposure Test

ECC	electrochemical concentration cell
ECMWF	European Center for Medium-range Weather Forecasting
ELF	extremely low frequency
ENAMAP	Eastern North American Model Air Pollution
ENSO	El Niño/Southern Oscillation
EOF	empirical orthogonal function
EPA	Environmental Protection Agency
EPOCS	Equatorial Pacific Ocean Climate Studies
ERL	Environmental Research Laboratories (NOAA)
ESG	Environmental Sciences Group (ERL)
FAA	Federal Aviation Administration
FGGE	First GARP Global Experiment
FOCAL	Francais Océan et Climat dans l'Atlantique équatoriaL
GARP	Global Atmospheric Research Program
GCM	general circulation model
GFDL	Geophysical Fluid Dynamics Laboratory (ERL)
GLERL	Great Lakes Environmental Research Laboratory (ERL)
GMCC	Geophysical Monitoring for Climatic Change (ARL)
GOES	Geostationary Operational Environmental Satellite
HDD	heating degree days
HEPAD	High Energy Proton and Alpha Detector
HF	high frequency
HRC	highly reflective clouds
IAMAP	International Association of Meteorology and Atmospheric Physics
IFFA	Interactive Flash Flood Analysis
IG	intermediate geostrophic
IMP	Interplanetary Monitoring Probe
INSAT	Indian Satellite
ISEE	International Sun-Earth Explorer
IUGG	International Union of Geodesy and Geophysics
JAWS	Joint Airport Weather Studies
JIMAR	Joint Institute for Marine and Atmospheric Research
JISAO	Joint Institute for Study of the Atmosphere and Ocean
JSPO	Joint System Program Office (NEXRAD)
LLNL	Lawrence Livermore National Laboratory
MAG	Mesoscale Applications Group (ESG/WRP)
MAPS	Multiple Aircraft Position System (NCAR)
McIDAS	Man-computer Interactive Data Access System
MCS	mesoscale convective system
MERIT	Minimum Energy Routes using Interactive Techniques (NASA)
METREX	Metropolitan Tracer Experiment
MHD	magnetohydrodynamic
MIZEX	Marginal Ice Zone Experiment
MRG	Mesoscale Research Group (ESG/WRP)
MSFC	Marshall Space Flight Center (NASA)
MST	mesosphere-stratosphere-troposphere

NADAP	National Atmospheric Deposition Assessment Program
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center (NESDIS)
NCPO	National Climate Program Office (NWS)
NDBC	NOAA Data Buoy Center
NECZ	near-equatorial convergence zone
NEPRF	Naval Environmental Prediction Research Facility
NEROS	Northeast Regional Oxidation Study
NESDIS	National Environmental Satellite, Data, and Information Service (NOAA)
NEXRAD	Next-generation Radar
NHC	National Hurricane Center (NWS)
NMC	National Meteorological Center (NWS)
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Navy Operational Global Atmospheric Prediction System
NOMAD	Navy Oceanographic Meteorological Automatic Device
NORPAX	North Pacific Experiment
NOS	National Ocean Service (NOAA)
NOVA	NOAA Operational VAS Assessment
NRC	Nuclear Regulatory Commission
NSBF	National Scientific Balloon Facility (NSF)
NSSL	National Severe Storms Laboratory (ERL)
NTIS	National Technical Information Service
NWP	numerical weather prediction
NWS	National Weather Service
OAO	Office of Aircraft Operations (NOAA)
OCSEAP	Outer Continental Shelf Environmental Assessment Program (NOAA)
ODW	Omega dropwindsonde
ORNL	Oak Ridge National Laboratory
OU	University of Oklahoma
OWRM	Office of Weather Research and Modification (ERL)
PACE	Precipitation Augmentation for Crops Experiment
PBL	planetary boundary layer
PCA	polar cap absorption
PEQUOD	Pacific Equatorial Ocean Dynamics
PMEL	Pacific Marine Environmental Laboratory (ERL)
POLYMODE	Polygon--Mid-Ocean Dynamics Experiment
PPI	plan position indicator
P-PRIME	Pollutant-Particle Relationships In the Marine Environment
PROFS	Program for Regional Observing and Forecasting Services (ERL/ESG)
QSTING	quasi-spectral time integration on nested grids
RDSS	Research Data Support System
RFC	Research Facilities Center (ERL)
ROM	Regional Oxidant Model
RRSD	research rapid-scan data
RSMAS	Rosenstiel School of Marine and Atmospheric Science (U. of Miami)
RTDS	Real-Time Data Services (SEL)

SANBAR	Sander's barotropic (model)
SAO	semiannual oscillation
SBUV	solar backscatter ultraviolet
SEFC	Southeast Fisheries Center (NMFS)
SEL	Space Environment Laboratory (ERL)
SELDADS	SEL Data Acquisition And Display System
SEM	Space Environment Monitor
SEQUAL	Seasonal EQUatorial AtLantic (experiment)
SERI	Solar Energy Research Institute
SESAME	Severe Environmental Storms And Mesoscale Experiment
SESC	Space Environment Services Center (SEL)
SFMR	stepped-frequency microwave radiometer
SIO	Scripps Institution of Oceanography
SLAR	side-looking airborne radar
SLOSH	sea-lake-overland surges from hurricanes
SME	Solar Mesosphere Explorer
SMMR	scanning multi-channel microwave radiometer
SOON	Solar-Observing Optical Network
SST	sea surface temperature
ST	stratosphere-troposphere
STACS	SubTropical Atlantic Climate Studies
STJ	subtropical jet
STORM	STormscale Operational and Research Meteorology
TAG	Trans-Atlantic Geotraverse
TAP	Transformation and Assimilation of Pollutants [by Natural Processes]
TESS	twin etalon scanning spectrometer
THRUST	Tsunami Hazard Reduction Using System Technology
TIROS	Television and Infrared Observation Satellite
TOGA	Tropical Oceans and Global Atmosphere
TVA	Tennessee Valley Authority
UHF	ultrahigh frequency
UNAMAP	User's Network for Applied Modeling of Air Pollution
USAF	U.S. Air Force
USGS	U.S. Geological Survey
UV	ultraviolet
VAD	velocity-azimuth display
VAS	VISSR Atmospheric Sounder
VED	velocity-elevation display
VHF	very high frequency
VISSR	Visible Infrared Spin Scan Radiometer
VLF	very low frequency
WMO	World Meteorological Organization
WMP	Weather Modification Program (ERL/ESG)
WMPO	Weather Modification Program Office (ERL)
WOCE	World Ocean Circulation Experiment
WPL	Wave Propagation Laboratory (ERL)
WRP	Weather Research Program (ERL/ESG)
WSFO	Weather Service Forecast Office
WSR	Weather Surveillance Radar
XBT	expendable bathythermograph

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