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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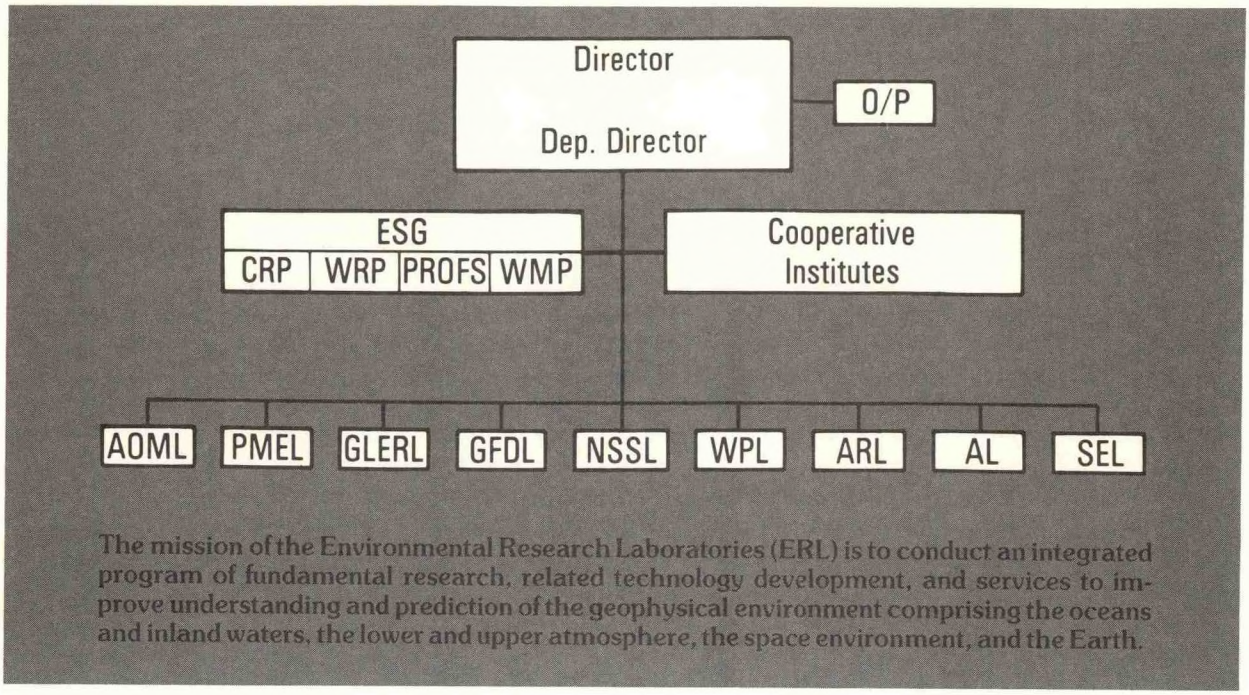


The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, 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, results, and plans may be found in the Laboratories' annual reports (which may be obtained directly from the Laboratories) and in the open literature. Interested readers are referred to the annual Environmental Research Laboratories Publication Abstracts.

ENVIRONMENTAL RESEARCH LABORATORIES

The Environmental Research Laboratories (ERL) are organized within NOAA's 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.

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, marine, and space research communities, NOAA service components (National Weather Service, National Ocean Service), Federal, State, and local governments, and the private sector.

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

Weather observation and prediction
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.

Observational Systems

A research facility used in several 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.

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 in clear air 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, and are research prototypes for the Profiler system being developed, to replace the radiosonde wind-profiling capability. Microwave radiometer devices for vertical sensing of water vapor and liquid water are also part of the PROFS Colorado network and are research prototypes for the Profiler system, to replace the radiosonde temperature and humidity profiling capability.

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 the National Weather Service), 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-air (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 the 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 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 and optical 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.

Cloud Physics Research and Technology Development

NOAA conducts cloud physics research 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.

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.

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. System design incorporates many of the advances mad 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.

AIR QUALITY RESEARCH AND 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 Laboratory (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 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 improving our understanding of the chemistry of NO_3, required for interpreting 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 if nitrogen oxide and nitrogen dioxide have been 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 measuring pre-acidic material transported across 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 in progress or completed 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 results of these field programs are being used 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 goals 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 are being 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 between 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 Research and Services, 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 as part of the international Tropical Oceans Global Atmosphere (TOGA) program. 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 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 has been on developing 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; construction of a global data set describing climate variations over the past 150 years; 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 ERL's 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 AND 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 maintains 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 space environment monitors on the Geostationary Operational Environmental Satellites (GOES) and the polar-orbiting TIROS-N and NOAA satellites. SESC, jointly operated with the United States Air Force 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 homeowners, recreational boaters, and oil and gas industry, fishing, and commercial transportation. 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 being 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 is considering 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. Improving forecasts and warnings requires 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. Information obtained is being 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 RESOURCES RESEARCH AND 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 topics 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 my 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 are determining 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 is examining 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 is 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 ASSESSMENT RESEARCH AND 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.

Marine Environmental Research

Marine environmental research is directed toward managing and protecting 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.

Submarine Hydrothermal Venting Systems

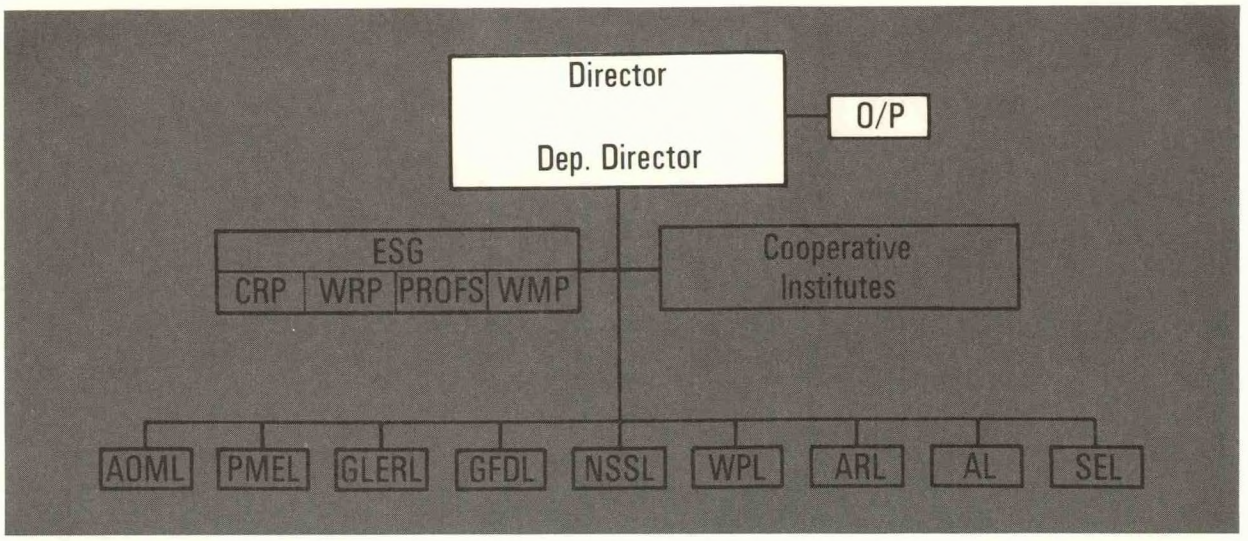
ERL has recently increased its research on submarine hydrothermal venting systems at seafloor spreading centers in response to the growing recognition of the environmental importance of the hydrothermal fluids. Certainly, factors such as possible economic importance of mineralized deposits have generated much of the recent interest in processes at seafloor spreading centers. However, the basic lack of understanding of the average environmental role of the hydrothermal fluids is the focus of ERL's research. Consequently, ERL's program is designed to assess the importance of hydrothermal fluids in altering the physical, chemical, biological, and geological characteristics of the marine environment into which the fluids are introduced.

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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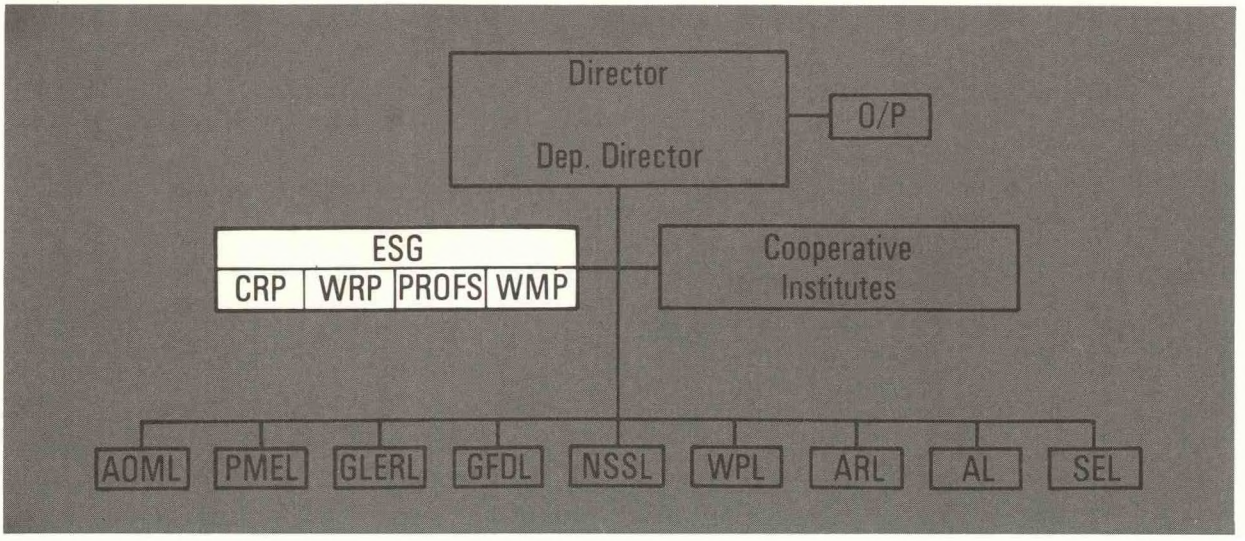
ENVIRONMENTAL SCIENCES GROUP
Boulder, Colorado

William H. Hooke
Acting Director



The Environmental Sciences Group (ESG) plans, conducts and coordinates well-defined, high-priority programs of environmental research and technology development, which frequently require an intensive, concerted, or inter-laboratory approach for success. Research findings and technological advances are actively transferred to other NOAA line offices and the national user community.

ESG
CRP

ESG currently includes the Climate Research Program (CRP), the Program for Regional Observing and Forecasting Services (PROFS), the Weather Modification Program (WMP) and the Weather Research Program (WRP). Ongoing research and development activities are directed toward understanding climate, precipitation, and convective weather processes; developing and evaluating advanced environmental monitoring, forecasting, and modification technologies; and building environmental data bases for use by the scientific community. ESG works with the cooperative institutes and other outside organizations to meet these responsibilities.

CLIMATE RESEARCH PROGRAM

The Climate Research Program (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 weeks to decades.
- Construction of computer models of polar ice sheets to ascertain their development and their responses to climatic change.

The research program represents a joint enterprise with the Cooperative Institute for Research in Environmental Sciences (CIRES) of the University of Colorado. CIRES enables NOAA and university scientists to collaborate on problems of mutual interest, improves NOAA's links with the university community, and facilities the participation of visiting scientists.

Accomplishments FY 1984

CLIMATE RECORD CONSTRUCTION

Marine Data Base

All but one of 19 products from the Comprehensive Ocean-Atmosphere Data Set (COADS) have now been completed for the period 1854-1979, in continued cooperation with the National Center for Atmospheric Research (NCAR) and the National Climatic Data Center (NCDC). Roughly 100 million global marine reports, observed primarily by "ships-of-opportunity", were collected, edited, and summarized statistically for each month of the period, using 2° latitude x 2° longitude boxes. Sets of 2° monthly summaries and individual reports with outliers trimmed by a statistical process, refined from the relatively noisy "untrimmed" summaries and reports completed last year, are now available at NCAR.

The trimmed 2° monthly summaries give 14 statistics for each of 19 observed and derived variables. The observed variables are air and sea surface temperatures, wind, pressure, humidity, and cloudiness. The derived variables are sea-air temperature difference, evaporation, wind stress, sensible and latent heat fluxes, etc. The statistics include the median, mean, number of observations, standard deviation, and centroids of observational location in time and space. Investigators who wish to use data in the form of individual reports have access to additional elements such as sea state or present weather. Decade-month summaries, inventories, and trimming performance data are among the other products now available for distribution by NCAR or NCDC.

Highly Reflective Clouds

The Highly Reflective Cloud (HRC) data set continued to be updated during FY 1984. An atlas of monthly HRC frequencies for the global tropics is scheduled for publication in December 1984. A software package that permits convenient extraction of HRC data for user-defined time and space parameters has been developed. HRC data are being calibrated with the GOES Precipitation Index, an independent satellite-based rainfall estimation scheme developed at NOAA's Climate Analysis Center.

Northern Hemisphere Land Data Base

The most extensive collection of long-term station temperature and precipitation data for Northern Hemisphere land areas has been compiled under a Department of Energy grant. A 5° x 10° latitude-longitude grid from 5°N to 85°N has been constructed from these data for the period 1851-1983. An atlas

of Northern Hemisphere temperature anomalies by season, year, pentads, and decades is being produced. This work has been done jointly by CRP, the University of Massachusetts, and the University of East Anglia (U.K.).

DIAGNOSTIC STUDIES OF CLIMATIC FLUCTUATIONS

El Niño/Southern Oscillation (ENSO) Events

Data from COADS have been used in detailed studies of the evolution of ENSO events over the past 50 years. The aim has been to delineate the differences and similarities of the nine separate events on record for the purpose of classifying their common features as an aid in future prediction.

Seasonal differences in the winter and spring weather over the United States and China associated with separate ENSO events are being studied to ascertain if these are consistently related to the ENSO.

Analysis of the 1983 El Niño research flight data was completed and an article was submitted for publication. Evidence was found of a moistening and destabilization of the lower troposphere over the eastern Pacific accompanying the increase of sea surface temperatures. Episodes of intense convection occurred relatively soon thereafter, in conjunction with the arrival of surface westerlies.

Studies of Monsoon Changes

Studies of the spatial and temporal variability of the structure of the Indian monsoon focused on the differences between organized convection over the subcontinent and that over the Indian Ocean. Considerable convective activity is found to occur offshore, a finding that contributes to the development of modeling experiments of the Asian monsoon system.

CRP

DIAGNOSTIC STUDIES OF SYNOPTIC ASPECTS OF CLIMATE

Variability of Convective Activity-Global Tropics

Regional indices of convective activity in the tropics have been analyzed. The indices, composed of 5-day mean HRC data for 1981-83, show an eastward progression of the active areas of convection from the Indian Ocean to South America with a concomitant decrease in convection over areas to the west. The eastward displacement of convection from western to eastern Pacific occurred in discrete jumps associated with synoptic-scale events. Possible precursors to these events are being looked for in changes of the Southern Hemisphere jet stream and subtropical high pressure belt.

Similar indices for the region encompassing South America indicate that the intense drought in northeast Brazil during 1982-83 was a regional phenomenon, since the rest of tropical South America had normal or above normal convection.

Influence of Synoptic-Scale Systems on ENSO Development

Analysis of daily surface charts revealed the development of equatorial westerly wind/convection episodes (WWCE) during the onset and mature phases of El Niño. THese organized atmospheric circulation systems had spatial scales on the order of 2000-3000 km and lasted typically for several weeks.

The WWCE's are a common feature of the climatology of the western equatorial Pacific. During the 1982-83 ENSO, WWCE's propagated eastward toward the South American coast, finally reaching the coast in the spring of 1983.

Analysis of Satellite Sounding Data in Connection with ENSO

Data from the TIROS Operational Vertical Sounder (TOVS) for the Pacific region for 1982-83 have been analyzed in conjunction with other meteorological parameters. Preliminary results indicate that TOVS data can be useful in defining fields of atmospheric moisture and stability associated with synoptic-scale systems.

Tropical-Extratropical Teleconnections

Synoptic-scale aspects of the teleconnection between the tropics and middle latitudes have been studied in an NSF-funded project. Analysis of upper-level winds and satellite imagery has revealed a common sequence of synoptic-scale events linking transient convective outbreaks in the tropical Pacific, disturbances on the subtropical jet, and cyclones over North America. This synoptic sequence occurred repeatedly during the 1982-83 "El Niño" winter season, and may be a factor in the storm climatology of the United States.

ICE SHEET MODELING

A joint project with the University of Melbourne, Australia, exploring the possibility that enhanced CO_2 concentrations would lead to accelerated flow ("surges") from the polar ice sheets, got under way with DOE funding at the beginning of 1984. As a basis for modeling, the complete physical characteristics of the Ross Ice Shelf drainage basin have been established on the assumption of steady state ("zero net mass balance"). The resulting ice flow velocities have been used for a parameterization of basal sliding, which will be tested with measurements now being made on one ice stream in a NASA-NSF project. The only existing model for self-induced surging of glaciers has been used to determine changes in temperatures and accumulation that could get the ice stream into a surging mode.

MISCELLANEOUS PROJECTS

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

Boundary layer studies of the marine atmosphere in progress for the past couple of years were continued. A new sampling technique has been developed and used to investigate the statistics of updraft and downdraft events. The analysis has provided information on event size and number, as well as the

conditional averages of the meteorological variables and flux contributions. The results provide new insights into the processes that transport heat, moisture, and momentum on scales ranging from 10 m to a few kilometers. The ultimate goal is to develop a parameterization of these transports in the subcloud and cloud layers, based on large-scale data obtained from remote-sensing platforms, such as satellites.

These results are important for understanding the modifications to air-sea transfers due to large SST anomalies associated with ENSO.

Analysis of Climatic Variability, Population Increases, and Water Supplies in the Western United States

The climate of the western United States tends to alternate between wet and dry regimes. Over the past 25 years, population in the region and water consumption have doubled. Although great steps have been taken to prepare for drought-induced water shortages through greatly expanded reservoir capacity, the greater demand and projections for yet larger increases have also raised the region's sensitivity to drought. On the other hand, the filling of the reservoirs in the western states has increased the danger from flooding due to prolonged periods of above-normal precipitation, particularly during spring runoff.

Studies are under way to delineate the temporal and spatial characteristics of historical wet and dry periods in the Colorado River and Great Salt Lake Basins, to aid in the development of strategies to mitigate future climate-related disruptions of water supplies in this region.

Plans FY 1985

CLIMATE RECORD CONSTRUCTION

CRP

Marine Data Base

Subject to funding approval, work is planned to update the Comprehensive Ocean-Atmosphere Data Set (COADS), including quasi-real-time monitoring of climatic indices; refine some products for ease of use; and explore aspects of data reliability using high-quality or high-density COADS subsets.

The first COADS release covers the period from 1854 to 1979. A second release is planned, which will expand the data set to include the years 1980-84. Individual reports for 1980-82 will be available after the first year of work. The completed database will include as many logbook or Global Telecommunication System (GTS) reports as are available, and will be produced according to standard COADS specifications. In parallel, a purely GTS-based data set will be assembled and analyzed in quasi-real-time, with emphasis on providing a monthly set of climatic indices.

Although they were designed with the goal of achieving relatively compact size together with ease-of-use on a variety of computers, the COADS 2° monthly summary products will need further format refinement before they are economical for routine analysis. The fine space (2° latitude x 2° longitude)

and time (monthly) resolution requires that a special format be perfected. This will be a packed-binary format with special compression of land areas or missing data, designed to present a relatively simple Fortran-user viewpoint of the storage details.

COADS is the most extensive marine data base now available for studies of the boundary between the ocean and the atmosphere. But problems, limitations, and inhomogeneities in the input data have in many cases not been corrected and are not yet fully recognized or understood. Examples are the change in measurement of sea surface temperature from bucket to intake, or diurnal effects on air temperature due to insolational heating of the ship's structure. A last phase of the planned work will study, over a 2-year period, some of these problems by using high-quality (ocean station vessel) or high-density (heavily traveled ship route) subsets.

Highly Reflective Clouds

Highly reflective cloud (HRC) data will continue to be updated for FY 1985. A comprehensive statistical analysis and evaluation of this data set will appear in the form of a user's guide to the HRC data set, as well as in a published article detailing the quantitative comparison of the HRC and GOES Precipitation Index. Other studies are planned, including an analysis of the long-term variability of tropical convection in both space and time.

DIAGNOSTIC STUDIES

ENSO Variability

The diagnostic work carried out in FY 1984 regarding ENSO classification will continue, and new parameters will be added to the list. Rainfall data from equatorial Pacific Island stations will be analyzed, as well as the changes in the sea level pressure field in the southwestern and central Pacific. The spatial and temporal variability of these fields during the ENSO cycle will be studied as an aid in ENSO prediction.

Analysis of Equatorial Westerly Wind/Convection Episodes (WWCE) During the 1982-83 ENSO

Analysis will continue on the fields of atmospheric moisture and stability, organized convection, surface and upper-level winds, and sea surface temperatures at different stages in the evolution of the WWCE's associated with the eastward shift of convection in the equatorial Pacific during the 1982-83 ENSO event. The aim of this research is to establish a synoptic model of the evolution of WWCE's and shed some light on the conditions that caused WWCE's to move farther east during the 1982-83 ENSO than in previous ENSO events. The search for possible precursors in the Southern Hemisphere circulation will be continued.

Tropical-Extratropical Teleconnections

Studies of the linkage between synoptic-scale events in the tropics and extratropics will continue and be completed during the second year of the

NSF-funded project. Occurrences of the synoptic sequence during ENSO vs. non-ENSO winters will be compared and contrasted in order to assess the role of this atmospheric process in the interannual variability of the climate of North America. The synoptic interactions associated with the strength of the general atmospheric circulation will be examined through diagnostic studies of the fluxes of westerly momentum in connection with tropical convective outbreaks and the exchange with the subtropical jet.

Diagnostic Interpretation of the Ocean Climate Record

Detailed regional analyses of SST and surface air temperature from COADS, as well as of the surface pressure and wind fields will be carried out in order to assess the reliability of the data as well as to estimate any corrections to be made. Work will be started to merge the ocean and land record in order to produce an integrated Northern Hemisphere record.

Analysis of Secular Climatic Fluctuations Over the Northern Hemisphere

The spatial and temporal variability of climatic change over the oceans and continents will be mapped. Emphasis will be placed on determining the zonal and meridional differences associated with different climatic regimes.

ENSO Monitoring

A set of climatic indices of ENSO development, based on statistical summary and analysis of near-real-time data will be produced. The data will be acquired from the Navy and Global Telecommunication System (GTS), by way of the National Meteorological Center, NOAA. Part of the development work for these indices will be to compile a set of verification statistics on each of them separately, and in combination. The aim is to develop a monitoring capability as near real-time as possible, in order to alert interested parties to the occurrence of anomalous weather conditions in the Pacific and Indian Oceans that may be precursors to an ENSO episode.

CRP

Other Studies of Climate Variability

A 3-year proposal to study long-term climatic fluctuations has been submitted to the U.S. Department of Energy jointly by the University of Massachusetts, the University of East Anglia (U.K.), and CRP. Its principal aim is to study a number of climatological problems related to the carbon dioxide question. These include an analysis of areal changes in precipitation and precipitation variability, with special attention to the Northern Hemisphere's grain-growing regions; relationships between precipitation and temperature variations interpreted in terms of atmospheric circulation changes; analysis of high-latitude climatic fluctuations, with a focus on surface and near-surface inversion climatology; and studies of regional climate variations and their relationship to large-scale hemispheric fluctuations.

ICE SHEET MODELING

The mass-balance descriptions of the Antarctica ice sheet will be extended to cover the whole of West Antarctica and some of the major drainage basins of East Antarctica. Improved parameterizations of basal sliding will be developed around models of basal drainage, taking into account new data for Columbia and Variegated Glaciers. A new model describing the dynamics and thermodynamics of a free-floating ice shelf will be programmed and tested.

WEATHER RESEARCH PROGRAM

The Weather Research Program (WRP) conducts research related to weather observation and prediction to increase the understanding of, and to improve prediction of, mesoscale weather systems. The genesis, evolution, and structure of convectively driven systems constitute the primary emphases of current WRP research. Attention is focused principally on moist convection over the United States; clouds ranging from individual thunderstorms to large mesoscale precipitation systems are under investigation. An important emphasis is on the transfer of results and potential techniques for predicting convection to the National Weather Service (NWS) and the national user community. Another major emphasis is on employing the NOAA research aircraft in mesoscale studies. Not only does WRP research contribute to long-range progress in furthering understanding of convective weather systems, but studies are also made that can be expected to have an early impact on forecasting of convection.

The three groups in WRP, Mesoscale Applications Group (MAG), Mesoscale Research Group (MRG), and Mesoscale Studies Group (MSG), all conduct applied and basic research on the following general subjects:

- Interactions between mesoscale processes, and both synoptic-scale circulations and cloud-scale processes as revealed by dynamical and thermodynamical analyses.

- The uses to which new remote-sensor data streams can be put to improve understanding and prediction of convectively driven weather systems.

- The spatial and temporal variations in convective and stratiform precipitation during the life cycle of mesoscale convective systems.

Accomplishments FY 1984

A 1-month project, called Airborne Investigations of Mesoscale Convective Systems (AIMCS) was conducted from 18 June to 18 July 1984 using the NOAA P-3 aircraft based in Denver. This project was designed to investigate large, slow-moving nocturnal mesoscale convective systems (MCS's) that develop over the High Plains. Convective systems of varying sizes were investigated and probed during the program. The goals were to collect data to investigate the internal structure of MCS's (particularly in the form of airborne Doppler radar), and to evaluate aircraft capabilities and the feasibility of flying such systems. Through the cooperation of the NWS, additional soundings were

taken on several nights at a number of NWS upper-air stations. In addition, the Regional And Mesoscale Meteorology (RAMM) Branch of NESDIS in Fort Collins collected special satellite data during the AIMCS program. An operational summary of this project is being prepared.

A five-year climatology of MCS's was completed and included in STORM (Storm-scale Operational and Research Meteorology) planning documents. Maps and other statistics were completed for 15-day periods for MCC's (Mesoscale Convective Complexes), beta- and alpha-scale cloud clusters, and convective lines. In addition, the ability to quickly diagnose infrared temperature characteristics of MCS's was automated using satellite data available from PROFS.

Two NWS Southern Region forecasters spent 4-month periods at WRP during FY 1984. They were here to pursue applied research activities related to mesoscale weather forecasting and analysis problems of significance to the Southern Region. These visits, made without their normal shift responsibilities and in coordination with researchers with longer-term goals of a similar nature, provided a unique opportunity to accomplish work that could not have been done effectively on station.

The climatology of cloud-to-ground lightning in north-central Colorado was developed for the summer of 1983. The study shows substantial agreement with a previous study of radar echo frequency in this region. Diurnal curves of lightning frequency were developed at NWS stations and at several mountain peaks and cities in this area. This study shows the advantage of lightning data in making large climatological studies with much less difficulty than with radar reflectivities. Furthermore, the data are much less complex to interpret and they identify the thunderstorms of interest to many users.

Research with data from the Kennedy Space Center (KSC) has been designed to improve forecasting of convection and associated lightning under light flow regimes in the summer. One study has been the development of a climatology of cloud-to-cloud lightning over the region surrounding KSC for the summer of 1983, including average diurnal curves at selected cities in the area. Another study used case days in the summer of 1983 to show how cloud-to-ground lightning relates to divergence and radar reflectivity in the KSC region, and how the information can be used in short-term thunderstorm forecasting at that facility.

A synoptic climatological study of importance to the Denver area was begun, in conjunction with staff of the Denver NWS forecast office, to examine conditions that produce blizzards and heavy snowfalls. In addition to having costly societal impacts along the populous Front Range, these storms are usually characterized by pronounced mesoscale variations in snow accumulation over eastern Colorado. Snowstorms of significance in the last 10 years are being examined for recurrent synoptic flows with the eventual intent of improving NWS forecasts of these critical storms. This project developed from a 3-month tour of duty to the Denver NWS office (as a shift forecaster) by a WRP staff member.

Integrated water vapor from the Denver profiler for the summers of 1982 and 1983 are being analyzed for diurnal variations. Vapor was found to decrease from 1800 MST through the nighttime hours to 1000 MST, then increase to 1800 MST on more than half the days. Results compared very well with

radiosonde-measured integrated water vapor. This diurnal pattern seems consistent with a mountain-plains daily circulation in the Denver area; however, several possible causative mechanisms are being considered.

The characteristics of dual MCC's that occurred on the night of 19-20 May 1979, as well as an MCS that traversed the SESAME area on 20 May 1979, were studied extensively with radar, mesonetwork, and upper-air data that have not been previously available in detail for such systems. The ratio of convective to stratiform precipitation, the internal circulations, environmental flows, and other features have been the main topics of investigation. Several results of these unique case studies had impacts on the operational strategies employed in the AIMCS program.

Research began into the nature of wind-field interpolation techniques based on the mathematical theory of vector point functions. It is increasingly clear that treating wind components as independent scalars for interpolation precludes proper diagnosis of the wind field, especially with respect to the all-important derivatives (i.e., divergence, vorticity, and deformation). Methods for dealing with this problem are being explored with a view toward developing practical and accurate algorithms as alternatives to current widely used approaches.

Patterns in the large-scale flow field conducive to MCC development have begun to be examined. As a first look at this massive data set, the 500-mb chart taken before the maximum extent of each MCC was examined and classified as to type of synoptic pattern. A large majority of the systems occurred with a quasi-stationary long-wave trough over the western United States and a flat ridge over the central states; MCC's developed within or just upwind from the ridge axis with westerly flow.

A technique using omega (vertical motion) diagnostics based on quasi-geostrophic theory of mass-momentum adjustments has been employed in several case studies. A strong correlation between the adjustment fields and the type of convective activity has become apparent. Also, significant departures from LFM (Limited Fine-Mesh) 700-mb vertical motion forecasts have been found. Experimental real-time computations of the Q-vector field during AIMCS were considered to be a useful supplement to other methods for analyzing areas of potential MCC development.

A new version of the Fritsch-Chappell parameterization code provided by scientists at Pennsylvania State University was incorporated into the two-dimensional WRP hydrostatic model, and simulations of idealized mesoscale convective systems were carried out. The 10-15 hour simulations successfully produces warming in the upper troposphere and associated large mesoscale circulation driven by the parameterized convective heating. However, the model failed to develop a convectively driven mesohigh near the surface. Further analysis has led to the conclusion that adequate simulation of the convectively driven mesohigh will require six to eight computational levels in the bottom 2 km of the hydrostatic model.

The treatment of the top boundary condition in fine-mesh mesoscale models is also under investigation. Preliminary indications point to the need for a boundary condition other than the one traditionally used in which the vertical motion vanishes at the top of the model, if model simulations are not to be contaminated by spurious downward reflection of gravity waves.

WRP staff taught at all five flash flood courses at the NWS Training Center in Kansas City during FY 1984, and also developed a series of teaching aids in response to student comments.

The preferred synoptic conditions under which dry microbursts occur have been identified using JAWS (Joint Airport Weather Studies) data from Denver in 1982, as well as from situations that resulted in recent aircraft accidents in the western states. Conditions that provide a favorable microburst environment consist of significant moisture (dew point depression of 6°C or less) near 500 mb. This moist layer fuels high-bases convection, which in conjunction with a nearly dry-adiabatic lapse rate from 700 to 500 mb, can produce localized, very strong downdrafts hazardous to aircraft takeoffs and landings. During the convective season, maps at 1200 GMT sometimes show large portions of the West to be covered by potentially favorable conditions for dry microbursts on that day.

Rainfall was estimated from satellite data for August 1979 over the central third of the United States in order to compare satellite-derived precipitation values with daily area-averaged rainfall from gauges in that region. On the average the unadjusted versions of the satellite techniques overestimated the rain when compared with the gauges, and the environmentally adjusted satellite rainfalls exceeded the gauge rainfalls by a factor of 2.0, but after adjustment the satellite rainfalls were 20% smaller than the gauge rainfalls; correlations for these rainfalls ranged from 0.6 to 0.7. On an hourly basis, the unadjusted satellite data overestimated by a factor of 2.2, the adjusted satellite rainfalls being 10% smaller than the gauge values. Correlation coefficients dropped to the range 0.5-0.6.

Situations in which significant severe weather outbreaks occurred within large-scale settings that were not typical of outbreak days were examined in two case studies by WRP in FY 1984, and a third early morning case study was started. These events represent a challenge to the longer term thunderstorm forecast system since they are not controlled by the evolution and movement of intense baroclinic weather systems.

A case study was begun of the Denver hailstorm of 13 June 1984, which caused the most devastating weather-related loss in the city's history in terms of insurance costs. Both standard and special data are being studied to document some of the features of this storm.

As the STORM-Central project's plans developed through FY 1984, WRP staff made major contributions on the NOAA level in meetings, documents, and interactions with agencies in project design, scientific goals, and research leading to the field program scheduled in the late 1980's.

Plans FY 1985

A project called O-K PRE-STORM (Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central) is planned to take place during May and June 1985. In cooperation with scientists from NSSL, the Hurricane Research Division of AOML, NCAR, and university groups, WRP will investigate MCS's from a base of operations in Oklahoma City. Both NOAA P-3 aircraft will be involved in the program, as well as special surface and upper-air networks,

additional ground-based Doppler radars, lightning detectors, and possibly profilers. Goals of the program are to investigate the evolution and structure of MCS's, and to test observational and operational strategies for the STORM-Central program's field phase.

Analyses of data collected during the AIMCS program in 1984 will proceed with a view toward improving forecasts and operations strategy in the 1985 O-K PRE-STORM program, and toward better understanding of the evolution and structure of MCS's that were observed during the program. Studies will use data from the P-3 platform, particularly from the Doppler radar, as well as upper-air soundings, ground-based conventional data, and special satellite information.

The climatology of 1983 MCC's will be completed and submitted for formal journal publication, and data for the 1984 summary will be compiled. During FY 1985, the automated analysis of infrared temperatures will be tested to complete this documentation more rapidly and objectively than in the past. This climatological data base will be used in a variety of research activities at WRP and elsewhere, especially in a detailed evaluation of several exploratory forecast efforts in an attempt to learn ways to improve NOAA field services.

Cloud-to-ground lightning data gathered over north-central Colorado will be stratified for the summer months to define the synoptic-scale conditions under which large numbers of flashes occur, compared with low-lightning days. In addition, the diurnal changes in the distribution of flashes over mountains and plains accompanying specific large-scale conditions will be analyzed for possible application to thunderstorm and lightning forecasting in mountainous areas.

Climatologies of lightning similar to the Colorado climatology will be developed for the Kennedy Space Center area in summer months for comparing changes in land-sea diurnal changes as a function of synoptic controls. The relations between radar echoes and lightning will be explored in order to identify better the types of reflectivity patterns producing cloud-to-ground flashes.

The snowstorm study for Colorado will continue to define the large-scale conditions under which heavy snowfall occurs at Denver, with a view toward real-time testing of the procedures during the winter at the Denver NWS. Further work, based on the results of the real-time testing, will define the pattern recognition techniques for applications during the winters of 1985/86; in addition, the study will be expanded to include heavy snow events that were confined to other population centers along the Front Range.

The strong diurnal cycle found in the Denver profiler water vapor data will be studied by considering the relations of winds and large-scale meteorological regimes to daily variations. Profiler wind data from northeast Colorado will also be examined for evidence of migratory short waves that may have been associated with the MCS's flown during AIMCS.

Analysis of the SESAME case study day of 20 May 1979 will be completed during FY 1985 in order to document as completely as possible the structure, dynamics, and interactions of a slow-moving nocturnal MCS.

Wind-field interpolation techniques and prognostic/diagnostic routines of direct utility in operational weather forecasting will be examined from a variety of perspectives, using such tools as desk-top microcomputers. The results are expected to affect both operational meteorology and research activities during FY 1985 through publications, talks, and demonstrations to NWS staff, and use in forecaster training courses and workshops.

Parameters used in forecasting convective weather systems, especially LFM grid-point data, will be studied using AIMCS 1984 forecasts and experimental forecasts made during two summers in coordination with other, operational NOAA agencies. Additional work will concentrate on LFM performance in past cases to establish relationships between predicted variables and occurrence of MCS's.

A major reformulation of the Fritsch-Chappell parameterization scheme designed to remove all physical inconsistencies will be completed and tested in the WRP two-dimensional model. Collaboration with scientists at NMC will be undertaken to begin testing the scheme on real data cases using an operational model. Work will continue on other aspects of the interaction of convection with its mesoscale and larger scale environment.

Interactions with NWS will continue in FY 1985 through such activities as formal forecaster training courses on flash floods and mesoscale forecasting given by WRP staff at the NWS Training Center, workshops and seminars at NWS facilities, exchange of staff for extended periods, cooperative applied research activities, and participation in the planning process for Experimental Forecast Centers as part of STORM-Central.

Synoptic environments of the dry microburst in western states will be evaluated for 1982 and 1984 in Colorado on both daily and monthly scales. In addition, studies will focus on the synoptic settings in which wet microbursts occurred in the JAWS area and have caused aircraft crashes in recent years in areas with high moisture.

Satellite-derived rain estimates will be made with the ERL technique for selected AIMCS cases with the objective of determining whether the transformation of the system from convective to stratiform rainfall can be recognized by the satellite.

PROFS

The Denver hailstorm study will examine the data for 13 June 1984, when unique photographs and PROFS mesonetwork information and other, nonstandard information can be used to specify some of the conditions that produced a convective event with such devastating results.

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 works closely with the weather research community--for example, other ERL groups 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 U.S. Air Force's Air Weather Service (AWS).

Two NWS employees are members of PROFS' senior staff, and a third will join in FY 1985 to coordinate work on NWS's Advanced Weather Interactive Processing System for the 1990's (AWIPS-90) to be done by PROFS. For the FAA, PROFS has installed an advanced workstation at the Denver Air Route Traffic Control Center (ARTCC). For NEXRAD (Next Generation Weather Radar), a joint program of NWS, FAA, and the Air Force, PROFS has coded and tested algorithms that will become part of the new national radar system.

PROFS has worked with groups from abroad as well. For example, Saudi Arabia is seeking advice on a national meteorological system, the Australian Meteorological Bureau and PROFS have exchanged consultants, and a group from the Swedish Meteorological and Hydrological Institute will visit in early FY 1985. Because of PROFS' innovative nature, visitors from Federal agencies, universities, private industry, and foreign countries continually tour the PROFS facilities for information and demonstrations. The Visitor Coordinator plans about 100 visits each month.

EXPLORATORY DEVELOPMENT FACILITY

The Facility Branch is responsible for the design, development, upgrade, operation, and maintenance of the PROFS Exploratory Development Facility (EDF). The EDF consists of the computers, data ingest interfaces, communication links, and display devices that allow the testing and evaluation of advanced weather information systems. It has been undergoing continual upgrades and changes since the beginning of PROFS. The system acquires and stores a large variety of meteorological data, analyzes and processes the data into products, and displays the products to forecasters using an interactive workstation.

Accomplishments FY 1984

In 1984, several new data interfaces were developed and others significantly upgraded. A SATCOM III (RCA Satellite Communications) satellite receiver was installed, a PDP-11/24 computer hardware interface was assembled, and the necessary software was written to acquire Limited-area Fine Mesh (LFM) model data from the National Meteorological Center (NMC). The Profiler ingest software was expanded to handle three additional sites (Lay Creek, Cahone, and Fleming, Colo.) in addition to Platteville and Denver. A substantially expanded Surface Aviation Observations (SAO) data set covering the entire United States was acquired through the AFOS (Automation of Field Operations and Services) connection in place of the earlier FAA 604 line. The reliability

of the two conventional radar interfaces was enhanced significantly by establishment of a dial-in capability for the PDP-11/23 computers at the remote radar sites. Also, the ability to down-line load the radar interface operating software from Boulder, in case of power failures, was developed. Careful monitoring of the mesonet data revealed several sensor problems that were subsequently corrected, thus measurably improving the data quality.

The overall efficiency of the PROFS computer network was substantially enhanced by interconnecting the processors with Ethernet, a 10-Mbps (10 million bits per second) local-area network. Ethernet increased the speed of data transfers among the computers by an order of magnitude and allowed more efficient sharing of terminal, printer, and mass-storage resources. Additional enhancements were obtained by upgrading all PDP computers to Version 4.1 of the RSX operating system and updating all nodes of the computer communications network to DECnet Phase IV.

In November 1983, in conjunction with the Interactive Meteorological Processing Conference held at NASA Goddard Space Flight Center in Greenbelt, Md., a fully functional PROFS workstation was assembled and demonstrated with archived data. Conference visitors expressed great interest in the rich variety of available data displays and the ease of operating the workstation.

In support of the Ocean Service Center (OSC) project of the National Ocean Service, a study was made to explore the applicability of PROFS techniques for OSC. The final report included a top-level system analysis and recommended system architecture for implementation.

A real-time workstation, connected to the PROFS EDF through a 56-kbps (56,000 bits per second) telephone link, was developed and deployed at the FAA ARTCC in Longmont, Colo., in June 1984. NWS forecasters at the ARTCC have found the workstation most valuable in advising the FAA controllers about weather conditions in the Colorado Front Range. In several documented cases, the PROFS data allowed controllers to make important re-routing decisions more accurately and faster, thus improving overall air safety.

PROFS

Throughout the year, the Facility Branch continued to supply real-time mesonet, Profiler, and/or Limon radar data to the NWS Denver Forecast Office, U.S. Department of Energy's Rocky Flats operations, Colorado State University in Fort Collins, Solar Energy Research Institute in Golden, and the ERL Wave Propagation and Aeronomy Laboratories. In addition, approximately 75 requests for archived data were serviced.

Plans FY 1985

- Upgrade the EDF computer network with the high-speed (70 Mbps) VAXcluster interconnect to allow rapid transfer of large blocks of data among processors and more efficient use of mass storage devices.

- Reconfigure the facility to support the real-time 1985 exercise and several projects: Central Weather Processor (CWP), Ocean Service Center, AWIPS-90, PROVAS (Profiler-VAS), and others.

in cases where either the desired information requires an interaction with the user or where the resulting display product is one that is seldom used.

During PROFS' real-time exercise in the summer of 1983, forecasters were forced to be content with only the scheduled products. Early in FY 1984 the first application programs were installed. The Applications team worked with the original authors of the programs, adding workstation-specific code, to produce some dozen programs for use during the 1984 cool-season exercise. The function of these programs ranges from simple information about where a thunderstorm is occurring in geographical terms to complex combinations of images from different sensors, e.g., radar reflectivity combined with visible satellite data.

These programs and others have been refined and thoroughly tested, and have been included in the workstation that PROFS has installed at the ARTCC in Longmont, Colo. Members of the Applications team are responsible for maintaining and enhancing the programs in support of the operational use of that workstation.

The VAS Applications team, in cooperation with NESDIS (National Environmental Satellite, Data, and Information Service) and the NOAA Operational VAS Assessment (NOVA), has upgraded the PROFS satellite data processing capabilities. Of specific interest are the addition of real-time VISSR (Visible and Infrared Spin Scan Radiometer) Atmospheric Sounder (VAS) data to the state-of-the-art workstation and the utility of the data as a mesoscale observation and forecasting tool. VAS data are available from the newer geosynchronous satellites (since GOES-4), which offer infrared data for 12 different spectral bands capable of a variety of uses. The VAS Applications team put together a new data base for archiving VAS multi-spectral imagery (MSI) and dwell sounding data, and wrote the first VAS MSI product software for the workstation. When the data base is complete, PROFS will routinely produce VAS upper-level water vapor imagery, VAS "split window" low-level water vapor imagery, and a stability image (a numerical combination of the two former images). In addition, the team has developed a data base to store processed VAS sounding retrievals to be used for workstation products and the mesoscale analysis package in the coming year.

The FAA is developing a Central Weather Processor (CWP), an electronic processor workstation and disseminator, for use by its meteorologists in the Center Weather Service Units (CWSU) at all ARTCC's. PROFS' role in CWP development is to identify and transfer the most suitable techniques for interactively describing, processing, and displaying meteorological data and analyses. The results of these analyses, tailored to air traffic control needs, will be graphics and text descriptions of icing, clear air turbulence, thunderstorms, low ceilings and visibilities, cloud tops, precipitation, and winds aloft. The PROFS CWP team has prepared a 3-year plan for meteorological applications development and demonstration. The plan and its resulting meteorological products rely heavily on the PROFS Mesoscale Analysis and Prediction System (MAPS) as the framework for data analysis. Already clear air turbulence and icing applications are under development.

The Analysis and Prediction team is currently in the midst of a long-term effort to develop MAPS. The goal is a robust, portable, multipurpose software system for objective analysis of mesoscale weather systems and for interactive

- Upgrade and expand the EDF data acquisition capabilities: establish an interface to the new NMC Domestic Data Service; switch over the lightning data acquisition to the new Lightning Location and Protection, Inc., network; and upgrade the Profiler data ingest subsystem.

- Continue the distribution of real-time and archived data to research and operational users.

EXPLORATORY DEVELOPMENT GROUP

During FY 1984, Advanced Data Systems merged with the Exploratory Development Group (EDG), which now comprises two branches: Science and Technology. The former produces software for the meteorological workstation, developing products and applications that forecasters can use to assess the current state and near-term future of the atmosphere, with emphasis on the local area. The latter selects promising technologies such as Doppler radar and satellites, and tailors them for use in a weather forecasting workstation.

Accomplishments FY 1984

SCIENCE BRANCH

The Meteorological Products team is responsible for the scheduler-generated data displays, or products, used in the PROFS workstation. These include most radar and satellite imagery, as well as graphic displays such as plots of mesonet and SAO data. Since this team was formed in October 1983, it has developed the following:

- An algorithm to draw range/elevation circles, given antenna elevation, as background to radar PPI's (plan position indicators).

- An effective display for the NOAA/WPL thermodynamic Profiler. In a single graphic, this product includes a 4-h time series of temperature profile change, potential temperature time/height "surfaces," and precipitable-water time series. **PROFS**

- An improved display of Profiler wind, time/height cross sections.

- Independent algorithms for isentropic cross section analysis.

The Meteorological Products team also planned and ran PROFS' first cool-season forecast experiment, from February to April. The objective was to learn how the PROFS system would work in forecasts of long-duration winter storms rather than short-lived convective events.

The Meteorology Applications team develops interactive and on-demand programs for the PROFS advanced forecaster workstation. Most displays of weather data, whether they be images, data plots, or vector graphics, are produced on a scheduled basis, and are thus available for nearly instant recall by forecasters at the workstation. Applications, on the other hand, are used

manipulation of observation, analysis, and prediction products. Ultimately, MAPS will support many users with diverse needs, both inside and outside PROFS.

The team is developing MAPS by iteratively refining prototype systems rather than by completely pre-specifying all software modules. At least three realizations of the system are currently planned. In FY 1984 the team has worked principally on the system realization that will support the 1985 real-time exercise. Beyond 1985 the system will incorporate a quasi-geostrophic prediction model, a surface analysis, and possibly a change of vertical coordinate from pressure to potential temperature.

TECHNOLOGY BRANCH

The Radar team completed a major upgrade to radar data ingest capabilities, adding full-resolution Doppler data, production of images, and NEXRAD algorithm products in real time to the PROFS workstation. Six NEXRAD algorithms are now in real-time operation. The communication bandwidth between the NCAR CP-2 radar and the PROFS EDF has been increased through the use of a microwave radio link with typical bit error rates less than 1 in 10^{12}.

The NEXRAD team continued work with the NEXRAD Joint System Program Office by coding and assessing algorithms and by providing test data sets. Eight algorithms were coded and run on real Doppler data to ascertain whether FORTRAN code could be written directly from the NEXRAD algorithm descriptions. Additional assessments of these eight algorithms included resolution sensitivity and parameter sensitivity studies. Other accomplishments were the coding and testing of three more algorithms, development of a synthetic data set, delivery of a set of documented Doppler data from the NCAR CP-2 radar, and acquisition of additional CP-2 Doppler data from interesting severe convective storms.

PROFS upgraded its GOES groundstation hardware and software to enhance the system's capabilities, streamline the design for reliability and easier maintenance, and produce system documentation. Several hardware changes were made to the frame synchronizer and sectorizer. A Mode AAA operational VAS capability was added in anticipation of NESDIS's switch to this new transmission mode in mid-1986. Bit-error-rate detection was added to improve quality control. The sectorizer was modified to perform exact sectorizing. Software changes were required to accommodate the changes in hardware and to provide new Mode AA research VAS data formats. One major effort was a new device driver for the frame synchronizer and sectorizer. To centralize satellite ingest and to achieve more distributed processing from a larger system point of view, more ingest and preprocessing tasks are now performed on the satellite subsystem.

PROVAS (PROfiler-VAS) is the system being developed jointly by PROFS and WPL, which takes data from the Profiler and the VAS and produces an estimate of the vertical profiles of atmospheric temperature and water vapor. These profiles from the combined data have less error than those produced by each system separately. During FY 1984 the PROVAS system was initiated, designed, and built to professional documentation and design standards for use during yearly PROFS exercises.

The video disk is one component of an advanced training method that combines computer-based instruction (CBI) and the PROFS data sets. That method is the centerpiece of a proposed national program that will continually train meteorologists from universities, research facilities, and NWS forecast centers in advanced forecast techniques and meteorological understanding. Development of the first instructional video disk began in January 1984 when the Interactive Meteorological Educational and Training System (IMETS) project was formed. The project's first task was to analyze and catalog data from the real-time exercise in summer 1983. Selected cases from the data will be put onto a video disk for use in CBI courses at a proposed training center for meteorologists. A forecast workstation was installed at PROFS, and a CBI demonstration package was developed that uses a prototype video disk and a microcomputer. In addition to specific technical accomplishments, the project has submitted a proposal to the National Science Foundation for funds to establish a national training center at St. Louis University. The center will serve research staff and students from the university, and operational forecasters from NWS and AWS.

Plans FY 1985

SCIENCE BRANCH

In August 1984, real-time ingest of gridded LFM data was added to the PROFS facility. The Meteorological Products team can now begin work suggested by other NOAA researchers, i.e., recontouring the LFM model output to reveal finer structure in the numerical data than can be seen in the output from NMC graphic products. Forecasters will be able to interactively select the contour interval for any of several analyzed and forecast field variables. The team will also write a report summarizing the product usage patterns of forecasters during the 1983 summer forecast experiment. Every product display command entered during the experiment was logged for later analysis; the team will determine which information forecasters find most useful when issuing warnings and routine forecasts.

PROFS

During FY 1985, the Applications team will concentrate on two activities, both in support of the real-time exercise planned for the summer of 1985.

- First, write new applications programs. There is a substantial list of desired programs from past experience, and many requests from forecasters are expected in the months to come. Forecaster training sessions are scheduled to go on during the winter, and many suggestions will probably be offered by the trainees.

- Second, upgrade existing programs. Since a new version of the workstation software will be forthcoming, some changes will be required simply to maintain the programs in working order. In addition, a more coherent structure to the applications as a whole is needed to simplify the task of the forecaster. Logically associated programs should be presented to the forecaster as such, thus allowing essential information to be accessed more rapidly.

The plans for VAS application development at PROFS are as follows:

- To establish a data base capable of performing the I/O (input/output) requirements to support routine VAS product generation. This encompasses a new VAS file format and the new software for the I/O function.

- To develop three initial VAS image products for use at the workstation:

  (1) Low-level water vapor image derived from two VAS bands, highlighting the areas of water vapor in the surface-to-700-mbar layer.

  (2) Upper-level water vapor image from a single VAS band, showing the water vapor distribution in the 700-mbar-to-tropopause layer.

  (3) A composite of 1 and 2 to determine the areas of instability.

The CWP team will develop and demonstrate preliminary meteorological applications for clear air turbulence, icing, winds, thunderstorms, precipitation, low ceilings and visibilities, and cloud tops. These applications, using both automated algorithms and meteorologist interactions, will be demonstrated to CWSU field meteorologists. Results of the demonstrations will be fed back into the applications work to improve performance and usefulness.

TECHNOLOGY BRANCH

The Radar team will streamline the real-time design to improve performance and ready the subsystem for the 1985 experiment. Major new work includes the workstation radar interface and possibly a high-speed image generator. This new radar subsystem will allow PROFS to address the NEXRAD AWIPS-90 interface questions.

Work with NEXRAD will include continued assessment of the algorithm descriptions, further parameter and resolution sensitivity studies, coding of additional algorithms, preparation of a data set containing both real and synthetic Doppler data, and displaced real-time product assessment.

The PROVAS system has been designed to allow the testing of various combinations of algorithms. Its flexibility will allow testing of recently proposed techniques, for example, inferring the vertical location of temperature gradient changes by means of the radar return power. Such vertical locations can then be used as a boundary condition on the retrieved temperature profile.

The IMETS project will concentrate on three activities in FY 1985:

- Secure funds to open and operate a video disk teaching center at St. Louis University and begin construction of the center by September 1985.

- Develop another PROFS video disk.

- Develop teaching material to complement the video disks.

SYSTEM ANALYSIS AND DESIGN

The System Analysis and Design Branch (SA&D) is responsible for specifying the system software and hardware architecture that best suits a particular project's needs. In most instances only some of PROFS' computer resources are available to any particular project, and resources may be shared with other activities. To establish resource requirements, SA&D typically performs functional analyses of project requirements, measures computer resource requirements of similar software, and performs, where feasible, system load simulations to evaluate resource utilization.

SA&D also performs software development relative to system control functions, such as the workstation executive, user interface, and the product scheduler. Before a system realization (configuration) becomes functional, SA&D integrates software and performs a system shakedown to detect software errors, performs load leveling, and verifies system response.

Accomplishments FY 1984

Since the PROFS real-time exercise in late FY 1983, SA&D has helped develop and integrate five system realizations:

- MERIT (Minimum Energy Routes using Interactive Techniques)--A NASA project to provide an interactive system for defining the minimum energy consumption route for aircraft.
- Cool-season exercise--An internal project to apply PROFS system capabilities to analyzing and forecasting winter weather.
- RADRES (Radar Resolution Study)--An internal project to evaluate performance of forecasters using different spatial resolution radar data.
- ARTCC--An implementation of a PROFS workstation in an FAA operational environment for purposes of evaluation.
- '84 Weather Watch--A system realization similar to the ARTCC configuration that allows real-time monitoring of the weather at PROFS.

PROFS

SA&D had prime responsibility for the U.S. Air Force's Automated Weather Distribution System Driver project and the FAA-sponsored Aviation Route Forecast project. In both cases the objective of the initial phase was to develop functional requirements, specify external interfaces, and perform a detailed functional analysis using the dataflow technique. The resulting documents were accompanied by detailed task breakdowns, schedules, and personnel resource requirements. The documents were suitable for specifying subsequent system development.

Plans FY 1985

Planned activities are significant enhancements of generic workstation capabilities such as dual display screens and improved user interface,

integration of several new data sources, and the addition of considerably more products such as the NEXRAD algorithms, PROVAS, and mesoscale analysis and prediction outputs. The workstation will be modified to incorporate additional AFOS functions, such as text preparation, dissemination, external requests for data, and alerting, and to provide greater flexibility in procedure development. The 1985 system will have most of the functionality of the system to be installed at the Denver Weather Service Forecast Office in 1986.

Under way is a study of data base management systems to characterize the PROFS data base and its utilization, to evaluate commercially available candidate data bases, and to recommend a path of action to handle present and anticipated data base management needs.

Another activity under way is development of a plan for a civilian meteorological processing system for Saudi Arabia. This activity is being performed through and in cooperation with the Office of the Federal Coordinator. The present plan is to develop a model facility for the system to be installed in Saudi Arabia.

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 1984

The major activities of the Test and Evaluation staff were analyzing and reporting results of the PROFS 1983 forecasting exercise. Improved accuracy in severe weather warning scores was obtained during the exercise. A detailed evaluation of precipitation probability forecasts has shown forecaster skill relative to conditional climatology for convective storm situations and has suggested yet further improvement in skill is likely in the future. A summary of conditional and sample climatological probabilities of precipitation during the Colorado convective season (May through August) has been prepared as a useful aid to weather forecasters.

Late in FY 1983, NWS and PROFS conducted a joint analysis of a digital radar hail detection algorithm system known as RADAP (Radar Data Processor). Significant improvement in warning scores was demonstrated by use of the algorithm alone; yet further improvements were obtained by experienced forecasters using the algorithm output as guidance.

T&E designed and conducted a test to study the effects of spatial resolution of Doppler radar data on severe weather warning operations in April 1984. The results of this test suggest that the AWIPS-90 system should include sufficient bandwidth and central processing capacity to ingest and process Doppler radar data obtained from NEXRAD's planned radar data acquisition system.

It was frequently demonstrated during the 1983 forecast exercise that temperature and humidity profiles obtained from passive radiometry smooth out vertical structure (inversions, dry layers) to the extent that the profiles are inadequate for short-term analysis and forecasting of severe weather. The T&E staff, in a joint effort with WPL, has undertaken a broad program to investigate possible methods to improve the accuracy and height resolution of the radiometry sensor system. Detailed analyses of 5,000 rawinsonde ascents from the NASA Atmospheric Variability Experiment to characterize the variability of mid-tropospheric inversions are well under way. A field experiment has been designed to obtain detailed and frequent rawinsonde, wind profiler, and radiometer data during frontal passage and subsidence inversion conditions.

The pilot forecast exercise conducted by the Exploratory Development Group produced mesoscale forecasts of winds, temperature, ceiling, visibility, and precipitation during the winter season of early 1984. Quantitative evaluation of those forecasts has been completed by the T&E staff. The results of these analyses will be forthcoming in early FY 1985.

Plans FY 1985

- Participate in the design and preparation of the PROFS 1985 forecast exercise, planned for mid-May to mid-August 1985.
- Complete the joint PROFS WPL project to evaluate the radiometer system for use in short-term mesoscale analyses and forecasts.
- Modify the RADAP algorithms as necessary, on the basis of Colorado 1983 severe weather data, for testing and evaluation during the 1985 forecast exercise.

WEATHER MODIFICATION PROGRAM WMP

The Weather Modification Program (WMP) oversees the Federal-State Cooperative Research Program in Weather Modification, which began in 1979. At that time 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. In FY 1984, Illinois was added.

Each state has different interests in weather modification. Scientifically, North Dakota is concerned about the evolution of rain and hail in convective clouds of the northern Great Plains; Utah's interests are in the scientific assessment of winter snow enhancement efforts in the mountains; Nevada's research interests are the downwind effects of seeding for winter snow in California; the research interests of Illinois are in summer rain processes as they pertain to stabilization of corn and soybean production. All four programs, which are in different climatic regimes, are of broad regional and national interest and represent sizable State investments. In the four efforts there is close cooperation among scientists and administrators of the programs and with the NOAA Program Manager.

Accomplishments FY 1984

COOPERATIVE RESEARCH—ILLINOIS

The Illinois State Water Survey obtained NOAA funding and formally entered the Federal-State Cooperative Research Program in April 1984. Work in earlier years, in part through other NOAA support, established the Precipitation Augmentation for Crops Experiment (PACE). Current sponsorship of the Illinois program will continue to support the PACE program in part. The long-term goal of PACE is to determine whether agriculturally useful increases in summer convective rainfall can be produced in the Midwest. Toward this end, broad, basic scientific background studies were initiated in FY 1984, and staff and equipment appropriate for these tasks were increased. Radar echoes from an extensive, existing data base are being characterized in terms of patterns in rain cell development and evolution. Meteorological satellite expertise was brought into the organization to initiate a range of convective cloud studies. Soil moisture instrumentation was acquired and installed in several benchmark soils to study rain infiltration and soil surface sealing. Also launched was a study of the agricultural economic impact of wet-summer vs. dry-summer precipitation.

COOPERATIVE RESEARCH—NEVADA

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

The work is and will continue to be focused on three tasks: (1) transport, dispersion, and capture of seeding agents; (2) stable isotopes and ice crystal growth in relation to liquid water locations in mesoscale systems; and (3) the distributions of liquid water and ice in Sierra Nevada winter storms.

Some remarkable new concepts in wet-weather tracer technology are beginning to emerge from this part of the Federal-State Cooperative Program in Weather Modification Research. The oxygen isotope ratio in snow ($^{18}O/^{16}O$), which is established when water substance freezes in a cloud, is providing a means to estimate where in a cloud and by what growth processes (vapor deposition or accretion) snow crystals gather their mass. Silver sampling in snow is demonstrating the confinement of ground-released particles (AgI) and

is showing what portions of cloud volumes are reached by particle plumes in clouds over complex terrain. The use of two compositions of particles with similar size and mass distributions, one active and one inactive as an ice nucleant, is being developed to distinguish between cloud nucleation and scavenging processes. The implications with respect to effective delivery of cloud seeding material (or, e.g., to the dispersion of powerplant effluents) into cloud systems is profound. All of these technologies have broad application in basic cloud studies, weather modification, and air quality.

COOPERATIVE RESEARCH—NORTH DAKOTA

The current North Dakota ice-nucleant generators and flares were tested for productivity at Colorado State University. A surprising result was the high variability among flares in the same cloud chamber, which raises questions about controlling the cloud-treatment amounts.

In July, a preliminary study of sulphur hexafluoride (SF_6) as an in-cloud plume transport and diffusion tracer was successfully conducted. The pioneering results indicated that the circulation in a growing convective cloud was very confined; continuous cloud base seeding generated plumes of only relatively small diameters (e.g., 100 to 500 meters) at a few thousand feet above the seeding altitude. In the SF_6 plumes there also was evidence of liquid-water-to-ice conversion by AgI in some of the cloud penetrations.

The 2-D and 1-D modeling of North Dakota convective cells is continuing. Graupel appears to be the dominant growth form of precipitation in these model results. Also, an investigation of the time between first and maximum echo heights was conducted for treated and nontreated cells. Treated cells, on the average, may have shorter growth times than the nontreated. Analysis is continuing.

COOPERATIVE RESEARCH—UTAH

A field program directed at defining the supercooled liquid water in Utah winter 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. Nevertheless, a very valuable data set was collected. One key analysis to date has demonstrated the utility of the use of multiple remote sensors to study and monitor winter orographic clouds. The use of a dual-channel radiometer to continuously monitor cloud water vapor and liquid, a polarized lidar to indicate the base height of liquid cloud layers and the presence and height of ice particles through the cloud volume, and a K-band radar (e.g., 1.79 cm) to indicate cloud top and to follow the transition from water phase to ice phase in the cloud volume, provide in combination a powerful tool to monitor and measure the availability, transition, and budget of cloud water. From data collected with these sensors, microphysical patterns in cloud evolution are being defined that will allow for better prediction of liquid water (particularly for cloud modification and aircraft icing), in relation to the structure of cold fronts. Additional studies of cloud transport over mountains are revealing the effects of meteorological trapping of cloud-seeding materials. The work is equally applicable to the trapping of emissions from powerplants and other sources in mountainous terrain.

Plans FY 1985

COOPERATIVE RESEARCH—ILLINOIS

FY 1985 will be the first full year of Illinois participation in the program. Analyses of radar echo evolution, based on the data acquired, will be completed. Satellite cloud studies will be integrated with the radar studies to identify cloud/echo types most likely to be suitable for increased precipitation efficiency, and thus for further cloud physics studies by remote sensing and aircraft. The Illinois State Water Survey will acquire, on a shared basis with other states in the program, a GOES (satellite) receiving system. The Survey will modify its HOT (Hydrometeorological Operational Tool) 10-cm radar to include a Doppler capability, which, with its existing CHILL (CHicago and ILLinois) 10-cm radar, will provide a dual-Doppler capability. Past Water Survey tracer work in convective clouds will be reviewed, as will the physics of all previous weather modification efforts in Illinois. Soil moisture measurements and economic models will be used to assess major impacts of real or hypothetical precipitation variations on agriculture production capacity and water quality.

COOPERATIVE RESEARCH—NEVADA

Work on several fronts, in accord with the three central tasks mentioned with the FY-1984 accomplishments, will continue in conjunction with a field program during the winter and spring of 1985: (1) development of tracer technologies and 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) development of new exotic chemical and isotope techniques for seeding assessment; (4) 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; and (5) determination of the chemical makeup of the snow falling downwind of the Sierra Nevada crest.

COOPERATIVE RESEARCH—NORTH DAKOTA

- The following items are the principal activities for FY 1985:
- Analyses of the pioneering 1984 preliminary studies of simultaneous cloud physics, and tracer data to determine plume and treatment characteristics over time and space.
- The initiation of a comparative exploratory field experiment on in-cloud diffusion and treatment signatures for a relatively fast and slow reacting AgI compound.
- A Doppler radar investigation of in-cloud circulations for treated and nontreated cases.
- Continued 2-D modeling of the presumed North Dakota precipitation process.

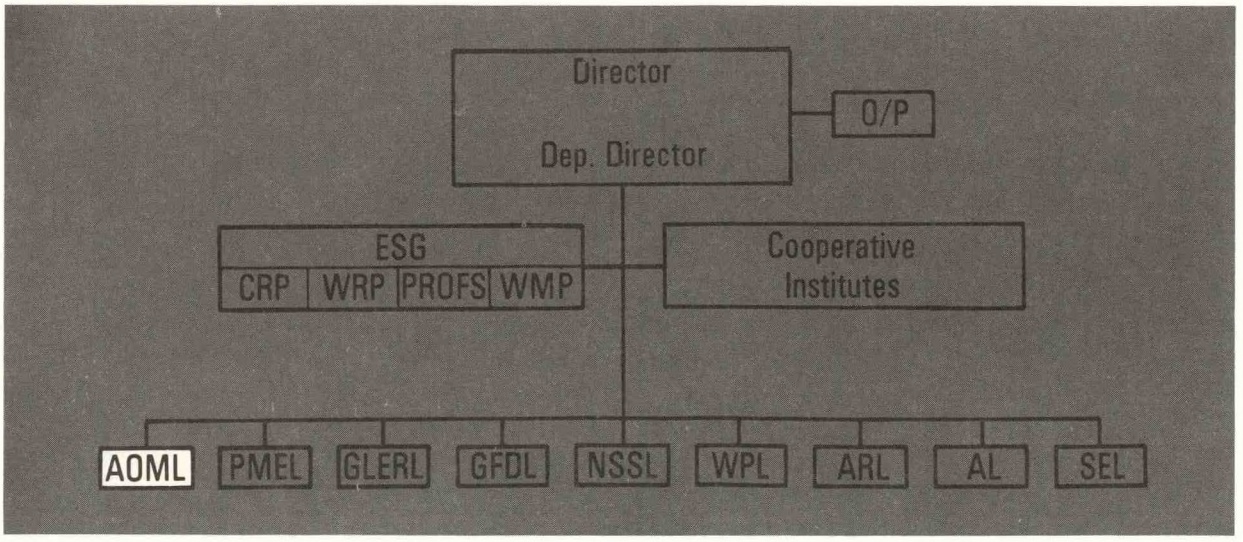
- A laboratory development of an AgI-AgCl-salt mixture suitable for use as a fast-acting ice nucleant in airborne flares.

COOPERATIVE RESEARCH—UTAH

A winter-spring 1985 field research program will be conducted in the Tushar Mountains. Key remote sensors will be utilized; these do indeed provide a foothold on the future for positive monitoring, prediction, and modification of supercooled liquid water, water-to-ice transitions, and the development of precipitation. Meteorological trapping of seeding materials will continue to be studied, since effective delivery is a crucial issue. New data from 1985 will be integrated with the valuable 1983 data set for in-depth analysis of both.

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. The research program is enlarged by the Cooperative Institute for Marine and Atmospheric Studies (CIMAS), a joint enterprise with the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. CIMAS enables NOAA and university scientists to collaborate on problems of mutual interest, and facilitates the participation of visiting scientists.

AOML's current research program concerns processes relating to climate, weather observation and prediction, marine assessment, marine observation and prediction, marine resources, and air quality.

CLIMATE RESEARCH

Climate research at AOML continues to focus on aspects of ocean heat transport and storage in relation to interannual and longer-term variations of atmospheric weather and climate. Increasingly, AOML activities in these areas must be seen as part of the NOAA contribution to national and international programs for climate research. The scope of problems being addressed more and more requires extensive cooperation and coordination between groups, especially for oceanographic field programs. Tradition and convenient access to sea-going research facilities result in a research program with emphasis on collection and analysis of oceanographic data. There is, however, increasing

use of numerical models for making interpretations and predictions based on the observations. The AOML program in climate research is conveniently described within the two categories of tropical ocean climate studies and subtropical Atlantic climate studies.

Accomplishments FY 1984

TROPICAL OCEAN CLIMATE STUDIES

Tropical ocean climate studies at AOML consist of participation in the continuing NOAA EPOCS (Equatorial Pacific Ocean Climate Studies) program, analysis and interpretation of tropical ocean data collected during the First GARP Global Experiment (FGGE) of 1979, and beginning work in connection with the international program TOGA (Tropical Ocean Global Atmosphere), which has objectives on the global scale very similar to those of EPOCS on the scale of the tropical Pacific. The common focus of this work is to describe, understand, and predict the large-scale air-sea interaction processes associated with the major mode of interannual large-scale climate variation - the El Niño/Southern Oscillation phenomenon.

During 1984, intensive effort was committed to compilation and processing of extensive data sets collected for description and analyses of the historic El Niño event of 1982-83. The data sets available include the following:

- CTD (conductivity-temperature-depth) and current measurements from 13 cruises along 85°W from 1981 through 1983. A draft manuscript on descriptive aspects of these sections has been completed. An early conclusion is that it appears possible to describe the thermocline variations in the eastern tropical Pacific during El Niño in terms of a small number of normal modes.

- More than 3,000 temperature profiles taken by XBT (expendable bathythermograph) from ships of several countries and the NOAA research aircraft. Analyses of these data show isotherm patterns suggestive of Kelvin and Rossby waves.

- Approximately 7,000 buoy days of data from satellite-tracked drifting buoys that, in companion with about 18,000 buoy days of data collected prior to the event, reveal that major changes in the surface currents are in fact associated with El Niño. The earlier data were used also to complete a major investigation showing that prominent long waves, of 20-30 day period, intermittently observed in satellite SST (sea surface temperature) data, are due to shear instability of the zonal currents, and appear to have a strong influence on the equatorial ocean heat budget.

An international workshop was convened at AOML to review observations of the El Niño shortly after its passing, and a draft atlas summarizing observations from many observers and institutions was completed. AOML has also made special effort to foster cooperative data collection and research activities with colleagues in Latin America. During FY 1984, two scientists from Ecuador were guests of the laboratory and CIMAS.

Using data obtained during the 1979 FGGE (First GARP Global Experiment), analyses and interpretation were continued to document the processes that are most important in the heat budget of the surface layers of the equatorial Indian and Atlantic Oceans.

An investigation was also initiated into the reality of and possible mechanisms for an apparent negative correlation between El Niño in the Pacific and hurricane frequency in the Atlantic region.

In connection with all of these activities, scientists of AOML participated in numerous scientific meetings, seminars, and workshops convened to review and share progress on understanding of larger scale tropical air-sea interaction and for formulation of plans for the international TOGA program.

SUBTROPICAL ATLANTIC CLIMATE STUDIES

The North Atlantic Ocean is believed to be particularly important for the large-scale meridional heat transport processes required by the prevailing climate of the earth. Knowledge of the ocean heat transport and its mechanisms are required for understanding changes of weather and climate on decadal time scales, and probably for modeling larger scale long-term ocean circulation processes of all kinds. During the past two years, work has concentrated on observational studies of the Florida Current, which have the objective of developing economical means of monitoring both the mass and the heat transport of this limb of the North Atlantic subtropical gyre over extended time periods. A 2-year time series of directly measured flow was used to evaluate and calibrate potential monitoring methods for the current. Both induced electrical potential difference and sea level differences were shown to offer excellent potential as monitoring techniques, the former with probably somewhat greater accuracy, and the latter with greater reliability. Both are economically and logistically attractive monitoring technologies, and work was initiated for transferring the monitoring operation to NOS (National Ocean Service).

More detailed investigations of the variation of the current, using EOF (empirical orthogonal function) analyses, revealed a definite winter/summer pattern in the EOF intensities, and showed the strongest EOF to be associated with a change in the flow on the western side of the current. **AOML**

The priority goals of the Florida Current having been met, observational resources were shifted to new focus with a research cruise to investigate the importance of flows along the topographic rise east of the Bahamas.

Plans FY 1985

TROPICAL OCEAN CLIMATE STUDIES

The main emphasis in these studies during FY 1985 will continue to be on documenting and analyzing the El Niño event of 1982-83. The El Niño oceanographic atlas summarizing NOAA and other observations will be published. Analyses will be made and reports written on variations of hydrographic struc-

ture observed in the eastern tropical Pacific during the event. Analysis of normal surface currents as determined by satellite-tracked drifting buoys will be completed as a basis for quantifying the circulation anomalies experienced during El Niño. Hypotheses concerning the effects of circulation anomalies on SST during the onset of El Niño will then be tested.

Data collected during FGGE will be used to compute the relative importance of various physical processes in the mixed layer for the Indian Ocean, to produce an atlas of the marine meteorological and heat budget fields in the Indian Ocean, and to estimate the temporal and spatial scales of variability in the equatorial Atlantic and Indian Ocean sea surface temperature and surface wind fields.

A major acceleration of climate-related research into the tropical oceans will occur with implementation of the TOGA program in FY 1985. Present plans are for a major U.S. thrust in the tropical Pacific, where AOML has been active with EPOCS in recent years. Among the priority activities to which AOML will contribute in this region are a "Real Time Component," and a "Rapid Response Experiment." For the Real Time Component, special effort will be made to compile and interpret observations of atmospheric and oceanic variations on time scales of a few days to a very few weeks in order to make projections of climate anomalies both to guide research and to provide a basis for advisories to the socio-economic sector. One of the principal scientific uses of the projection will be to trigger the Rapid Response Experiment in which observational resources will be focused on obtaining more detailed information on the development of El Niño in the ocean. AOML scientists will contribute to planning and implementation of both of these activities. Cooperative relationships with institutions in Latin America will be used for deployment of satellite-tracked drifting buoys and collection of temperature data from regional vessels to provide data input to the Real Time Component, and contribute to the Rapid Response Experiment. Drifting buoys are well suited to these uses as their data are routinely reported in real time. Temperature data also will be telemetered via satellite as soon as the formatting and transmitting equipment can be purchased and installed on the observing vessels. It is planned that Latin American scientists will continue to be given opportunity to visit AOML for training and cooperation in analysis of the data collected in the cooperative observing programs.

AOML will participate in two different approaches to use of models for integration and interpretation of data from the Real Time Component. The GFDL ocean model will be set up on a computer at the National Meteorological Center (NMC) and used for simulation studies of the 1982-83 event, and to compute the ocean response to surface winds for comparison with data compiled in the real-time component. A scientist from AOML will participate in and guide these numerical modeling experiments at NMC. The GFDL model is large and produces very detailed output. Analysis of the model results is itself a major task. At AOML, work will begin on development of a four-dimensional data assimilation procedure capable of assimilating observations of oceanographic-atmospheric fields into simpler numerical models of the relevant systems, whatever the distribution of those observations in space and time.

SUBTROPICAL ATLANTIC CLIMATE STUDIES

Analysis of the direct measurements of the Florida Current will be completed to provide as complete a kinematic and dynamic description as possible of the temporal and spatial variations of this major current. New observations will be made in the Caribbean Sea and the Windward Passage to determine in more detail the sources of the Florida Current transport and variability. Data analysis on sea level and pressure gauge data will continue with a view toward optimizing the use of sea level data and of extending the sea level observing network throughout the Antilles and the Caribbean Sea. This network is expected to be accomplished in the context of the sea level program of the Intergovernmental Oceanographic Commission.

Work will continue on application of EOF and other kinds of statistical analysis and modeling procedures to all the data from the Florida Straits, to identify the active modes of variation as quantitatively as possible. Optimal interpolation methods will be used to evaluate each of a number of candidate observing systems.

It is envisaged that climate-related studies of AOML in the subtropical North Atlantic will gradually evolve into a major NOAA commitment to a larger national or international program such as the TOPEX ([Ocean] Topography Experiment) program or the World Ocean Circulation Experiment (WOCE), currently in discussion and preliminary planning for the next decade.

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 NMC of the National Weather Service (NWS) in problems of hurricane prediction, with the National Center for Atmospheric Research (NCAR) on scientific investigations of the inner cores of hurricanes, and with GFDL in the area of hurricane modeling.

Accomplishments FY 1984

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

The results of a study on drop size distributions in tropical convection in hurricanes indicate some departure from the Marshall-Palmer fit to the drop size distributions. A gamma distribution functional fit was found to give the best fit to the observed data set. A simple parameterization of rain was formulated on the basis of this fit.

The gamma fit to drop size distributions and a recently reported new fit to the Gunn and Kinzer drop terminal velocity data were used to derive a relationship between the Doppler mean velocity and the radar reflectivity factor. This relationship is required in the most common method of separating the terminal fall speed motion from the air motion in Doppler radar data.

A study on the distribution of ice in the convection of Hurricanes Ella (1978), Allen (1980), and Irene (1981) showed that above the 0°C isotherm level, only updrafts > 5 m s^{-1} contained liquid precipitation. Downdrafts contained very high (> 150 l^{-1}) concentrations of ice particles. These downdrafts were always adjacent to updrafts > 5 m s^{-1}. Graupel was the predominant particle type in the convective regions, and irregular particles similar in appearance to aggregates predominated elsewhere.

An analysis correlating particle type and concentration with radar displays for Hurricanes Allen (1980) and Irene (1981) was completed. This study documented that the regions of high (>30 dBZ) radar reflectivity above the 0°C isotherm were positively correlated with both strong updrafts and the occurrence of liquid precipitation. Strong negative radial gradients of radar reflectivity at the outer edge of the eyewall were often associated with downdrafts and high concentrations of ice particles.

Convective and Mesoscale

The analyses of the airborne Doppler radar data from Hurricane Debby (1982) were completed, and the results clearly indicate that the NOAA airborne pulse-Doppler radar is a very good tool for determining mesoscale wind fields over large regions in a hurricane environment.

Following the success of the Debby analysis, a similar analysis of the airborne Doppler data for Hurricane Alicia (1983) was started. From Alicia, we have some of the first examples of vertical incidence Doppler radar data from aircraft. These data give a direct measurement of the vertical air motion (plus the particle fall speed) at different altitudes above and below the aircraft along the flight track. A technique was developed for removing the particle fall speeds from the vertical incidence data. The vertical velocity cross sections constructed using this technique show details of the vertical air motion in and around the eyewall. For the first time, mesoscale updraft motion (0.5-1.0 m s^{-1} on average) was actually measured above the bright band in the nonconvective region adjacent to the eyewall.

A major accomplishment was the production of a color movie of the digital radar data recorded during the landfalls of Hurricanes David and Frederic. The movie has been shown at numerous conferences and meetings during the year and is an excellent vehicle for showing the time evolution of the more important precipitation features of these storms. A similar movie for the landfall of Hurricane Alicia is in production.

Synoptic-Scale

Omega dropwindsonde (ODW) data gathered during Hurricane Debby (1982) were analyzed. The impact of the data on the operational objective analyses

and the dynamical hurricane track models was evaluated as part of a cooperative effort with NHC and NMC. The dynamical Movable Fine Mesh (MFM) hurricane track model can be initialized with either the operational Hough analysis or an optimum interpolation analysis. The shortest wave resolved by the analyses has an east-west wavelength of about 1500-2000 km. Both analyses were unable to resolve the hurricane vortex or a cutoff low located about 500 km to the north of Debby's center. Each of these circulations had a horizontal scale of about 500 km. The cutoff low was clearly defined by the ODW data, and it had a significant influence on Debby's track. The resolution of the objective analyses that initialize the MFM must be improved if circulation features with scales of 500 km are to be resolved. MFM track forecasts were found to be very sensitive to small variations in the initial analyses.

Final processing of the ODW data for Hurricane Olivia (1982) was completed, and the data were distributed to scientists at several laboratories and universities.

A study aimed at gaining a better understanding of the effect of aircraft turns on the accuracy of ODW winds was completed. Data collected by the Office of Aircraft Operations (OAO) during test flights in 1982 and 1983, when one of the P-3's made several turns near a stationary ODW on the ground, were analyzed for this purpose. The capabilities of three wind-finding algorithms were evaluated, and the advantages of each algorithm were determined.

Air-Sea Interactions

Software was developed for viewing Doppler radar radial velocities in the hurricane boundary layer in a range-height mode and for properly detecting and removing surface contamination of the data. Boundary-layer wind structure in a developing principal rainband in Hurricane Debby (1982) was investigated using airborne Doppler radar data as well as aircraft measurements of wind and the thermodynamic variables at several levels. Preliminary results indicate that the airborne Doppler radar is an effective tool for study of the hurricane boundary layer. Detailed vertical profiles of the horizontal wind are possible from the 200-m level upward with a resolution of 150-200 m. Even more detailed profiles may be obtained through adjustments to flight legs.

AOML

A data base of more than 100 land and ocean observation platforms was developed for Hurricane Alicia, which struck the Texas Gulf coast in August 1983. These data have been composited with respect to the storm center for three analysis periods: (1) over the open Gulf of Mexico, (2) at landfall, and (3) several hours after landfall. During landfall, the outer rainbands on the east side of the storm continued to develop in a preferred area of mesoscale low-level confluence and spiral northwestward, contributing to heavy rainfall and damage in the Galveston Bay coastal region.

A preliminary, color version of the sea-state catalog (in loose-leaf form) was begun. The catalog consists of color Hasselblad photos taken during reconnaissance overflights of Hurricanes Alicia and Dean during 1983. Surface wind speeds from 12 to 33 m s^{-1} are represented. The purpose of this project is to improve the accuracy of sea-level wind speed estimates based on visual observations of sea state taken by U.S. Air Force weather reconnaissance observers.

Detailed slide sets of vertical sea-state photos (mostly black and white) were prepared and presented to the 54th Weather Reconnaissance Squadron at Anderson Air Force Base, Guam, and the 53rd and 920th Weather Reconnaissance Squadrons at Keesler Air Force Base, Miss., for their use in training programs. Workshops on sea-state wind estimation were given at each location. In addition, an overview of the efforts to improve sea-state surface wind estimation as well as the potential of remote microwave sensing of surface winds was presented at the Pacific Command Tropical Cyclone Conference in Tokyo.

HURRICANE TRACK PREDICTION

This program is conducted jointly with the National Hurricane Center. A final version of the scan analysis for deep-layer mean (DLM) winds to be used to initialize the SANBAR (Sander's Barotropic) model was completed and tested. Forecasts were run using this analysis package, combined with the old prognostic model, using archived data for the 1979 to 1982 hurricane seasons. This new package demonstrated an improvement over the former operational package at the 12- to 72-h forecast intervals (error reduced by 22 km at 72 h) for the 4-year sample. The reduction in average forecast errors was shown to be significant (at the 95% level) from 24 to 48 h.

With a fine-grid version of SANBAR, forecasts were made for Debby (1982) using the ODW data available on 15 and 16 September. On 16 September, the ODW data had a much greater effect than on 15 September, both in the analysis and in the forecast. The scan analysis was able to assimilate the extra data accurately, resulting in the reduction of the 24- to 72-h forecast errors.

The DLM scan analysis is now on the AFOS (Automation of Field Operations and Services) and FAX circuits. In addition, at the requests of forecasters at the San Francisco and Hawaii Weather Service Forecast Offices, the scan analysis has also been implemented for the eastern Pacific to generate upper layer (200-600 mb), lower layer (600-1000 mb), and deep-layer (100-1000 mb) mean and shear (upper layer minus lower layer) maps for the AFOS and FAX circuits.

Testing was done using DLM wind data derived from the VISSR (Visible Infrared Spin Scan Radiometer) Atmospheric Sounder (VAS) in cooperation with the National Environmental Satellite, Data, and Information Service/Development Laboratory in Madison, Wis. The VAS-derived winds were used for eight of the Hurricane Debby (1982) cases and for nine cases (Hurricanes Alicia, Barry, and Chantal) from the 1983 season. The small number of cases available for the 1982 and 1983 hurricane seasons prohibits conclusive results.

Recent research with statistical hurricane track prediction models has produced results dealing with the orientation of grid systems in statistical tropical cyclone track prediction models, and with sampling errors in statistical models of tropical cyclone motion. The orientation method developed is being applied to a revised operational forecast model at NHC. Preliminary tests indicate that the new method has a strong potential for significantly reducing forecast errors, particularly by substantially reducing the slow speed bias characteristic of previous models.

HURRICANE VORTEX DYNAMICS

Studies involving the performance of our prototype nonhydrostatic hurricane model were conducted and have shown a vortex-scale evolution of the model when the model is integrated with a conventional Kessler-type microphysical parameterization and a bulk ice-phase microphysics parameterization. They have also shown mesoscale features in the ice model that were forced by melting of ice particles. These studies have established the important role of ice-phase processes in the model simulation and have indicated the potentially important role of cloud microphysical processes in the mesoscale structure of tropical cloud systems.

Two new sets of experiments were performed to confirm and elucidate the role of ice-phase microphysics in the structure and evolution of this axisymmetric model. In the first set, two key factors in the ice-phase physics, production rate of precipitating ice and bulk fallspeed of the various types of ice particles, were isolated by judicious simplification of the original ice-phase parameterization. Results show that melting ice always creates a characteristic downdraft signature below the zero-degree isotherm, and that the strength and horizontal extent of the downdrafts depends on the terminal fallspeed of the ice particles. In the second set of experiments, the transient growth of parameterized ice particles in the earliest stages of cloud formation is being examined for a different parameterization of suspended ice crystal nucleation.

Observations from Hurricanes David of 1979 and Gert of 1981 have led to formulation of a conceptual model of the asymmetric structure of hurricanes. In this model, a stationary band of convection, termed the Stationary Band Complex (SBC), extends outward toward the east side of the vortex. The SBC lies in a part of the vortex where the Rossby number (defined in terms of the local azimuthal mean wind and the distance from the storm center) is of order unity. It coincides with a convergent asymptote in the streamline analysis and marks the innermost limit to which relative environmental flow can penetrate the highly rotational core of the vortex. An axisymmetric convective ring can develop from the SBC as it becomes more circular and wraps around the core of an intensifying hurricane. The cyclic intensity changes associated with these latter features are, however, confined largely to the vortex core where the Rossby number can be of order 10^2. Thus, an intense hurricane may be characterized as an axisymmetric, cyclicly varying core embedded within an asymmetric, largely steady-state envelope that resembles a weaker hurricane or a tropical storm.

AOML

On 17 and 18 August 1983, 30 h of continuous aircraft and radar observations were collected in Hurricane Alicia. Analysis of these data is largely complete and shows contraction of the original evewall, formation of an outer convective ring, and track variations associated with moving reflectivity features in the eyewall.

HURRICANE MODELING

This modeling work is based on a long-range plan to understand and predict the motion of a hurricane. Although there are several operational models for hurricane prediction, it is recognized that basic studies of

various physical and dynamical factors affecting the motion, as well as changes in intensity, are needed to make substantial improvements in the accuracy of prediction. The major question is to understand interactions among various scales of atmospheric motions and between different dynamic regimes. Progress in such understanding requires further tests with numerical models. To facilitate individual studies, which may range from the cloud scales of hurricane internal dynamics to the synoptic scales of tropical circulations, and also to ensure an efficient synthesis of these studies, a general-purpose base model is under development, using an accurate and flexible numerical method for grid-nesting. The method, tentatively called QSTING (Quasi-Spectral Time Integration on Nested Grids), can also be applied to other meteorological models that require high resolution in limited domains.

Of the mathematical-numerical problems in grid nesting, one is the Gibbs phenomenon, which may manifest itself as small, but far-reaching, oscillations of a field variable, when a sharp peak that is well resolved in a high-resolution domain is projected on outer domains of lower resolution. This is a serious problem with a hurricane model, where sharp wind maxima and a pressure minimum are expected to occur in the inner mesh of the highest resolution. We have found that a filter on fine-mesh fields, at the time of projection to the coarse-mesh domain, can adequately attenuate false oscillations, without damping the explicitly time-carried fields of the fine-mesh domain. Note that terms "fine" and "coarse" are used in a relative sense. In our multiple-nested model, a mesh is fine and coarse in relation to its supermesh and submesh, respectively. By moving inner domains as a hurricane moves, the Gibbs phenomenon arising from the intense hurricane core can be thus controlled.

Even with the moving-mesh model, however, signals of various scales still cross the interfaces of nested domains, because of local advection and wave propagation. The limits imposed by the change of resolution cannot be overcome by choice of a numerical method. Those small-scale signals that could not be resolved or would be severely distorted in the coarse mesh must be dissipated within the fine mesh, before they reach the interface. The practical limit of transmissible short waves further depends on the computational dispersion property of particular numerics employed by a model. The QSTING method allows four times more usable information to be carried than the finite difference method would for the same resolution. Even then, short waves below the limit must be removed before they reach the interface. To achieve the desired effect, we have introduced spatially variable filters with filtering power increasing outward to the interface. Since theoretical means to help the design of such filters are limited, we have had to depend on empirical tests with a one-dimensional model, and our present solution to this problem is not as definitive as we wish it to be. It is believed, however, that we have reached the point that further studies should be made in the context of physically more realistic spectral mix, which is not available in the one-dimensional test model.

The question of the physical validity of using a nested-grid model for hurricane prediction studies is not trivial, when we consider the role of cumulus convection in the hurricane and the need for incorporating mesoscale dynamics. There are many studies in the meteorological literature where nested grids or variable resolution models have been used. In most of them,

however, the outer region of coarser resolution is merely a buffering space of inner activities. With the present model of superior numerics, there is a greater possibility of simulating truly two-way interactions between the hurricane inner core and its synoptic environment, provided that the major portion of predictable information is carried in the scales that are comparable with, or greater than, locally defined radii of Rossby deformation. The deformation radii vary from a few tens of kilometers in the hurricane core to a thousand in the tropical synoptic environment, and the resolution of a model may vary in proportion. A convincing test of this simple speculation requires a three-dimensional nested-grid model. The present version being two-dimensional, there is still much work to be done.

OBSERVATIONAL STUDIES OF THE SOUTH FLORIDA SEA BREEZE

The field phase of the sea-breeze experiment was designed to provide a description of the mixed layer, cloud layer, and evolution of the sea-breeze circulation from shortly after sunrise until midafternoon when deep convection is normally prevalent. The role of the sea breeze in organizing the development of deep convection is being examined. Airborne Doppler radar data were collected on two days. These data are being used to specify the kinematic structure of mesoscale precipitation lines that were initiated by the sea-breeze circulation.

The analyses of the flight-level data have concentrated on comparing and contrasting the structure of the sea-breeze circulation on one day in 1980 and on a second 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 the 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. Interpretation of the data is aimed at understanding the role of the sea-breeze circulation in the timing of deep convection.

Preliminary analyses of airborne Doppler radar data from two of the sea-breeze flights have been completed. On one of the two days, high-quality data were recorded of a mesoscale precipitation line that was initiated by the sea-breeze circulation. Westward propagation of the line and its vertical structure may have contributed to the rainfall production. The representativeness of this case is being examined through study of FACE (Florida Area Cumulus Experiment) radar data. **AOML**

Plans FY 1985

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

The analysis of microphysical data in conjunction with radar data from a hurricane water budget experiment will dominate FY-1985 activities if the experiment is completed this hurricane season as planned. Detailed analyses

of the water contents and fluxes and transports will be completed for all flight segments and coordinated with Doppler radar and conventional radar data analyses.

Documentation of the two-dimensional image processing will treat the artifact rejection and the ice/water discrimination in detail, and a complete program listing will be included.

The ice data sample that has been reduced and surveyed will be analyzed in relation to dynamical features of the storm. An attempt will be made to composite the data with respect to updrafts in the eyewall. The data will be interpreted according to where the source regions of the ice occur, and the nucleation and/or multiplication processes necessary to produce the observed ice particle distributions.

Convective and Mesoscale

The analyses of the convective and mesoscale features of Hurricanes David, Frederic, and Alicia will be completed. During the landfall of Hurricane Alicia, radar data were recorded at several elevation angles approximately three times each hour. Software will be written to display these data in constant-altitude plan position indicator format. The three-dimensional structure of the convective-scale and mesoscale features in Hurricane Alicia will be examined with both land-based and airborne radars.

If nature supplies a suitable storm during the 1984 hurricane season, a hurricane eyewall experiment will be carried out. Analysis of the resulting data will begin in 1985.

Synoptic-Scale

Cooperative studies with NHC and NMC will continue to examine the effect of the ODW data on the operational analyses and hurricane track models. ODW data collected during the 1984 hurricane field program will be processed and distributed to other institutions. The data will be used in diagnostic and prognostic studies of hurricanes and in the evaluation of remote soundings from VAS.

Air-Sea Interactions

The Doppler radar study of Hurricane Debby's boundary layer will be completed.

The landfall study of Hurricane Alicia will be continued with analyses of the gust and damage fields and their relationship to the precipitation structure. The surface temperature dew point, and sea surface temperature fields will be investigated for evidence of adiabatic cooling, dry air intrusion, and upwelling.

It is planned to acquire additional color sea-state photographs for use in developing color-related descriptors of sea-state corresponding to Beaufort categories 3 through 19. In addition, high-altitude photos will be acquired as part of other experiments and added to the sea-state catalog.

During the Air-Sea Interaction Experiment planned for the 1984 hurricane season, photos will be compared with stepped-frequency microwave radiometer measurements as well as with surface winds measured by air-deployed drifting buoys. This study will also use highly reliable inertial navigation system flight-level wind measurements made near cloud base, and models of the planetary boundary layer (PBL), to reduce flight-level winds to the surface. Airborne Doppler radar measurements in the PBL will also be used for estimating surface winds.

HURRICANE TRACK PREDICTION

With the revised operational barotropic model, forecasts using ODW and VAS-derived wind data available from the 1984 hurricane season will be verified. The results for the 1984 season, combined with the results from the 1982 and 1983 seasons, will be used to suggest and/or make appropriate modifications to the model for best use of the additional data sources.

Research to develop an objective analysis scheme for the large-scale environment of hurricanes, which incorporates ODW and other available data such as rawinsondes, NOAA P-3 data, and Air Force reconnaissance data, has started. Gridded temperatures, moisture, and wind fields for Hurricane Debby (1982) will be produced at 50-mb intervals using a spline analysis package (SAP) coupled with a vertical filtering scheme. Horizontal filtering with the SAP will make it possible to remove the larger scale components of the data fields and examine the smaller scale components that will be subjected to statistical optimum interpolation. Development of this optimum interpolation scheme will be based on simple statistical assumptions and dynamical constraints. The goal is to retain information on the vortex scale and synoptic scales while filtering out information on the gravity wave and convective scales.

HURRICANE VORTEX DYNAMICS

Analysis of the ice nucleation experiments with the prototype nonhydrostatic hurricane model will be completed. Some time will be devoted to modification and simplification of the original ice-phase microphysics that will make it more economical and realistic. **AOML**

The details of a set of numerical experiments, including initial and boundary conditions, have been formulated to investigate the interaction between an isolated vortex and its environment, and its effect on hurricane asymmetry and motion. A quasi-spectral multinested-grid numerical model will be used in a barotropic, primitive equation (one-layer, shallow-water) form on a beta plane. The influence of divergence and advective nonlinearities will be evaluated in a parameter range, relevant to hurricanes, that has not previously been investigated. Near the vortex center, the local Rossby radius of deformation will be of the same order as the vortex scale, and the Rossby number will be very much greater than 1.

The analysis of the Hurricane Alicia data will be completed. These data appear to confirm earlier work on convective rings and the SBC. They also provide insight into the origin of convective rings.

HURRICANE MODELING

Procedures for moving the nested grids will be tested. The model will be used in a theoretical study of vortex motion on a beta plane. Studies of the hurricane boundary layer will be carried out.

OBSERVATIONAL STUDIES OF THE SOUTH FLORIDA SEA BREEZE

The airborne Doppler radar observations of the development of deep convection in the sea-breeze convergence zone will be completed and published. The analyses of the 1980 and 1981 aircraft data will be completed and documented.

TROPICAL WIND ANALYSIS

New research directed at objective analysis of ATOLL (Analysis of the Tropical Ocean Lower Layer) and 200-mb winds to extract information on the Atlantic tropical circulation is under way. The ATOLL analysis is an invaluable, virtually untapped data source. Objective analysis techniques will be applied to these data for the development of both a climatology and a history of quasi-steady and propagating disturbances for 1975 through 1983. During 1985, it is planned to complete the transfer of grids to AOML's mainframe computer system; the evaluation of raw data coverage; and the 10-day and monthly means for individual years and composites (9-year averages). This climatology will be issued as a technical report in collaboration with NHC.

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) and (2) Pollutant-Particle Relationships In the Marine Environment (P-PRIME), in which natural processes are studied to develop information essential to addressing specific environmental problems.

Accomplishments FY 1984

TAP

In FY 1984 AOML continued the development of interactive biological-chemical models of metal speciation as it relates to effects on ocean planktonic populations that serve as food sources to larval fish.

In cooperation with the SEFC (Southeast Fisheries Center), AOML conducted a cruise to the New York Bight aboard the NOAA Ship Researcher in January 1984. The purpose was to apply AOML-SEFC toxic metal/organic matter/plankton interaction models to highly anthropogenically impacted waters and to test

hypotheses regarding kinetics of formation of organic ligands in temperate, rather than tropical or subtropical, waters. Cruise results include the following:

- The New York Bight, although it appears to have a substantial chelation capacity for trace metals, appears to have an unusually small overall buffering capacity for acids.

- Sewage sludge, regardless of age and pretreatment, does not appear to be necessarily deleterious to either plankton or bacterial populations. In fact, under some conditions, e.g., nitrogen limitation, the addition of sludge may be beneficial to the productivity of the planktonic community.

- Present, commonly used, analytical methods for "Total Metal Concentrations" may be inherently artifactual in that they appear to be dependent upon the quality of dissolved organic material in the seawater sample analyzed. Methods tested included Anodic Stripping Voltammetry and Co-precipitation Atomic Absorption Spectrophotometry.

- Organic compounds (triglycerides) formed in cold waters are not inherently different than those formed in subtropical and tropical waters, and their autoxidation and condensation result in fulvic and humic materials with significant chelation capacity for metals. In fact, waters in the New York Bight Apex, near Montauk Point, Long Island, and off Georges Bank all had an excess of chelation capacity; i.e., dissolved metals were 100% complexed.

- Although complete, the complexing of metals in New York Bight waters is fragile in that almost any perturbation of the system releases free metal. These perturbations include collection and storage of samples and addition of triglycerides in the form of fish liver oil. Both of these procedures resulted in the release of free metals in samples collected.

P–PRIME

In FY 1984 AOML continued to contribute to understanding of the fate of river-borne pollutants at river/ocean interfaces. The basic hypothesis tested was that river deltas act as irreversible sinks for some pollutants that are scrubbed from the river outflow by biogenic and inorganic particles. Efforts were focused on the outflow of the Mississippi River, which represents the drainage from 41% of the contiguous United States. Specific results from the FY-1984 program include the following. **AOML**

- Determination of the combined particulate and dissolved river burden for lead clearly indicates a reduction of approximately 40% from levels in the mid-1970's. This is an apparent result of legislated reduction of lead in gasoline (gasoline additives account for 10%-12% of lead consumed in the United States and are the major source of pollutant lead) that was effected in the mid-1970's.

- A model was developed using distribution coefficients (K_D's) to define the partitioning of pollutants, e.g., lead and cadmium, between river-dissolved and particulate fractions. This model allows definition of the dissolved load at a river outfall for a given total pollutant burden.

K_D's developed for the Mississippi River have been demonstrated to be generic, and are transferable to other river systems, e.g., the Brazos.

- It was demonstrated, by analysis of interstitial water, that rapid particulate removal and burial of lead in sediments results in irreversible removal of it from the overlying water column. This is not the case with cadmium and manganese since diagenetic processes in the sediment remobilize these metals and allow diffusion back into the overlying water.

- Suspended particulate matter (SPM) flux from rivers varies on an hourly and daily basis as well as on a seasonal one. This is controlled to a large degree by tidal forces, which also control whether the major escape of SPM is by surface flow or near-bottom flow.

- SPM not removed near the river mouth is removed from the water column by biopackaging, i.e., ingestion by marine organisms and formation of fecal pellets.

Plans FY 1985

TAP

In FY 1985, AOML activities conducted in the TAP program will be dependent upon NOS/OAD (National Ocean Service/Ocean Assessment Division) decisions regarding proposals submitted to them. Present plans are centered on three basic activities:

- Conducting a second research cruise to the New York Bight area to study the speciation of metals and effects of sewage sludge input on this speciation when warm, stratified conditions exist and biological production is at or near maximum.

- Continue analysis of data and samples collected in the TAP program with the goals of (1) conducting a statistical analysis of biological samples relative to metal speciation, and (2) understanding the kinetics and binding constants of natural metal-organic complexes and their relationship to environmental variables such as temperature, light, and salinity.

- Developing biochemical methods for determining secondary productivity and the effects of environmental changes in this productivity.

P–PRIME

No further activity is planned in the P-PRIME program, owing to withdrawal of NOS/OAD funding.

MARINE OBSERVATION AND PREDICTION

AOML research in marine observation and prediction is described within three areas: (1) acoustical measurements of ocean currents, bottom topography

for charting and navigation, particulate distribution and transport processes; (2) development of new techniques to observe atmosphere, ocean, and surface parameters and application of remote-sensing techniques to study the physical processes of importance to maritime interests of the United States; and (3) research into improvement of current vectors and sea-state maps using two CODAR (Coastal Ocean Dynamics Applications Radar) units deployed in the Miami/Fort Lauderdale, Fla., area as a fully developed operational system in collaboration with the U.S. Coast Guard, the National Hurricane Center (NHC), and WPL.

Accomplishments FY 1984

ACOUSTICAL MEASUREMENTS

Data from the Chesapeake Bay experiment were analyzed; successful transverse Doppler measurements of the vertical component of the flow field associated with short-period internal waves were made. A theoretical explanation of anomalous experimental measurements of the acoustic backscatter from sets of different diameter particulates was derived using the concept of total acoustic cross section.

A cooperative program was established with elements of NOS to carry out the research that is required to understand the complex interaction of sound, including its transmission and reflection, with the diverse types of bottoms encountered in U.S. coastal and near-coastal waters. Ultimately, improved navigational charts and improved bottom topography and bottom-type maps will result.

TECHNIQUES DEVELOPMENT

Recent emphasis has been on the effects of wave refraction by ocean currents and the growth of waves in complicated geometries. The fundamental limiting factor to existing wave prediction models is the process of wave growth for a strongly curving windfield such as a hurricane or severe winter cyclone. Such storms, moreover, annually claim many lives. Radar-derived directional wave spectra have been obtained, which reveal some new insight into this process and suggest that most numerical models do not properly predict the direction and hence the height of waves for extreme conditions. This implies that other types of ocean models that attempt to predict the momentum transferred to the ocean by the atmosphere (storm surge models, for example) may be significantly in error for storms that are outside the class of calibration storms.

AOML

CODAR OPERATIONAL DEMONSTRATION

During FY 1984, AOML has been working with the Coast Guard, NHC, and WPL for the purpose of developing an operational demonstration of a two-unit CODAR observing system in the Miami/Ft. Lauderdale area. The system would provide, on a regional scale, in near real-time, observations of ocean surface currents and sea state. If shown to be operationally feasible, the system would be

turned over to a planned NOS Ocean Service Center beginning in FY 1986. Progress during FY 1984 consisted primarily of planning and coordination activities between the various groups that would be involved. The necessary equipment and personnel were all identified, and the site selection process was initiated.

Plans FY 1985

ACOUSTICAL MEASUREMENTS

- Deploy and operate a coherent transverse Doppler current measurement system at the Port of Miami in conjunction with the deployment of an Ametek-Straza Doppler current profiler by NOS personnel and with the Port of Miami circulation survey to be conducted by a contractor.

- Upgrade data analysis equipment and continue processing of data from previous year experiments.

- Continue analysis of Chesapeake Bay experiment acoustical data.

- Continue development of estuarine and oceanic particulate and pollutant transport models.

- Conduct laboratory experiments on the acoustic cross section of naturally occurring sand grains as well as field experiments using high-frequency acoustics to measure sediment in the benthic boundary layer in cooperation with Canadian and University of Miami investigators.

- Explore the possibility of cooperation with NASA to utilize zero-g environment for scattering experiments to avoid problem of particle settling in gravitational field.

- Develop a model or models of echo formation from various bottom types.

- Implement these models on the AOML computer system.

- Design an experimental program to provide data for model development and for model validation.

TECHNIQUES DEVELOPMENT

Hurricane imagery will be processed to yield two-dimensional wave spectra for comparison with model hindcasts. Ice imagery will be processed to yield ice concentrations and compared with in-situ results to determine tvpe sensitivity. Laser profilometer data will be processed to yield spectra of the roughness elements corresponding to the imagery.

CODAR OPERATIONAL DEMONSTRATION

All WPL CODAR equipment will be transferred to AOML by the start of FY 1985. Sufficient equipment exists to establish two shore stations and a data

dissemination station at NHC. Additional equipment purchases are necessary for the telecommunication links between stations and NHC, and for routine maintenance. AOML will establish shore stations at the Navy site in Fort Lauderdale, and at the Coast Guard site on Fisher Island. Data processed into current vector maps will be disseminated by NHC, and development of sea-state maps will begin at AOML.

MARINE RESOURCES

AOML conducts research in marine resources in two specific areas. One program studies the effects of venting of fluids within hydrothermal areas along seafloor-spreading centers on the ocean environment. This research is part of the NOAA/VENTS program. The second consists of research as to environmental controls on the year-class-strength of commercial U.S. fisheries. This project is a lead-in effort to the developing NOAA Fisheries Oceanography Cooperative Investigations (FOCI) initiative.

Accomplishments FY 1984

VENTS

In FY 1984, AOML spent considerable effort in a NOAA-wide task of developing the NOAA/VENTS program. This included the development of relevant and testable hypotheses, devising means of testing them, and the definition and allocation of resources. This was done through AOML participation on the VENTS Council. As part of this effort, AOML defined a research program on slow-spreading hydrothermal centers designed to determine the quality and quantity of hydrothermal venting and its effect on ocean systems. A major, multidisciplinary cruise was conducted to a representative section of a slow-spreading ridge (the Mid-Atlantic Ridge between 11°N and 26°N). By use of geophysical models developed during a cruise, in FY 1982, four sites of hydrothermal venting were confirmed by use of chemical indicators in the water column, near-bottom temperature measurements, hydrothermal constituents in sediments, and hydrothermal minerals on the seafloor.

In addition, previous work conducted in the TAG (Trans-Atlantic Geotraverse) hydrothermal area at 26°N was synthesized and published, including clear evidence that episodic "black smoker" type hydrothermal venting has been occurring in this area at a frequency of approximately every 10,000 years for the past million years.

FISHERIES–OCEANOGRAPHY RESEARCH

AOML is conducting research with a goal of understanding environmental controls on the year-class-strength of commercial fisheries so that such control can be predicted, thus allowing (1) better management of these fisheries and (2) better investment planning for their exploitation. Present efforts are directed to understanding how offshore (shelf) fronts control the feeding success of larval fish and thus, their survival and postlarval recruitment in estuaries where juvenile stages develop. The hypothesis being

tested is that a major control on the feeding success of larval menhaden and shrimp is the position, timing, and quality of offshore oceanic fronts such as those at the Mississippi River outflow to the Gulf of Mexico and at the Gulf Stream boundary with southeast U.S. shelf waters. In FY 1984, AOML research, conducted cooperatively with the Southeast Fisheries Center, documented a relationship between growth of Gulf menhaden, spot, and croaker larvae and the distribution of their food along hydrographic fronts at the Mississippi outflow. In addition, a biochemical tool (nucleic acid analysis) was perfected for determining the potential protein growth rate of larval fish, allowing us to establish the suitability of specific ocean fronts as feeding environments for larval fish.

Plans FY 1985

VENTS

Work will continue on determining the quality and quantity of hydrothermal venting along slow-spreading centers and the effect of venting on the ocean environment. In FY 1985 a second cruise will be conducted along the 11°N to 26°N section of the Mid-Atlantic Ridge to complete analysis of hydrothermal activity at the four sites positively identified during the FY-1984 cruise. In addition, a cruise will also be conducted to the Gorda Ridge off the west coast of the United States. The ridge is another representative slow-spreading ridge completely within the U.S. Exclusive Economic Zone. This cruise will be dedicated to developing geophysical criteria for locating hydrothermal activity on that ridge as well as for searching for geochemical signatures resulting from such activity.

FISHERIES–OCEANOGRAPHY RESEARCH

In FY 1985, AOML will continue to work cooperatively with SEFC to determine the environmental controls at oceanic fronts on feeding success and survival of larval fish. The FY-1985 effort will be focused on fronts created at the Mississippi outflow to the Gulf of Mexico and their effect on the feeding success of brown shrimp and Gulf menhaden larvae. A cooperative AOML-SEFC cruise will be conducted to the outflow area aboard the NOAA Ship Researcher in May-June 1985.

AIR QUALITY

AOML conducts research on air quality in two specific areas: (1) mature oceanic sources of acid rain precursors, and (2) radiatively important trace substances in the atmosphere. The latter is a lead-in effort to the developing NOAA/RITS (Radioactively Important Trace Species) program.

Accomplishments FY 1984

ACID RAIN

In FY 1984, AOML continued research on oceanic sources of compounds that are injected into the troposphere and react to form chemical species that produce acid rain. AOML's work was conducted on the premise that the production of these compounds is controlled by biological processes in the photic zone. The existence of a significant concentration of 1-alkenes in the upper ocean was documented, and it was further demonstrated that the transfer of these compounds across the air-sea interface, and subsequent oxidation, could account for the formic acid anomaly existent in the troposphere. This process is a significant contributor to the acidity of rain in remote regions. A joint ship-aircraft sampling program was completed in the equatorial Pacific along 150°W between 10°N and 10°S to study both biological and photochemical processes as they relate to the distribution of atmospheric gases. During this cruise a distinct vertical distribution in the turnover rates of sulfur-containing amino acids in the water column was documented. In addition, the existence of a diel cycle in these turnover rates was confirmed. These findings are important to understanding the biological processes that release sulfur-containing acid rain precursors, such as dimethyl sulfide and dimethyl sulfone, to the troposphere. In addition, AOML identified a maximum in the concentration of ammonia in precipitation in the equatorial Pacific Ocean.

RITS

AOML research in oceanic sources of radiatively important trace substances in the atmosphere is conducted as a lead-in effort to the developing NOAA/RITS program. Research in FY 1984 was conducted as a piggy back operation to AOML Acid Rain research. Part of this effort was an investigation of the existence of volatile components in the upper ocean and lower troposphere that are infrared absorbers (or which, when transferred to the lower troposphere from the ocean, could react to form such absorbers). A large suite of volatile samples was collected during the AOML joint shipaircraft equatorial Pacific study along 150°W, and analysis is proceeding. As part of this cruise effort, AOML also confirmed the existence of an ozone minimum in the equatorial Pacific in May-June 1984.

Plans FY 1985

ACID RAIN

AOML will continue to conduct research on oceanic sources of compounds controlling the acidity of rain. A significant part of the FY-1985 effort will consist of analysis of samples on hand from the 1984 effort and synthesis of the results of research conducted to date. AOML will also conduct a cruise to the trade wind region of the Atlantic to study the interaction of continentally derived tropospheric species with trace gases produced in the upper ocean of the subtropical North Atlantic Ocean.

RITS

During FY 1985, AOML will continue to conduct lead-in research to the NOAA/RITS program. A major emphasis will be placed on analyzing volatile samples collected in the upper ocean during the FY-1984 cruise and correlating their chemistry with that of tropospheric samples collected during the same operation. Similar studies will be conducted during the AOML Acid Rain research cruise to the subtropical North Atlantic in FY 1985.

PACIFIC MARINE ENVIRONMENTAL LABORATORY
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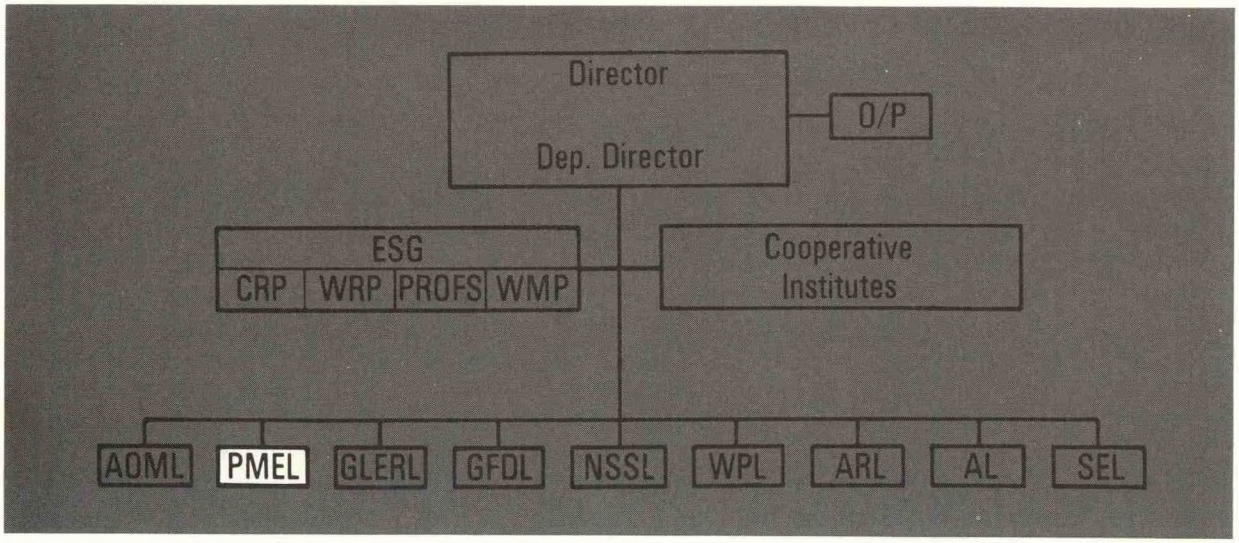

The Pacific Marine Environmental Laboratory (PMEL) is a mission-oriented government laboratory that conducts interdisciplinary scientific investigations in oceanography, marine meteorology, and related subjects. The current PMEL programs focus on climate, marine environmental assessment, marine observation and prediction, and marine resources. Studies are conducted to better understand the complex physical and geochemical processes that determine the extent of human impact on the marine environment; to define the forcing functions and the processes driving ocean circulation and the global climate system; and to improve environmental forecasting capabilities and other supporting services for marine commerce and fisheries. Products of PMEL's research are environmental information and predictive models that are disseminated by means of scientific papers, technical reports, and presentations at scientific and public gatherings.

Two cooperative institutes, the Joint Institute for Study of Atmosphere and Ocean (JISAO) and the Joint Institute for Marine and Atmospheric Research (JIMAR), established between NOAA and the University of Washington and Hawaii, respectively, provide a bridge between the academic community and PMEL scientists working in climate dynamics, environmental chemistry, tsunamis, and estuarine processes.

CLIMATE RESEARCH

During recent years there has been an increasing awareness of the impact of short- and long-term climatic changes on resource systems, particularly food and energy, and conversely, a concern about the impact of technology and population growth on world climate. When the National Climate Program Act was

passed in 1978, NOAA became the lead agency for U.S. research in climate dynamics. PMEL scientists have been heavily involved in the formulation and implementation of the NOAA Ocean Climate Program.

To predict climatic change, it is necessary to understand the processes of heat, moisture, and momentum exchange between the ocean and atmosphere, as well as the large-scale transport of heat by the atmosphere and ocean. The ocean climate research program investigates the problem in studies of both local (small-scale) and basin wide (large-scale) ocean dynamics and the coupled ocean-atmosphere circulation. Laboratory participation in multi-institutional field experiments has established the groundwork for present efforts in two national climate programs: Equatorial Pacific Ocean Climate Studies (EPOCS) and Tropical Oceans and Global Atmosphere (TOGA). These studies are testing the hypotheses that ocean surface temperature anomalies in equatorial regions have a pronounced effect on atmospheric circulation in both temperate and equatorial latitudes. A major research goal is to determine the relative importance of the physical mechanisms that generate anomalies in sea surface temperature distributions in the equatorial ocean.

Heat transport by major western boundary currents, the Gulf Stream and Kuroshio in the Northern Hemisphere, are also postulated to have an important impact on world climate. During 1984 a PMEL study focused on the Florida Current as part of the Subtropical Atlantic Climate Studies (STACS).

PMEL is also conducting two unique marine-chemistry research activities for NOAA under the National Climate Program. These activities relate to the ocean's behavior as a sink for atmospheric carbon dioxide, which has been steadily increasing over the past century. One project measures the flux of human-made fluorocarbons into the ocean in order to trace gaseous diffusion across the ocean-atmosphere boundary. The other project is examining the role of biologically produced, particulate calcium carbonate as an absorber of carbon dioxide at high latitudes. Together these studies will help determine the potential of the oceans for absorbing carbon dioxide.

Accomplishments FY 1984

EQUATORIAL DYNAMICS

El Niño/Southern Oscillation (ENSO)

During certain years, large interannual changes occur in the heat content of the upper layer of the tropical Pacific. Associated with these oceanic changes (anomalies of 2° to 5°C in sea-surface temperature are observed) are perturbations in the atmospheric circulation which appear to initiate the ocean changes. After the near-surface heat content of the ocean is modified, further atmospheric perturbations are generated by process of air interaction with the ocean. The phenomenon of mutual interaction of the tropical ocean with the global atmosphere on interannual time scales has been termed the El Niño/Southern Oscillation (ENSO) problem, and is the main focus of the NOAA-sponsored EPOCS program.

Research at PMEL on the ENSO problem is coordinated through the EPOCS program. During the past year our field program continued deep sea current moorings; measurements of wind, current, and temperature at the Equator in the eastern Pacific; north-south transequatorial sections to measure velocity, temperature, salinity, and dissolved oxygen across the major components of the current system in the eastern Pacific; and time series of sea level at the Galápagos Islands. Ship-of-opportunity subsurface and surface temperature data were also analyzed.

Equatorial Dynamics During 1982-83 ENSO Event

The 1982-83 ENSO episode presented an excellent opportunity to study several aspects of the heating and cooling cycle of the upper equatorial ocean. Shipboard and moored temperature and current meter measurements have been used to describe and document the eastward movement of heat in the upper water column to a depth of 200 m. The onset of the 1982-83 El Niño was observed in June 1982 for locations west of the dateline, in July for locations in the central Pacific such as 160°W, in August at our mooring sites (0°, 95°W, and 0°, 109°30'W), and in September at the coast of Peru. From mid-August 1982 to mid-December, the heat content rose steadily in the eastern Pacific. Maximum values occurred 1-2 weeks earlier at 109°30'W than at 95°W. During September and October, the heat content increased very rapidly. At 95°W the time rate of change of heat from mid-August to mid-December was 5-10 times larger than could be accounted for by surface heat flux, assuming the net surface heating during 1982-83 was not much different than during the 1972-73 El Niño. Between mid-December 1982 and 1 March 1983, there was a rapid drop in heat content with the onset of subsurface cooling and, consequently, the reestablishment of the thermocline at its former depth. This was associated with the deceleration of the eastward currents and the onset of westward flow at depths where the equatorial undercurrent normally occurs. Although a decrease in the heat content at 109°30'W continued after 1 March 1983, the upper ocean heat content at 95°W increased again, reaching a secondary maximum around 1 June. This maximum was associated with a sea level rise at the Galápagos Islands.

Some of the large-scale heat and salinity changes that occurred during the 1982-83 El Niño may be attributed to local air-sea interaction (e.g., lowering of surface salinity by precipitation) and others may be attributed to a combination of local air-sea interaction and advection. A program of sampling of surface salinity and subsurface temperature (by XBT's) has been carried out from merchant ships of opportunity. Low salinities observed near the Equator along a trackline between 20°N, 158°W, and 20°S, 180°W, were primarily the result of the greatly increased rainfall in the central Pacific, related to eastward movement of the warm water and associated atmospheric convection. Effects of lower salinities on the mass field accounts for about one-third of the total dynamic height change observed at island stations.

Additional merchant ship sampling was done along lines that cross the Equator at 160°E and 100°W. These measurements showed that a drastic shift in the mass field occurred, resulting in the appearance of a westward pressure gradient between the western and central Pacific from mid-1982 to the beginning of 1983. For a 5-month period the dynamic height of the sea surface was

either higher in the east than in the west or roughly equal. These time changes of the mass field represent a change in the forces that drive the currents at the Equator.

Since 1979 PMEL has maintained an array of bottom-moored pressure gauges at the Galápagos Islands to study low-frequency equatorial waves. These gauges, combined with others in the equatorial wave guide, have provided a continuous record of the onset and demise of the large (~0.5 m) sea level perturbations associated with the 1982-83 ENSO event. The timing of this onset was demonstrated by gauges on Galápagos (0°3'S, 91°28'W) and Jarvis (0°23'S, 160°W) Islands, which showed the latter leading by 28 days. The 28-day travel time corresponds to an eastward phase speed of 3.2 m s^{-1}, which is near that expected for a first vertical mode equatorial Kelvin wave. Cross correlation of these two sea level records showed significant correlation peaks corresponding to the 28-day delay and a 56-day delay. This latter peak was identified as a second vertical mode Kelvin wave. This identification was supported by demonstrating that a combination of first- and second-mode waves in phase at Jarvis would, through modal dispersion, lead to the slower sea level rise time observed at Galápagos. A final significant, positive cross correlation peak between Jarvis and Galápagos was observed, Galápagos leading Jarvis by about 80 days (corresponding to a westward phase speed of 1 m s^{-1}). This peak was tentatively ascribed to a first vertical, first meridional mode equatorial Rossby wave. Both the second-mode Kelvin wave and the Rossby wave play prominent roles in theories of equatorial ocean dynamics. PMEL's measurements are the first evidence for these signals in the observational data.

Dynamical studies of the near-equatorial circulation suggest that small-scale turbulent mixing should play an important role in the momentum balance. Analysis of horizontal-velocity shear and density data collected using the PMEL profiler TOPS (Total Ocean Profiling System) along 110°W from 10°N to 7°S were used to study the variability of fine-scale Richardson Number (Ri) statistics in the depth interval 150-900 m. In this regime, shear and strain are dominated by the fine-scale rather than the mean fields. Results showed that the extraequatorial band (4°-10°N) exhibited shear and strain spectra as well as Ri statistics that were consistent with middle-latitude internal-wave model predictions. However, near the Equator an enhancement of shear and strain variance is found along with an accompanying increase in the occurrence of Ri less than one-fourth, suggesting large regions of active mixing. Middle-latitude internal wave models cannot explain this enhancement; the inclusion of equatorial trapped waves or other processes is required.

Satellite imagery has shown that during part of the year the sea surface temperature (SST) front between colder water at the Equator and warmer water to the north is wavelike in structure. These fluctuations in the position of the temperature front have wavelengths of approximately 1,000 km and propagate westward at about 40 km/day. Surface temperatures in vertical sections of temperature drawn from the XBT data are in quantitative agreement with satellite SST's along the Equator. These XBT sections show a phase shift to the west. If this pattern extended far enough off the Equator, it would indicate a geostrophically induced equatorward flux of heat. This result agrees with heat flux calculations from drifting buoys. These calculations have shown that eddies, which are located in the trough of the waves and translate westward with the wave phase, effect an equatorward transport of heat that amounts to about two-thirds the poleward heat transport of the divergent Ekman transport.

Statistical Analysis of Historical Data

Global marine data sets recently have been compiled from ships' deck logs. These data sets have been examined for evidence of long-term, large-scale climate changes as reflected in fields such as sea surface temperature and sea level pressure. However, there is considerable uncertainty about the reliability of results based on these historical data sets, since the ship-of-opportunity observations contain both random and systematic errors and since the observations are generally sparse in time and space. Rigorous statistical techniques have been developed for analyzing data sets back to the level of individual ship observations. Appropriate autoregressive models were determined for the daily, monthly, and annual time scales. These models are used to generate artificial, but realistic, time series of daily values of SST and sea level pressure. These artificial time series correctly reproduce the statistical properties of the actual data. By use of Monte Carlo techniques, time series can be randomly sampled and probability distributions constructed of the sampling errors as a function of location and averaging period. These distributions can then be used to place confidence limits on climatic signals.

El Niño Effects Off the Pacific Northwest Coast

A compilation of sea levels showed that El Niño events of 1941, 1958, and 1982 had large coastal effects off Washington and British Columbia. Significant positive temperature anomalies were observed to extend more than 200 km offshore and to depths of about 500 m. The effects at middle latitudes (47°-48°N) appear to have been generally similar for the 1941, 1957-58, and 1982-83 El Niños. The sea-surface temperature anomalies were larger in 1958 than in 1983; however, the 1958 event seemed to decay more quickly. The offshore extent of the anomalies was about the same in all three events. Unusually warm water extended out to about 127°W, more than 200 km and about half the extent off California. The temperature sections strongly suggested northward flow along the continental slope in February 1958, near the peak of the El Niño, implying a southern source of water. The vertical distributions (to ~500 m) show that a relatively large volume of water was involved.

STACS

PMEL

Cross Stream Voltage Measurements of Florida Current Transport

Measurement of the voltage difference across the Florida Current from Jupiter Inlet, Fla., to Settlement Point, Grand Bahama Island, utilizing submarine telephone cables has been established as a useful method for accurately and continuously recording the fluctuations in transport. The cable voltages are converted to transport units by multiplying with a linear calibration factor found by comparing the cable voltage data with transport values from velocity-profiling data. The rms difference between cable and profiling data was small (less than 3% of the mean).

The Florida cable consists of an insulated copper wire surrounded by steel armor. One problem encountered is that sudden voltage changes have been observed since 1983 that are due to random switching of the cable-to-seawater ground contact during normal operation of the cable (from mainly copper to mainly armor). An analysis technique has been developed that effectively

removes these sudden jumps by least-squares fitting a Heaviside function to locally detrended series. Results indicate that the cable can be used, provided the seawater contact at Settlement Point is the Ag-AgCl electrode in the seawater basement of the cable block house. Eliminating all the offsets would require repairing or replacing the cable.

Telephone Submarine Cables

Telephone submarine cables cover many parts of the ocean and are particularly well suited to observe western boundary currents. Telephone cables, however, contain repeaters that are used to amplify the voice signal and are powered by a shore-based constant current source. The return path for d.c. power current is through seawater via the ground points near the current source and at the far end of the cable. The d.c. current flowing through the repeater causes a constant voltage drop across each repeater. Measurements of the voltage difference between the ground points of telephone cables contain three parts: (1) the voltage difference caused by ocean currents; (2) the voltage caused by geomagnetic variations; (3) the voltage caused by the sum of the voltage drops across all repeaters. The time-dependent part will be due to repeater noise caused by variations in the d.c. current source, temperature effects on the repeaters, and aging of the repeaters. Preliminary analysis has shown that for transatlantic submarine cables the net transport will vanish and the cable voltages can be used to measure ambient water temperature. For typical voltage measurements a cable could sense mean sea floor temperature fluctuations as small as 0.0001°C. A time history of such fluctuations would be useful for ocean climatic studies.

CARBON DIOXIDE RESEARCH

Since about 1850, human activities, including the burning of fossil fuels and deforestation, have resulted in an increased amount of CO_2 in the atmosphere, from somewhere around 270 ppm to a little more than 340 ppm. This phenomenon is thought to affect the Earth's radiation balance and thereby increase the Earth's temperature. Major repositories for fossil-fuel-derived CO_2 are terrestrial vegetation, the atmosphere, and the oceans; each of the last two contains close to 50% of the excess according to recent estimates. The buildup rate of atmospheric CO_2 depends on the oceanic uptake rate of carbon dioxide, which is controlled by diffusive and convective mixing processes, by sinking and decomposition of biogenic particulates, and by air-sea exchange rates.

Because the oceans can act both as a source and as a sink for atmospheric carbon dioxide (particularly in upwelling and downwelling areas) PMEL scientists conducted an interdisciplinary study of the dynamics of the carbon dioxide system in the surface and intermediate waters of the central South Pacific during FY 1984. The purpose of these investigations was to study the dynamics of the CO_2 system and gas exchange along meridional transects that include major upwelling and downwelling regions of the South Pacific.

During February through May, two meridional sections were made of total carbon dioxide, pCO_2, alkalinity, freons, suspended matter, calcium, salinity, temperature, oxygen, and nutrients in the central South Pacific. In addition,

atmospheric and surface ocean carbon dioxide measurements were made in cooperation with scientists from GMCC. The preliminary data indicated a significant meridional gradient of seawater pCO_2 concentrations along the 150°W transect. Maximum supersaturation occurred near the Equator and just north of the subtropical convergence. The equatorial pCO_2 concentrations were similar to values obtained during the pre-El Niño 1979-80 FGGE expeditions, although broad regions of anomalously warm surface water and high pCO_2 concentrations were still encountered in south equatorial latitudes. These results provide additional evidence that the equatorial zone near 150°W has, for the most part, returned to pre-El Niño conditions and upwelling-induced supersaturations are prevalent from about 6°N to 4°S. The atmospheric data also show pCO_2 enrichments in the region between 15°N and 12°S, suggesting that the supersaturated water is releasing significant amounts of CO_2 to the atmosphere.

The results of the freon measurements clearly demonstrate their usefulness as a conservative tracer of upwelling processes in the equatorial region. At 10°N, low-freon water (<0.2 pmoles l^{-1}) rises to within 200 m of the surface. This feature coincides roughly with the 26.5 sigma-t surface. This vertical displacement is the result of divergence along the north equatorial current. Near the Equator, a doming of the freon contours occurs as a result of the Ekman divergence. A subsurface freon maximum occurs south of 2°S, between 50 and 150 m. This freon maximum is associated with a salinity maximum developed by the subsurface geostrophic flow toward the Equator. Farther to the south the freon isolines slope downward, coinciding with the deepening thermocline. These results indicate that the general patterns of the freon distributions closely follow water mass movements in the equatorial zone and, therefore, are an excellent tracer of the dynamic processes occurring along the Equator.

Plans FY 1985

HAZARDOUS WAVES

- The field program launched in 1983 to study the processes affecting heat content of the upper layer of the ocean along the Equator between 140°W and 110°W will be continued. This program will involve deep-sea moorings with subsurface current meters and thermistors, measurement of surface winds and air temperature, and profiling measurements of temperature, salinity, and velocity (TOPS and Ametek-Straza Doppler-shift acoustic current profiler). This EPOCS program is coordinated with the Tropic Heat Program sponsored by the National Science Foundation. **PMEL**

- The 6-year records of currents and temperature at 100°W (continuing this year) and of sea level at the Galápagos (to be terminated this year) will be analyzed for evidence of zonally propagating signals along the Equator as part of EPOCS.

- The predictability of El Niño events will be studied, using statistical procedures applied to updated historical sets. Dynamical models predicting El Niño events will be verified, using recently devised data/model intercomparison theory.

- Additional satellite imagery will be processed and compared with ship, drifting buoy, and mooring data to investigate equatorial long wave dynamics. The effect of the presence or absence of long waves on the lateral fluxes of heat and momentum near the Equator will be examined. In addition, special effort will be made to process the satellite data to compute SST's in the equatorial Pacific from April to November 1982 in order to describe accurately the onset of the El Niño.

- The merchant-ship-of-opportunity data set will be analyzed further to determine the vertical and horizontal structure of the major changes in the thermal and dynamic height field during the 1982-83 event. Comparisons between ocean numerical models and the thermal data will be carried out to provide model verification.

- An ocean numerical modeling effort will be undertaken in support of the EPOCS and TOGA programs. FY 1985 will see the acquisition of computer equipment, installation of a variety of numerical ocean models, and the beginning of a large-scale upper ocean and lower atmosphere data analysis effort.

STACS

- The collecting and analyzing of cable voltage from Florida Straits will continue. An effort will begin to turn operations over to NOS. Active submarine telephone cables will be tested for voltage and temperature measurements, and electromagnetic modeling of the Florida Current will be pursued. Time domain analysis for electromagnetic response functions will be used to remove geomagnetic noise.

CARBON DIOXIDE RESEARCH

- Initiate an oceanic CO_2 monitoring program in the North Pacific.

- Complete development of the pCO_2 sampling system.

MARINE ENVIRONMENTAL ASSESSMENT

Marine environmental assessment at PMEL emphasizes understanding the complex physical and geochemical processess that ultimately determine the health of the marine system and its ability to assimilate pollutants. Included in this area are studies of suspended-sediment transport and geochemistry, distributions of hydrocarbons and synthetic organics, coastal and estuarine circulation, theoretical modeling of pollutant transport processes, and a program in marine sources of acid rain. 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. Two major activities at PMEL are studies of the long-range fate of chronic pollutants in marine waters and oceanic precursors to acid rain.

Accomplishments FY 1984

LONG-RANGE-EFFECTS RESEARCH

In response to the Marine Protection, Research and Sanctuaries Act of 1982 and the National Ocean Pollution Research and Development and Monitoring Planning Act of 1978, PMEL has addressed environmental concerns associated with transport and marine disposal of municipal waste water and the reaction of marine systems to continuous influx of pollutants. Under the NOAA Long-Range-Effects Research Program, PMEL is examining the role of suspended particulates in transporting pollutants or in removing them from the marine system. In support of these studies researchers are investigating the mechanisms by which heavy metals and organic pollutants adhere to particulates. As these processes become better understood, we will be able to assess the long-term effect of chronic, low-level input of pollutants into the marine system.

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.

Pollutant Transport in the Water Column

Pollutants are derived from both natural and human sources, including riverine, atmospheric, municipal and industrial sewage discharge, and dredging operations. Mass balance calculations for many indicate that human sources exceed the natural sources and buildup in sediments occurs over decadal or longer time scales. The assimilative capacity of an estuary is a function of the individual pollutant's physiological effects on the indigenous marine life, residence time in the estuary, biological availability and uptake, and the physical and chemical transformations occurring in the water column and in the sediments. During FY 1984, PMEL scientists have made significant advances in understanding of the physical and chemical processes controlling the distribution and fates of toxic trace metals and hydrocarbons in the Puget Sound Estuary.

Studies of the transport of water and particles in the main basin of Puget Sound are important because they allow us to evaluate this estuary as a trap for dissolved pollutants as well as particle-borne pollutants and to 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 plays a dominant role in 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. 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.

A firm mathematical foundation for the concept and consequences of refluxing has been developed. Refluxing between the seaward-flowing surface layer and the landward-flowing deep layer of a reach leads to the build-up of pollutants, which would not occur in the classic "conveyor-belt" view of fjord circulation. A mathematical model applied to Puget Sound reveals that conservative pollutants are broadcast throughout the system, reaching significant levels landward as well as seaward of their site of introduction. This model provides a tool to study the effects of present and proposed pollutant inputs on a basin-wide scale.

Cross-channel variability of axial currents at a location in the southern part of the main basin of Puget Sound was studied using 21 current meters on six moorings across East Passage in March-April 1983. Mass transport calculations show a net up-estuary flux of 22,000 m^3 s^{-1} through East Passage. Flow in this part of Puget Sound is geographically controlled, and the net flow is clockwise around Vashon Island. At subtidal time scales, three circulation modes were evident during the 31-day period of observation: (1) an out-estuary wind-driven flow in the near surface (upper 10 m), (2) a near-bottom layer (150-200 m) dominated by density currents that propagate up-estuary after generation at the entrance sill to Puget Sound, and (3) an intermediate layer (25-75 m) modulated at fortnightly intervals by nonlinear mixed tides.

In the main basin of Puget Sound, primary production and the concentration of phytoplankton pigments in euphotic zone suspended matter vary sharply on weekly scales. These variations create a natural tracer for following the transport of particulate matter out of the surface waters. Weekly concentration of pigments in the sediment trap material quantitatively followed the pigment concentration in the euphotic zone suspended matter. Such a coupling indicates a rapid vertical transfer of surface-originating particles by organic aggregates. The concentration of carbon in the flux, however, varied on a broad seasonal scale after smoothing of short-term variations in production. The relative stability of the carbon flux arises from at least two sources: (1) a balance between terrestrial sources of carbon during the high-runoff winter season and in-situ primary production in spring and summer, and (2) cycling of carbon through the zooplankton population.

The carbon delivered to the basin floor as measured by settling particles captured in the sediment traps can account for only about one-third of the carbon utilized by benthic oxygen uptake and sediment burial. Additional transport pathways are important. Field and theoretical investigations into this process suggest that the annual mass of particles delivered to the deep water by refluxing is comparable with that delivered by settling.

The relative trapping efficiency of the various metals by the sediments is largely dependent upon scavenging of trace metals by particulate materials suspended in the water column and their subsequent deposition. From a 2-year study of trace metal fluxes in the main basin of the sound, PMEL scientists have shown that scavenging by hydrous oxide and organic phases causes rapid

uptake and sedimentation of several trace metals. For example, our mass balance calculations indicate that of the total amount of lead and copper entering Puget Sound, more than 90% is retained in the underlying sediments. Hence, the scavenging processes by particulates provide a most efficient mechanism for retaining toxic metals within the estuary.

A new way of estimating the settling velocity spectrum of wastewater effluent has been developed. Previously available methods are inaccurate because the settling column experiments must be run at particle concentrations at which particle coagulation is known to occur. In this new method, particles at very low initial concentrations settle to their isopycnic levels in a linear-density stratified column. Particle size distributions are determined by Coulter Counter from drawn samples. By using this method, the wet density and size distribution of particles in a sample from a wastewater treatment plant were measured in the 1.0-1.4 g cm^{-3} density and 1.0-64-μm size ranges. Supplementary measurements of size and density beyond these ranges provided sufficient coverage to construct a composite settling velocity distribution. The method is believed to provide results free of flocculation effects because the measurements may be made on samples at low initial concentrations (<10 mg l^{-1}).

Bottom Boundary Layer Processes and Pollutant Accumulation

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.

Particulate-borne pollutants in estuaries are often resuspended from the bottom and transported by tidal and other currents. Predicting how far such pollutants are transported and where they are deposited permanently requires a detailed understanding of the processes at work in the bottom boundary layer.

A high-resolution model for the unstratified bottom boundary layer is being developed at PMEL to predict profiles of currents, bottom stress, and turbulent diffusivity needed in studies of sediment resuspension and transport. The model has been calibrated with observed tidal currents in Puget Sound and by comparison with analytical theory. **PMEL**

A comprehensive review was completed on the tides and tidal currents in the Puget Sound region which brings together in one publication knowledge from a host of scattered and largely unpublished sources as well as new observations taken by scientists at PMEL. The study shows that the general distributions of the tides and tidal currents are known but that the tidal dynamics and the smaller-scale tidal features need to be studied further before the tidal regime is understood in detail. This work provides essential information for the calibration of tide models for Puget Sound.

The first estimates for an in-situ erosion rate of fine-grained sediment in a marine environment have been made using an advection-diffusion model developed at PMEL that was tuned to observations of time-dependent currents and sediment concentration made near the bottom of Puget Sound. Using a power

law form for the erosion rate as a function of bottom stress, the erosion rate was found to depend on the fourth power of the bottom stress. The power law also fits results from laboratory studies. The rapid increase in resuspension with increasing bottom stress indicates that the stress must be modeled accurately to give realistic predictions of sediment transport. A number of boundary layer models have been developed at PMEL to study and predict the behavior of suspended sediment, bottom stress, and turbulence in the presence of tidal and other time-dependent currents. An active field program is being carried out in connection with the modeling effort. This boundary layer research will provide bulk formulas for use in regional models of sediment transport.

The high-resolution boundary layer model has been adapted to shallow flume conditions and extended to include suspended sediment. Predictions of sediment transport for different flow conditions match observations and give additional evidence for the power law form of the erosion rate. One result of this work is that there does not appear to be a critical stress for fine-grained sediment below which the sediment is not resuspended. Even when the currents are small, some resuspension and transport are occurring.

The major particulate hydrocarbon transport processes appear to be rapid vertical transport through the water column and resuspension and lateral transport in the bottom nepheloid layer. The hydrocarbons are ultimately trapped in the fine-grained bottom sediments of the main basin. The sediments record the changing inputs during the past century. Hydrocarbon concentrations from sediment cores increase since the 1900's, reflecting the industrialization and urbanization of the area.

Recent analysis of 210-Pb and 137-Cs profiles from cores taken to greater depths in the main basin, with a coring device that minimizes core distortion, shows that the bottom material is accumulating at rates from 0.49 g cm^{-2} yr^{-1} to 1.12 g cm^{-2} yr^{-1}. These rates indicate that the surface layer, which is subject to bioturbation, can be as thick as 35 cm, suggesting that at some locations the bulk of pollutants dating as far back as the early 1960's is still being actively mixed in the surface layer and is still accessible to the biota. Though these sedimentation rates are less than one-third those of the longer term rates for sedimentation in Puget Sound based on geophysical data, they are reasonable in light of current knowledge of volumes of recent sediment input from riverine and shoreline sources.

The overall goal of the bottom boundary layer work is to quantify the patterns and redistribution processes for contaminants. In the past year, an integration of previous work was continued 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 large.

ACID RAIN RESEARCH

The ocean is a major source of sulfur to the atmosphere. Plankton in the ocean's photic zone produce dimethylsulfide, a reduced organic sulfur compound, which diffuses from the surface waters into the atmosphere. In recent years there has been increasing interest in quantifying this sulfur source. This interest has developed from concern over acid rain and the

influence of marine and terrestrial sources of organic sulfur on the chemistry of precipitation. These data are necessary to assess the significance of anthropogenic sulfur emmissions. With prevailing westerly winds, the west coast of the United States is particularly susceptible to oceanic sulfur sources. There are many areas in the Pacific Northwest that are ecologically sensitive and have a very low buffering capacity for acidic precipitation.

PMEL has conducted several cruises in the north Pacific Ocean to measure the concentrations of dimethylsulfide. These concentrations are used to calculate the oceanic input of sulfur to the atmosphere. The flux is calculated using the stagnant film boundary layer model. Adopting a mean surface concentration along the west coast of the United States of 50 ng S 1^{-1} and a piston velocity of 2.6 m day^{-1}, the mean flux of sulfur to the atmosphere is 36 kg km^{-2} yr^{-1}. If we assume an area along the coast extending out 1000 km to be the area affecting the coastal states, the net flux of sulfur to the continent is 0.065 Tg yr^{-1}. This is approximately 20% of the combined total anthropogenic emissions from California, Oregon, and Washington, and is equivalent to the input from Mount St. Helens during the eruptive period of March 1980 to September 1982.

Plans FY 1985

LONG-RANGE-EFFECTS RESEARCH

- Quantify source and sink terms for hydrocarbons in Puget Sound.
- Investigate hydrocarbon associations with suspended and settling particulates.
- Calculate the time scales associated with the flushing of a conservative substance from a refluxing fjord system.
- Compare predicted concentrations from the Puget Sound Reflux Model with independently measured tracer concentrations.
- Assess annual variations in flow and transport from the existing data base and measure cross-channel variations at the site of the longest time series in the northern part of the basin. **PMEL**
- Extend the boundary layer models to include the interactions of time-dependent currents, turbulence, suspended sediment, and trace metals in the bottom boundary layer.
- Develop simple transport models of suspended sediment to predict erosion and deposition patterns for selected sections of Puget Sound.
- Develop models for density intrusions and their effects on sediment and pollutant transport.
- Quantify recycling processes for trace metals from sediments.
- Study trace metal uptake by and release from marine plankton.

- Use recently acquired data to look at small-scale variability in sedimentation rates and relate these to the hydraulic and erosional regimes.

ACID RAIN RESEARCH

- Conduct additional cruises off the west coast of the United States to assess the seasonal variability of dimethylsulfide concentrations.

- Carry out laboratory studies to measure the solubility and diffusivity of dimethylsulfide in seawater.

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. Research subjects include sea-ice processes, hazardous winds, hazardous waves, fisheries oceanography, and tsunami propagation and run-up. PMEL scientists work closely with colleagues from operational service components of NOAA, such as the Northwest Ocean Service Center and the Navy/NOAA Joint Ice Center. Studies of sea-ice processes are also applicable to NOAA's climate research. These studies of coastal meteorology, physical oceanography, and sea-ice processes are carried out through a combination of field measurements, remote-sensing techniques, and numerical modeling.

Accomplishments FY 1984

SEA ICE RESEARCH

MIZEX-West Experiment

Over the past year, scientists from PMEL have completed analysis of data from several past experiments in the Bering Sea ice pack. Research results have been used to implement the NOAA sea-ice forecasting model at the National Meteorological Center (NMC) and to plan future studies.

Major results are from the Marginal Ice Zone Experiment (MIZEX), which took place in the southern Bering Sea in February 1983. The experiment was a multidisciplinary, multi-institutional program that addressed a broad spectrum of physical processes related to the marginal ice zone. As part of this experiment, PMEL placed an array of eight ARGOS-tracked transponders on the ice at 60.6°N, 170°W, on 10 February. The transponders were tracked westward and then southward around St. Matthew Island until 28 February when the last transponder broke out of the ice and ceased transmitting. These stations measured mean winds and temperatures every half hour at a height of 3 m, and mean ocean currents and temperature at a depth of 2 m under the ice. The transponder tracks show that the array maintained its original shape over the entire period of 10-22 February in spite of a near collision with St. Matthew Island, supporting the idea that ice-ice interaction was negligible. The wind

factor, the ratio of ice speed to wind speed, and drift angle of the floe to the right of the wind showed no discernible variation as a result of the transponders' proximity to the island.

The two dominant forces that control ice motion in this region are the wind drag and the water drag. Surface winds and temperatures during MIZEX agreed well with synoptic scale weather patterns. Current directions were well correlated with the wind directions and nearly colinear. The air and water drag on the ice were computed by integrating momentum balance equation and substituting wind speeds, current velocities, and ice drift velocities measured on individual floes. For the southern Bering Sea, drag coefficients were found to be .0030 for air referenced to a wind speed at 10 m, and .020 for water drag at -1.1 m. A similar air drag value was calculated from turbulence measurements made by the NOAA P-3 aircraft, suggesting that aircraft offer an excellent method of obtaining air drag coefficients for regional ice drift models. During MIZEX it was also confirmed that wind acceleration at the ice edge is a result of reduced friction because of fewer floes and baroclinic forcing, as predicted by modeling studies.

Modeling of Sea Ice Drift

A critical issue for modeling ice drift in the Bering Sea is to understand the influence of bathymetry on the wind drift of ice since most of the ice-covered Bering Sea is less than 70 m deep. The free-drift equations for ice motion, which assume momentum balance between air and water stress and the Coriolis parameter, have been solved during this past year for ice floes in a shallow sea of neutral density stratification, typical of many high-latitude continental shelves. Steady solutions for ice drift and current velocity have been obtained as functions of wind stress, ice thickness, and water depth. The ocean is modeled by second-order closure using the high-resolution boundary layer model developed at PMEL, which allows continuous solutions from 5-m depth to deep water.

The solutions show that there is little dependence on water depth for depths greater than 30 m, because turbulent mixing is a decreasing function of water depth and offsets other influences of finite depth. However, for water depths less than 30 m, ice velocities can change rapidly with wind speed and water depth; and the presence of turbulence from tidal shear is very important for coupling wind-driven ice drift to the bottom. For the deep-water limit, the second-order closure solution confirms analytic solutions, used in the NOAA ice-forecasting model, that indicate an increase of 20% in the ratio of ice speed to wind speed as the wind speed increases from 10 to 20 cm s^{-1}.

PMEL

Ice Extent Forecasting Model

A model to forecast sea ice extent for the Bering Sea, developed at PMEL, was operationally tested at NMC during the 1983-84 ice season. The model balances ice advection and thermodynamic processes to determine a new ice edge location from forecasts of winds and air temperatures derived from the NMC spectral atmospheric forecast model. The experimental forecasts began in mid-December and were available in digital format to analysts at NMC and the Joint Ice Center (JIC). On 31 January the first experimental graphic product was sent on the facsimile circuit to the NWS Alaska Region for evaluation by

the Ocean Service Unit. Forecasts subsequently were sent to Alaska on Tuesday, Thursday, and Saturday until 28 June when the Bering Sea became ice free. A joint numerical evaluation project is being carried out by scientists from PMEL and NMC. Preliminary results indicate that the movement of ice in the southern and central Bering Sea is predicted to within 15% when forecast winds match the observed winds. Also, the forecast model was found useful at six days, apparently because the ice is an integrator of atmospheric and oceanic processes and because the spectral atmospheric model appears to perform well in winter at 60°N latitude.

The ice model does not contain enough physics to be applicable to the extreme northern Bering and Chukchi Seas, so that extension of the forecast model northward depends on tackling some difficult scientific problems. The principal missing physics is the effect of barotropic and baroclinic currents and the influence of islands and headlands on the drift of the ice.

Ice Edge Physical Oceanography

Currents on the central Bering Sea shelf between the 50-m and 100-m isobaths are weak and variable during the ice-free months. The resultant northwestward flow has mean current speeds of less than 5 cm s^{-1}, and frequent flow reversals occur. An intensive suite of current, temperature, and salinity data was obtained in winter 1982-83 during MIZEX-West. These data show that over the February-April 1983 period, which coincided with greatest southward ice extent, the otherwise sluggish flow was strongly augmented by a northwestward baroclinic current that underlies the ice edge. Within this current the observed mean speeds exceeded 10 cm s^{-1}, and no reversals to eastward flow were observed. The baroclinic current appeared to be filamentous, having higher speed cores separated by regions of lower speed. The current was about 100 km wide and parallel to the ice edge.

The baroclinic ice edge current is due to the combined influence of localized ice melting along the ice edge and regional temperature and salinity differences between the Bering shelf water and the warmer, more saline water to the south. Its location appears to be related both to that of the ice edge and to local bathymetric features. Its associated ocean frontal structure must interact strongly with the ice edge location both through advection by the northwestward currents and through frontal heat transfer processes. The northwestward transport of water, considerably greater than during ice-free periods, would be expected to affect regional biological processes as well.

Predicting Currents in the Bering Strait

Bering Strait provides the only avenue of exchange between the Pacific and Arctic Oceans. This exchange is critical to the regional mass and heat budgets, and thereby to the regional ice cover. The exchange also substantially influences the density structure of the Arctic Ocean and the input of nutrients to the Arctic Ocean. Finally, recent work suggests that the ice drift itself is primarily determined by a balance between currents and winds.

Superimposed on the strong mean northward flow through the strait are large fluctuations at synoptic time scales, apparently forced meteorologically. These fluctuations include reversal of the flow through the strait, driving both water and ice southward into the Bering Sea.

Two-thirds of the variance of the flow through the strait is predicted by the local geostrophic wind. The physical basis for this high predictability is the convergence of the wind-driven flow occasioned by the various restrictive passages and coastlines, first and foremost being Bering Strait itself. This convergence sets up a barotropic pressure field in the ocean, which modifies the flow. The observed currents, oceanic pressure gradients, and geostrophic winds are all compatible with this simple conceptual model.

Tides in the Bering Sea

Recent observations by PMEL and others of bottom pressure and currents on the Northeastern Bering Sea Shelf have been analyzed for tides and tidal currents to document the oceanographic conditions and calibrate numerical models for the Navarin Basin, an economically important region west of St. Matthew Island. The analysis showed that the diurnal tides dominate the outer shelf. The diurnal amplitudes decrease exponentially inshore from the shelfbreak at a rate consistent with subinertial Sverdrup waves. The phase lags of the diurnal tides vary little over the shelf. The semidiurnal amplitudes vary considerably. The semidiurnal phase lags are earliest at the shelfbreak and increase toward the north and east. The semidiurnal tides on the outer shelf appear to be under the influence of an amphidromic system located off Cape Navarin.

The tides become progressively smaller and more semidiurnal toward Bering Strait. There are some seasonal variations in the observed tides with slightly large diurnal amplitudes on the outer shelf and smaller semidiurnal amplitudes in the strait in late winter. A comparison with numerical models shows that the models reproduce the general features of the observed tides and tidal currents on the Northeastern Bering Sea Shelf.

HAZARDOUS WINDS

During February and March 1983, a study of mesoscale marine winds was carried out over the coastal waters of the northwestern Gulf of Alaska. A closed low-pressure region was centered over the south Alaska Peninsula, and its associated occluded front curved eastward, then southeastward from the northeastern tip of Kodiak Island. Perhaps the most striking feature of the mesoscale pressure field is the perturbation pattern over Shelikof Strait. Surface pressures were as much as 0.5 mb higher on the west side of the strait than on the east side. The undisturbed geostrophically balanced winds in the vicinity of the entrance to Shelikof Strait were about 8 m s^{-1} in strength with a strong easterly component. This flow behavior maintained itself to about a third of the way down the strait where it quickly backed to northeasterly, following the channel axis, and accelerated to 15 m s^{-1}. Gap winds persisted through this part of the strait but decelerated as they approached the southern terminus. At the exit the flow abruptly changed to a more geostrophically balanced wind field. Farther south, as the aircraft approached the storm center, the winds became southerly and light.

The complicated wind regimes in straits, which develop in response to different large-scale pressure fields, have also been theoretically investigated by scale analysis of the equations of motion. Adjustment of the mass and motion fields in straits that are 10's of kilometers wide, such as

Shelikof Strait and the Strait of Juan de Fuca, is governed by four non-dimensional numbers: along- and cross-strait Rossby numbers, a drag coefficient, and a stratification parameter that relates the internal Rossby radius of deformation to the width of the strait. The wind field will be in approximate geostrophic balance with an imposed cross-channel pressure gradient. An along-channel pressure gradient is primarily balanced by ageostrophic acceleration of the wind field down the axis of the strait, the gap wind. Vertical motion and the accompanying horizontal divergence in the near surface wind field can be large even for moderately stable stratification. As a consequence, there may be particularly abrupt transitions of the surface wind field at the exits of straits, where there is a rapid change of the scaling parameters to match coastal conditions.

The scale analysis also applies to open coasts; the Rossby radius of deformation replaces the width of the strait as the offshore length scale. For the mountainous coasts of Alaska, Canada, and Norway, a typical Rossby radius is about 80 km; within this distance an alongshore pressure gradient will be principally balanced by the ageostrophic terms in the momentum equation, and gap wind type accelerations should occur near shore. Since the coastal Rossby radius is smaller than the grid size of present numerical weather prediction models, geostrophic adjustment is not correctly modeled for land-falling storms along mountainous coasts.

HAZARDOUS WAVES

This project conducts research in ocean wave dynamics, especially coastal wave phenomena that create hazards to life and property. Previous research by PMEL led to the development of an improved algorithm for forecasting sea state on the Columbia River Bar. Two extensions of this work were completed in the last year. First, the algorithm was adapted to the entrance at Grays Harbor, Wash. Second, both procedures were automated by designing and implementing an interactive computer program incorporating the Bar forecast model in cooperation with the Northwest Ocean Service Center. As a consequence, the procedure is more systematic and consistent, and the preparation time for an operational forecast has been significantly reduced. The algorithm has provided a 25% improvement in wave-forecasting accuracy.

Further analysis of the remote-sensing data acquired at the Columbia River entrance during previous experiments has shown several instances in which focusing of wave energy by wave-current refraction is important for wave amplification and the existing (one-dimensional) forecast algorithm underpredicts wave height on the Bar. For a given wave period, the amount of refraction depends primarily on details of the surface current distribution, such as the degree of lateral shear, and also on the incidence angle of waves relative to the main current axis. The relative importance of these two factors of the Columbia River is unknown, and a numerical study is planned to explore the sensitivity of wave height amplification to each.

FISHERIES-OCEANOGRAPHY RESEARCH

Fisheries-oceanography planning activities and program development continued in anticipation of future initiative funding. A plan was developed for the Fisheries Oceanography Experiment (FOX), a multidisciplinary study to be

conducted in Shelikof Strait, Alaska, in winter-spring 1984-85. This investigation will improve understanding of environmental factors that influence pollock behavior and abundance. Comprehensive sampling of the biota is planned to be carried out from March to June 1985, and currents, water properties, and winds will be measured before and during this phase. Cooperative studies and planning workshops were coordinated with IRIS (International Research Investigations of the Subarctic), a regional council that involves U.S. and Canadian fisheries researchers in the northeast Pacific. Time series of oceanic observations (both physical and biological) are being documented for use by researchers.

To improve understanding of the large-scale circulation patterns in the FOX region, an analysis of current observations of 10 months duration at two sites in the Alaskan Stream off Kodiak Island was completed. This study revealed that the flow in the Alaskan Stream is relatively steady in comparison with other western boundary currents, the transfer of eddy momentum is quite small and is toward smaller scales, and a cross-shelf transfer of heat by eddy processes does occur. Sea level and other time series data have been used to describe the westward extension of the coastal Kenai Current. It retains its flow characteristics in these waters, and its subsequent transport through Unimak Pass also affects circulation and conditions in the shallow eastern Bering Sea.

TSUNAMIS

The U.S. Office of Foreign Disaster Assistance of the Agency for International Development has commissioned NOAA through PMEL to conduct a 3-year project known as THRUST (Tsunami Hazard Reduction Using System Technology). The goal of the project is to demonstrate that a satellite-based regional warning system can be assembled and integrated into an established disaster warning and relief network of a developing nation.

In June of 1983 the contract was awarded. The project began in September 1983 when the project team conducted a site visit to Chile. After the THRUST concept was discussed with the Chilean Navy Hydrographic Institute, the final research and demonstration plan was established. Since that time, the knowledge and skills of three NOAA components, two subcontractors, an AID advisor, a program director, and a project coordinator have been used to complete the first year's work.

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The system being developed uses existing seismic instrumentation connected to satellite communication to establish a warning system. This system will enable Chile to obtain rapid data acquisition and analysis, and quick information dissemination.

In addition, bottom pressure recorders have been deployed in the equatorial Pacific to record the characteristics of passing tsunamis in the open ocean. These deployments are for 6-month intervals. Several small tsunamis have been recorded, as well as signals from distant storm events.

Plans FY 1985

SEA ICE RESEARCH

- Conduct APEX (Arctic Polynya Experiment). This experiment in the northern Bering Sea will study regional currents and sea ice drift to provide the scientific basis for extending the sea ice forecasting model to the northern Bering and Chukchi Seas.

HAZARDOUS WINDS

- Plans will be developed for major west coast experiment "Ocean Storms", to occur in fall 1986.

HAZARDOUS WAVES

- The Columbia River Bar algorithm will be updated, and an improved superstructure icing algorithm will be developed.

FISHERIES-OCEANOGRAPHY RESEARCH

- Conduct FOX (Fisheries Oceanography Experiment). This experiment will measure seasonal and storm-driven currents near the southern end of Shelikof Strait, Alaska, a rich pollock spawning ground. An intensive study period in March 1985 with the NOAA ship Discoverer and a NOAA P-3 research aircraft will concentrate on ocean divergence and advection caused by local wind effects. FOX will also support improved meteorological forecasting for southern Alaska.

TSUNAMIS

- An expanded tsunami effort will combine modeling activity with the continuation of THRUST.

MARINE RESOURCES

Hydrothermal venting, which occurs along sea floor spreading centers, represents a basic input of heat and materials into the oceans. The effect of hydrothermal venting on the marine environment is the focus of PMEL's marine resources program, "VENTS". Research efforts have been specifically designed to define and quantify the chemical, geological, and physical oceanographic processes evolving from the venting of hydrothermal fluids. Current studies of hydrothermal venting have focused on the Gorda and Juan de Fuca ridges.

Accomplishments FY 1984

The Marine Resources Research Division at PMEL was created in January 1984 to conduct research into seafloor spreading processes such as the venting

of high temperature fluids from geologically active areas of mid-ocean ridges. The principal activities of this new division were establishment of the VENTS program, reprogramming of the efforts of the former Marine Geology and Geophysics Group of the National Ocean Service, and relocation of activities from Rockville and Seattle to the Mark O. Hatfield Marine Science Center in Newport, Oregon. The VENTS program is designed to assess the consequences of high-temperature hydrothermal venting. From a geochemical perspective, these hydrothermal venting systems have significant impact (at least on local to regional scales) on the oceanic thermal and mass budgets. The venting systems are a major source for mineralization of sea floor sediments and a primary source for the formation of a variety of metallic sulfides. Further, the close association between active venting and characteristic vent-communities provides an important element in NOAA's ongoing research in marine living resources. In FY 1984 one objective was to define research that will provide a more integrated examination of the overall importance of the venting systems.

Four separate VENTS experiments were conducted during FY 1984, which were partially a legacy from the several pre-VENTS research efforts. In March and April, the NOAA ship Surveyor conducted seafloor investigations, including collection of bathymetry from the Hec, Heckle, and Vance Seamount Chains. Contouring at 10-m intervals was completed aboard the ship during the cruise. Measurements were taken to fill gaps in data from the Gorda Ridge between the Blanco Fracture Zone and the Escanaba Trough, to compare and contrast the tectonics of the Gorda and the Explorer Ridges (two ridges close to the continent), and to examine the effects of the nearby continent on ridge structure.

In May and June, the Discoverer was utilized for the "PENTAFLUX" experiment on the southern Juan de Fuca Ridge, which focused on geochemical sampling and characterizing of vent-associated plumes and nearby sediments. Sediments on the Juan de Fuca Ridge and along its flanks to distances in excess of 100 km normal to the ridge axis displayed a pronounced hydrothermal signature. Elevated abundances of iron and manganese in the sediments and methane and suspended particulate matter in the water column proved to be excellent indicators of hydrothermal activity. Shipboard techniques have been developed for pseudo-real-time detection of these parameters, resulting in the ability to define the intensity and distribution of the hydrothermal plume.

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SLEUTH (System for Locating Eruptive Underwater Turbidity and Hydrography), which was designed and deployed by PMEL during FY 1984, has proved to be a unique continuous sensor for the detection of hydrothermal plumes. Ultra-sensitive and precise detectors for light scattering, temperature, and conductivity on the SLEUTH mainframe were towed through the lower several hundred meters of the water column to define the plume distribution over the ridgecrest. SLEUTH-detected regions of enhanced hydrothermal activity were then surveyed with discrete sampling devices to provide a more complete geochemical description of the hydrothermal plume at its origin. Some of the most hydrothermally enriched samples yet collected from a surface vessel resulted from these operations.

Hydrothermal fluids and particulates were also collected from several regions of the Juan de Fuca Ridge using the research submersible Alvin. These samples were several hundred thousand times more enriched than those obtained from surface, ship-based operations. Specially designed titanium samplers capable of withstanding temperature and pressure differentials of 380°C and

600 atmospheres were deployed directly within hydrothermal vent orifices less than 10 cm in diameter, through which hot gas and metal-charged fluids were rapidly discharged. Concentrations of the various hydrothermal fluid components will be estimated from the these samples and employed for modeling of plume processes. Some exploratory water samples were taken at Blanco Trough, the Surveyor and Cascadia Depressions, and over a topographic high along Rift B on the southern Juan de Fuca Ridge. Box cores were collected at all but the last site.

A mooring with sediment traps and current meters was also deployed, to be recovered by the USGS Alvin in October 1984 during a USGS cruise. This will extend observations obtained during PENTAFLUX.

Operational dives by Alvin for VENTS were conducted during July and August. The July dives were an investigation of proposed active venting sites in the Escanaba Trough, on the Gorda Ridge, in the "pull-apart" basins of the Blanco Fracture Zone, at the southern Juan de Fuca Ridge (where the PENTAFLUX work had been done earlier), along the axial portion of the central and northern Juan de Fuca Ridge, and on the Endeavor Ridge sector. This was the first series of Alvin dives along the Northeastern Pacific Ridge System and was considered to be exploratory. Dives were located along the whole ridge system at sites that prior information indicated had the highest probability of active hydrothermal venting for representative sectors of the ridge crest. The data collected support the general model that indicates lack of active hydrothermal venting along the southern Gorda Ridge, and progressively increasing activity northward along the Juan de Fuca Ridge. Relatively important evidence of venting (smokers and living vent communities) was found at the Axial Seamount and on Endeavor Ridge. Successful attempts were made to sample mineralized sediment, vent organisms, or other deposits associated with the active vents. Water samples were collected at the venting sites for chemical analyses of both the water and the suspended particulates.

The August series of Alvin dives was along the convergent plate boundary at the subduction zone along the base of the Oregon-Washington continental slope. VENTS-supported investigation of interstitial and extruded water samples provided insight into an unexpectedly abundant benthic community that was discovered during the dive series. The community bears strong initial similarities to the hydrothermal vent communities (tube worms and large clams) found along the spreading centers, although high-temperature water is not present. On the basis of shipboard examination, methane was identified as a possible basic component of a localized chemosynthetic primary production.

A 1-day workshop on "Long Range Research Objectives at the Gorda and Juan de Fuca Ridge Environments" was held at the Hatfield Marine Science Center in June. This was jointly sponsored by the VENTS Program and Oregon State University marine biologists.

A major requirement for the activity planned at Newport is the acquisition of VAX-based data processing capability to be used to process and analyze "SEABEAM" and similar data for research use. The administrative requirements and the necessary clearances and approvals went relatively quickly, and delivery of initial hardware was made in late August.

Plans FY 1985

- Continue to develop ADP processing system for SEABEAM data. First prototype research charts are planned for completion by March 1985.

- Conduct research cruise to Gorda Ridge to search for active, high-temperature hydrothermal venting systems.

- Conduct research cruise to Axial Seamount, Endeavor Ridge, and southern Juan de Fuca Ridge to sample and characterize vent fluids and near-field geochemical processes at known active vent sites.

- Conduct a workshop to report on the status of recent VENTS research to be held at Newport in March 1985.

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GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
Ann Arbor, Michigan

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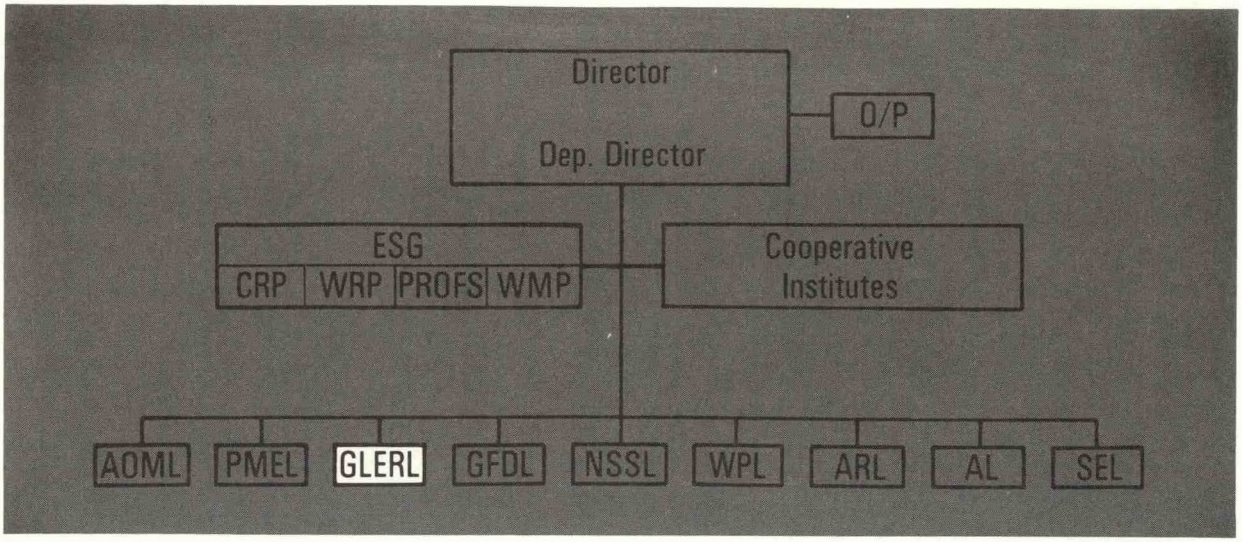

The Great Lakes Environmental Research Laboratory (GLERL) conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters, with special emphasis on the Great Lakes. It performs field, analytical, and laboratory 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 five groups: Synthetic Organics and Particle Dynamics, Ecosystem and Nutrient Dynamics, Lake Hydrology, Physical Limnology and Meteorology, and Environmental Systems Studies. 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 improved understanding, prediction, and specific information about the Great Lakes. Biogeochemical studies of the cycling and dynamics of nutrients and toxic contaminants are needed to improve understanding and prediction of processes occurring in the Great Lakes ecosystem and to provide more precise scientific information relevant to the management of wastes, water supplies, and fisheries. Models to simulate and predict the transport and fate of contaminants as a function of human input to the lakes are needed to support management decisions on wastewater and regulation policies. More precise

scientific information on lake water levels, connecting channel flows, and ice distribution is useful to those concerned with erosion control, transportation, recreation, and power generation. Studies of the lakes' physics improve understanding and prediction of the circulation, the thermal structure, and the transport and dispersion of chemical and biological variables in the ecosystem; numerical forecast tools result in products applicable to pollution transport and dispersion. Research on physical phenomena like surface waves, seiches, and surges provides improved understanding and numerical prediction methods that are applicable to 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 nearshore zone (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 1984

Seasonal composition and abundances of epibenthos were examined to determine how much microcrustacean biomass occurs in the sediments relative to overlying waters in nearshore Lake Michigan. These forms peaked at different times in the sediments (spring and early summer) than in pelagic waters (late summer or not at all).

The survival and viability of the meroplanktonic diatom Melosira granulata is being investigated in cooperation with University of Michigan scientists. This diatom remains viable for periods of at least 100 years while buried in the sediments and is capable of photosynthesis immediately upon exposure to light.

The effects of nutrient patchiness on the composition of natural assemblages of algae were examined in laboratory experiments. Patchy supply resulted in dominance of a single blue-green algal species, whereas homogeneous supply resulted in co-dominance among the blue-greens, flagellated greens, and a diatom. These results demonstrate that the mechanism of nutrient supply can affect algal composition in the Great Lakes.

Correlation of benthic invertebrate abundance with measurements of nutrient release from intact sediment cores indicated that Pontoporeia hoyi may suppress silica release from sediments by burying the silica-rich sur-

ficial floc layer. This information is needed to understand and model the dynamics of nutrient release from Great Lakes sediments.

Ammonium excretion rates by several life stages (nauplii to adult) of the marine copepod Eucalanus pileatus were measured in two controlled food environments to assess the importance of life stage and food abundance on nutrient regeneration by zooplankton. When food was abundant, animals of all stages released ammonium at similar rates per unit ash-free dry weight, but at low food levels, late-stage juveniles and adult females released ammonium significantly more slowly than did the nauplii or early stage juveniles.

A temperature-diffusion model was calibrated for a 20-year data set from Lake Washington, and estimates of vertical turbulent diffusion coefficients were completed. These diffusivities were used to model a nearly conservative substance--total alkalinity.

Documentation of the results of the major (e.g., current meter moorings) year-long (1979-80) Lake Erie experiment was completed. Analyses of thermistor chain profile data define the seasonal development and decay of stratification in the central basin and its response to storm wind events. Currents measured in the lower half of the central basin water column were mostly return flows (beneath the surface wind drift) driven by the surface pressure gradient. A complex system of Lake Erie circulation gyres was often observed; it was close to that predicted by models, although there was a tendency for one of the central basin gyres to become dominant and envelop the whole basin in either uniform clockwise or uniform counterclockwise flow. The currents were somewhat more barotropic than predicted by full Ekman layer current models. Tide-like currents, driven by the longitudinal seiches of Lake Erie, occur in the island passages between the western and central Lake Erie basins.

GLERL and the Canada National Water Research Institute are working together to synthesize knowledge and recent Lake Erie research accomplishments in a series of articles. A key topic is a synopsis of the Lake Erie current meter studies described above. Analyses of the current meter measurements done with a new objective analysis method are also discussed and compared with the results of a time-dependent numerical circulation model. The objective analysis method uses the observed currents as constraints on an energy and vorticity minimization scheme and low-pass filtered current meter data to arrive at a two-dimensional stream function field. The numerical model uses the rigid lid approximation and demonstrates the sensitivity of the circulation pattern in the flat central basin of Lake Erie to the curl of the imposed wind stress (e.g., a difference of 3 m s^{-1} in the eastward component of the wind speed over a north-south distance of 100 km is sufficient to generate a one-gyre circulation pattern in the central basin).

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A study recently completed describes currents and water temperatures measured in the four main passages between Green Bay and Lake Michigan and at several sites within the bay during summer and fall 1977. Monthly resultant currents indicate counterclockwise circulation in the bay during dominant southwesterly wind, while there is a rapid reversal of this pattern during episodes of northeasterly wind. Oppositely directed two-layer flow through the mouth is a common feature during the stratified season. Cold hypolimnetic lake water entering through the mouth and extending far into the bay remains stratified and promotes flushing.

A two-dimensional, vertically integrated circulation model has been used to study the importance of Ekman layer physics to the sedimentation patterns of southern Lake Michigan. One experiment used a circularly symmetric idealization of Lake Michigan's southern basin, a "typical" Great Lakes storm system (represented by one day with strong west wind and four days with no wind), and a sediment source assumed uniform over the surface of the idealized lake. The results of a comparison of sediment deposition and erosion for models with and without Ekman physics confirm the theory that deposition tends to occur preferentially in cyclonic gyres. The next step will involve a 6-month simulation using real Lake Michigan bathymetry and wind forcing and a comparison of results with observed sediment patterns.

Studies have been conducted with current drifters in Lake Michigan to determine whether they can be used confidently as indicators of particle trajectories. A cluster of three drifters was deployed in a patch of rhodamine B dye. Dye concentration was determined by fluorometry and the center of mass calculated from continuous sampling profiles. Separation of the centroid of the drifters and the dye center of mass was compared with wind data and used to calculate the slippage velocity.

Recent work in synthetic organics and particle dynamics has concentrated on making laboratory measurements of Kp (the equilibrium partition coefficient) for a series of radiolabeled organic compounds ranging over four orders of magnitude in solubility onto the settling particulate matter collected monthly in offshore Lake Michigan sediment traps. Initial results indicate there is less than an order-of-magnitude change in Kp on the settling material over a single season.

In addition, a substantial fraction of the operationally defined "dissolved" contaminant was found to be weakly bound to natural dissolved organic matter by extensive laboratory work on the three-phase system (particulate-bound-dissolved). Bioavailability of organic xenobiotics from water is reduced when dissolved organic carbon (DOC) is present; DOC can be measured by short-term static uptake experiments.

Approximately 100 sediment traps were deployed and retrieved throughout Lake Michigan over the past year. From these measurements, the rates of settling of particulate matter and, after chemical analysis, the fluxes of various contaminants can be estimated. Sample analysis for several contaminants is currently under way. Initial analyses of the data have two major results: First, it appears that traps deployed offshore above or immediately below the thermocline during stratification are useful in estimating the new load (predominantly atmospheric) of material entering the lakes, and second, resuspension during the unstratified period (November-June) is very great and provides a mechanism for intimate coupling between the water column and recent sediments.

The regional radionuclide source function has been put together and entered on the VAX 11/780 computer system for use in calibrating long-term contaminant response models. In addition, the contaminant model for Lake Michigan was developed into a coupled lakes model for the Great Lakes system.

In another effort, residence times for DDT, PCB, and the polycyclic aromatic hydrocarbon (PAH) anthracene were estimated for the surface microlayer.

The analyses focused on estimating the response times of the surface microlayer to departures from equilibrium conditions. Equilibrium conditions were determined from literature-based values of model parameters, which included settling, photolysis, eddy transport, partitioning, and volatilization. Results indicated that little additional effort is needed on microlayer research.

Work on thermal forecasting models is also progressing. To date, three different types of one-dimensional thermal forecasting models have been programmed and soon will be tested against data from Lakes Erie and Michigan. The three types used are (1) inertial deepening, (2) turbulent erosion, and (3) eddy diffusion. Each model is unique and has attractive features, but suffers from one or more limitations (e.g., adjustable coefficients). The most accurate model will be selected by rigorously comparing model simulations with observations.

Most contaminants of concern adhere to particles and rapidly settle out into the sediments. An important process for remobilizing contaminants from sediments involves direct uptake by benthic invertebrates and transfer up the food web to higher trophic levels. Studies focus on measuring the uptake of contaminants by benthos and developing models of this process and the trophic transfer process. Our field results indicate that the common benthic amphipod P. hoyi and oligochaete worms have significantly higher concentrations of PAH than do the surrounding sediments. Two models have been developed. The first is a nonsteady-state model for the time-dependent uptake, depuration, and metabolic decomposition of PAH by P. hoyi. The necessary temperature-dependent coefficients are being refined by laboratory studies. A second model, being developed under contract, uses the concept of bioenergetics to propagate caloric energy (and contaminants) up the food web. Results from model calibration runs for alewife, a mid-trophic-level planktivore, indicate that a substantial fraction of the fish's PCB body burden is derived from feeding on benthos.

Work currently being pursued will determine the relative bioavailability of material attached to the sorbed phase and the dissociation of sorbed xenobiotics. The seasonal toxicokinetics of PAH to P. hoyi are currently being repeated with measurements of sorption to DOC, lipid content of the animals, and organism size to attempt to define some of the variables that appear to cause the apparent seasonal variation in the toxicokinetics. In addition to these studies, there are under contract two projects on the development of techniques to measure chronic effects of PCB's and PAH on benthic invertebrates. The first of these involves the analysis of the distribution of free amino acids in the organism and changes when the organisms are exposed to chemical stresses. The second procedure is designed to measure changes in the rate of activity (sediment mixing for the oligochaetes being tested) when the organisms are exposed to chemical stress.

The field portion of our Hi-Sed program has been completed with the collection of cores from the regions of high, recent, sediment accumulation in Lake Superior. We now have carefully collected sets of cores from all five Great Lakes. Results have supported previous reports of a near-surface layer of mixed sediments. A major advance is the development of a nonsteady-state model and an associated computer program to simulate the effects of zoobenthos feeding and mixing on sediment tracer and contaminant profiles.

A qualitative study of the temporal impacts of St. Clair River dredging on the flows in the St. Clair, Detroit, and Niagara Rivers and on the levels of Lakes Michigan-Huron, St. Clair, and Erie has been completed. Maximum impacts occurred near the end of the dredging project for the St. Clair and Detroit Rivers and Lake St. Clair and lag by about a year impacts on Lake Erie and the Niagara River.

A series of software packages, from data acquisition through model application, has been developed for ultimate use in generating deterministic runoff outlooks in near-real time. Development of the near-real-time data acquisition system is continuing. Procedures have been initiated for including substantial amounts of Canadian meteorological data on the National Weather Service (NWS) weather wire and for the rapid receipt of data from second-order stations.

Equivalent channel sections based on measured hydrography have been used to revise the upper Detroit River unsteady flow model. The model is currently being modified to include the various islands and channels. A new dynamic calibration procedure has been developed; it will significantly improve the model results over those obtained from the static calibration procedure that has been used by all agencies in the past.

The Great Lakes hydrologic data base recently published provides Great Lakes researchers and managers with a readily available comprehensive source of data.

The Large Basin Runoff Model, data reduction packages, and several large data bases were transferred to the U.S. Army Corps of Engineers; a corps employee was trained in use of the model.

A recently developed automated computer forecast package for Lake Superior uses near-real-time meteorological data to produce operational outlooks of basin runoff for improving lake level regulation. The package is composed of (1) data acquisition and reduction by a computer system that monitors interagency data links and updates provisional meteorological station networks, (2) the automatic computation of weighted subbasin meteorological data files from the provisional station data, and (3) the semiautomatic distributed-parameter application of GLERL's Large Basin Runoff Model with suitable graphical interpretations.

The study of the St. Clair and Detroit Rivers winter flow regimes continued with successful completion of the field season for continuous current measurements in the St. Clair River at Port Huron. The season was marked by severe cold spells during December and January, causing frazil ice and a record ice jam in April.

Data analysis and evaluation from the 1983 Lake Michigan Ecosystem Experiment was completed for water column nutrients, sediment trap chemistry, community level phytoplankton growth, and zooplankton grazing. This data set is unique because all the processes known to contribute to growth and loss of phytoplankton were measured simultaneously from the same water mass.

Data from the Lake Michigan Ecosystem Experiment suggest that the quality of water in the lake has improved a great deal over the last year. Transparency of the water column has increased dramatically. The hypothesized

reason for this change is an increase in large cladocerans and a reduction in algae due to increased predation on, and rapid decline of, the alewife population. The decrease in the alewife population was caused by stocking of salmonids and other game fish in Lake Michigan.

The abundance and importance of small (<1 μm diameter) cyanobacteria in Lake Superior were demonstrated. Bacteria-sized phytoplankton accounted for about one-half of the total primary production and exhibited growth rates of two to four divisions per day. Microzooplankton, such as protozoa, appear to be consuming this production, These very small organisms constitute an important, but previously unrecognized, part of the Lake Superior food chain.

Experimental data on the relative importance of phosphate and silicate limitation reveal that diatoms outcompete blue-green and green algae because they have transport constants for phosphate uptake that operate more effectively on low substrate concentrations. This could account for diatom supremacy during all periods except when silica limits diatom growth.

Phosphate uptake kinetics and computer simulations suggest that mixed microbial assemblages have half-saturation constants from one-half to one-third lower than those shown previously in laboratory cultures. Phosphorus stress apparently induces microorganisms to produce high-affinity uptake systems, thus allowing relatively rapid growth rates at low ambient phosphate concentrations. This helps explain the controversial paradox of high phytoplankton growth rates when phosphate concentrations are very low in lake and ocean waters.

The relation between zooplankton feeding rate and food concentration for laboratory cultures of algae and for lake seston was determined in order to test an effective food concentration model. Results concurred with the model and demonstrated that feeding rates determined with algal cultures cannot be applied directly to lake seston.

Frame-by-frame analysis of 140 films of copepod feeding showed that the copepod Diaptomus sicilis is not an optimal forager (i.e., does not necessarily select the most abundant available food), and supported the accuracy of the effective food concentration model. This information is needed for an understanding of how zooplankton obtain food and affect the composition of phytoplankton seston in the Great Lakes.

GLERL

Film analysis also showed that both the current-field produced and the feeding behavior of D. sicilis differ from those of marine copepods. These results explain why D. sicilis can specialize on small particles for food and also why, for it, there is an invariant relation between particle selection and particle size. Based in part on these results, a model is being developed to describe the feeding rate of this copepod in mixtures of different particles such as those found in lake water.

Calcite particles at the same concentration and size found during calcite whiting in Lake Michigan were found to depress zooplankton grazing significantly. This depression was greater than that observed for clay particles of the same concentration. Whitings in fecal pellets accelerate the downward flux of the pellets up to tenfold.

Nutrient transformation studies on silty Lake Michigan sediments indicate that nitrogen released by macroinvertebrates as ammonium is rapidly converted to nitrate (nitrification) and then converted to nitrogen gas (denitrification) by microbes. These processes must be quantified to determine the importance of sediment mineralization as a nutrient supply mechanism in the Great Lakes.

Microcosm experiments indicate that invertebrate-mixing activities enhance phosphorus release from sediments, but that mixing beyond a threshold level has no effect on the rate of phosphorus release, (i.e., phosphorus release is not related to animal density). These studies are part of an effort to quantify the importance of aerobic sediments as a source of phosphorus in Lake Michigan.

Microcosm experiments demonstrated that invertebrates can enhance release of phosphorus from intact sediment cores. This source of phosphorus may explain why disproportionately high levels of primary production have been observed for nearshore regions.

A new study was initiated to examine the role of P. hoyi in sediment pelletization in Lake Michigan. This phenomenon may affect nutrient and contaminant cycling in lake sediments.

Under a grant, phosphorus regeneration rates of the predatory copepod Cyclops bicuspidatus thomasi were examined as functions of temperature and prey. Temperature, prey density, and hunger level significantly and predictably altered phosphorus release rates.

Microbial transformation rates of labile organic materials dissolved in lake waters were examined by measuring concentration decreases of low levels of amino acids added to Lake Michigan water. Amino acid turnover was slow (<1 nmole L^{-1} h^{-1}) during summer in offshore Lake Michigan.

First-order estimates of bacterial growth in the Lake Michigan Ecosystem Experiment also indicate that turnover of organic carbon by bacteria is slower than previously expected. These results indicate that bacteria may play a less important role in nutrient and energy cycling in the nutrient-poor lakes than in nutrient-rich systems.

Plans FY 1985

Sediment trap samples from Lakes Michigan, Superior, and Huron will be analyzed for mass, contaminant organic, and nutrient concentrations. Fluxes will be calculated.

Concentrations of PAH will be measured seasonally in the major Lake Michigan benthic organism P. hoyi and compared with model predictions based on measured uptake and depuration rates.

Equilibrium partition coefficients (concentration in solid phase/concentration in dissolved phase) will be measured for a wide range of organics on particles collected in sediment traps. This will permit estimation of the

impact of seasonal changes in particle composition on the phase distribution of contaminant organics.

Uptake from sediments and water depuration rates of contaminant organics by three major Great Lakes invertebrates will be measured using radiolabeled compounds.

A nonsteady-state sediment mixing model will be tested and calibrated with sediment radionuclide data. The model simulates the effect of bioturbation and resuspension on sediment cores over time.

Radionuclide, contaminant organic, and trace metal analyses of cores from the regions of highest sediment accumulation in each of the five Great Lakes will be completed. The nonsteady-state sediment mixing model will be used to interpret the profiles and the historical response of the lakes to contaminant loads.

The Lake Washington ecosystem model will be expanded to include total phosphorus and oxygen budgets. Analysis of long-term nutrient trends will also begin. Model outputs will then be compared with field data to test the models.

The dynamics and importance of subsurface phytoplankton populations in Lake Michigan will be determined. These populations are the dominant primary producers during summer stratification.

Lake Superior will be studied to detect microbial food webs, as well as to determine the importance of picoplankton. These small organisms appear to account for about one-half of the primary production in the lake.

Data collected from the 1983 and 1984 field phases of the Lake Michigan Ecosystem Experiment will be analyzed and summarized. A single field experiment will be carried out in 1985.

Measurements of bacterial growth rates and phytoplankton organic excretion rates in Lake Michigan during the 1984 field season will be analyzed and prepared for publication. In 1985 these measurements will be repeated with special emphasis on specific organic compounds excreted by phytoplankton and used by bacteria.

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Experimental data on the kinetics of phosphate and silicon uptake by phytoplankton will be evaluated to determine how silicon limitation affects phosphate uptake by diatoms and how diatoms and blue-green algae compete for phosphate in Lake Michigan.

Experimental data on species-specific growth rates, phytoplankton standing crops, and the kinetics of inorganic and organic phosphate will be analyzed to test the hypothesis that microscale nutrient plumes from zooplankton provide a quantitatively significant phosphate source for algae.

Experimental data on the kinetics of phosphate uptake by microorganisms will be assessed to determine what primary forms of dissolved phosphorus are preferred by phytoplankton and bacteria and how these two types of organisms compete and coexist in planktonic environments.

A laboratory will be built for making high-speed motion pictures of zooplankton feeding and other interactions between zooplankton and phytoplankton. This laboratory will allow us to continue the observations of zooplankton-phytoplankton interactions that we started on the high-speed microcinematography equipment at the Skidaway Institute of Oceanography.

The feeding response of zooplankton in mixtures of different species of algae will be determined so that a general model can be developed.

The significance of feeding history in relation to the feeding of zooplankton when they encounter new mixtures of algae (for example, during vertical migration into a new patch of algae) will be explored.

A seasonal study on the amounts of lipids in various species of Lake Michigan macroinvertebrates will be completed. The results will yield seasonal caloric information on these organisms and provide insight relevant to the biotic cycling of toxic organic compounds.

The caloric content of benthic macroinvertebrates in southern Lake Michigan will be estimated from ash-free dry-weight, lipid, and benthic abundance data. These data will be combined with reported turnover time data for P. hoyi to estimate the energy flow through this dominant macroinvertebrate in the lake.

Particle-size selection and gut throughput rates of P. hoyi will be examined to define the role of this amphipod in particle dynamics and pollutant transfer.

The distribution and feeding behavior of P. hoyi will be examined in depositional areas of Lake Superior. This organism is a major source of food for fish in the upper lakes.

Microcosm studies to quantify phosphorus release from Lake Michigan sediments will be conducted.

Analysis of invertebrate distributions will be completed to assess long-term trends in Lake Michigan benthic fauna.

A time-dependent solution (as opposed to a steady-state solution) algorithm for predicting Great Lakes phosphorus dynamics will be coupled with an optimization algorithm for the purpose of identifying, on a yearly basis, least-cost phosphorus management strategies that will produce desired phosphorus concentrations. Recommendations may change annually because of changing costs of treatments and the natural variability associated with annual phosphorus inputs, ice cover days, and lake hydrodynamics.

Current velocities in the benthic boundary layer of Lake Michigan will be measured to determine the climatology of high-current-speed events causing bottom sediment resuspension.

The GLERL Great Lakes Basin Supply Forecast package and near-real-time hydrometeorological data acquisition and reduction system will be finalized for Lake Superior and further developed for Lakes Erie and Champlain.

The experimental study of the St. Clair and Detroit Rivers winter flow regimes will be expanded. Remotely monitored electromagnetic current meters will be used to make simultaneous point-flow measurements in both rivers. These point measurements in the St. Clair River will be supplemented with continuous vertical profile current measurements taken with an acoustical Doppler current profiler.

The slippage between satellite-tracked drifter buoys and dye patches will be observed during varying wind conditions to develop correction factors for comparing drifter tracks with the results of spill model predictions.

Satellite-tracked drifters will be used in a study of the Niagara River plume.

Models of rotational wave motions in Lake Michigan will be compared with wave properties measured with current meters. Steady, seasonally varying currents observed in the lake will be used to describe prevailing lake-scale circulations.

Data on the distribution of sediment in the southern basin of Lake Michigan will be used to test a numerical model of sediment transport, resuspension, and deposition. Early results of this study show that the effect of the Ekman boundary layer transport of sediment is important. When this effect is included and when realistic wind patterns are used, the model can reproduce the observed sediment patterns.

The Upper Great Lakes Connecting Channels Study is a new program (see the International and Interagency Activities section of this report) that will address problems of synthetic organic pollutants and nutrient overenrichment. Current plans for GLERL activities involve the following:

- Calibrating models of conservative contaminant behavior from existing data.
- Examining nutrient regeneration from sediments.
- Field and laboratory studies to assess the status of contaminant problems in Lake St. Clair.
- Development of a hierarchy of models for determining the fate, transport, and effects of selected nutrients.

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- Development of mass balance budgets for selected nutrients and chemicals.

Activities planned in conjunction with NOAA's Manned Undersea Research and Technology Program in the Great Lakes include the following:

- Measurement of in situ erosion rates and documentation of erosion and/or deposition in time scales of weeks to months.
- Collecting core samples to determine the extent and cause of microscale patchiness in benthic distributions.
- Determinations of the efficiency of the Ponar grab sampler.

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 NWS to assure that GLERL products meet the needs of operational forecasters. Follow-up on forecast accuracy and fine tuning of forecast procedures, in collaboration with 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 1984

A wind-generated wave prediction model has been developed theoretically and tested numerically against a 2-month data set from a GLERL tower and a NOAA Data Buoy Center (NDBC) NOMAD buoy in Lake Erie with remarkable agreement between observed and computed wave height (0.2-m rms error, 0.93 correlation coefficient). Validation and comparison with NWS operational forecast procedures is under way. Interactive wave prediction software, implemented on the GLERL VAX computer, has been made available to five Great Lakes Weather Service Forecast Offices to facilitate model validation as a local marine weather forecast tool. The response so far has been very favorable. A further test of the wave prediction system for a storm-generated synoptic wave field in Lake Michigan observed by the NOAA aircraft/laser profilimeter also yielded remarkable agreement between model and observations for the total lake.

An analysis of 1981 NDBC data examines the various universal correlations of wave parameters that serve as the basis linking theoretical predictions to actual measurements. It was found that there are really no universal relations per se among the parameters. Therefore, a model using one of the available universal relations, as many numerical prediction models do, can be quite accurate at times and erroneous at other times. In practical applications, the only correlation that shows consistency is that of nondimensional frequency versus nondimensional energy.

We have used the 1981 Lake Erie coastal boundary layer experimental data to examine the probability distributions for both deep and shallow water waves. Results show that both the Rayleigh distribution for wave heights and the Longuet-Higgins distribution for wave period overpredicted the highest waves in a record, and underpredicted the intermediate waves. By applying a two-parameter Weibull distribution to both height and period data and using parameters determined from the data, the accuracy of the fit was improved significantly.

The representation of shallow water wave spectra is another basic tool for linking theoretical analysis with measurements. Earlier works simply modified the deep-water saturation range exponent with an equivalent shallow-

water exponent in the spectrum equation. A theoretical model developed by the National Aeronautics and Space Administration (NASA) was examined; the agreement between the NASA model simulation and measurements is fair but not overwhelmingly good. However, when the GLERL generalized spectrum representation is applied, the agreement between model results and measurement is excellent. Thus, the GLERL model can be applied to both deep and shallow water waves. Hence the spectral representation is independent of water depth.

The new spill model, PATHFINDER, has been made operational on the GLERL VAX 11/780 computer system. The initial design of GLERL's ice dynamics simulation model is complete, and the model has been programmed on the VAX computer and the code tested for internal consistency.

Four satellite-tracked buoys were deployed in ice in the central and eastern basins of Lake Erie this past January. Flights were made every 2 weeks to observe ice conditions and make ice measurements in the vicinity of each buoy. The tracks revealed continuous ice movement, often at surprisingly high speeds. Interpretation of ice movement will be aided by the ice reconnaissance maps obtained from Canadian ice observers.

The record ice jam in the St. Clair River during April 1984 was observed and documented by aerial and ground reconnaissance. The field season of the St. Clair River current meter program during winter 1983-84 was successful, despite the record ice jam. The experimental measurement indicates that computed St. Clair River flows during ice conditions may be no better than those for the Detroit River, contrary to previous assumptions.

The GLERL hydrologic response model was used to predict the impacts of the record St. Clair River ice jam on lake levels and flows. The analysis and results received nationwide attention.

An official NOAA atlas of Great Lakes ice, published by GLERL, will be the standard reference on Great Lakes ice cover for some years to come. It documents important advances in our understanding of the Great Lakes ice cycle.

An analysis of the regional ice cover of Lake Erie relative to percentage ice cover exceedance for discrete ice cover concentrations and discrete regions of Lake Erie was completed in 1983. The analysis was used by the National Research Council in its study of the Lake Erie ice boom for the International Joint Commission.

GLERL provided more than 4,200 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 1985

The GLERL wave prediction model will be modified for arbitrary water depth, thereby making it applicable to nearshore coastal area wave predictions.

A project synthesizing wind, wave, and temperature data recorded from NDBC NOMAD buoys will continue; it will be used for developing climatological information on Great Lakes waves.

The interactive version and the centralized computer version of the GLERL wave forecast model made available to NWS will be further tested for operational use.

Wave characteristic measurements from a satellite-reporting wave buoy will be compared with those from the NDBC NOMAD buoy in Lake Erie. These observations will be used for further validation of the wave forecasting model.

A complete review and possible extensive restructuring of the ice program will be undertaken because of recent personnel changes. It is anticipated that this activity will cover the period January 1985 to September 1985.

Aerial spectral reflectances will continue to be measured with a programmable band radiometer. Most measurements will be spectral reflectances of various individual and composite ice types under clear skies.

Digital imagery gathered by the NOAA-7/8 satellites will be geometrically corrected and used for analysis of lakewide shortwave radiation reflectance from the ice cover. Identification of ice types in the imagery will be based on large-area ice reflectance measurements.

Ground-based measurements of shortwave spectral reflectance of snow and freshwater ice types will continue with modified instrumentation.

A new field measurement program will be designed to assess the importance and extent of under-ice phytoplankton and zooplankton activity. The program will involve the GLERL Lake Hydrology and Ecosystem and Nutrient Dynamics Groups.

Development of GLERL forecast models of thermal structure will continue. These models simulate temperature decline and initial ice formation for Lake Superior.

FACILITIES

Two major types of compounds are analyzed by GLERL's chemistry laboratories: trace synthetic organic materials and nutrients. The synthetic organics, primarily PAH, are extracted from various ecological matrices, cleaned, and analyzed on glass capillary gas chromatographs. These chromatographs are currently being interfaced with GLERL's VAX 11/780 to upgrade data analysis capability.

The uptake and release rates of selected PAH by benthic organisms are being followed through use of carbon-14- and tritium-labeled-compound metabolism. Compounds are extracted, cleaned, and counted by liquid scintillation. Numerous water samples from Lake Michigan were analyzed for various forms of phosphorus and silica and other water quality indicators as part of the Lake

Michigan Ecosystem Experiment. The purpose was to define processes contributing to phytoplankton dynamics, bacterial growth, and ecosystem carbon flow in Lake Michigan.

The biology laboratories' equipment and instrumentation include a multichannel Coulter Counter used to measure particle-size selection and zooplankton grazing on natural lake algae and seston. An array of instruments, including a liquid scintillation spectrometer, is used to investigate nutrient uptake, growth rates, competition for nutrients by algae, and cycling rates of selected algal nutrients. Facilities also include a full complement of sampling gear and instrumentation, growth chambers, stereo and inverted microscopes, and cultured populations of phytoplankton and zooplankton species for model studies. A mobile trailer has been fitted for lakeside investigations of the physiology and feeding rates of planktonic and benthic organisms.

The process of zooplankton feeding and other zooplankton/algal interactions occupies a central role in models of eutrophication and toxic organic cycling. Progress in developing mechanistic models has been hindered by the inability to observe the feeding process directly because of the small size of both the zooplankton and algae and the high frequency (50 Hz) of zooplankton appendage movement. High-speed microcinematography was used to make the first observations on these processes for a freshwater copepod. This was done at the Skidaway Institute of Oceanography. We are now in the process of duplicating the microcinematography apparatus at Skidaway to study the feeding mechanisms of Great Lakes zooplankton in detail. A special feature of our laboratory will be accurate temperature control.

The ice laboratory makes it possible to extend the winter measurement season and to expand opportunities for measurements of ice characteristics. The facility consists of a work room and an ice storage room. The work room, held at -7.0°C, can be used to conduct experiments on natural ice harvested in previous field seasons, as well as to calibrate instrumentation for the ice research program in an environment similar to that encountered in the field.

Natural and artifically produced radionuclides introduced into the Great Lakes serve as excellent model contaminant and process indicators. The particle dynamics laboratory can be used to detect and measure very low levels of many such radioactive substances present in water, sediment, and biota. The laboratory was established as part of the cooperative program with the University of Michigan's Great Lakes and Marine Waters Center.

GLERL

The GLERL computer facility supports data acquisition, data reduction, graphics, and modeling applications for scientists and technicians in the research groups. A VAX 11/780 superminicomputer supports general purpose applications (e.g., graphics, data reduction and analysis, modeling, word processing), and a Hewlett Packard 9603 minicomputer supports data acquisition tasks. Within a year, a link to the National Bureau of Standards-ERL Scientific Computing Facility in Gaithersburg, Md., will probably be established. The NBS facility will offer a very powerful computing capability that will support GLERL modeling applications.

The R/V Shenehon is the primary platform used in support of open lake field investigations. The vessel is 65.6 ft long, with a 6.5-ft mean draft, a

600-nmi cruising range, and a 10-kn cruising speed. A hydraulic articulated crane is used for deployment and retrieval of heavy instrument moorings. Winches handle hydrographic wire and multiconductor cable for sample casts and in situ measurements of water variables. An on board laboratory facilitates onsite physical, chemical, and biological experiments. A loran-C navigation system provides the capability and precision for the boat to return to an exact site in the lakes for equipment retrieval.

The marine instrumentation laboratory staff selects, calibrates, repairs, and, when necessary, adapts or designs instruments to collect data in the lakes and their environs. Engineers and technicians in this unit work closely with GLERL researchers to ensure that instruments are compatible with the purpose of the experiment.

The GLERL library staff 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 library collection consists of materials in the areas of climatology, hydrology, hydraulics, ice, limnology, mathematical modeling, meteorology, oceanography, sedimentation, and wave motion, with emphasis on the Great Lakes Basin.

INTERNATIONAL AND INTERAGENCY ACTIVITIES

GLERL staff were active on several International Joint Commission boards and committees including the Levels and Flows Advisory Board; Technical Information Network Board; Health of Aquatic Communities Work Group; Task Force for Lake Michigan Surveillance; Task Force for In-Place Sedimentary Contaminants; the St. Marys, St. Clair, and Detroit Rivers and Lake St. Clair Task Force of the Surveillance Work Group; the Aquatic Ecosystem Objective Committee Work Group; the Modeling Task Force of the Science Advisory Board; and the Lake Erie Task Force of the Surveillance Work Group.

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 staff participated in the activities of the International Association of Sediment Water Science, the International Coordinating Committee on Great Lakes Hydraulic and Hydrologic Data, the Regional Response Team for Spills of Oil and Hazardous Substances, Joint United States-Canadian Ice Information Working Group, the International Association for Great Lakes Research (President, 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 Great Lakes Hydromet Steering Committee, and the National Research Council Panel on Niagara River Ice Boom Investigations.

The Laboratory has recently become involved in an international (United States-Canada) and interagency (United States: Environmental Protection Agency, NOAA, Corps of Engineers, Fish and Wildlife Service, Michigan Department of Natural Resources; Canada: Department of the Environment,

Environmental Protection Service; Department of Energy, National Water Research Institute; Inland Water Directorate; Department of Fisheries and Ocean; Ontario Ministry of the Environment) multiyear study on water quality and marine pollution problems in the upper Great Lakes connecting channels (St. Clair River, Lake St. Clair, Detroit River, St. Marys River). The primary marine pollution issues to be addressed are synthetic organic pollutants and nutrient overenrichment. A GLERL staff member is a member of a management committee developing a detailed study plan for the research and monitoring program.

Activities involving participation with other NOAA units included the Marine Environmental Quality Task Force, Quality Assurance Working Group, Manned Undersea Research and Technology Program--National Marine Fisheries Service, New Bedford Harbor PCB Contamination Assessment Team, Marine Environmental Quality Review, and the Estuarine Review. GLERL staff participated in several Sea Grant activities including the University of Wisconsin Site and Subprogram (Microcontaminants) Reviews, and the Ohio State University Site Review. In a joint program with the Ohio State Sea Grant, GLERL is developing a recreational planning guide for Lake Erie. GLERL has also worked extensively with NWS and the Atmospheric Environment Service of Canada on an operational, interactive wave model.

GLERL scientists were also active in providing information to several local agencies, such as the Kalamazoo River Preservation Agency and the Technical Advisory Committee of the Huron River Watershed Council.

GEOPHYSICAL FLUID DYNAMICS LABORATORY
Princeton, New Jersey

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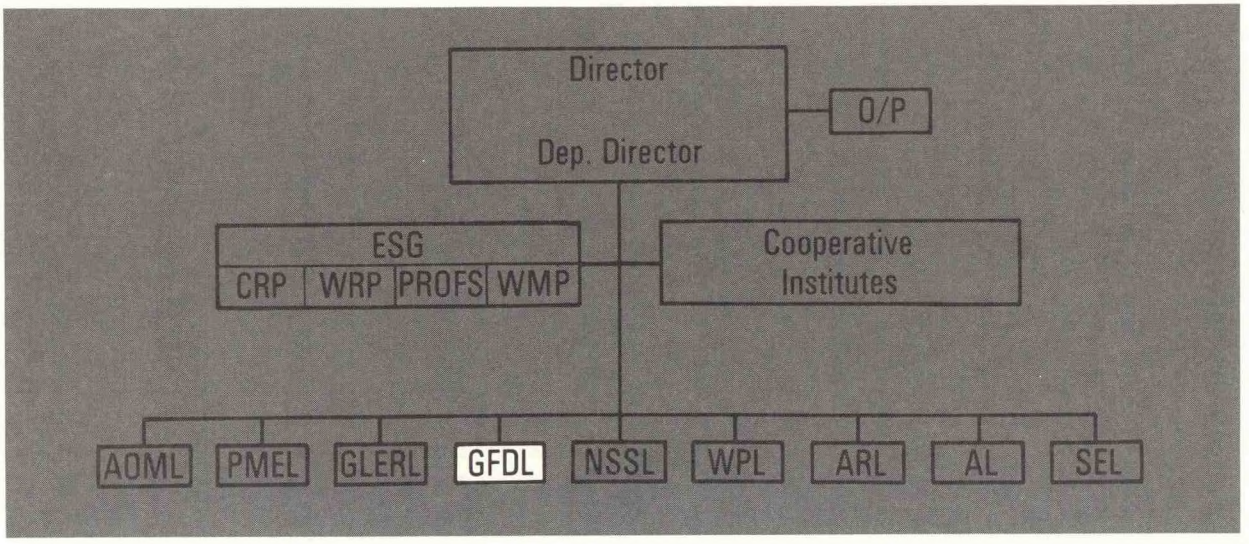
Acting Director



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 constituents.
- Earth's atmospheric general circulation within the context of the family of planetary atmospheric types.

The scientific work of the Laboratory encompasses a variety of disciplines: 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.

WEATHER SERVICE

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

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 so, is the accuracy dependent on the prediction of the ambient synoptic flow? Research to develop mathematical models for improved weather prediction will also contribute to the understanding of such fundamental meteorological phenomena as fronts, hurricanes, severe storms, and tropospheric blocking.

Accomplishments FY 1984

Monthly forecast experiments, carried out for eight January cases with a general circulation model (GCM) incorporating GFDL "E-physics", show that monthly forecasts appear feasible, though the current skill is marginal. The skill scores for 1000-mb geopotential height are higher than those for 500-mb height for all cases.

The GCM's with refined subgrid-scale parameterizations exhibit improved overall performance of monthly forecasts. The refined physics increases the capability of simulating blocking ridges and improves the prediction of geographical locations of planetary-scale waves. It is also revealed that the root-mean-square geopotential height errors have distinct geographical distributions with respect to the models, and that these errors consist mostly of the climatic drift of the respective models. This suggests that further advances in monthly forecasting skill can be expected.

A theory of the baroclinic instability of a zonally varying flow has been developed. This theory has implications for the relation of the positions of storm tracks to the large-scale planetary wave pattern, and for the role of transient eddies in the maintenance of large-scale anomalies.

The continuous data insertion method in the four-dimensional data assimilation has been improved by applying a linear normal mode initialization to the injected data and using a wider range of data collection for determining insertion data. There is an indication that such analysis improvements can yield improved long-range forecasts.

The effects of a long mountain range on a landfalling hurricane were investigated. The mountain affects the distributions of the low-level wind and the precipitation intensity to a significant degree. The decay rate of the storm is increased as compared with a case excluding the mountain effects. The enhanced decay was associated with reduction of the convergence of latent and kinetic energy during the storm's passage across the mountain range. The mean easterly flow, which carried a vortex, was notably modified by the mountains to influence the movement of a storm. This result adds another capability in the requirements for significant improvements in hurricane forecasting skill.

A study on the evolution of a real hurricane was initiated with the preparation of a numerical model and real initial data. Hurricane David, 1979, was chosen for the first experimental case, and initial fields were retrieved from the FGGE level III-B data set produced at GFDL. This is the first effort at GFDL to explore forecasting skill for real hurricanes.

Simulations of an isolated shower cloud of 1 hour duration have been carried out with periodic and open lateral boundary conditions, with similar results. Using a continental sounding for moisture and temperature, a strong single cell develops which gives maximum precipitation of approximately 1.0 cm in rainfall lasting for one-half hour. The simulations indicate a significant model net vertical momentum flux which is downgradient in all instances. This suggests that GCM parameterizations of moist convection should include the effect of vertical momentum transfer.

Two independent numerical simulations of the evolution of realistic cold fronts indicate that latent heat released by moist convection substantially modifies the larger scale frontal circulation.

Simulations with the GFDL high-resolution mesoscale model have been carried out to assess the impact of initial and boundary data inaccuracies on the simulation of Meso-Convective Systems (MCS's) and their environments. It was found that in most MCS's, the environmental convergence of a pre-existing front was responsible for the growth of the storm vorticity, whereas latent heat release was required to produce explosive storm growth.

A meso-beta scale simulation of an MCS over Oklahoma and Texas has produced a realistic simulation of precipitation and cloud patterns during the period 10-11 April 1979. It was found that insertion of observed wind and temperature data in the initial and boundary conditions had a major impact in the simulation.

GFDL

A 48-h simulation using a limited-area model nested in a global spectral model seems to have captured the explosive behavior of the Presidents's Day snowstorm (19-29 February 1979). The model data are now being analyzed to determine the mechanisms that led to the explosive storm growth.

Plans FY 1985

The effect of sea surface temperature anomalies on monthly forecasts will be investigated.

Nonlinear eddy fluxes of heat and momentum associated with local baroclinic instability will be derived. Local instability of realistic flows will be analyzed.

The newly designed hurricane model will be used to investigate the development processes of Hurricane David.

Investigations of the role of latent heat in frontogenesis will continue.

Detailed analysis of simulations of SESAME-I mesoscale convective systems will be carried out.

Investigations on the numerical simulation of deep continental convection will continue.

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 climatic impact of human activities such as the release of CO_2 and other gases in the atmosphere. The phenomena that are studied include large-scale wave disturbances, with period of a few weeks, and their role in the general circulation of the atmosphere; the seasonal cycle, which must be defined before departures from it (interannual variability) can be understood; interannual variability associated with phenomena such as the El Niño/Southern Oscillation; very-long-term variability associated with the ice ages; and the meteorologies of various planets, the study of which enhances our perspective on terrestrial meteorology and climate. To achieve these goals, both observational and theoretical studies are necessary: Available observations are analyzed to determine the physical processes by which the circulations of the oceans and atmospheres are maintained; 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 1984

A higher resolution (3° latitude) version of the GFDL "SKYHI" general circulation model has been integrated for more than 18 months. The improved horizontal resolution has led to a number of improvements in the simulated circulation. Specific improvements include tropospheric zonal winds and jet stream; planetary wave amplitudes and propagation to the stratosphere; onset of sudden stratospheric warmings; and a reduction in the model tendency to yield excessively cold stratospheric winter polar regions. These improvements allow a more detailed look into the model dynamics as well as into model sensitivity to climatic perturbations.

Work is under way on the effect of smaller scale gravity waves on planetary waves in the stratosphere and mesosphere. Early results from this work indicate that such interactions produce an important mechanism for mechanical

dissipation of planetary wave energy. This discovery has important implications for our understanding of dynamics and transport in the middle atmosphere.

An attempt has been made to simulate the climate of the last glacial maximum by use of a general circulation model of the atmosphere coupled with a mixed-layer model of the ocean. Given the distributions of continental ice sheets, surface albedo, and the reduced CO_2 concentration of the ice age, the model generates sea surface temperatures that compare favorably with the sea surface temperature at the last glacial maximum as reconstructed by geologists. When the same model is used for the study of the anticipated climate change due to a doubling of CO_2, it yields an increase of global mean surface air temperature of 2.2°C.

It has been pointed out that the concentration of atmospheric carbon dioxide during the late Cretaceous epoch was several times higher than the modern concentration. To evaluate the climatic consequences of large changes in atmospheric CO_2, numerical experiments were conducted for a wide variety of CO_2 concentrations (150 to 2400 ppm by volume) using a coupled ocean-atmosphere GCM with idealized geography. According to the results from these experiments, the high-CO_2 world is characterized by high surface-air temperature with small meridional gradients, high deep-sea temperature, an intense hydrologic cycle, and large poleward moisture transport. These results suggest significant progress toward explaining the large differences between Cretaceous and contemporary climates. Moreover, they add credibility to current concerns on the possible climate impact of increasing CO_2.

Numerical experiments are nearing completion that test the sensitivity of an idealized nine-level GCM to large decreases in the solar constant. The qualitative dependence of sensitivity to solar constant changes has some similarity to previously published results with a two-level model, which differed significantly from the results predicted by the commonly used simple energy balance models.

Work is continuing on the comparison of stationary eddies produced by GCM's and eddies predicted by a linear model based on the primitive equations. It has been demonstrated that a useful first approximation to the stationary eddy field in the extratropical upper troposphere can be obtained with such a linear model. This suggests that significant improvements in the theoretical understanding of stationary eddies in the atmosphere may be forthcoming.

GFDL

An analysis of the structure of stationary Rossby waves in vertical shear has been completed. It explains why the response to stationary forcing in the troposphere is equivalent barotropic far from the source and why there tends to be a maximum in geopotential amplitude near the tropopause.

Calculations with an idealized two-layer quasi-geostrophic model show that the eddy heat and potential vorticity fluxes increase much less rapidly as the meridional extent of the unstable region increases than is predicted either by weakly nonlinear theory or by the popular "baroclinic adjustment" hypothesis.

Spectral analysis of results from GCM calculations indicates that stationary ultralong waves gain kinetic energy but lose available potential energy through the nonlinear interaction with transient waves. This loss is much

larger than the gain and is compensated by a zonal-to-eddy conversion of available potential energy.

Calculations of infrared radiative cooling rates using line-by-line methods have begun. These will be used as international standards against which the results of the parameterized algorithms employed in GCM's can be compared. This is part of the WMO-sponsored International Comparison of Radiation in Climate and Circulation Models.

Two extensive tape libraries with global atmospheric and oceanographic analyses were prepared for distribution to the scientific community by the National Climatic Data Center and the National Oceanographic Data Center, respectively.

An extensive compilation of monthly general circulation statistics based on the FGGE level III-B analyses produced at GFDL and a comparison with the analyses by the European Center for Medium-Range Weather Forecasting for the Special Observing Periods were documented.

A 15-year GCM run with changing sea surface temperatures prescribed according to observations in the Pacific between 30°S and 30°N gave an excellent simulation of El Niño/Southern Oscillation phenomena in the atmosphere, especially in the tropics. This result lends optimism that properly coupled atmosphere-ocean models will be able to simulate these phenomena. The observed anisotropy in transient disturbances with various time scales was found to be an important factor in determining the nature of the local exchange of kinetic energy between eddies and the time-mean flow.

In order to balance the poleward flow of atmospheric angular momentum, it was concluded from observational calculations that the return flow of angular momentum from middle to low latitudes does not occur in the oceans. Thus, by inference it must occur in the solid earth.

Observational evidence was found for a meridional divergence or source of water vapor over land as well as both oceans in the subtropics of the Northern and Southern Hemispheres. This "land source" of water is supplied by eastwest convergence from the oceans.

The birth of Jupiter's Great Red Spot (GRS) has been simulated by a model that describes the weak solitary barotropic instabilities that act at the large planetary scales. The longevity of the GRS has been simulated by a large vortex that appears to last indefinitely.

Plans FY 1985

The basic 15-year (1958-1973) and FGGE (1979) data sets will be used to evaluate regional balances of angular momentum, energy, and water vapor.

The FGGE analyses generated at GFDL will be used in a study of the diurnal cycle of the atmosphere.

Model simulations of meteorological phenomena accompanying the El Niño/Southern Oscillation will be compared with observation.

A global model of the coupled ocean-atmosphere system with high computational efficiency will be constructed for the study of climate sensitivity. The performance of this model will be tested extensively.

Efforts to identify and isolate the causes of systematic biases in current spectral and finite difference general circulation models will be under way, with continued emphasis on improvements in model physical processes.

The study of the transient and equilibrium response of climate to an increase of atmospheric carbon dioxide will be continued by use of a coupled ocean-atmosphere model with limited computational domain and idealized geography.

The influence of cloud radiation feedback processes upon the sensitivity of climate will be investigated by use of a global atmospheric GCM coupled with a mixed-layer ocean model. With a similar coupled model, additional numerical experiments will be conducted and analyzed to identify the physical factors responsible for the cold climate of an ice age.

Analyses of the albedo-feedback experiments with an idealized GCM will continue. Attention will be focused on the factors that determine how far equatorward the snowcover boundary must be before the model experiences a rapid increase in sensitivity.

Studies with linear primitive equation models on a sphere will continue. The extent to which the linear model can simulate the seasonal cycle in planetary wave structure will be examined. An attempt will be made to simulate the extratropical anomalies in extended GCM integrations with observed Pacific sea surface temperatures (SST's). The same GCM integration will be used to test the ability of a simple linear viscous model of the low-level tropical flow to simulate the anomalous flow due to SST anomalies in the Pacific.

Simple linear and nonlinear models of the tropical upper tropospheric flow and interactions between this flow and extratropical eddies propagating into low latitudes will be examined, with particular attention to the possibility of reflection of incident Rossby waves by tropical winds.

A space-time spectral analysis will be made of the low-frequency oscillations in the tropics simulated by a spectral general circulation model. A set of experiments will be made by the use of a simplified general circulation model to study the effects of transient waves on the zonal mean flow in the presence of surface friction.

GFDL

The results of the International Radiation Model Comparison study will be analyzed, with the goal of improving the radiative parameterization in GFDL GCM's.

Analysis will be under way on the dynamical behavior of the (3° resolution) SKYHI model including sudden stratospheric warming diagnosis, impact of gravity waves on planetary waves, and identification of satellite sampling errors.

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 work that will be completed within the next 5 years includes analyses of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Capability will be developed to solve for a number of trace constituents simultaneously; then interdependent experiments will be run involving ozone and its precursors, partitioned components of total reactive nitrogen, carbon monoxide, etc. Also, development of a dynamically active ozone photochemistry will be completed for inclusion in the GFDL troposphere-stratosphere-mesosphere (SKYHI) GCM. In addition, this model will be developed for passive tracer studies.

Accomplishments FY 1984

A simple model has been developed that illuminates the mechanisms leading to the observed poleward-downward meridional slopes of stratospheric trace constituents. In particular, the quantitative role of chemical processes in "flattening" these slopes has been clarified. The theory also predicts the way that the global average vertical "eddy diffusion" coefficient varies as a function of chemical sources and sinks.

By keying off the above results, a simple model has been developed that predicts the structure of trace constituent temporal variability, given a particular chemistry. These two results allow the possibility of predictions of time mean and variable trace constituent structure, given such knowledge for one constituent and the appropriate chemistry for any other constituent. If such predictions prove to be valid upon observational testing, the problems of modeling systems with many species should be substantially simplified.

The vertical mixing of a passive tracer initially confined to the boundary layer has been examined. For long-lived convection a well-defined inflow-outflow circulation develops so that mixing through a depth of 5 km is much stronger than for a short-duration shower cloud. Tentative results show small mixing to the upper troposphere. A primary conclusion is that vertical mixing appears strongly dependent on the duration of the convective cells.

Plans FY 1985

Efforts will continue on the "combustion nitrogen" and "tropospheric ozone" series of numerical experiments, with emphasis on greater realism. Work will be initiated on multiple, interactive trace constituent modeling.

A more detailed analysis of the convective transport of a passive tracer will be under way, with an exploration of the effects of including water-soluble trace gases.

MARINE QUALITY

Research at GFDL 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 (tritium, radon, etc.) 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 1984

A time-dependent carbon cycle model has revealed that the response time of atmospheric carbon dioxide to changes in the oceanic circulation is about 200 years. This discovery may explain the low amounts of carbon dioxide during the last ice age, as well as providing an important feedback mechanism on the current increase in carbon dioxide from use of fossil fuel.

Analysis of transient tracer data and supporting modeling efforts have shown that seasonal convection and isopycnal mixing dominate over Ekman pumping in thermocline ventilation. This suggests that seasonal and high-latitude processes must be especially accurate to produce good simulations of oceanic tracer transport.

Plans FY 1985

Work on the global carbon cycle will be extended by combining the existing geochemical model with a detailed three-dimensional model of the ocean circulation.

OCEAN SERVICES

Various models that can be used to predict oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, one-dimensional models of the turbulent surface layer of the ocean predict the sea surface temperature and heat content of the upper ocean. More complex three-dimensional models are being developed to study phenomena such as the time-dependent development of Gulf Stream meanders and rings, the generation of the 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.

Accomplishments FY 1984

A high-resolution model of the tropical oceans has been developed and used for realistic simulations of the seasonal cycle in the tropical Atlantic

and of the 1982-1983 El Niño event. Of particular interest is the result that an intensification of the North Equatorial Countercurrent, between 5°N and 10°N, was responsible for a large part of the eastward transfer of warm surface waters in the Pacific in 1982 and 1983. This result, using observed surface winds for forcing, offers encouragement that properly coupled atmosphere-ocean models may successfully simulate the El Niño phenomenon.

An eddy-resolving model of the ocean including the effects of both wind and thermal driving has been developed. An analysis of the solutions shows an extensive mixing along isopycnal (constant density) surfaces. This process is absent in lower resolution models. Eddy transport of heat is a small, but significant component of the total poleward heat transport by ocean currents. This has an important bearing on the design of ocean models for climate studies. The model indicates that, in contrast to heat transport in the atmosphere, oceanic eddy heat transport may be largely equatorward rather than poleward.

New observational evidence was found for the reality of a large annual cycle in the oceanic heat transport.

Plans FY 1985

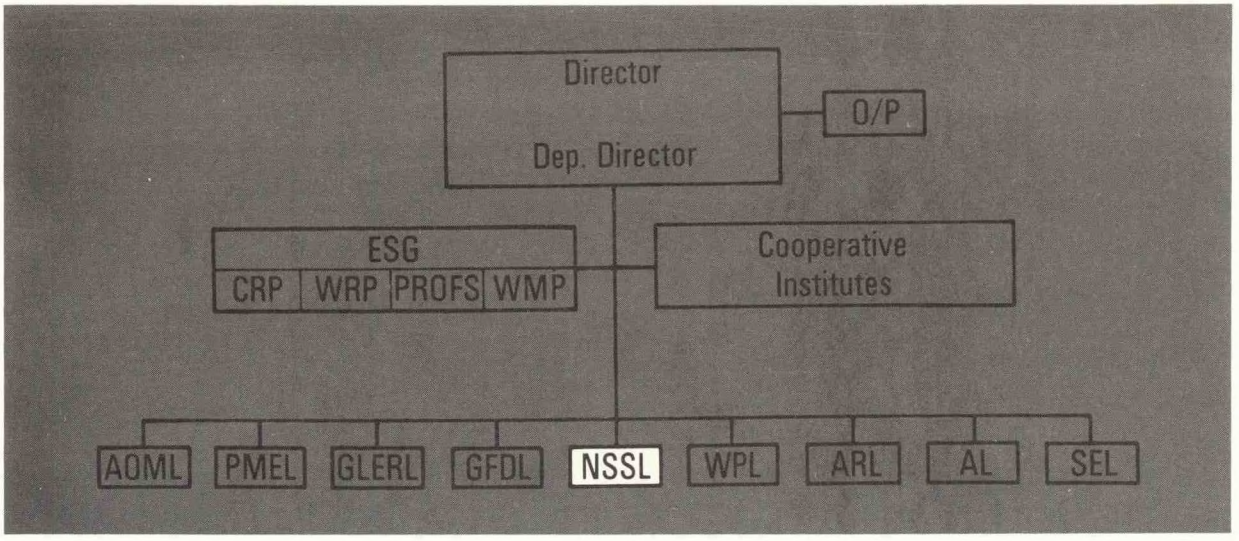
Detailed comparisons between measurements of the seasonal cycle in the tropical Atlantic and model simulations will be undertaken.

The mass and heat budgets of the seasonal cycles of the tropical Atlantic and Pacific Oceans, and of the 1982-83 El Niño event, will be studied to determine how heat and mass transports in the ocean change seasonally and interannually.

The resolution of the global general circulation model will be improved, and tests carried out to determine the rate of water mass formation.

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 41-km baselines provide unique capabilities for recording atmospheric circulations both in precipitating weather systems and the optically clear boundary layer. A comprehensive range of instrumentation for measuring parameters of both in-cloud and cloud-to-ground lightning 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. A program of storm observing is conducted annually during the spring season, and typically involves groups representing about 20 different organizations.

NSSL

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. NSSL also participates in worthy projects outside of Oklahoma. Thus, the NSSL staff was the coordinative focus for a course on mesoscale meteorology offered in Boulder, Colo., and attended over a period of two weeks by 177 persons from many places and organizations. The NSSL staff also had key roles in experiments at the Langmuir Laboratory in N. Mex., and participated in an experiment managed by the Boulder-based Program for Regional Observing and Forecasting to evaluate displays of Doppler velocity and reflectivity as part of the severe-weather warning process. One

of NSSL staff was a member of the NOAA Natural Disaster Survey Team that investigated the Carolinas tornado outbreak of 28 March 1984. Finally, the Laboratory is working closely with the Joint System Program Office (JSPO) of the Next-Generation Weather Radar (NEXRAD) program to help develop an effective national weather radar network for the late 1980's and beyond.

During the past year, Laboratory scientists have produced new storm forecast techniques, and new methods for diagnosis and analysis of thermodynamic fields in storms as presented in a variety of reports and publications. In two books NSSL has contributed an advanced text on weather radar and a comprehensive survey of the thunderstorm in its relationship to the social organism.

METEROLOGICAL 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. Analysis and interpretation of storm flow fields expand our understanding of external and internal forcing, thermodynamics, cloud physics, and cloud dynamics, which contribute to intense thunderstorms and their attendant phenomena. Subsets of the group objective are addressed by two projects: Modeling and Dynamics, and Storm Evolution and Analysis.

Accomplishments FY 1984

MICROPHYSICAL PROCESSES IN STORMS

Insights into thunderstorm processes including hail growth, separation of electrical charge, and production of heavy rainfall emerge from a clear understanding of the physics of water substance in clouds. A new diagnostic model presents microphysical and thermal variables within observed thunderstorms. The model proceeds from Doppler airflow measurements and an environmental sounding through the relevant thermodynamic and microphysical processes to calculate fields of potential temperature and water vapor, and concentrations of both liquid water and ice within storms. The diagnosed internally consistent storm structure reveals influences on precipitation cores by recycling of millimeter-sized ice, graupel, and droplets as well as the larger influences of transport processes on larger scales. The calculations, known as microphysical retrieval, also help identify errors in analyzed fields. When observed and retrieved radar reflectivities are compared, localized bias errors in wind analysis are sometimes suggested. These biases lead to anomalous precipitation content and thermal structure via the continuity principles within the model. When the wind field errors are corrected, the resulting implied and observed reflectivities are in much better agreement.

Studies of hail growth with Doppler-derived wind fields, a numerical model, and information from surface hailstone collection help to reveal how hail growth is related to storm structure, intensity, and evolution. Analysis of hailstone structure revealed that almost all growth was in the wet mode, i.e., not all the undercooled liquid water accreted by the growing hailstone

froze immediately on contact. The model results indicate that two major growth trajectories existed in the storm, and that the fall-out position of one trajectory coincided with hailfall position as documented from a collection vehicle. In agreement with the results of the hailstone structure analysis, all the mass of the modeled hailstones that fell in the collection area was accreted in the wet mode; this growth in the model occurred at ambient temperatures at or above -17°C.

The microphysical structure and general evolution of storms can be studied with Doppler velocity spectra collected at vertical incidence. A new technique using such spectra acquired at two radar wavelengths provides more accurate estimates of air velocity and drop size distribution. The technique must be applied with cautious attention to hardware quality and configuration, since accuracy in estimates is very sensitive to data quality.

TORNADIC STORMS

Improved understanding of the fields of velocity, pressure, temperature, and water quantities within tornadic storms should lead to greater understanding of tornadogenesis and ultimately to improved warning criteria. Data from the tornadic Binger, Okla., storm of 1981 have been analyzed to determine the origin of the "echo-weak hole" within the mesocyclone region. Following calculation of the wind field from dual-Doppler radar data, a microphysical retrieval method has added information on the water and thermal fields. Major reflectivity features such as hook echo, main precipitation shaft, gust front, cell core, slanted reflectivity ridge from hook echo to gust front, and bounded weak echo regions are well retrieved in the model. Recycling of millimeter-sized graupel and raindrops in the updraft seems important to the formation of the precipitation core. The echo-weak hole within the mesocyclone is likened to a soda straw--rotation causes the sides to be impervious to radial influx, while the top and bottom of the tube draw in little precipitation because of low precipitation content and downward air motion, respectively.

A theoretical study of rotation in thunderstorms has shown that streamwise vorticity, i.e., vorticity along the wind direction in the storm's reference frame, causes the updrafts of supercell storms to rotate cyclonically. Streamwise vorticity is present in the environment when the storm-relative winds veer with height. Convection can generate vertical motions and vertical vorticity through a process represented by the tilting term in the vorticity equation, and updrafts are thereby caused to rotate cyclonically and downdrafts anticyclonically when the storm-relative winds veer with height. The theory has led to a technique for diagnosing storm severity from observations on storm motion by radar or other means, and a nearby atmospheric sounding.

NSSL

Methods for retrieval of pressure and buoyancy have been applied to Doppler velocity data from the Del City tornadic storm (20 May 1977). The direction of maximum pressure gradients across the updraft core in the pretornadic stage was in nearly the direction of the environmental wind shear vector at each altitude. In the tornadic stage a pronounced pressure minimum (~3-4 mb below ambient) coincides with the low-level mesocyclone. A pressure deficit near the surface is induced by the strong cyclonic vorticity there--this reverses the vertical gradient of perturbation pressure with sudden

formation of the rear downdrafts commonly observed in tornadic thunderstorms. An investigation using the same approach, applied to the tornadic storm of 8 June 1974, revealed pressure forces that create a flux of air parcels into the mesocyclone from higher levels on the storm's rear. Downdrafts fill the mesocyclone in final stages, and updrafts weaken nearby.

The evolution of tornadic thunderstorms over northwest Oklahoma on 2 May 1979 has been investigated using dual-Doppler radar observations. The advance of a rainy downdraft behind the Lahoma gust front stimulated low-level convergence and development of a possible gust front tornado. Perturbations in the updraft and vertical vorticity produced the long-lived Lahoma mesocyclone. Air parcel trajectories within the storms illuminate the process of dissipation of both the Lahoma mesocyclone and first Orienta tornado. The trajectories during mature stages show air parcels entering from low levels and rising cyclonically within the mesocyclone updraft. Mesocyclone updraft separation, downdraft infiltration, and vertical vorticity reduction are the major dissipative features of the Lahoma mesocyclone. The Orienta tornado dissipated as downdraft air reduced the buoyancy of the mesocyclone inflow.

Visual and photographic observations of four tornadoes were made by intercept teams during NSSL's Spring Program. One was a cyclonic-anticyclonic tornado pair concurrently observed by Doppler radar. Attempts to deploy TOTO (Totable Tornado Observatory) in tornado paths were hampered by erratic tornado movement and abrupt changes in intensity.

THUNDERSTORM EVOLUTION AND STRUCTURE

Important forecast and warning insights are often gained by investigation of smaller convective entities because these sometimes evolve to produce or maintain larger storm complexes. Doppler data collected on 19 June 1980 reveal that a group of small cells evolved into an isolated supercell storm. The storm initially propagated to the right of the mean wind, but as the size and intensity of the individual cells increased (and center-to-center spacing remained constant), the reflectivity structure appeared to become steady. The increase in size and intensity was attributed to an increase in potential buoyant energy in the storm inflow and a slight increase in the storm-relative vertical wind shear. During 2½ hours of dual-Doppler data collection, maxima in reflectivity and updraft speed increased dramatically with transition to a supercellular structure.

A large squall line produced strong outflow winds, frequent cloud-to-ground (CG) lightning, and locally heavy rainfall on 19 May 1977. Study has shown that small rain-producing cells preceding the line were an integral part of the line's mesoscale organization and contributed strongly toward maintaining the intensity of preferred sections of the line. Description of this work along with that of other recent and past work is included in a comprehensive review of extratropical squall lines and rainbands.

FORECASTS AND WARNINGS

For the past 12 years, NSSL has been informing the Oklahoma City National Weather Service Forecast Office (WSFO) of severe weather signatures that

appear on Doppler radar displays at the Laboratory. During the 1984 spring data collection period, color displays were transmitted of Doppler velocity fields with superposed lightning strike locations to the WSFO. This project (Project DOPLIGHT 1984) demonstrated effective transmission of combined Doppler and lightning data over a high-grade telephone line. The forecasts and warnings were significantly improved by the availability of processed Doppler radar and lightning data.

A useful relationship has been found between maximum hailsize produced by a storm and the strength of the single Doppler velocity signature of divergence near storm top. The relationship appears to hold great promise for hailstorm warnings by distinguishing between storms that produce very large hail (diameters of 7 to 10 cm) and those that produce relatively small hail (2 to 4 cm).

An atlas prepared at NSSL shows single Doppler velocity signatures as aids to Doppler scope interpretation by radar operators. The signatures include simulated Doppler velocity patterns in the optically clear atmosphere, in widespread precipitation, and within severe thunderstorms. The idealized velocity fields are shown to be good approximations to actual Doppler velocity measurements.

Since NSSL's inception over 20 years ago, it has been actively involved in improving short-term storm warnings. Recently, we have been developing a mesoscale numerical forecasting model based on the Anthes-Warner (Penn State) model. Following comprehensive model testing, simulated data for a frontal/dry-line low-pressure situation have been used to initialize the model. Resulting development of the subsynoptic low-pressure system is being evaluated.

DATA ACQUISITION AND PROCESSING

Multiple Doppler radar studies of severe thunderstorms during the past decade have revealed many of their structural details that would otherwise have remained unknown. Ability to follow evolving vertical velocity fields has been especially revealing. However, researchers are starting to realize that errors in the reconstructed vertical velocity components can be significantly greater than those explained theoretically from radar geometry. A study of potential error sources in actual data sets is showing that major errors are not attributable to incorrect storm advection, incomplete sampling of low-level divergence, or large variance of Doppler velocities. Work is continuing in order to isolate and study other possible error sources.

The NOAA P-3 aircraft, equipped with a Doppler radar that scanned orthogonally to the aircraft track, was flown in Oklahoma as part of the NSSL Spring Program. Through the use of both ground-based and P-3 radar data, we expect to be able to document the life cycle of a tornadic storm that simultaneously produced cyclonic and anticyclonic tornadoes observed also by storm intercept teams. In another case, in cooperation with NASA, data were collected simultaneously with downward-looking sensors on an aircraft at very high altitude and on the P-3. The in situ P-3 data will help calibrate the data obtained from higher altitude. Data gathered from a sea-breeze-induced storm in Florida by the P-3 were analyzed to examine the sensitivity of the data to

different analysis methods. The differences in the analyses could be explained by statistical error propagation and effects of circulation changes with time.

Rawinsonde measurements provide information important for storm forecasts and warnings to managers of weather observing programs. For several years, rawinsonde data acquired by Air Force and Army units have been sent by phone line from the field to NSSL where they have been plotted in a time consuming process. In 1984, data was transmitted directly to a minicomputer that plotted soundings automatically at NSSL. Raw data also were sent directly to ERL's CDC 750 computer in Boulder for archiving.

Plans FY 1985

- Work on the tornadic Binger storm will be extended, including investigations into storm kinematics, dynamics, and microphysics.

- Doppler radar data from the 1984 Thunderstorm Research International Program (TRIP) experiment in New Mexico will be analyzed. Microphysical retrieval experiments will be performed using high-resolution wind data collected at frequent intervals, and diagnosed fields will be related to independent aircraft and balloon observations.

- Theoretical investigations into the formation of mesocyclones will continue.

- The lifetimes of thunderstorm features as related to NEXRAD scanning strategies will be examined in a report for FAA.

- Formal documentation of the 19 May 1977 squall line will completed, and dynamic retrieval experiments using data from the 20 May 1977 tornadic storm will be documented.

- Study of the Agawam, Okla., severe thunderstorm of 6 June 1979 is expected to reveal the role that storm dynamics and kinematics play in the storm-splitting process.

- The mesoscale numerical model will be run using a case study for 9 May 1979 as initial conditions. We expect to be able to determine local convective forcing mechanisms and modification of the planetary boundary layer. The first phase of initialization technique development for the mesoscale forecast model will be completed.

- Algorithms for defining fine-scale atmospheric structure from combined rawinsonde and satellite radiance data will be applied with objective analyses of radar data to a case study for 27 August 1982.

- Experimental design studies for sensor placement during STORM-Central field experiments will be completed.

- The field phase of a cooperative hailstorm investigation to use in situ measurements, surface hail collection, multiple Doppler radars, and

numerical models is planned for Spring 1985. A major feature of the study is to initialize and check model results with actual in-cloud and surface-collected hailstones.

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, 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. The Storm Electricity Group concentrates its analyses on data simultaneously obtained with Doppler radar and our many storm electricity sensors.

Accomplishments FY 1984

DOPPLER RADAR

Storm Initiation

An analysis of convective development along a frontal zone (30 April 1981) has demonstrated the utility of single Doppler radar in short-range forecasting. Winds obtained from single Doppler radar data using the Volume Velocity Processing (VVP) linear technique, under the assumption of uniform wind, compare quite well with rawinsonde measurements. The location of the frontal zone aloft, clearly defined in the wind field, was coincident with a layer of upward air motion measured from Velocity Azimuth Display (VAD) techniques. Storms developed with the onset of warm air advection and increased vertical motion, all of which were detected by radar. The locations of storm formation were displaced horizontally from the surface frontal position. However, the region where storms began and their subsequent motion could have been anticipated from a map derived from Doppler data analysis of frontal height above ground and detailed thermodynamic analysis.

Prestorm cloud formation has been related to boundary layer convergence in the vicinity of a dry line, 17 May 1981, with the cooperation of NASA Goddard Space Flight Center. A cluster of dense clouds and strong convergence on a scale of 10 km precedes severe storm development by only about 30 min. Moreover, widespread vertical motion was not observed prior to this development.

In general, Doppler divergence measured with data from a single radar has been found to agree well with dual Doppler analysis. However, the position of cumulus clouds is not always well correlated with convergence areas of the scale resolvable with the VVP analysis (~40 km). Research has begun into using variance of radial velocities obtained from a single radar to estimate convergence associated with the individual cumulus clusters. This affords much improved resolution over the linear wind methods. Early results are encouraging, and we anticipate developing this idea further in FY 1985.

Analysis of radar data has begun in order to examine the relationship between reflectivity and precipitable water in the boundary layer (using radiometer data from WPL). Data analyzed to date reveal an enhancement of reflectivity at the top of the mixed layer starting about noon. The enhancement is attributed to intermittent mixing of cool moist air with warm dry air at the inversion. Both total precipitable water and reflectivity below the inversion increased steadily before the enhanced reflectivity was observed. We are investigating how much of the increased boundary layer moisture can be attributed to latent heat flux (evaporation).

Enhancement of Observing Capabilities

A technique to whiten the sidelobe powers of an array antenna has been identified. Its purpose is to reduce sidelobe interference with measurements of Doppler shifts in the mainlobe. The method employs antenna pattern switching so that, ideally, the sidelobes contribute incoherently to the Doppler spectral moements while the mainlobe power adds coherently. First calculations suggest that the average nonwhite power residue in the sidelobes can be 14 dB below the average sidelobe power of an equivalent nonswitched pattern. Furthermore, it is shown that with additional signal processing the power from sidelobes can be filtered out.

Performance of a weather Doppler radar with a staggered pulse repetition time has been compared theoretically with one using a random (but known) phase of the transmitted pulse. As a standard for this comparison, the specifications of the forthcoming Next Generation Weather Radar (NEXRAD) have been used. Random phase processing offers a better overall performance with an advantage of at least 13 dB in the removal of overlaid echoes. But the staggered scheme allows for automatic velocity dialiasing and should be much simpler to implement.

The effects of natural shields on Gaussian shaped antenna patterns have been quantified. The solution of ensuing diffraction integrals for the pattern shape is expressed in terms of complex error functions. It is shown that ground clutter can be reduced by as much as 20 dB by proper choice of antenna site. This finding has significance for radars that are meant to observe low-level wind shear in and around airports.

Theoretical investigation of various schemes to obtain differential reflectivity has begun. We have found that switching between fields offset from the vertical by +45° and -45° provides considerable reduction of the dwell time required for estimating differential reflectivity.

A conceptual study of how to track balloons with a NEXRAD-type radar has been completed. It is suggested that computer-controlled scan over a small

azimuth-elevation sector should produce good quality velocity estimates if echo power is fitted by a least-squares method to azimuth and elevation.

We are continuing to assess the accuracy of techniques that estimate the wind component transverse to the direction of a Doppler radar beam. For that reason we have examined Fourier spectra of mean Doppler velocity on a circle centered at the radar. For a 50-km radius we have found that harmonics with wavelength less than 50 km are at least 60 dB below the longer wavelength harmonics.

Radar-Lidar Investigation of Quiescent and Stormy- Weather

A detailed comparison of wind fields obtained by an airborne Doppler lidar with those synthesized from two Doppler radars has been completed. It was determined that errors in lidar-derived wind speed and direction came from a Schuler resonance in the inertial navigation system, which caused an erroneous indication of aircraft velocity perpendicular to the heading. This led to an erroneous subtraction from the lidar-measured radial velocities. When this Schuler resonance was accounted for, differences between lidar and radar indications were less than 0.75 m s^{-1}. Lidar and single Doppler radar radial velocities collected on another day agreed within 1 m s^{-1} through a full 360° circle around the Norman Doppler radar.

Research on the structure of the convective atmospheric boundary layer observed with the instrumented NSSL/KTVY tall tower, airborne Doppler lidar, and ground-based radars established that the vertically averaged winds in the boundary layer are insensitive to baroclinicity, supporting a hypothesis advanced in the literature in 1975. However, the computed momentum flux profiles are affected by baroclinicity. A persistent spectral peak in the spectrum of turbulence observed with lidar, radar, and tower is consistent with the presence of horizontally symmetric cells with a horizontal wavelength four times the boundary layer height, as suggested by theory.

Real-Time Weather Data Processing

Much of NSSL's work in this area relates closely to the NEXRAD project, whereby a new national radar system for severe storm warning is to replace the current WSR-57 radars toward the end of this decade. We have completed a program that displays heights of constant reflectivity, from which we identify areas of deeper convection (ADC). The locations of ADC are a basis for short-term forecasts of convective precipitation.

Computer software was developed to combine and compress Doppler velocity and lightning data so that their essence can be transmitted to users at the reasonable cost of a 9600-baud line. The DOPLIGHT data were displayed on a color terminal in the National Weather Service Forecast Office at Oklahoma City and facilitated the warning process during severe storm episodes.

An algorithm to detect and track gust fronts has been developed and tested. The algorithm contains two procedures that operate independently on the data. In one, locations of maximum radial convergence are detected and grouped into gust lines, so that fronts with strong radial components can be

identified readily. When fronts are aligned along radar radials, the mesocyclone-shear algorithm is used. Tracking with both procedures is accomplished by least-squares fitting and projecting in time a second-order polynomial in range or angle. It seems possible to project the front's position 10 min into the future with rms errors of only a few kilometers.

Gust Fronts and Downbursts

A study of the symmetry of intense local downdrafts (downbursts) from convective storms is under way. Several cases have been selected for detailed analysis. A downdraft on 30 May 1982 was found to have a velocity change as large as 20 m s^{-1} over a distance of 1 km. The affected region was elongated (10 km x 5 km ellipse) and rotated cyclonically. On 17 May 1983, downdraft winds were locally as strong as 35 m s^{-1} and shear was 3.75 x 10^{-3} s^{-1}. Investigation continues of several gust front episodes from 1982 through 1984. Initial inspection of some Doppler data point to a possible wave phenomenon at both sides of the gust front. Rawinsonde and tower observations are used together with vertical cross sections of reflectivity, velocity, and Doppler spectrum width to understand the structure of these fronts and waves.

A feasibility study of a Doppler Downburst Detector has been completed. It seems that a wide-beam radar scanning overhead could detect downward-moving air if spectral processing were utilized.

Thunderstorm Turbulence

A study of the turbulent energy budget in a severe storm from its onset to maturity was completed, and various terms of the turbulent kinetic energy equation have been evaluated. From the time of the first echo, the average kinetic energy density increases considerably. Also, the total kinetic energy of the storm increases to a steady state value near the equivalent of 230 kt of TNT. We have found that convergence of the horizontal energy flux contributes significantly to the energy change within the storm. Even though the storm is evolving, the mean winds over the storm at various heights hardly change from the environmental values over the period of observations.

NASA Langley Research Center and NSSL are sharing 1981 Doppler radar and F-106 aircraft turbulence measurements. Two important conclusions have been obtained concerning radar estimates of turbulence based on the Doppler spectrum width. First, we have observed that Doppler spectrum widths are independent of the viewing angle of the radars; widths measured from two radars with orthogonal beams agree within 1 m s^{-1}. Second, we have obtained extremely good consistency between eddy dissipation rates calculated from the Doppler spectrum width and those estimated from the spatial spectra of mean velocities.

An investigation of the effects of a bilinear velocity height profile on the Doppler velocity and spectrum width has been undertaken. Good agreement between the width predicted by this model and the measured spectrum width has been obtained.

Investigation into turbulence and the structure constant of refractive index in a solitary wave has begun. Links between spectrum width measured by

Doppler radar, vertical profiles of refractive index deduced from tall-tower measurements, and reflectivity have been established.

Data acquired in thunderstorm penetrations made by NASA F-106 and concurrent Doppler radar have reinforced statistics showing a correlation between Doppler spectrum widths (second moment of the Doppler radial velocity) and aircraft-measured turbulence.

The evolution of gust fronts and downdrafts is being studied to identify source region and to determine if characteristics of areas where these phenomena originate can be used to forecast the timing and magnitude of subsequent weather hazards.

STORM ELECTRICITY

Assessment of Errors in Automatic Ground Strike Location

Use of systems to locate ground strikes continues to increase rapidly within the continental United States. Since about two-thirds of our country is now covered by such systems, which are used daily, it is important to know their accuracy. We completed a study of systematic site errors in the NSSL system using both a simple statistical technique and comparison with actual ground truth data for lightning at long ranges (200-300 km), obtained with the University of Mississippi/NSSL mobile laboratory. We found site errors, i.e., locally caused errors in azimuths, of up to 12 degrees. We have successfully determined correction curves for our data collected prior to 1984.

System detection efficiencies that are quite high have been reported, but undocumented, for ground strike locating systems. We have found that our system detects about 70% of flashes within 300 km. Although this is somewhat lower than reported elsewhere, it is more than adequate for many applications, such as storm tracking.

Mobile Balloon Flights to Measure Electric Fields

Using the mobile storm electricity laboratory and a second vehicle for transporting and launching balloons in storm inflow regions, we joined with scientists from the University of Mississippi in developing storm intercept and balloon-launching techniques that now allow us to fly a series of balloons into the same storm. These balloons are instrumented to measure electric fields in addition to the standard meteorological sounding parameters. A half-dozen successful flights were made into severe and tornadic storms during spring 1984 in an effort to learn about the distribution of storm processes and hazards within them.

NSSL

Cloud-to-Ground and Intracloud Lightning in Tornadic Storms

Research continued on lightning rates in tornadic storms on 17 May 1981. It was found that intracloud lightning rates are highest during the tornadic stage, but that cloud-to-ground (CG) lightning rates increase significantly in the vicinity of the mesocyclone after the tornadic stage of a storm ended.

This investigation extends and supports initial results of the research on tornadic storms that was begun with data collected on 22 May 1981.

Lightning and Vertical Storm Structure

We have continued our use of the 70- and 10-cm wavelength radars at Wallops Island, Va., to investigate the distribution of lightning within thunderstorms and squall line cells. The very long wavelength makes the 70-cm-wavelength radar unique for its ability to locate lightning even in intense precipitation. By combining vertical scan data from both radars, we have found that there are two centers of lightning activity, separated vertically. The lower center is at about 6 km and the upper one at about 12 km. This is independent corroboration of our conclusion reported last year of two such lightning "cores" in Oklahoma storms. New understanding gleaned from this study is being incorporated into operational procedures used in applied research on lightning hazards to aircraft.

Lightning Hazards to Aviation

As part of our continuing involvement in a joint program with other agencies and the National Interagency Coordinating Group (NICG) on atmospheric electricity hazards, we have continued to make measurements of lightning involved in direct strikes to an instrumented NASA F-106B research aircraft. During this past year, we found that the F-106 always triggered lightning to itself and never intercepted an existing flash. Radar measurements of the direct lightning strikes to the aircraft show that the channel usually propagates bidirectionally outward from the aircraft. This observation on lightning within storms is the first experimental evidence indicating that streamer development is not a unidirectional process as had been reported in some laboratory studies.

Another aspect of our work with the NICG was to serve on the steering committee for organization of the 9th International Aerospace and Ground Conference on Lightning and Static Electricity held in Orlando, Fla., in June. There were approximately 60 papers presented and 330 registrants.

Equipment Improvements

In response to discovery of large site errors in the NSSL CG ground strike locating system, we moved the Norman site, which was the major contributor to these errors. In addition, data acquisition and "quick-look" playback of the ground strike locations have been improved with additional hardware.

A modification to the VHF lightning-mapping system was completed to allow continuous all-hemispheric mapping of lightning within storms.

Lightning Ground Strike Climatology

A final report on lightning strike density in the United States was completed for the Nuclear Regulatory Commission. Thunderstorm duration data

were compiled from 450 weather stations for a 30-year period, and lightning strike data from Oklahoma and Florida were analyzed to determine a relationship between thunderstorm duration and lightning strike density. The resulting maps of annual lightning strike density in the United States present significantly better estimates of strike density than similar maps based on thunderstorm-day data.

Plans FY 1985

- In order to develop improved operational capabilities for forecasting the locations where storms develop and their intensity, we shall continue in-depth examinations of the prestorm radar data with other data sources and theory. Variance of Doppler (radial) velocity fields will be related to development of cumulus clouds.

- To predict downdrafts and gust fronts, a study of their origin and evolution will continue.

- Studies of advanced techniques to reduce velocity and range ambiguities in Doppler radar will be conducted.

- Wind-profiling capability of weather radars will be examined both theoretically and experimentally.

- NEXRAD algorithms for detection and tracking of hazardous weather will be improved.

- A polarization capability on the Cimarron Doppler radar will be implemented and signal-processing techniques to estimate differential reflectivity will be studied.

- Relationships between microphysical and electrical processes will be studied using dual-polarized and vertical-pointing Doppler radar and electrical measurements.

- The VHF lightning-mapping system will be modified for greater simplicity and reliability in acquiring data of high quality.

- We will continue to contribute to the NICG on atmospheric electricity hazards, including analysis of in-flight lightning strike data. **NSSL**

- We will be analyzing physical characteristics of +CG flashes and analyzing mesoscale and synoptic conditions associated with a storm having an unusually high percentage of +CG flashes.

- We will complete analysis of flash rates and mesocyclone development for two tornadic storms and determine electric field profiles in different storm areas and compare them with storm structure.

COMPUTER AND ENGINEERING SUPPORT AND DEVELOPMENT

This group (CESD) develops techniques and equipment, maintains observational facilities, and supports observational programs associated with 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 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 1984

COMPUTING AND DATA PROCESSING

An award was made to purchase a DEC VAX 11/780 computer system consisting of 12-megabyte memory, 1778-megabyte disk storage, and three magnetic tape drives. This system will be used for interactive editing of Doppler radar data, for editing and archiving of other NSSL-collected data, and as a remote job entry link to the CDC 750 in Boulder.

NSSL's Perkin-Elmer 3242 was upgraded to 8 megabytes of memory; it continues to drive a color graphics unit for the display of real-time radar products and is used for quality control of data from radars, lightning sensors, and weather sensors in the NSSL surface network and on the tall tower.

Universal format tapes were produced for Doppler radar data and distributed to one university for evaluation. During the spring collection program, 477 Doppler radar data tapes were recorded.

NSSL supplied data sets to these users:

Alberta Hail Project	(G.S. Strong)
CIMMS	(G. Lesins)
NASA	(G. Heymsfield)
NASA, Huntsville, Ala.	(S. Goodman)
NWS, Silver Spring, Md.	(K. Shreeve)
Oklahoma University	(H. Bluestein)
Parks College	(R. Pasken)
Rice University	(G. Byrne)
Sperry Corporation	(W. Heiss)
Systems and Applied Sciences	(G. Smythe)
Texas A&M	(G. Sickler)
Texas Tech University	(K. Mehta)
University of Arizona	(N. Feldman)
University of Quebec at Montreal	(I. Zawadski)
University of Tennessee	(M.A. Abidi)
University of Wisconsin	(R. Ferrare, R.N. Mower)

FACILITIES ENGINEERING

During the first quarter of FY 1984 the CESD Group participated in a program with the Air Force for evaluation of the weather detection capability of an airborne radar. Weather radar data from the NSSL ground-based radars were used as the benchmark for this comparison and evaluation.

As in the past, much of the group effort in both engineering and support centers around the spring data acquisition program. During this year, all base facilities, i.e., tall tower, a 28-station surface network, two Doppler radars, WSR-57 surveillance radar, and the air traffic control facility were operated from 1 April through 15 June in support of this program.

Data from the Doppler radar at Norman were routinely transferred to the Weather Service Forecast Office at Will Rogers Airport in quasi-real time during the Spring Program. These data proved useful to the duty forecaster; the records kept during the experiment are being studied in order to evaluate this capability in relation to an effective evolution in data sources for the National Weather Service.

Screening of radar data has been greatly facilitated at NSSL through frequent photography of the Norman Doppler data displays during data acquisition. The slides have been developed and cataloged, and have usually been available for viewing within 2 days after the event. The file is retained as a permanent part of the Laboratory data base.

Design, fabrication, and testing of both the coherent and incoherent radar ground clutter cancelers were completed. Data needed for a comprehensive performance evaluation have been acquired, and analysis will be completed during FY 1985.

Design of dual polarization capability for the Doppler radar at Cimarron is continuing although receipt of the microwave hardware necessary to implement the capability has been delayed. The stringent design requirements for NSSL hardware, particularly the switchable ferrite circulators, have presented a challenge to the manufacturer.

Plans FY 1985

COMPUTING AND DATA PROCESSING

NSSL

- The new VAX 11/780 will be installed early in 1985 and additional support equipment will be added as follows: electrostatic plotter, 7-track magnetic tape drive, and a two-monitor color graphics system. By mid-year, a Class VI supercomputer should be operational in Gaithersburg, Md., and a data communication link will be established between NSSL and the Class VI. By the end of FY 1985, all major computing will be shifted to the Class VI machine.

FACILITIES ENGINEERING

- The NSSL radar system was configured for ground-based testing of an airborne radar manufactured by Sperry Corporation. The data acquisition program and evaluation by comparison with the NSSL ground-based radar will be completed during the first quarter of FY 1985.

- The NSSL radar facilities will be operated in support of data acquisition during winter storms in the second quarter of FY 1985. This program is supported by the National Science Foundation and administered by the University of Oklahoma.

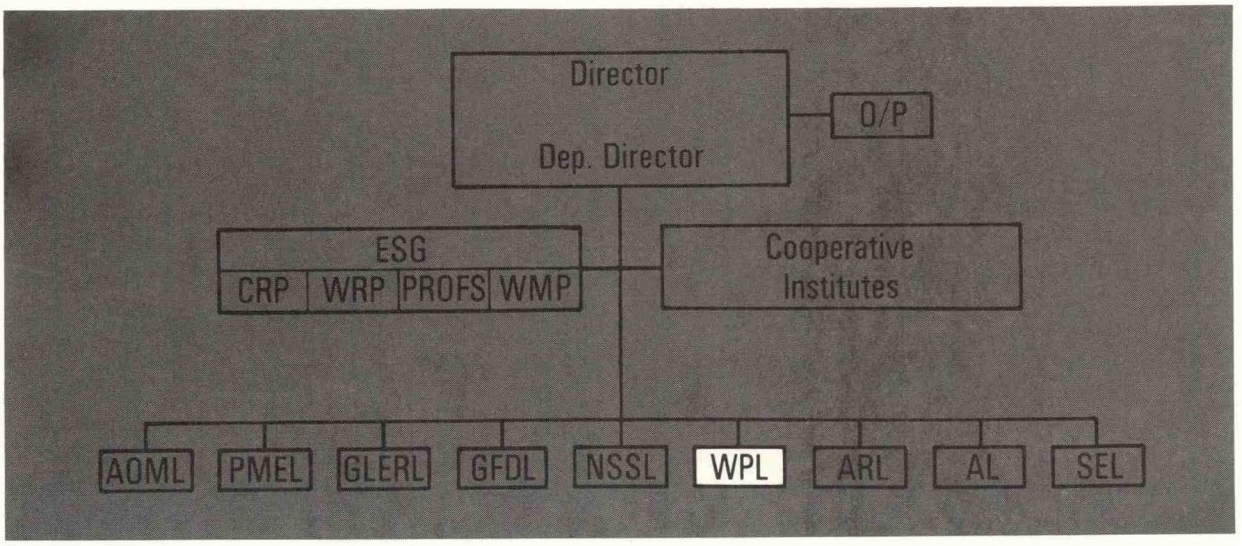
- Assuming delivery of critical microwave hardware, NSSL will establish a Doppler radar dual-polarization capability on the Cimarron radar system during the second quarter of FY 1985. The dual-polarization radar measurement has potential for improving the radar rainfall estimates, identifying hail, and studying physical processes attending electrification and hydrometeor deformation.

- During the third quarter of FY 1985, NSSL will host participants of the Oklahoma-Kansas PRE-STORM Program, a prologue to the STORM-Central Program in 1988. Major facility changes will involve deployment of 42 surface weather stations throughout Oklahoma and expansion of the cloud-to-ground lightning location network to cover a large portion of the southern Great Plains. Other research plans include a hail study program, dual-Doppler radar studies, storm electricity studies, and preliminary evaluation of dual-polarization Doppler radar potential.

- General facilities expansion and modification plans include the commissioning of a second-generation data logger on the NSSL instrumented tower; design, fabrication, and installation of a radar signal preprocessor and an expanded real-time display terminal on the Cimarron radar; and the design and installation of a differential reflectivity calculator to operate in real time.

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. The following presentations give a brief rationale for the research programs, and summarize the FY-1984 programs and FY-1985 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. Such services are 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 1984

SENSOR DEVELOPMENT

An 8.6-mm-wavelength scatterometer for observation of cloud and precipitation particles was fabricated and tested on warm (i.e., ice-free) clouds near Hilo, Hawaii.

Appropriate software was completed to permit the use of an array processor in the processing of FM/CW radar data.

An acoustic microsounder operating in the 6-7 kHz range was developed to measure atmospheric structure between 10 and 100 m above the ground. It was tested successfully during the DOE/EPA complex terrain field program in Brush Creek Canyon, With Doppler capability added, this device will greatly enhance WPL's capability for wind measurement over irregular terrain.

WPL's 2-kHz bistatic Doppler sodar was modified to operate in a two-axis monostatic mode. Two such systems were deployed in support of EPA's Tracy powerplant experiment and the Brush Creek experiment.

WPL evaluated the performance of four commercially available Doppler sodars. This study was conducted for EPA to determine the capabilities of acoustic Doppler sounding in environmental monitoring programs.

The second, third, and fourth phases of the Flatville experiment sponsored by the Army Research office, were completed. Amplitude, phase difference, and angular fluctuation data were taken at a range of frequencies from 140 GHz to 180 GHz in clear air, rain, fog, and snow. The measurements are in the process of being compared with the data from our extensive meteorological instrumentation consisting of high-speed humidity, temperature, and wind fluctuation sensors; one- and two-dimensional aerosol probes, and an array of path-averaging sensors that measure wind, rain, and refractive turbulence.

WPL has developed a technique for inferring the path-averaged momentum flux from turbulence microscale measurements on paths of up to 250 m. Progress was made during the fiscal year on measuring the intensity variance (scintillation) at both 10.6-μm and millimeter wavelengths. These three measurements, combined with scintillation data at an appropriate mid-infrared frequency, will give us sensitivity to turbulent water vapor, temperature, and wind speed fluctuations, and ultimately the ability to measure the path-averaged fluxes of these quantities.

Line-of-sight optical devices have demonstrated the ability to measure path-averaged values of boundary layer parameters such as wind speed. WPL has designed and built an optical wind and refractive turbulence profiler that will produce high resolution profiles of wind and refractive turbulence on both horizontal and slant paths of several kilometers.

In the process of developing a rain and drop-size distribution gauge that gives path-averaged values over hydrologically important distances (several kilometers), WPL has taken the first measurements of the effects of rain on phase difference spectra. Previous sensors, whose measurements are based on amplitude fluctuation, have had limited paths because of the onset of multiple scattering in heavy rain. Techniques based on phase difference are insensitive to multiple scattering and appear to work on much longer paths.

RESEARCH

A gravity/shear wave experiment was conducted in May 1984 in which all wave events detected during the 1-month period by the newly expanded microbarograph array at ERL's Boulder Atmospheric Observatory (BAO) were recorded, processed, and displayed, New techniques were developed to display wave and turbulence parameters in graphical form. Scientists at WPL and Georgia Institute of Technology are analyzing the data.

The laboratory also participated in Project Phoenix II, a major convective boundary layer study performed in cooperation with the National Center

for Atmospheric Research (NCAR) and the University of Oklahoma. WPL's contribution included boundary layer measurements from dual-Doppler radars, sensors on the BAO 300-m tower, and rawinsonde flights.

In conjunction with Phoenix-II, WPL conducted a microburst experiment at the BAO, integrating data sets from the tower, the optical triangle convergence-measuring system, radars, lidar, and aircraft. Their different signatures provide the basis for a better definition of microbursts and their structure.

A stable-layer experiment, designed to study the structure of very thin shear layers, yielded more examples of the intense layering observed in an earlier experiment, Their implications to radar transmission in the boundary layer are being examined.

A report was made to EPA on the development of a technique for indirectly estimating boundary layer parameters for dispersion modeling.

Analysis of wind shear events during the 1983 Joint Airport Weather Studies (JAWS) experiment was completed.

Several Front Range meteorological events were analyzed in detail, in a report on Project Aeolus.

A multiwavelength, multipolarization study of chaff in the boundary layer was performed in conjunction with NCAR's dual-polarization radar.

Polarization signatures expected of prolate ice crystals in cirrus clouds have been computed for radar wavelengths of 8.6 mm and 3 cm.

An experiment was performed in conjunction with Aeromet, Inc., to study properties of stratiform clouds on the slopes of Mauna Loa in Hawaii. This was in preparation for a more extensive study, using the 8.6-mm-wavelength radar and the 20-30 GHz radiometer, that will be performed, funds permitting, during the summer of 1985.

Plans FY 1985

SENSOR DEVELOPMENT

WPL will participate in one more Flatville field program in FY 1985. We will also analyze existing data tapes to determine atmospheric propagation effects on millimeter waves and relate these effects to the state of the atmosphere as indicated by our extensive meteorological data set.

In connection with the flux measurement program, WPL will continue to investigate the turbulence spectrum in the region near the inner scale, analyze the Flatville millimeter-wave scintillation data for sensitivity to humidity fluctuations, and search for an optimal, mid-infrared frequency suitable to complete the three-frequency flux measurement technique.

WPL will work with the U.S. Geological Survey (USGS) and the National Ocean Service (NOS) to analyze different active optical techniques for obtaining higher precision in geodetic leveling.

Slant path measurements of turbulence parameters and wind have not progressed rapidly because of the difficulty of folding the optical path to obtain the necessary single-ended operation. Working with the Air Force, WPL will build and test an optical instrument that will work on a slant path, using a tower-mounted retroreflector.

The polarization properties of microwave-reflecting chaff at wavelengths ranging from 8.6 mm to 10 cm will be investigated to assess the suitability of chaff as a depolarizing target in precipitation.

Doppler wind-sensing capability will be added to the microsodar, thereby providing WPL with a truly mobile wind-sensing capability between 10 and 100 m.

RESEARCH

The infrared Doppler lidar, and the multiwavelength lidar (operating at visible and ultraviolet wavelengths) will be used to measure backscatter from lenticular wave clouds. By inverting the three-wavelength measurements, the cloud particle size distribution will be obtained, allowing the study of particle growth in such simple, laminar clouds.

The lidars will also routinely monitor upper troposphere and stratosphere turbidity in support of GMCC and NESDIS ozone measurements.

Analysis of the data from Project Phoenix-II will continue with emphasis on elucidating the fine-scale structure of the boundary layer.

A study of the statistics of gust fronts and microbursts measured during the JAWS project will be completed, for application to improving aviation safety.

Analyses of orographic flows, which can affect aircraft response at commercial flight altitudes, will be carried out.

An experiment will be conducted at the BAO to study atmospheric processes on the meso-gamma scale, using WPL in situ and remote sensors. The experiment will focus on events relevant to airport meteorology and air quality. **WPL**

Development of a Front Range boundary layer model that replicates the Denver vortex will be completed; data from the Phoenix-II experiment will be used for model validation.

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 to air pollution studies are discussed in the section on Air Quality.)

Accomplishments FY 1984

MESOSCALE SENSOR DEVELOPMENT

The pulsed, infrared, Doppler lidar was improved through implementation of computer-controlled azimuth and elevation scanning. This allows pre-programmed scan patterns to be developed for measuring winds in canyons or along aircraft glide slopes without wasted time for turnarounds or scanning irrelevant regions. The spectral moment processor was calibrated at the BAO tower.

A new pulsed, coherent, CO_2 laser has been developed for WPL through a contract let to the private sector. This laser will provide an increase in average infrared output energy by a factor of 100 over the present unit. It passed its acceptance tests in September 1984, and it will be shipped to Boulder in October.

Side-by-side operation of the 915-MHz Profiler and the Doppler lidar at Stapleton Airport provided an independent check on Profiler wind measurement accuracy. The two remote sensors usually agreed closely, within 1 m s^{-1}. Dynamic or changing meteorological conditions resulted in less close agreement; the reasons for these differences are under investigation.

Two-dimensional (horizontal and vertical) maps of liquid water and water vapor in cloud were developed using the technique of radiometric tomography, in which the data from two spaced radiometers are combined.

The steerable-beam 20-30 GHz radiometer has been implemented to provide continuous real-time profiles of water vapor.

A new technique for measuring entrainment in clouds, utilizing depolarization of circularly polarized radar waves by chaff, has been evaluated and has undergone preliminary tests.

The 3-cm radars have new microwave circuitry that has decreased undesired leakage so that estimates of Doppler spectral widths are more reliable.

Second-moment turbulent quantities have been computed from fluctuations of the Doppler velocity obtained by radar. The method has potential application in the formation and dissipation of stratus clouds.

Coefficients for statistical retrieval of total precipitable water from dual-channel radiometer data are normally derived from long-term radiosonde

data; it has been found that they can be estimated, as a function of climatic mean surface pressure, for locations where radiosonde data are not available.

MESO-BETA AND -GAMMA SCALE RESEARCH

Measurements with the NOAA P-3 research aircraft during Arctic Cyclone Experiment, 1984 (ACE, 1984) described the structure of previously unexplored arctic atmospheric phenomena. Highlights of this experiment were the documentation of (1) the Spitzbergen coastal ice edge atmospheric frontal zone, (2) warm frontal structure over the polar ice cap, (3) the three-dimensional structure of a polar low, (4) a frontal occlusion south of Iceland, and (5) a Norwegian Sea convergence line.

Measurements from the BAO tower, acoustic echosounder, and research aircraft documented the density current hydraulic head structure at the leading edge of surface cold fronts. The analysis constitutes a description of the role of ~1-km-scale frontal heads in triggering intense squall-line mesoconvection.

Results from the Arctic gas and aerosol sampling program (AGASP) 1983 provide the first direct documentation of stratospheric-tropospheric exchange in arctic latitudes. Measurements documented the injection of stratospheric ozone and El Chichón volcanic debris into the Arctic troposphere during tropopause folding events.

WPL continued numerical studies that simulate the combining of high vertical resolution and temporally continuous radar wind profiles with low-vertical-resolution but temporally continuous ground-based and satellite radiometric temperature profiles. The results, published in collaboration with researchers from the University of Miami, demonstrate the value of wind profiler soundings in enhancing the vertical structure of radiometrically derived thermal retrievals.

The Doppler lidar was operated near the BAO tower in July, and succeeded in measuring several downburst wind events, including one detected before it reached the ground. Subsequent gust arc dynamics were also recorded and observed in real time on the Doppler processor color display. These events are now being analyzed in an attempt to explain the dynamics of such short-lived wind shears.

WPL

During DOE's Atmospheric Studies in Complex Terrain (ASCOT) 1984, the Doppler lidar measured wind cross sections in Brush Creek Canyon near De Beque, Colo. The development of down-valley winds, side canyon drainage, and subsequent up-valley flow after mid-morning were observed and recorded for later evaluation. The lidar trailer with its real-time wind display in color was chosen as experiment command post by the project field manager.

The FAA was informed on the performance of its wind shear alert system during the JAWS project. The results are being used as a basis for making improvements in the FAA wind shear alert systems.

WPL participated in an FAA-sponsored experiment to determine the feasibility of reducing the vertical separation of commercial jet aircraft operating in orographic flows. Orographically induced altitude variations at commercial flight altitudes were discovered to be larger than FAA had realized.

The two 3.2-cm-wavelength radars participated in a storm electrification experiment at the Langmuir Laboratory near Socorro, N. Mex., in conjunction with investigators from NSSL, New Mexico Institute of Mining and Technology, and NCAR.

Joint measurements by millimeter-wave radiometer and radar have identified the amount and location of supercooled liquid in a winter snowstorm.

WPL participated in atmospheric radar projects relevant to national security at Kwajalein Atoll.

Plans FY 1985

MESOSCALE SENSOR DEVELOPMENT

The new coherent infrared laser, providing 2 joules per pulse at a 50-Hz repetition rate, will be tested in the laboratory, then integrated into the present lidar.

A Data General S-120 computer has been procured and will be installed in the 8.6-mm-wavelength radar. This will allow the implementation of software for real-time data display.

Investigation will be started into the possibility of reconfiguring the antennas of both the 8.6-mm and 3.2-cm wavelength radars to allow greater polarization sensitivity.

MESO-BETA AND -GAMMA SCALE RESEARCH

The analysis and publication of observations from the Arctic Cyclone Experiment, 1984, a collaborative effort between NOAA, the Navy, NASA, CIRES, and the Norwegian Meteorological Service will be continued.

Jet streams, fronts, extratropical cyclones, and mesoconvective weather will be studied, using the WPL "Colorado Triangle" radar wind profiler and radiometric water vapor mesoscale network.

Field experiments with profilers, weather radars, radiometers, and lidars will be conducted, to demonstrate the application of WPL remote-sensing instrumentation to the observation, diagnostics, and forecasting of mesoscale weather systems.

A study of entrainment and mass flow through tropical cumulus clouds will be undertaken using the 8.6-mm-wavelength radar and chaff. This will take

place, funds permitting, in cooperation with the University of Washington, the Illinois State Water Survey, University of Illinois, and NCAR on the island of Hawaii.

A data set on warm clouds using 8.6-mm-wavelength radar, scatterometer, and dual-channel radiometer, with in situ sensors will be obtained, funds permitting.

Joint measurements on the properties of clouds using dual-polarization Doppler radars and a steerable dual-channel radiometer will be expanded.

The spatial distribution of tropospheric water vapor and its continuum absorption at low surface pressure will be measured using dual channel radiometry.

Radiometer measurements of path-integrated liquid and vapor in support of geodetic metrology will be continued.

The 3.2-cm-wavelength radars will continue to participate in studies of cloud and storm structure.

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 1984

The 405-MHz wind profiler was built and is now undergoing engineering tests. This first version will be used to confirm the scattering properties of the atmosphere at this frequency.

The Colorado wind profiler network was operated in support of further tests, and applications that included use of the data by the FAA to study aircraft separation standards over mountains, and air traffic control procedures in the Denver area. The data were also used to study preconvective storm convergence and vorticity patterns, and as part of the data base for a PROFS FY-1984 exercise. An inexpensive personal-computer-based profiler

display was developed and is being used at the Denver National Weather Service (NWS) forecast office and by meteorologists in the NESDIS Regional and Mesoscale Meteorology (RAMM) group at Colorado State University.

Operation of the six-channel microwave radiometer was continued and the data used in a study of the remote detection of hazardous aircraft icing conditions and in a cloud detection experiment. Concepts for introducing higher vertical resolution into the thermodynamic profilers were developed, including an improved method for the automatic detection and measurement of the height of the tropopause. These concepts use wind profile information to derive the temperature field, which is then used to introduce baroclinic zones and temperature inversions into the passive radiometer-derived profiles.

Ground-based temperature profiles have been combined successfully with temperature profiles from the orbiting NOAA satellites. Similar combinations have been simulated with sounding data from geostationary satellites. Software for combining the ground-based and satellite data in real time has been prepared.

Brightness temperatures affected by the microwave transmission characteristics of reflectors wetted by rain have been calculated and computed for millimeter-wave radiometers.

Comparisons of backscattered intensities from the zenith for the 10-cm-wavelength FM/CW radar and the 33 cm-wavelength Stapleton profiler were made. These indicated that the inner scale of turbulence increases rapidly to more than 5 cm above the top of the boundary layer, indicating that 10 cm is not a suitable wavelength for wind profiling above the boundary layer.

Plans FY 1985

A special task team will be formed to design and implement a Profiler network to support the National Stormscale Operational and Research Meteorology (STORM) program and Profiler operational evaluation by NWS. This network will contain 30 wind profilers and a hub for data collection and network control. In FY 1985 this project will concentrate on the creation of a wind-profiling design that can be transferred to industry for mass production and wide availability to multiple users.

Research on the development of instruments and/or techniques that are capable of producing high-resolution temperature/moisture profiles will be accelerated. This effort will examine the feasibility of various sensor combinations and the application of the principles of atmospheric dynamics to achieve the desired height resolution.

A triangular array of three wind/humidity profilers will be operated on the high plains of eastern Colorado, to study the ability of such an array to monitor moisture convergence, and hence to contribute to cloud and precipitation forecasting.

R&D ON THE GLOBAL SCALE

WINDSAT (wind-measuring satellite system) is a concept for measuring the global wind field at multiple levels in the atmosphere, twice each day, by means of a pulsed, infrared, Doppler lidar on a polar-orbiting satellite. WPL has worked on the WINDSAT project for several years. Because of funding restrictions, and in the absence of a clear requirement for continuing analysis of WINDSAT from NESDIS or NWS, the project was terminated during FY 1984. We will continue to develop Doppler lidar technology with our trailer-based system, and be ready to assist in any reopening of the WINDSAT concept in the future.

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 1984

A report was provided to the Department of Energy on the use of acoustic echo sounders for the study of flows in complex terrain.

Data were analyzed and reported to EPA sponsors from the Small Hill Impaction experiment conducted near Farmington, N. Mex., and from the CONDORS (Convective Dispersion Observed by Remote Sensors) experiment at the BAO tower during FY 1983. The data were obtained with the multiwavelength lidar, acoustic sounders, tethersondes, sonic anemometers, and optical transverse wind sensors. EPA is using the data to validate plume dispersion models.

The same set of experiment equipment participated in a 3-week experiment at the Tracy powerplant near Sparks, Nev., in September 1984. Transport of the seeded plume was observed with the lidar to ranges in excess of 5 km.

The ASCOT field program is currently using the WPL-designed transverse optical wind sensor as the instrument of choice to measure flows in complex terrain. Twelve optical paths were set up and used during the FY-1984 ASCOT experiment. **WPL**

Radar data from project CONDORS 83, a plume transport and diffusion experiment performed in cooperation with EPA, have been analyzed for the six highest priority cases. In this experiment, oil fog and aluminized chaff were released at different heights from the BAO tower, and tracked by WPL's lidar and radar systems.

The 8.6-mm-wavelength radar measured wind flow associated with a large explosion as a part of the Defense Nuclear Agency's Direct Course experiment.

For EPA, we evaluated the performance of various in situ sensors routinely used for turbulence measurements in environmental monitoring applications.

Plans FY 1985

Analysis of radar data from project CONDORS 83 will continue. The data will be combined with lidar and in situ data from BAO tower sensors for use by EPA researchers,

Analysis of data from the September 1984 Nevada plume experiment at the Tracy powerplant will be completed.

Large eddy structure analysis of data collected during the 1982 EPA Small Hill Plume Impaction experiment in Farmington, N. Mex., was completed.

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 1984

CODAR (Coastal Ocean Dynamics Applications Radar) was operated for 2 months on the east coast of Florida to map surface currents during the December 1983 STACS (SubTropical Atlantic Climate Studies) program. The 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 1985

Analysis of the STACS data sets will continue, to determine the adequacy of CODAR to measure total transport and to study the dynamics of surface signatures of subsurface features.

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 1984

In January and February 1984, WPL led a multi-agency, multination Arctic Cyclone Experiment, using the NOAA P-3 research aircraft to (1) develop and evaluate remote-sensing techniques for monitoring sea state and ice; (2) study the meteorology of the Arctic, with emphasis on the Icelandic low and polar lows; and (3) measure CO_2 exchanges between the air and sea in the polar oceans. NASA, the U.S. Navy, and Norwegian and Icelandic agencies participated in the experiment. The NASA P-3 research aircraft participated in the Iceland phase with a full complement of remote-sensing instruments. More than 100 hours of research flight time provided great quantities of data over the Greenland Ice Cap, the ocean front north of Iceland and the ice zone in the Denmark Strait, the area around Spitzbergen, and off the west coast of Norway. Observations of a mature polar low were obtained on 27 February 1984.

A new microwave radiometer built by the University of Massachusetts was flown for the first time onboard the NASA aircraft during the Arctic Cyclone Experiment. (It was later installed onboard the NOAA P-3 aircraft and successfully obtained data during the summer 1984 Marginal Ice Zone Experiment--MIZEX. This instrument also participated in research flights of Hurricane Norbert in the eastern Pacific.) Commonly known as the Stepped Frequency Microwave Radiometer (SFMR), the University of Massachusetts instrument provides information on the type and concentration of sea ice, ocean surface wind speeds, rain rate, and the microwave emission properties of snow and ice.

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

Two CODAR vans were prepared, and one was used during the winter 1983-1984 STACS program in Florida. These vans will make future CODAR field operations much more economical. In addition, the real-time display and the detailed documentation on CODAR have been completed.

Results of the CODAR work in the Alboran Sea have shown wide variability of the surface current jet in the Strait of Gibraltar.

Plans FY 1985

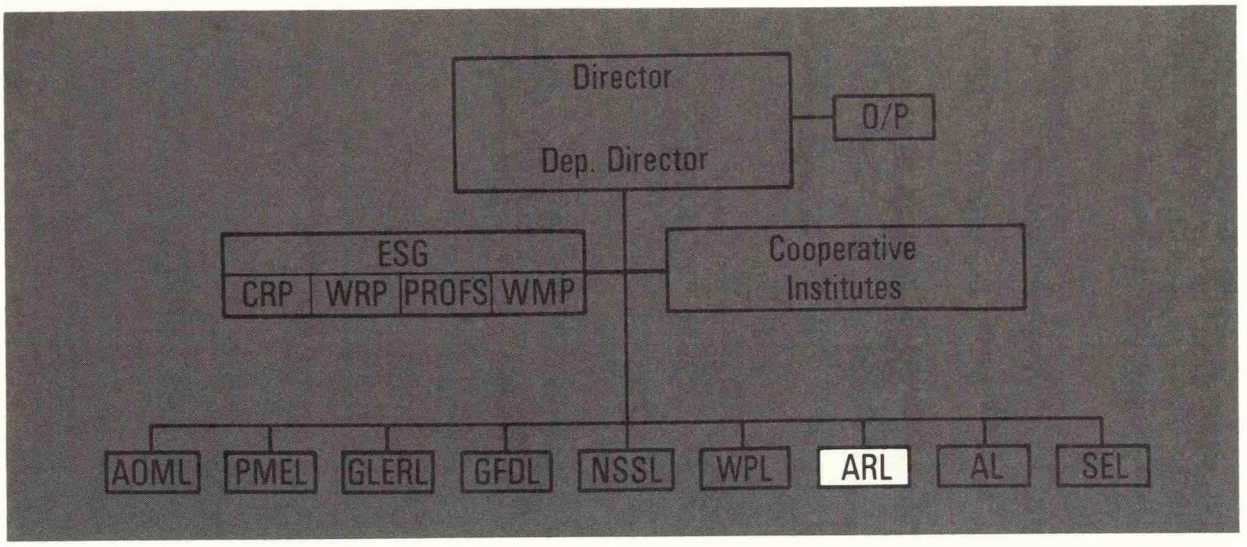
WPL

Available to WPL from the University of Massachusetts is a new radar scatterometer to measure surface wind velocity fields and to participate in experiments to study surface scattering characteristics. This instrument operates in the same frequency band as the European ERS-1 satellite-borne scatterometer. If funds become available, this instrument will be made flight ready and installed onboard the NOAA P-3. It would then be ready to participate in a PMEL experiment and/or the NASA Rain-Ocean Measurement experiment in the spring of 1985. The latter experiment is important for the understanding of the effects of precipitation on ocean surface scattering and the attenuation of microwave signals through the precipitation. Future satellite-borne instruments will need this information for the proper interpretation of scatterometer and altimeter data obtained over severe storms.

WPL and AOML plan (subject to funding availability) to set up the two CODAR systems at Fisher Island and Ft. Lauderdale and run them for about 1 year. The surface current measurements will be used in assisting search and rescue efforts by the Coast Guard, and in oceanographic research by NOAA.

AIR RESOURCES LABORATORY
Rockville, Maryland

Lester Machta
Director



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 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 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 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 Department of Defense, 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 ultraviolet (UV) radiation is done through analysis and modeling of its secular variation and intensity and through direct measurement of 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 GMCC baseline observatories. 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 1984

A major atmospheric transport and dispersion study, the Cross-Appalachian Tracer Experiment (CAPTEX) was completed successfully in October 1983. The DOE, EPA, Electric Power Research Institute, National Weather Service (NWS), Atmospheric Environment Service of Canada and Ministries of the Environment of Ontario and Quebec all participated in CAPTEX '83 under the direction of NOAA/ARL. There were five releases of a perfluorocarbon tracer gas at Dayton, Ohio, and two releases at Sudbury, Ontario. Tracer concentrations were measured in 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 area are considered to be significant pollutant sources affecting air quality and contributing to acid rain in the New England states and southeastern Canada. Seven sampling aircraft were used to determine the vertical distribution of the tracer. Both the density and frequency of upper-air soundings were doubled over the experimental area.

The thousands of CAPTEX air samples have been analyzed, and data are being compiled on magnetic tape along with extensive meteorological measurements. The data clearly show the path and dispersion of the tracer gas as it passes through the sampling array. CAPTEX will provide a unique data base to evaluate and improve the transport and dispersion modules of long-range pollution models.

ARL's year-long Metropolitan Tracer Experiment (METREX) in the Washington, D.C., area began in November 1983. The experiment is designed to provide data to evaluate dispersion models in an urban setting and to develop and compare dispersion climatologies over adjacent urban and rural areas. Perfluorocarbon tracers are being released at two different sites every 36 hours. Average monthly tracer concentrations are measured at about 90 sites, and continuous 8-h samples are being collected at three sites to provide more detailed data on individual plumes. A third perfluorocarbon tracer, PMCP, has been developed for atmospheric dispersion studies and is being tested in METREX.

Plans FY 1985

CAPTEX data processing will be completed early in FY 1985, and the data will be made available to the atmospheric science community. A CAPTEX model evaluation workshop planned for mid-1985 will provide an opportunity to present

and evaluate model results, suggest means of improving model performance, and discuss the lessons to be learned from CAPTEX for planning future large-scale atmospheric transport and dispersion experiments.

The year-long METREX experiment will be completed in December 1984, and results will be used to improve modeling of urban-rural effects on atmospheric dispersion.

ARL will participate in the DOE Atmospheric Studies in Complex Terrain (ASCOT) dispersion experiments in September-October 1984 in Colorado. All three perfluorocarbon tracers will play a key role in delineating nocturnal valley flows and early morning venting of pollutants out of Brush Creek Valley, located in an oil shale development area.

ATMOSPHERIC TRACERS

Accomplishments FY 1984

A preliminary elevated plume study was conducted near Reno, Nev., in November 1983. A 4-week full-scale elevated plume study was carried out near Reno in August 1984. Measurement techniques were similar to those utilized for the Hogback Ridge field experiment. EPA sponsored this research as a part of its Complex Terrain Model Development program.

The data measurements from the Shoreline Environmental Atmospheric Diffusion Experiment-1 (SEADEX-1) field program (conducted along the western shoreline of Lake Michigan) have been processed, summarized, and made ready for reporting. NRC sponsored the analyses and report preparations as a part of its Shoreline Atmospheric Environment research program.

Analysis and reporting of the meteorological and tracer data for the Convective Diffusion Study was completed. The field study was sponsored by EPA.

Gaseous tracer release and sampling support was provided during the ASCOT field measurements in the latter half of September 1984, in complex terrain near Rifle, Colo.

The climatological description and data for the Idaho National Engineering Laboratory were upgraded. The revisions were made to include additional information and to include continuations of data collections performed since 1966. The revision consists of two two-part volumes to support the engineering analysis of local and regional meteorology, climatology, and dispersion climatology. Condensed short contributions were prepared from these revisions for inclusion in the multivolume Idaho National Engineering Laboratory Environmental Characterization Report. **ARL**

Plans FY 1985

The meteorological and tracer measurements performed during August 1984, using tracer emissions from a powerplant stack near Reno will be tabulated,

analyzed, and reported to EPA as part of the Complex Terrain Model Development program.

The gaseous tracer support for the ASCOT program is planned to continue into October 1984. A reporting of the tracer releasing and sampling will be prepared.

A description and listing of the meteorological and tracer gas data taken during SEADEX will be provided to NRC, the sponsor.

ACID DEPOSITION

Accomplishments FY 1984

There is no question that the acid rain problem has continued to be one of the major environmental questions before the U.S. public. Heightened concerns, both national and international, have been expressed with significant evidence of forest damage. These environmental attacks may be broader than just acid rain and could include the impact of other chemicals in the atmosphere, such as ozone. Along with other ERL scientists, researchers in ARL have worked to provide the best scientific input to decision-makers who must eventually decide on national pollutant control strategies. Also considerable effort was put into international activities that involved both Canada and Europe. In the national effort under the Interagency Task Force on Acid Precipitation, ARL participation has included taking an active leadership role in a number of areas.

To date, ARL's program has been involved in three research areas: Natural Sources, Atmospheric Processes, and Deposition Monitoring. In all three areas, our program was given very high marks in the first program review of the Federal effort (Boston, 1983). Important progress has been made in particular areas:

- New analytical techniques for measuring sulfur-containing species were developed and field tested.
- A special study was carried out to evaluate the inflow of natural acid-forming materials from the Gulf of Mexico.
- The meteorological aspects of long-range transport during CAPTEX have been better defined using inert tracers.
- The Western Atlantic Ocean Experiment (WATOX), which is aimed at measuring the flux of sulfur and nitrogen compounds off North America, produced its first estimates of transboundary fluxes for these compounds.
- The Global Trends Network, after three years of measurement, showed that the acidity in remote areas was higher than generally expected and that organic acids were important in remote areas.
- Dry deposition research progressed enough so that prototype monitors have been sent to the field for testing.

- Special studies at the atmospheric research sites included intercomparison of wet sampling procedures and the establishment of gas and aerosol measurements.

Plans FY 1985

Ongoing activities will be supplemented by the following new activities in 1985:

- A major field experiment will be conducted during March/April 1985 under WATOX. Along with measurements from the King-Air, a special set of ground measurements will be made along the East Coast and Bermuda.

- In cooperation with EPA, mountain-top observatories to measure acid deposition will be developed.

PLUME TRANSPORT & DISPERSION

Accomplishments FY 1984

Available information on atmospheric turbulence in the Planetary Boundary Layer (PBL) has been re-examined, and a revised set of recommended procedures for evaluating dispersion has been produced. These methods focus on the need to take PBL scaling factors into account, even near the surface.

Work on scaling the depth of the PBL is continuing. Numerical models are being used to investigate the relative importance of different factors, and supporting theoretical arguments are being developed. For the daytime case, classical arguments concerning free convection form the basis for much of the new work. For the nocturnal case, the roles of gravity waves and of decoupling at night are receiving most attention. A modified experimental program to investigate the occurrence of turbulence intermittency during strongly stable conditions has been initiated as an outgrowth of the PBL monitoring program conducted at Oak Ridge during previous years.

The automatic video digitization system developed during the last two years has been used in a field study to investigate plume dispersion associated with a large fire, in Virginia during 1983. Video records of the plume have been edited and are now available for distribution. **ARL**

The Laboratory is continuing to play a role as a reviewer of alternative and potentially competing dispersion models. For purposes associated with power-plant siting, codes developed for the NRC have been examined in considerable detail. Possible sources of errors have been identified, and the consequences of the most critical errors have been assessed for selected circumstances.

The METREX study is explained elsewhere in this report. A team from Oak Ridge has participated in most of the METREX experiments conducted to date. Oak Ridge participation has been to provide information on the evolution of the PBL during the performance of tracer release experiments.

Plans FY 1985

Work on evaluating methods for testing numerical models will continue. The Laboratory will participate in a model evaluation workshop being organized for early FY 1985 by the Savannah River Laboratory. The emphasis of the contribution will be on the theory and philosophy of model testing. Special attention will be given to the need to ensure that model outputs and experimental data bases share important common features, arranged so that models are not asked to explain variations in nature that they are incapable of addressing.

Studies of the effects and causes of nocturnal turbulent intermittency will concentrate on the area surrounding Stone Mountain, Ga., where a cooperative study with Georgia Institute of Technology is about to commence.

COMPLEX TOPOGRAPHY

Accomplishments FY 1984

The ATDD continues to contribute to the DOE's ASCOT program. A major field study in northern Colorado took place at the close of FY 1984. A preliminary study, designed to get ready for the subsequent major investigation was conducted during June, and several exploratory visits to the area in question were also conducted. A team of eleven ATDD scientists and technicians operated tethersonde profiling apparatus during periods of intensive study, and contributed some exploratory measurements of turbulent exchange in conditions of nocturnal drainage flow. A new focusing on quality assurance and quality control of experimental data was led by ATDD. A coordinated effort was organized to compare data from different instruments, to provide standards for comparison, and to guarantee that no erroneous values will be included in final data tabulations.

Attempts to simulate flow features in complex terrain continue. A new drainage flow model has been developed, compared with data obtained in selected circumstances, and coded in a way that will allow tests to be conducted using the newly obtained ASCOT field data.

Plans FY 1985

Analysis of data obtained during the intensive field study conducted in September-October 1984 will commence. Data will be reduced and summarized for inclusion in an official ASCOT publication. Selected subsets of the data will be identified for use in testing and improving the drainage flow models developed as a consequence of earlier research under this activity.

As FY 1985 progresses, the laboratory's role in designing and organizing field studies under the ASCOT program will become increasingly important. By the end of FY 1985, it is expected that ARL will have accepted the major burden of work related to field operations of the multilaboratory ASCOT program.

ATMOSPHERE-CANOPY INTERACTION (FOREST METEROLOGY)

Accomplishments FY 1984

A study of the effects of forest structure, phenology, and Earth-Sun geometry on the spatial, temporal, and spectral variability of deciduous forest radiation regimes was completed. Data collected were also used to evaluate several published phytoactinometric models. Results indicate that currently available models of radiative transfer in plant canopies do not acceptably simulate deciduous forest radiation regimes during the fully-leafed phenological phase, largely because of clumping of foliage. The models tend to underestimate radiation penetration and overestimate canopy reflectance.

An investigation of thermal radiation within the deciduous forest canopy was initiated. Data have been obtained in winter, spring, and summer in leafless, leaf expansion, and fully-leafed canopy states. A preliminary intensive study of thermal radiative transfers in the fully-leafed deciduous forest was conducted in collaboration with the Colorado State University, EG and G Energy Measurements Group in Las Vegas, and the Army Engineers Waterways Experiment Station. A similar series of measurements is planned for early in 1985 in the leafless forest.

Periodic measurements of vertical turbulent exchanges of momentum, sensible and latent heat, and mass (specifically of carbon dioxide, ozone, sulfur dioxide, and various hydrocarbon and particulate species) continued, largely in conjunction with studies of dry deposition. Fluxes of hydrocarbons were observed above the spring leafless forest in collaboration with Brookhaven National Laboratory. A major study of carbon dioxide fluxes was conducted in collaboration with the University of Nebraska. A comparison between different fast-response carbon dioxide sensors was also conducted.

Development of models to describe interaction between a vegetative canopy and the atmosphere has been hindered by the lack of data describing turbulence within plant canopies. This matter has been a major concern, but the lack of adequate technology has prohibited the matter from being addressed directly until recently. Exploratory investigations of in-canopy turbulence and micropressure fluctuations within the trunk space of the fully-leafed deciduous forest were made in early 1984.

Climatological monitoring and data reduction for the Walker Branch deciduous forest meteorology research site continued. The data set required for a climatological assessment of bulk canopy radiative properties as a function of season was completed, and data reduction is under way.

ARL

The group was host to an international conference on Forest Environmental Measurements at Oak Ridge, Tenn., in October 1983. More than 80 scientists attended, from West Germany, Sweden, The Netherlands, Australia, England, France, Scotland, Belgium, Ivory Coast, Uganda, and Canada, as well as the United States.

Plans FY 1985

Periodic measurements of vertical turbulent exchange above the deciduous forest canopy will continue with increasing emphasis on the effect exerted by the canopy. In addition, greater emphasis will be placed on within-canopy flux measurements. The goal of these efforts will be to define relevant source and sink distributions.

Processing and analysis of data collected in previous studies of canopy-atmosphere turbulent exchange will continue. Wind component data from near the forest floor will also be processed and interpreted. These analyses and interpretations will help to define FY 1985 and later measurement programs.

A study of the thermal radiation exchanges in the leafless forest canopy is now being planned and will be performed in the winter of 1984-85.

Climatological monitoring at the Walker Branch site will continue, with increasing emphasis on the influence exerted by the biological (physiological) functioning of plant canopies on exchange between the atmosphere and the surface.

DRY DEPOSITION

Accomplishments FY 1984

Since there is no instrumentation suitable for routinely monitoring dry deposition, the national program to obtain dry deposition information on a routine basis is designed to infer dry deposition fluxes from other quantities. Suitable methods have been developed at ATDD, and tested during the last two years. A small network of prototype apparatus has been set up, at a total of five sites. Dry deposition flux estimates will be provided of sulfur dioxide, nitric acid vapor, and sulfate, nitrate, and other species associated with submicron aerosol exchange. A sixth site will be added early in FY 1985.

Three of the selected locations are research stations where direct measurements of appropriate dry deposition fluxes are made at various times throughout each year, using micrometeorological methods or any other technique that provides an independent measure of the dry deposition flux. These special core research sites are located at Oak Ridge, Tenn.; Argonne, Ill.; and State College, Pa. Several studies to evaluate dry deposition fluxes directly were conducted during the last ATDD-hosted field studies involving collaborators from Argonne National Laboratory, the University of Denver, and EPA's Environmental Sciences Research Laboratory. In addition, ATDD participated in an intensive field study conducted at State College, Pa., during the year.

The pilot dry deposition monitoring program is being conducted in close collaboration with EPA, DOE, and USGS.

A facility to evaluate data derived routinely at monitoring sites has been set up at ATDD. Models describing the exchange processes involved have been

developed, coded, and simplified for routine application. The first routine data tapes from the network pilot program were analyzed during August.

Plans FY 1985

Several additional pilot stations for deposition monitoring will be constructed and distributed to locations where tests can be made against other techniques. In particular, a collaborative program with USGS will be initiated, to compare alternative dry deposition assessments at a calibrated watershed adjacent to Panola State Park in Georgia.

Operations at the three core research sites coordinated by ATDD will be directed toward independent investigations of processes influencing dry deposition, and toward a routinely scheduled program of intercomparison between direct methods of dry deposition flux measurement (e.g., snowpack accumulation and covariances) and the results of inferential techniques (especially concentration interpretation).

Measured atmospheric concentrations of selected trace gas and aerosol species will be documented routinely, together with the deposition velocity information needed to infer dry deposition rates. Data will be provided to EPA for archiving as 1-week averages.

OZONE

Accomplishments FY 1984

Total-ozone and ozone-profile data for the world have been updated through the summer of 1983. Ground-based and satellite measurements indicate a 5%-7% decrease of total ozone in North America, Europe, and Asia in late 1982, resulting in record low (since 1958) total-ozone values in North America and the north temperate zone in early 1983. Total-ozone values appear to be returning to normal later in 1983. Umkehr and ozonesonde-derived estimates of layer-mean ozone in the north temperate zone indicate that this decrease of total ozone was mostly due to large (10%-15%) ozone decreases in the low stratosphere, though the contribution of the high stratosphere is not easily determined because of the bias introduced into Umkehr observations by the stratospheric dust from El Chichón. It is concluded that the decrease in total ozone in late 1982 was more likely due to anomalies in atmospheric circulation than anomalies in the photochemistry of the high stratosphere, but noted is the possibility that the volanic eruption of El Chichón influenced the photochemistry of the low stratosphere. **ARL**

Plans FY 1985

The total ozone data and ozone-profile will continue to be updated to ensure that the recent ozone decrease was indeed temporary and does not reflect photochemical influences on the high stratosphere.

AIR QUALITY MEASUREMENTS

Accomplishments FY 1984

Evaluation of data from the 1983 Whiteface Mountain study was concluded during 1984. Analysis of two-stage Nuclepore filters by proton-induced X-ray emission (PIXE) spectroscopy showed that most (85%-90%) of the aerosol sulfate was in the accumulation mode and that approximately 90% of total sulfate originated west and southwest of the Whiteface Mountain site. Scavenging of sulfate aerosol by clouds was found to be quite efficient, i.e., greater than 95% in clouds of 0.5 g m^{-3} liquid water content. Cloud-rainwater samples from west-southwest industrial regions had the highest concentrations of $SO_4^{=}$, NO_3^{-}, Pb, Ba, and Ca^{++}, but samples from the west-northwest had the highest concentrations of Cd, Mn, Sr, F^{-}, and K^{+}.

The ratios of measured pH to pH calculated from the sum of sulfate and nitrate, or to the sum of anion minus cation concentrations were usually about 1.05; i.e., the calculated acidity was slightly greater than the measured value. However, in most of the samples from polluted systems the ratios were significantly less than 1. Organic acids are believed to constitute the unaccounted acidity in the measured samples.

A possible mechanism has been identified whereby concentration of dissolved substances can occur on the surfaces of exposed vegetation, especially on the needles of coniferous trees. Along with this identification is the information that the effect on vegetation is mostly dependent upon cloud acidity near the termination of cloud exposure.

In an experiment conducted at the Boulder Atmospheric Observatory 300-m tower, in an airmass with sulfate concentration less than 1 g $m^{=3}$, particulate matter of diameter D < 3 m was collected to afford 1-h increment data analysis for sulfur and soil by PIXE analysis. In-cloud removal efficiencies of initially dry aerosol were 80%-98% for sulfur and 35%-77% for soil aerosol. Total accumulation mode mass was reduced by >90% following cloud development. Nucleation scavenging appears to be the dominant mechanism by which precipitation sulfate was formed.

A Beech King-Air C-90 twin-engined aircraft was obtained by interagency agreement from the Department of the Interior and was equipped for aerosol size distribution measurements, aerosol filter sample collections, gas sample collections, in situ analysis of some trace sulfur-containing gases, and in situ analysis of ozone.

Preliminary results from measurements in and immediately above the boundary layer near the Louisiana coast during August and early September 1984, indicate that the concentration of dimethyl sulfide (DMS) in the clean marine atmospheric boundary layer was 37 ± 29 pptv, but that when offshore air flow carried continental air to the same location (i.e., 20-50 miles offshore), the DMS concentration was reduced to 6 ± 3 pptv. The clean air value is in reasonable agreement with reported mid-Pacific ocean surface measurements, but greater than reported Gulf of Mexico concentrations (<10 pptv). The "continental air" was identified as such on the basis of factor-of-2-to-4 greater concentrations of CO and non-methane hydrocarbons. This air had necessarily crossed the DMS-productive coastal zone and had presumably

received a similar DMS input from the Gulf as had the "clean air" samples. However, the higher concentrations of CO imply proportionately higher concentrations of hydroxyl radical, OH, and therefore a higher destruction rate for DMS.

In all samples from above the boundary layer the DMS concentration was less than the analytical limit of detection.

Preliminary measurements of several physical and chemical parameters, associated with clouds, in two cases of onshore flow of air across the Washington coast were performed in cooperation with the Atmospheric Science Department, University of Washington. The data suggest that the physical and chemical properties of Pacific maritime, cloudy air passing over this region change over relatively small spatial and temporal scales (100-200 km and 5-15 h). This tentative conclusion concerning the scales for air mass changes differs from the assumption usually made of air mass characteristics and transport distances in the eastern United States.

Plans FY 1985

Research will continue on quantification of the concentrations of sulfur-containing acid precursor gases and acidic aerosols in the marine environment, near the coastal zones, and inland in areas of climatological inflow for marine air masses that traverse large areas of the continental United States. The work will be concentrated at the continental boundary of the Gulf of Mexico; the Atlantic states south coastal region and the Pacific northwest coastal regions are also significant inflow areas, and may be included in the measurements. The Gulf effort will be conducted during late spring, summer, and early autumn, when the probability is greatest of finding onshore-moving air masses.

Similar research will be conducted at the middle Atlantic coastline, during both winter and summer, during periods of continental air outflow to the ocean atmosphere. The research will be carried out through use of a twin-engined aircraft equipped for in situ and/or laboratory measurements of trace sulfur-containing gases; for in situ ozone analysis; for filter collection of aerosols to be analyzed later for sulfate, nitrate, chloride, bromide, and sulfur dioxide; for in situ measurement of temperature, dew point, and aerosol size distributions.

The flux of acids and acid precursors into the midwestern and eastern United States, as well as the flux outward from the east coast, will be estimated. **ARL**

Research will be conducted in the Grand Canyon to determine air flow patterns associated with definable meteorological conditions and with solar heating of canyon walls. This work will be carried out with an aircraft equipped with side-looking radiometers for measurement of canyon wall temperatures, and with Doppler radar and a gust probe for the measurement of atmospheric turbulence. Output from this project will assist National Park Service personnel in identifying times when atmospheric conditions are suitable to conduct understory burning and other necessary forest management practices without adversely affecting visibility and visual range in this important Class I visibility area.

AIR QUALITY DISPERSION MODELING

Accomplishments FY 1984

The major emphasis in NOAA support to the EPA research program continued to be the development and evaluation of air quality simulation and meteorological models, including the collection of critical data bases. The range of activities was wide.

A multiyear effort to implement the first generation Regional Oxidant Model (ROM) was completed. The model was applied to a simulation of the northeastern United States during the period 3-5 August 1979, which is one of the high ozone periods investigated in field experiments by the Northeast Regional Oxidation Study (NEROS) and the Prolonged Episode Pollution Experiment (PEPE). The simulation showed that the bulk of the air mass present in the region when the simulation began was still within the domain after 36 hours. The highest ozone concentration predicted by the model was 230 ppb over Lake Erie on the second day of the simulation. Aircraft data support this prediction. An extensive verification and archive system was developed to prepare raw data collected during the NEROS field studies for use in the ROM. Standard procedures for verification of meteorological data were completed. Raw data for 3-5 August have been processed, and work is continuing on the remaining data collected during the 1979 and 1980 field studies. A computer module that generates hourly 1/6° latitude x 1/4° longitude gridded dry deposition velocity maps for SO_2, and $SO_4^=$ for the eastern United States (105°W-66°W, 24°N-50°N) has been produced. The influence of temporal variations in surface boundary layer flow on deposition is handled using state-of-the-art parameterization schemes.

Further, variations in surface characteristics and vegetation are explicitly handled by a matrix relationship developed for nine individual land use categories as used in the ROM. A final value, unique to each grid, is a composite of individual subgrid land use values apportioned by percentage of areal coverage. The Biogenic Emissions Software System has been upgraded to provide (1) variation of emission factors by temperature and light intensity and (2) direct calculation of biomass as a function of tree diameter. The in-house contractor has submitted a draft report documenting the function and operation of the system.

During FY 1984 the spatial and temporal characteristics of the New York City and Boston ozone plumes, the magnitude of ozone and precursors transported into these cities, and the relationships between surface ozone concentrations and mixed-layer values were investigated.

A relatively simple Photochemical Box Model (PBM) was developed for use in screening high level O_3 episodes during stagnant conditions in urban areas. The PBM is a mass-conservative numerical model and requires inputs of hour-averaged emissions, meteorological parameters, and boundary concentrations to produce hour-averaged O_3 concentrations for the box volume; a User's Guide provides guidance on using the PBM.

An investigation into the performance of short-term, urban, photochemical, air quality simulation models for NO_2 predictions was performed. The study, which was a reanalysis of results for three models previously evaluated for

their performance of short-term O_3 predictions, showed that serious problems remain in using these models for NO_2 and that the St. Louis Regional Air Pollution Study base was too deficient in high hour-average NO_2 values for use as a test bed for NO_2 model performance.

A model was developed describing the diurnal behavior of the layer of surface-based turbulent mixing and the winds and temperatures averaged over this layer. The model also represented the conditions at the top of the mixing layer by time-dependent equations for the wind and temperature. The surface heat flux and friction velocity were both well represented by the model when compared with actual measurements taken on Day 33 of the Wangara, Australia, field experiment. These results show that it is possible to use a single layer for the modeling of the diurnal behavior of the mixing layer as long as conditions at the top of the layer are also included. This allows for some representation of the nocturnal gradients in wind and temperature.

Numerical experiments were conducted to compare several different methods of handling the horizontal advection of material in mass-conserving gridded air quality models. The results show that the FCT algorithm preserves the peak concentration areas better than the SHASTA algorithm, although it requires more computation time, and the BIQUINTIC algorithm, which requires the most computation time of the methods studied, may be preferable in some models because of its independence of restrictions on step size.

Vertical velocity turbulence data collected by an instrumented aircraft on horizontal flight paths over the St. Louis metropolitan area have been extensively analyzed to determine spatial variations in vertical velocity statistics and length scales in the urban convective boundary layer. Results support laboratory numerical model results, which indicate more time is spent in descending motions with positively skewed vertical velocity distributions in a convective boundary layer. Magnitudes of vertical statistics and the peak wave length of the vertical velocity spectrum were greater in urban than in nonurban locales.

Through use of a simple inversion rise model, surface-layer values, flux-profile relationships, and similarity scaling laws for the convective atmospheric boundary layer, it was shown that meteorological parameters for dispersion models can be deduced using simple and readily available measurements. The required parameters are mixing height and profiles of wind speed, wind direction, horizontal turbulence, and vertical turbulence. Available measurements include the early morning temperature profile from a radiosonde ascent; single-level surface-layer values of wind speed, wind direction, and horizontal turbulence, two levels of mean temperature near the surface; and an estimate of local surface roughness. Except for wind direction each of the required parameters can be estimated with an average error of 10% to 30%.

A routinely applied atmospheric dispersion model was modified to evaluate alternative modeling techniques that allow for more detailed source data, onsite meteorological data, and several dispersion methodologies, using data for two TVA powerplants. A significant finding was that more sophisticated models did not appreciably outperform the routinely applied models, perhaps, in part, because the lateral standard deviation of wind direction available was the 1-h average of 5-min values (rather than a 1-h value), thus eliminating the longer period fluctuations that are important in estimating 1-h concentrations in addition to the shorter-period fluctuations.

A system of meteorological processors that provides a choice of methodologies for computing meteorological parameters required as input to the computer code has been completed. The Branching Trajectory Model, which replaces Heffter's trajectory model, has been installed and the Complex I and II models extensively tested. A new method for ozone exposure estimates providing characterization of hourly frequency distributions has been proposed.

Major modifications have been made to MESOPUFF, a Lagrangian, variable trajectory, puff superposition model, to enhance its capability for treating temporal changes and spatial variations in the transport, chemical transformation, and wet and dry deposition processes of sulfates and nitrates from multiple point and area sources. The methodologies incorporated into the modified version, designated as MESOPUFF II, and preliminary evaluation of several model algorithms are documented in a project report. A user guide contains instructions and examples of input data and output results.

The Pollution Episodic Model (PEM), an urban particulate model that treats the transport, dispersion, chemical transformation, and dry removal processes for one or two reactive or nonreactive pollutants for up to 24 hours, was evaluated with measurements from the St. Louis Regional Air Pollution Study. Results of 20 cases show that PEM predicted 12-h average concentrations of SO_2 and fine and coarse sulfates to within a factor of 2, while fine and coarse total particulate mass concentrations were overestimated by factors of 3 to 4.

The ENAMAP-2 model has been completely rewritten to correct known defects and add several features. The new model uses a three-layer puff during the day and a four-layer puff at night. Mixing heights, deposition parameters, and grid correction factors vary from grid to grid, and mixing height may vary diurnally and seasonally.

A user's guide for INPUFF, a single source, Gaussian, puff dispersion algorithm, was completed. INPUFF is an integrated puff model primarily for applications where plume models are not applicable. It is designed to model semi-instantaneous or continuous point sources over a spatially and temporarily variable wind field. INPUFF was executed using the Savannah River Laboratory's Mesoscale Atmospheric Transport Studies data base. The data base consisted of data from 15-min releases of SF_6 over 14 days during 1983, along with aerometric and upper-air data. The results of the model runs were sent to Savannah River Laboratory in June 1984. Results of the INPUFF and other model runs will be compared at the DOE - American Meteorological Society Air Pollution Model Evaluation Workshop in October 1984.

An evaluation of commercially available sodar looked at the ability to measure wind speed, direction, and vertical turbulence at heights to 300 meters. Findings from comparisons with sonic anemometer measurements on the NOAA Boulder Atmospheric Observatory tower indicate that wind speed and direction are measured reasonably well, but that the turbulence measurements have relatively large scatter.

Data from the National Crop Loss Assessment Network were modeled with a new mathematical model based on a previous leaf injury model. The model estimated reductions in crop yield for seven plant species for each of the 1,824 site-years of 1981-1983 hourly O_3 concentration data available in the National Aerometric Data Bank. Ambient O_3 concentrations reduced the total U.S. crop yield an estimated 5% for years 1981-1983.

Plans FY 1985

Direct meteorological research support to EPA will continue on the development and evaluation of air quality dispersion models for inert and reactive pollutants and the associated meteorological models on all temporal and spatial scales, using available data bases. An important area of concern will be the problems associated with model uncertainty and model evaluation procedures. This includes development and evaluation of urban dispersion models for ozone and particulate matter; preparation of an assessment of diffusion research status and needs; continued work on development of a regional scale, particulate matter, dispersion model; completion of a revised climatological dispersion model; study of the problem of extrapolating turbulent fluctuation with height; development and evaluation of a second-generation ROM; and various transport, deposition, and diffusion studies.

FLUID MODELING

Accomplishments FY 1984

Studies continued to be conducted in the EPA Fluid Modeling Facility, consisting of a water channel/towing tank and one large and two small wind tunnels, in support of the EPA research program. A major effort in 1984 was the study of flow in complex terrain.

A series of tows was conducted in the stably stratified saltwater towing tank to test the validity of the assumption of a dividing streamline (a flat surface that divides to go around opposite sides of a topographic obstacle) as currently used in several complex terrain models. This assumption allows modelers to simply divide the flow field into two regimes: a horizontal flow in a lower layer and potential flow in an upper layer. One set of tows was made normally (inverted model) with a dividing-streamline height of half the hill height (h), effluent was released at 0.6, 0.7, and 0.8 h, and the resulting hill-surface concentration patterns were measured; a second set of tows was made under identical conditions except that the model was raised out of the water to the point where the water surface was precisely at the dividing-streamline height (i.e., half the hill height), thus forcing a flat dividing-streamline surface (the water surface). Comparison of the two sets of surface concentration patterns suggested that the flat dividing-streamline assumption is quite reasonable.

Recent wind-tunnel and towing tank studies on aerodynamics and plume dispersion in complex terrain were designed to contain basic physical understanding of flow structure and diffusion, to provide guidance in locating sources, and to provide "rules-of-thumb" for estimating surface concentrations when a source is located in complex terrain. Terrain amplification factors were compiled for a large variety of hill shapes, slopes, aspect ratios, and source positions from the neutral wind tunnel studies. From the stratified towing-tank studies, the dividing-streamline concept was shown to be a highly useful indicator in determining whether a plume would impact on a hill surface or surmount the top. Limitations of the towing tank for simulating strongly stratified flows over two-dimensional hills were also pointed out.

ARL

Stable atmospheric flow over a ridge and a valley was simulated in the saltwater-stratified towing tank. Flow visualization experiments were conducted using dye streamers and models with sinusoidal cross sections to provide qualitative data on the structure of the flow field over the ridges and within valleys, as well as quantitative data on the height of the dividing streamline. These data agree with existing theories based upon the potential energy barrier associated with flow over a ridge.

Additional experiments were conducted to test the feasibility of towing-tank simulations of strongly stable atmospheric flows over very long (two-dimensional) ridges. They showed that steady-state conditions are not established in a finite length towing tank and, hence, cast doubt upon the validity of previous laboratory studies.

A wind-tunnel study was conducted of dispersion from a source upwind of a three-dimensional hill of moderate slope. The study was specifically designed to examine the deformations of the plume effected by the hill, and to aid the mathematical modelers in developing and testing their complex terrain models.

Under a cooperative agreement with the North Carolina State University, a wind tunnel study was conducted to examine the flow structure and dispersion in the wakes of axisymmetric hills. Two conical hill shapes with slopes of 17° and 25° were used. Pollutant sources were placed on the tops and at the downwind bases of these hills.

A wind tunnel study was conducted in response to a request from EPA with regard to revisions of the good-engineering-practice (GEP) regulations on stack height. Terrain amplification factors were measured for a large matrix of source positions (locations and heights) both upstream and downstream of each of two idealized model hills, an axisymmetric hill and a two-dimensional ridge. The results showed that a "window" of 40% excess concentration extended to 1.8 hill heights (h) in the vertical, 14 h upstream and 10 h downstream for the three-dimensional hill, and 2.2 h in the vertical, 8 h upstream, and 15 h downstream for the two-dimensional ridge. Maximum terrain amplification factors were found on the downstream sides of the hills, with values of 6.8 and 5.6 for the 2-D and 3-D hills, respectively.

A 2-month study of concentration and velocity profiles downwind of isolated block buildings was conducted in the meteorological wind tunnel. Measurements of concentrations and velocity will be used to delineate the effects of building scale, building orientation, wind speed, and boundary layer characteristics on their nondimensional distributions.

Methodologies for analyzing videotaped images of smoke-visualized plumes are being developed. A sample videotape of a plume in the wake of a block building was recorded in the EPA Fluid Modeling Facility's meteorological wind tunnel. This tape is being used to assess the capabilities of video digitization equipment at North Carolina State University.

A Quality Assurance Plan was prepared for the Fluid Modeling Facility. This plan specifies the standard operating procedures for the facility's wind tunnels, water channel/towing tank, and associated equipment and instrumentation. These procedures are to be followed in order to ensure that (a) proper techniques are applied in the acquisition of data, (b) traceability of data is maintained, and (c) quality assurance techniques can be applied in assessing the accuracy, reliability, and representativeness of acquired data.

Under a cooperative agreement with the North Carolina State University, the first phase of a wind tunnel study was conducted to examine the effectiveness of screens in reducing wind speeds near storage piles. This provides an intermediate step in constructing a mathematical model to predict the effectiveness of the screens in reducing fugitive dust emissions. Various screen types, placements, shapes, and sizes were tested, and a paper was presented for one shape of storage pile (an idealized conical shape). Contour maps of surface wind speed reduction factors were prepared showing that, as expected, the more material (i.e., the larger the size or the lower the porosity), the more effective was the screen in reducing wind speeds.

Plans FY 1985

Work will continue in the Fluid Modeling Facility, using the wind tunnels and water channel/towing tank, on the study of flow in complex terrain, around buildings, and in the wake of automobiles. This includes studies of flow and diffusion in the wakes of three-dimensional hills; effects of shear and hill slope on upwind vortex formation; wake of streamlined vehicles in a shear-free boundary flow; GEP stack heights with respect to complex terrain and influence of obstacles/buildings on plume dispersion and meander.

ACID RAIN MODELING

Accomplishments FY 1984

A major effort is under way, in support of the EPA research program, to develop and evaluate regional and mesoscale acid deposition models. The comprehensive regional model is being developed at the National Center for Atmospheric Research (NCAR) through an agreement with the National Science Foundation. Some of the component modules are under development at several of the DOE National Laboratories. Module development included both field studies and numerical modeling activities in FY 1984.

The development of a regional acid deposition assessment model at NCAR continues on schedule. The mesoscale meteorological components are completed, and three-dimensional meteorological fields to drive the chemical/transport of the model are being generated for representative episodes. A preliminary version of the gas phase chemical schemes has been completed and documented.

ARL

Observations using NASA's airborne UV DIAL (differential absorption lidar) system provide new and convincing evidence to substantiate the hypothesis that vertical transport of pollutant materials out of the mixed layer does occur by penetrative cumulus convective clouds. Horizontal transects were flown above an air mass known to have experienced active cumulus clouds earlier. The range-resolved measurements show the aerosol and ozone concentration of the dissipated cloud field to be well above background, comparable with mixed layer values and highly correlated and organized in tilted layers.

A major program to study and to model the transport and transformation of mixed-layer pollutants by nonprecipitating cumulus convective clouds is under

way. A large field study, VENTEX-84 (VENTing EXperiment) was conducted in July and August 1984 in the vicinity of Lexington, Ky. Observational components of this coordinated study include boundary layer and cloud mass inflow measurements by Argonne National Laboratory, cloud population and special cloud dimension statistics by Research Triangle Institute, mixed and cloud layer structure, and data to compute mass flow rates between the mixed and cloud layer interfaces, as well as transformation rates resulting from cumulus clouds by Pacific National Laboratory personnel. Parameterization based on these studies will be incorporated into a computer module for use in regional scale transport and deposition models.

A field program to study the effect of the emissions from a large urban area on downwind acid deposition was carried out in the Philadelphia metropolitan area. A network of wetfall samplers in a control area in southern New Jersey, and another network in a target area in southeastern Pennsylvania were used to collect rainfall. The results show that there can be as much as a factor-of-2 increase in nitrate deposition and a smaller increase in sulfate deposition under the conditions of the experimental design, namely, an easterly transport flow with steady rainfall. The maximum impact of the urban area must occur beyond 60 km from the city. Other related activities included a new regional-scale tetroon-tracking system based on loran-C navigational stations was developed in cooperation with ARL's Field Research Division. The system was deployed in support of CAPTEX '83. The resulting data have been documented and are included in the CAPTEX data base.

An airborne, two-wavelength lidar has been modified to detect the presence of fluorescent dye particles (FDP). This new technique can be applied to track the movement and dispersion of air parcels spiked with a cloud of FDP on regional transport scales. A successful field demonstration was performed in association with CAPTEX '83. During this initial study, discrete-circular clouds of FDP released over Ohio were successfully tracked over the Appalachian Mountains and were observed to be stretched in the longitudinal direction.

A new statistical procedure, which gives optimum interpolation weights and confidence limits on the interpolated surface, has been applied to acid deposition data. Results indicate that isopleth maps of acid deposition have a great deal of uncertainty in the position of the isopleths. As a result, small year-to-year changes in isopleth position are generally not significant. These results have important consequences in model validation as well as data analysis.

The Eastern North American Model of Air Pollution (ENAMAP) was modified to improve the organization and physical parameterizations. The modified version has been tested using ambient SO_2 and $SO_4^=$ concentrations and sulfur wet deposition data obtained during July 1978. Model input data for 1980 have been processed for model participation in the joint EPA-Environment Canada International Sulfur Deposition Model Evaluation Project.

A group of European, Canadian, and U.S. regional sulfur deposition modelers have been assembled to simulate 1980 ambient concentrations, and dry and wet depositions of SO_2 and $SO_4^=$ across eastern North America. Standardized data sets for model input have been processed, and a draft report describing the study and the model input/output data sets has been completed. A panel of

U.S. and Canadian statisticians has constructed the model evaluation framework. Evaluations will involve traditional descriptive statistics plus innovative analysis procedures.

A workshop was conducted at Woods Hole during September 1984 on Sources and Evaluation of Uncertainty in Long-Range Transport Models. The workshop was arranged by the American Meteorological Society under the joint sponsorship of the United States and Canada, an outgrowth of the previous U.S./Canadian Memorandum of Understanding on Transboundary Air Pollution.

A contract was negotiated with TRC Environmental Consultants, Inc., to prepare a design plan for a comprehensive field study to relate pollutant sources to acidic deposition. The plan, which recommends a nested-grid approach for measurements focused on individual sensitive receptor areas, was provided in September. Work on this contract continues, as sensitivity analyses are defining uncertainties involved with model input parameters.

An ARL representative served on special assignment as Chairman of the Atmospheric Processes Task Group C under the National Acid Precipitation Assessment Program (NAPAP). In this role, the Chairman established the interagency research plan for FY-1986 in concert with the NAPAP Task Force and the nine remaining Task Groups. The Chairman was also responsible for monitoring the ongoing FY-1984 research activities and for updating the FY-1985 interagency research plans.

Plans FY 1985

Work on the development of the Regional Acid Deposition Model and its modules will continue. Work on the development and evaluation of the mesoscale acid deposition and assessment model will expand with additional field work near Philadelphia, and with an increase in modeling activities using the data already available. Some of the mesoscale modeling activities will be conducted with the assistance of NASA. The results of the AMS workshop on Sources and Evaluation of Uncertainty in Long-Range Transport Models will become available. Activities associated with the International Sulfur Deposition Model Evaluation will continue.

DISPERSION IN COMPLEX TERRAIN

ARL

Accomplishments FY 1984

Work continued on two major field and modeling programs to study the dispersion of pollutants in complex terrain. These programs support the EPA research program. The Complex Terrain Model Development Program is a multiyear field and modeling effort to examine and model the impact of powerplant plumes in mountainous terrain. Field studies were conducted in previous fiscal years at Cinder Cone Butte in Idaho and Hogback Ridge in New Mexico. In 1984 during August, 128 hours of dual-tracer and smoke diffusion experiments were conducted from the Tracy powerplant near Reno, Nevada. Gas chromatographic analyses from the 110 samplers, located within 10 km of the

plant, were excellent. Groundbased and airborne lidar measurements and photographs of the smoke plume were obtained also. These data, supported by extensive meteorological measurements, provide significant input to the Complex Terrain Model Development Program.

A scientific assessment established the applicability of existing complex terrain models for EPA regulatory use and summarized the current status and needs for additional research.

Plans FY 1985

Work will continue on the development and evaluation of the Complex Terrain Model using the data base collected in physical modeling experiments in the Fluid Modeling Facility, and in the field at Cinder Cone Butte, Hogback Ridge, and the Tracy powerplant.

CLIMATE

SUN-CLIMATE RELATIONSHIPS

Accomplishments FY 1984

The Sun-Climate Staff completed analysis of solar UV radiation observations from the Nimbus-7 satellite in the 160-400 nm wavelength range for the second year of these measurements, and at the selected wavelength of 200 nm for the first 4 years of observations. These radiations control the production of ozone and heating in the stratosphere, which may modulate tropospheric planetary waves and influence climate. Previous studies of short-term (13-day and 27-day periodicity) UV variations caused by solar rotation and active region evolution were expanded to include extensive statistical studies of the time and frequency domain characteristics of these short-term variations. Intermediate-term variations lasting 4 to 8 weeks, which in 1979 and 1980 happened to be approximately semiannual variations, have been studied in the 205-nm flux for 1979-1982, through the peak of solar cycle 21. The solar cycle variation of the UV flux peaks approximately 2 years later than the peak of the sunspot cycle. The solar UV flux model based on solar plage data gives a current solar cycle variation of about 25% at 205 nm. Comparisons of the model with 4 years of 205-nm observations suggest that the model overestimates the solar cycle variation. Employing 8 years of ground-based measurements of the chromospheric solar infrared line of helium near 1 μm in wavelength to estimate the 205-nm UV flux from their relation during the 4 years of UV measurements gives about 13% for the current cycle.

The rocket-flight UV spectroradiometers were tested and preliminary calibrations conducted. Problems with too high a value of scattered light were detected, analyzed, and then corrected by adding a state-of-the-art blackening to the internal non-optical structures and by adding several stray-light baffles. The instruments have now been prepared for final calibration.

Studies continued of the association of U.S. climatic anomalies with meteorological and oceanographic conditions in the tropical Pacific. It was found that the onset of below normal summer precipitation in the wheat-belt states during the 1950's and 1970's occurred subsequent to (1) above normal temperatures in the tropical Pacific the preceding winter, and (2) the occurrence of a "minor" sunspot maximum. On this basis, below-normal summer precipitation in the Wheat Belt has been predicted for 1990 or 1991 and for the four summers that follow.

Studies have shown that precipitation over certain regions of the United States varies with the phase of the lunar synodic (29.531 day) cycle. For example, in Georgia during winter, precipitation of more than a few tenths of an inch per day is 30% more frequent during and immediately following full moon than during other phases of the synodic period. This lunar phase dependence changes during the other seasons.

The use of specification models continues in the development of experimental monthly temperature and precipitation outlooks for the United States. Outlooks are provided to the National Climate Program Office, the Climate Analysis Center of the National Weather Service, and ERL at Boulder, Colo.

The University of Arizona, under a NOAA grant, has completed development of a ground-based solar spectrometer to measure solar spectral variability. It will be deployed in Mt. Lemon, near Tucson, Ariz., in September 1984, and measurements will be initiated.

Plans FY 1985

In cooperation with NESDIS, we will analyze the solar UV flux measurements in the 160-400 nm wavelength range from the SBUV/2 ozone monitor that is to be flown on the NOAA satellite series as a joint NASA and NOAA effort starting in FY 1985. Analysis of Nimbus-7 and other satellite measurements of the solar UV flux will be continued with emphasis on trying to improve our estimate of the solar cycle variation. Intermediate-term UV variations (several months) will be studied in an effort to try to improve our model of these variations and to clarify the differences in their characteristics from those of associated intermediate-term variations in the classical solar activity indices, the 10-cm radio flux and sunspot number. The main calibrations of the solar UV spectroradiometers will be completed. Stratospheric temperature and ozone data measured concurrently with the solar UV flux will be studied to identify their reponses to UV flux variations for short and intermediate-term variations. **ARL**

Basic research will continue on the identification of climatic variability with solar, lunar, and other periods and of causes and mechanisms for these climatic changes. Specifically, the sensitivity of precipitation in the United States to gravitational tidal forcing will be evaluated.

Measurements of solar spectral variability will continue on Mt. Lemon during the year.

TEMPERATURE

Accomplishments FY 1984

Global temperatures obtained from the 63-station radiosonde network have been updated through the spring of 1984, and are in the process of being updated through the summer of 1984. Despite the eruption of El Chichón (Mexico) in the spring of 1982, Northern Hemisphere surface temperatures were 0.5°C above average, and tropospheric 850-300 mb temperatures 0.4°C above average, during 1983. However, temperatures in the 300-100 mb "tropopause layer" were 0.3°C below average, and in the low-stratospheric 100-30 mb layer 0.4°C below average, during 1983; these latter show that the stratospheric warming induced by El Chichón has completely disappeared. The combination of warm troposphere and cool stratosphere means that the Northern Hemisphere lapse rate was greater than normal in 1983. Tropospheric temperatures were lower in the winter and spring of 1984, suggesting that the El Chichón dust cloud may finally be having a cooling effect on hemispheric temperatures now that sea-surface temperatures in the eastern equatorial Pacific have returned to normal following the pronounced El Niño episode.

Plans FY 1985

The temperature data in troposphere and stratosphere will continue to be updated throughout the world, with emphasis on detection of tropospheric cooling due to the El Chichón eruption.

SUNSHINE DURATION AND CLOUDINESS

Accomplishments FY 1984

Sunshine duration and cloudiness data for the contiguous United States have been updated through the summer of 1983. In 1982 cloudiness was 5% above average and sunshine 3% below average, apparently the result of the very warm sea-surface temperatures in the eastern equatorial Pacific (El Niño). By the summer of 1983, these anomalies were diminished. During the last 30 years, there has been a significant tendency for U.S. cloudiness to be above average (and sunshine below average) in years when Indian summer-monsoon rainfall is below average, and vice versa. However, there is no evidence that United States cloudiness and sunshine are related to the quasi-biennial oscillation in the tropical stratosphere, or Northern Hemisphere surface temperature.

Plans FY 1985

Sunshine duration and cloudiness data for the United States will continue to be updated to ensure that the large increase in cloudiness, and decrease in sunshine, in 1982 was indeed due to El Niño.

HUMIDITY

Accomplishments FY 1984

Because of questions concerning the representativeness and significance of humidity changes measured by radiosonde, the evaluation of humidity at the 63-station radiosonde network is just commencing. The necessity of obtaining humidity data at significant points as well as at the mandatory pressure surfaces is still under consideration.

Plans FY 1985

Relative humidity, mixing ratio, and precipitable water will be monitored at the same 63 radiosonde stations used for temperature monitoring.

SOLAR RADIATION FACILITY

Accomplishments FY 1984

Pyranometers were replaced at all 38 network stations, and pyrheliometers were replaced at 10 stations. Recalibration of the old pyranometers that were installed in 1982 is in progress; early results show that for 17 instruments of one type the ratio of 1984/1982 calibrations is .993, and for 4 instruments of the second type the ratio is 0.981, confirming the 1% per year degradation found previously. For four pyrheliometers recalibrated the average ratio is .995.

The Sixth New River Intercomparison of Pyrheliometers was held at the Desert Sunshine Exposure Test Laboratories near Phoenix in November 1983. Despite the high quality of these intercomparisons, WMO recognition of the comparison as a regional one was withheld for a variety of reasons including the inability of the WMO working group on radiation to define acceptable protocol for recognition in time for the comparison.

Two NWS stations have been added to the nine-station turbidity network in a pilot program to provide turbidity data for the verification of direct radiation measurements at those stations.

Four pyranometers from the International Energy Agency round-robin test program were calibrated and tested over a 5-month period. The objective is to describe instrument characteristics to allow measurements to be corrected to an uncertainty of ± 0.5% in the operating modes used in solar collector tests.

Regular transfer calibrations of the working standard and control pyranometers by the absolute cavity radiometer have verified a steady drop in sensitivity of about 0.5% to 1.0% per year in one type of pyranometer. This finding emphasizes the need for regular and frequent recalibration of field instruments.

Plans FY 1985

The pyranometers and pyrheliometers returned during 1984 will be tested for a year and then returned to the network. The long test period allows instruments to be placed where the individual instrument characteristics are least detrimental to the measurements.

The Sixth International Pyrheliometer Comparison (IPC) is scheduled for 1985 in Davos, Switzerland. Participation in the IPC is the only recognized method for a Regional Center such as ours to acquire the World Radiometric Reference scale, which is the basis for calibrations.

As many as 20 more NWS stations will be provided with sunphotometers and reduction tables to provide turbidity data for quality assurance of direct radiation data.

AEROSOLS AND RADIATION

Accomplishments FY 1984

The extremely large aerosol loading above Barrow, Alaska, observed in the GMCC optical depth data obtained during the Arctic Gas and Aerosol Sampling Program (AGASP) in the spring of 1983, was determined to be due in part to stratospheric debris from El Chichón. The stratospheric, background tropospheric, and transient tropospheric components were quantified and reported. The results agree well with satellite measurements of stratospheric aerosol, which showed the maximum in El Chichón aerosol over Barrow occurring in March-April 1983.

Total radiation balance measurements were begun at the South Pole. This is a new GMCC long-term monitoring project to gather information for heat budget studies in the interior of the Antarctic.

A fully automated solar radiation observatory was placed in operation at Mauna Loa. The purpose of the solar measurements is to monitor radiative features of total column aerosol, water vapor, and clouds. The facility consists of a medium-sized active solar-tracking spar capable of supporting 200-300 pounds of instruments, a 32-channel analog voltage data acquisition system, and an automated observatory dome control. Several solar photometers operate continuously at the facility.

During the AGASP flights near Barrow, Arctic haze events observed at the GMCC station showed large increases in aerosol backscatter coefficients (σ_{sp}) and optical depth. In general, a main layer was located at about the 700-mb level; it was not associated with a region of high relative humidity; and it was strongly correlated with surface-based measurements. The Arctic haze phenomenon appears to have its primary source in Eurasia with long-range transport to Arctic regions in winter and spring.

An aerosol chemistry experiment at the South Pole showed that aerosol sulfur is correlated with concentrations of condensation nuclei (CN), having an annual cycle with a maximum in the austral summer and a minimum in winter.

Aerosol sodium is correlated with σ_{sp} and shows a series of large events during late austral winter. These data suggest that the sulfur is associated primarily with the smaller-sized background aerosol particles and that the sodium is associated with sea salt transported to the interior of Antarctica by storms occurring during the austral winter.

Measurements of CN, σ_{sp}, and optical depth at Whiteface Mountain, N.Y., were continued during 1984. Past data have shown that hazy episodes at Whiteface correlate strongly with high values of σ_{sp} and that these episodes occur when air mass trajectories are from the west and pass over the Great Lakes industrial regions. Coincident optical depth and surface-based measurements can be used to estimate the vertical extent of the haze layer and the total overburden.

A light-weight, inexpensive balloon-borne sensor was developed for measuring cloud height and cloud thickness. Cloud presence is sensed by an increase in horizontally scattered light, detected by a silicon photocell mounted within a light-diffuser glass bulb. The sensor couples to a regular 1680-MHz radiosonde so that data telemetered to a ground receiving station include pressure, temperature, and humidity. Ten successful flights were made at Boulder. The cloud sensors may be useful for studying transport of water vapor into the stratosphere by very large cumulus clouds, or providing validation data for satellite measurements of cloud height and cloud thickness.

Plans FY 1985

Plans have been formulated for a GMCC project to maintain a continuously updated data set on the aerosol state of the stratosphere. The data set will be derived from the newly organized lidar network and limb-viewing satellite observation system. The data will be used for correcting Umkehr observations and for studies of mechanisms for climate change.

An aerosol experiment will be carried out at the Samoa GMCC observatory to measure the size distribution of sea salt and explain it in terms of multiwavelength σ_{sp} measurements. Past measurements of σ_{sp} at Samoa show a scattering function that increases with increasing wavelength, unlike measurements at other sites which usually show decreasing scattering with increasing wavelength.

GMCC will participate in a second AGASP experiment planned for the spring of 1985. Two important goals of this experiment will be the measurement of aerosol chemistry profiles, especially aerosol sulfur, and the comprehensive measurement of aerosol optical extinction profiles. Attempts will be made to directly observe radiative-dynamical effects of the strongly absorbing Arctic haze. **ARL**

Total radiation balance measurements, similar to measurements made at the GMCC South Pole station, will begin at Barrow.

Advanced modern commercial sunphotometers will be acquired and deployed to obtain high quality information on the spectral characteristics of global background aerosol optical depth, and in support of the automated Dobson network for developing an understanding of the effect of haze on the Umkehr measurement.

OZONE

Accomplishments FY 1984

A classic set of Umkehr data obtained at Mauna Loa Observatory since 17 May 1982, following the eruption of El Chichõn volcano in late March to early April 1982, has illustrated dramatically the adverse effects of stratospheric aerosols on Umkehr observation. By early 1983 aerosol-induced errors, which had originally exceeded 100% in some Umkehr layers, decreased to less than 20%. Stratospheric aerosol optical depths at Mauna Loa decreased from 0.27 to 0.05 during May to December 1982, and remained nearly constant in 1983.

Low total-ozone values were observed at Mauna Loa during August 1982 through July 1983, compared with ozone amounts measured in 1981/1982 and 1983/1984. Decreased ozone amounts were measured also at other Northern Hemisphere stations. Partial destruction of ozone by El Chichón aerosols has been postulated as the cause of the ozone decrease. At Mauna Loa, the low ozone values coincided with a minimum that occurred in January/February 1983 in the quasi-biennial ozone oscillation and, therefore, are believed to have resulted primarily from stratospheric circulation changes that cause the quasi-biennial oscillations in ozone.

Processing of ozone data obtained during 1983 at Mauna Loa with ECC ozonesondes was completed in FY 1984, yielding monthly, seasonal, and annual means as a function of altitude to 5 mb. The data are useful for validation of satellite-derived ozone profiles and as first-guess statistics for the reduction of Umkehr data. The sonde data showed markedly lower ozone amounts above the ozone maximum in December 1982, compared with December 1983, due most likely to stratospheric circulation differences over Mauna Loa during the two years.

Standard Umkehr, Short Umkehr, and SBUV ozone profiles, observed concurrently over Boulder, were intercompared and found to agree best in layers 3-7 (>90% correlation), but not as well in the lowermost and uppermost layers as predicted by theory. The comparison has partially revealed the nature of the differences that will require future investigative efforts to improve the correspondence between the ground-based Umkehr and satellite SBUV observational systems.

GMCC organized a global network of lidar stations to monitor the turbid state of the stratosphere for applications to problems of climate and remote sensing (in particular, the Umkehr measurement). The network consists of three U.S., three European, two Japanese, one South American, and one Australian lidar station. Data will be routinely archived and published at the World Ozone Data Center, Toronto, and archived at NASA Langley Research Center. WMO has announced its support for the network.

A team of six scientists from GMCC, Universities of Chicago and Wisconsin, Atmospheric Environment Service (Canada), NESDIS, and NASA Goddard, statistically examined the long-term Umkehr data record from 13 stations for trends, after correcting the record for volcanic stratospheric dust errors. It was concluded that the corrected record shows a downward ($-0.3\%\ yr^{-1}$) trend in ozone concentration near 35-40 km. The magnitude of the trend is

very close to the most recent theoretical photochemical prediction of a fluorocarbon-caused depletion. The long-term Mauna Loa transmission record was used to quantify the magnitudes of stratospheric dust enhancements from volcanic injections.

Work that began in June of 1982 to automate seven Dobson spectrophotometers for Umkehr observations was completed in FY 1984. Five of the seven instruments have been installed at field stations, and are operational. The stations are Boulder, Colo.; Haute Provence Observatory, France; Poker Flat, Alaska; Mauna Loa Observatory, Hawaii; and Perth, Australia. Calibrations in Boulder have indicated that Umkehr layer ozone amounts measured by each of the instruments agree on the average to within ±5% of mean ozone amounts measured simultaneously with World Standard Dobson Spectrophotometer No. 83.

Total-ozone observations with Dobson spectrophotometers were continued at Bismarck, N. Dak.; Caribou, Maine; Tutuila Island, Samoa; Mauna Loa, Hawaii; Wallops Island, Va; Nashville, Tenn.; Boulder, Colo.; Tallahassee, Fla.; Fresno, Calif.; Huancayo Observatory, Peru; and Amundsen-Scott, Antarctica. First total-ozone measurements from the newly established Poker Flat, Alaska station were received in March 1984.

A long-period variation in total ozone is observed at Mauna Loa and other Northern Hemisphere stations, with the ozone decrease rate at Mauna Loa being about 3% per decade. Whether this decrease is due to ozone depletion by chlorofluorocarbons, or is the result of long-term variation in the strength of the stratospheric circulation between equatorial and polar regions, is unknown.

Tests on high-altitude (to 40 km) ECC sondes were continued sporadically in Boulder during FY 1984. The performance of six instruments was compared with that of other kinds of ozone-measuring devices (including UV photometers) in March 1984 aboard a balloon gondola flown to 41 km altitude from the National Balloon Flight Facility in Palestine, Texas. Measurement precision (95% confidence interval level) exhibited by the instruments generally ranged between ±2% and ±10%, depending on altitude. Between 5 and 3 mb, the ECC sondes may have measured ozone amounts too low by 10%-20%.

The NOAA/GMCC Dobson Spectrophometer Central Laboratory in Boulder continued to upgrade and calibrate Dobson instruments in the global total-ozone station network. Work is under way to refurbish New Zealand Dobson instrument No. 17 which was damaged by a flood in late 1983. In August, Australian Dobson instrument No. 115 was optically aligned and calibrated, and training was provided to Australian technicians to perform such work.

ARL

Plans FY 1985

In an agreement with NESDIS, GMCC will conduct total-ozone, Umkehr, and ozonesonde observations, beginning in January 1985, to obtain, process, evaluate, synthesize, and intercompare ozone data needed for validation of SBUV/2 satellite measurements of atmospheric ozone. Total-ozone and Umkehr observations will be made at the five operational automated Dobson instrument stations, as well as at Huancayo, Peru, and Pretoria, South Africa. Total-ozone data from an additional nine foreign cooperative stations will be used for validation of the satellite observations. GMCC will conduct periodic calibration

checks on the Dobson instruments at these stations. Ozonesonde observations are slated for three stations: Boulder, Colo.; Mauna Loa, Hawaii; and Poker Flat, Alaska (or Edmonton, Canada). Weekly balloon instrument launches are planned.

Work to upgrade the Standard Umkehr and Short Umkehr inversion algorithms will commence this year. Upgrading will consist of using new ozone absorption coefficients and better a priori ozone statistics, and accounting for the temperature dependence of ozone absorption. Included in the upgrading process will be an attempt to improve the correspondence between the Umkehr and SBUV observing systems.

Automated Dobson instruments for Umkehr observations will be installed at Huancayo and Pretoria early in 1985.

An intercomparison of Dobson ozone spectrophotometers will be held at Melbourne, Australia, in November/December 1984 under sponsorship of WMO and under the direction of GMCC staff. Participating countries will be Australia, India, Japan, New Zealand, and the United States.

A highly successful program established in 1981 to check on the calibration status of Dobson spectrophotometers in the global total-ozone station network by means of traveling, calibrated standard lamps will be repeated in 1985.

CARBON DIOXIDE

Accomplishments FY 1984

The concentration of atmospheric CO_2 was measured continuously at Barrow, Mauna Loa, Samoa, and the South Pole. A new instrument control and data acquisition system for the CO_2 monitoring program was installed at Barrow, and the field operations manual was revised to reflect changes in the operation of the CO_2 measuring system. In support of the continuous and flask CO_2 analysis programs, 168 reference gas tanks were calibrated for CO_2 concentration.

The continuous analyzer CO_2 data for 1982 were made available to the carbon cycle research community in the form of monthly means of the provisionally selected background data set archived with the DOE Carbon Dioxide Information Center (CDIC). In addition, provisional daily concentrations for the four stations in 1982 were archived with WMO.

The full CO_2 records from the four stations were corrected for systematic errors (e.g., pressure broadening effect, analyzer non-linearity), edited for instrumentally faulty data, and converted to the x81 mole fraction scale. An algorithm for the selection of CO_2 concentration data representative of background conditions was developed and applied to the Mauna Loa CO_2 record for 1973-1982. Selection of background data from the Barrow, Samoa, and South Pole records began.

The CO_2 flask sampling network continued to operate and now provides samples from 24 stations including Christmas Island, in cooperation with Scripps Institution of Oceanography (SIO), and Cape Grim, Tasmania, in

cooperation with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. More than 7,000 flask samples were analyzed for CO_2 concentration, providing a detailed record of the global variation of atmospheric CO_2 in space and time. The 1983 flask data were processed to final values, and a preliminary selection of background values was made. From these data, the globally averaged CO_2 concentration for 1983 was calculated to be 342.4 ppm, representing an increase of 1.4 ppm over 1982.

The flask network CO_2 concentration data for the period 1968-1982 were archived with DOE/CDIC and WMO. The selected flask data for this period were analyzed for seasonal variation, latitudinal gradients, secular increase, and natural and anthropogenic variations of these parameters. In particular the relationsip between atmospheric CO_2 concentration, gradients, and growth rate and the El Niño/Southern Oscillation phenomenon was studied. It was found that a marked decrease in the CO_2 growth rate preceded the minimum of the Southern Oscillation Index and was followed by a period of higher than normal CO_2 growth rates of 2-3 ppm yr^{-1}.

In a cooperative program involving GMCC, CSIRO, and the Oregon Graduate Center, more than 1,000 flasks from the CO_2 flask network were analyzed by gas chromatography for CH_4 (methane) concentration. A 1.5-yr record now exists of the global distribution and variation of the atmospheric concentration of this climatically important trace gas.

Following laboratory testing and evaluation, field programs were undertaken using recently acquired gas chromatographs for the measurement of CO_2 and CH_4. On the joint Soviet-American Gases and Aerosols (SAGA) expedition in the Pacific Ocean aboard the Soviet vessel Akademik Korolev, continuous measurements were made of atmospheric CO_2 and CH_4 and the partial pressure of CO_2 in surface ocean waters. The gas chromatography measurements agree well with those from simultaneously collected flasks and with the distribution of atmospheric CO_2 concentration derived from the flask network data.

A similar program was carried out during the CO_2 Dynamics Study aboard the NOAA ship Discoverer in cooperation with PMEL. On this cruise the partial pressure of CH_4 in the surface water was measured as well. On both cruises significant areas of undersaturation and supersaturation of CO_2 in surface waters were found. A gas chromatograph identical to that used on the cruises was installed at the Mauna Loa Observatory to conduct a field comparison of the gas chromatographic and infrared techniques and to obtain a continuous record of atmospheric CH_4 at Mauna Loa.

A comparison of the GMCC and SIO records of atmospheric CO_2 concentration for the period 1973-1984 at Mauna Loa was begun. In conjunction with this comparison a field project was conducted to compare the GMCC and SIO analyzers at Mauna Loa, and an attempt was made to locate and quantify possible sources of discrepancy between the two systems. **ARL**

A data base consisting of meteorological information as reported on flask sample sheets for the period 1979-83 was created. These data were used in selecting the background data from the 1983 flask data set.

The variability of atmospheric CO_2 concentration at Barrow during the winter of 1979-1980 was studied. It was found that periods of high CO_2 concentration were correlated with high concentrations of anthropogenic aerosols. A study of air mass trajectories indicated Eurasian sources for these polluted air masses.

Plans FY 1985

Monitoring of the atmospheric CO_2 concentration at Barrow, Mauna Loa, Samoa, and the South Pole will continue. New instrument control and data acquisition systems will be installed at the Mauna Loa, Samoa, and South Pole stations. Provisional daily means for the four stations during 1983 will be archived with WMO. The selection of background data from the full continuous analyzer data sets through 1982 will be completed.

Air samples for CO_2 analysis will be collected at the 24 sites of the CO_2 flask sampling network. The possibility of replacing the site at Cape Mearnes, Ore., with a site on the Olympic Peninsula, Wash., more suited to background measurements will be investigated. The 1983 flask data will be archived with the DOE/CDIC and WMO. The representativeness of the flask network will be evaluated using flask sample data obtained on several cruises during 1982 and 1983. A report will be prepared describing in detail the local geography and conditions at the flask sampling sites.

The measurements of CH_4 in flask air samples from the network by gas chromatography will continue. The results from the first year of measurements will be reported. The CH_4 analysis system will be streamlined by automating the data acquisition system, and upgraded through the purchase of a new gas chromatograph to replace an older instrument currently on loan from the Oregon Graduate Center.

The comparison of the NOAA and SIO records of CO_2 at Mauna Loa for 1973-1984 will continue. The NOAA record from Mauna Loa will be studied using the time series analysis software package entitled "SABLE".

The measurement of CO_2 and CH_4 by gas chromatography at Mauna Loa will continue. The results will be compared with those obtained by the infrared analyzer system. Gas chromatographic measurements of atmospheric CO_2, CH_4, pCO_2, and pCH_4 in surface waters will be made aboard the NOAA ship Discoverer in cooperation with the CO_2 Dynamics Study of PMEL.

An international intercomparison of CO_2 measurements by several laboratories will be initiated by GMCC under WMO sponsorship. This program consists of circulating a tank filled with a CO_2-in-air standard gas among participating laboratories for analysis. The analysis results will be sent to WMO.

The variability of atmospheric CO_2 at Samoa will be studied with respect to meteorological conditions and variations in other trace species.

DATA ACQUISITION AND QUALITY CONTROL

Accomplishments FY 1984

NOAA staff completed the installation and acceptance testing of a 6-kW photovoltaic power system at the GMCC station in American Samoa. The system was purchased and installed with funds provided by the DOE Federal Photovoltaic Utilization Program. The photovoltaic power system and associated batteries supply approximately 0.8 kW of uninterrupted power to sensitive scientific equipment at the station. Since continuous operation began in February 1984, the system has operated without failure.

Testing of an instrumentation control and monitoring system (CAMS) to be used at the GMCC observatories was completed and installed at the Barrow and Samoa stations. The CAMS is a compact, microcomputer-controlled system using the Z-80 STD BUSS to interface memory, input-output ports, and monitoring electronics. The peripherals include a cartridge tape recorder, a push-button pad and display, and a printer. The system acquires data in both analog and digital form and controls the operation of relays to provide calibrations to the infrared analyzer measuring carbon dioxide. Using the display and printer provided with CAMS, staff at the GMCC stations will be able to tabulate and monitor the quality of data in real time. In addition, CAMS displays a series of flags to indicate major discrepancies in the observations.

Plans FY 1985

In addition to monitoring and documenting the performance efficiency of the new power system in Samoa, we plan to test alternative methods of battery-charge maintenance to obtain more efficient charging on sunny days. If any of these methods are successful, it is planned to increase the load to capacity 1.0 kW.

CAMS units will be installed at the Mauna Loa and South Pole observatories early in FY 1985. Work will continue on streamlining the routine station data processing in GMCC.

A new GMCC program will operate and maintain instrumentation to acquire, process, and evaluate data needed for validation of satellite ozone data in an agreement with NESDIS.

GMCC will acquire Dobson data at 16 sites, 7 of which will be equipped with automated Dobson instruments providing Umkehr observations. In addition, GMCC will maintain, calibrate, and repair as necessary the instruments at the automated Dobson stations. **ARL**

GMCC will make ozonesonde flights and acquire ozone profile data at three sites in order to compare ozone profiles with SBUV/2 measurements.

GMCC will oversee the acquisition of lidar data from sites already making lidar measurements (includes Mauna Loa Observatory and WPL lidar measurements at Boulder) in order to assess the stratospheric aerosol correction to SBUV/2, and Umkehr ozone measurements.

GMCC will obtain, process, tabulate, synthesize, and intercompare data sets of Dobson-derived total ozone, Umkehr ozone profiles, ECC sonde ozone profiles, and lidar-derived aerosol profiles to help analyze SBUV/2 measurements of atmospheric ozone.

Development work will be conducted on ECC ozonesondes to optimize the instruments for the measurement of tropospheric ozone, and to reduce the cost of the instruments.

TRACE GASES

Accomplishments FY 1984

Weekly atmospheric baseline measurements of chlorofluorocarbons (CFC-11, CFC-12) and N_2O continued at Point Barrow, Alaska; Niwot Ridge, Colo.; Mauna Loa Observatory, Hawaii; and Tutuila Island, American Samoa. Biweekly measurements have been made at South Pole with a newly installed gas chromatograph.

A fully automated gas chromatograph and data system for the measurement of the radiatively important species CFC-11, CFC-12, CCl_4, CH_3CCl_3, and N_2O was configured and tested at the Boulder laboratory.

Monthly stratospheric balloon-borne water vapor soundings were made from Boulder, using frost-point hygrometers. With soundings for more than 3 years, a climatology of the seasonal behavior of water vapor in the stratosphere over Boulder has been delineated. Two successful balloon intercomparisons were obtained between frost-point hygrometer instruments and several other types of stratospheric water vapor sounding instruments. This work confirmed a result obtained in 1983, which showed that frost-point hygrometers yield stratospheric water vapor concentrations lower than does the Lyman-alpha instrument of the Aeronomy Laboratory by about 0.7 ppmv at 4 ppmv.

With surface ozone measurements at the four GMCC baseline observatories now extending for up to 10 years, it is possible to look for long-term changes in the tropospheric ozone content of the atmosphere. At Mauna Loa, where recent ozonesonde profiles have confirmed the validity of the surface measurements as representative of mid-tropospheric ozone behavior, an upward trend in the ozone content at about 700 mb seems to be emerging. Although this trend cannot yet be judged statistically significant at the 95% confidence interval level, the results in the next several years will need to be carefully watched.

Plans FY 1985

Atmospheric baseline measurements of N_2O and chlorofluorocarbons will be continued at the GMCC observatories and Niwot Ridge.

New gas chromatographs will be purchased and automated for in situ measurements at the GMCC baseline stations of CFC-11, CFC-12, N_2O, CCl_4, and

CH_3CCl_3. Feasibility studies will be conducted for the measurement of other radiatively important halocarbon species such as CFC-22 and CFC-13.

A gas chromatograph for analyses of air samples for CH_4 and CO will be purchased to build on the GMCC, CSIRO, and the Oregon Graduate Center cooperative program. Tests will be conducted to assess the suitability of the equipment for use in global CO monitoring.

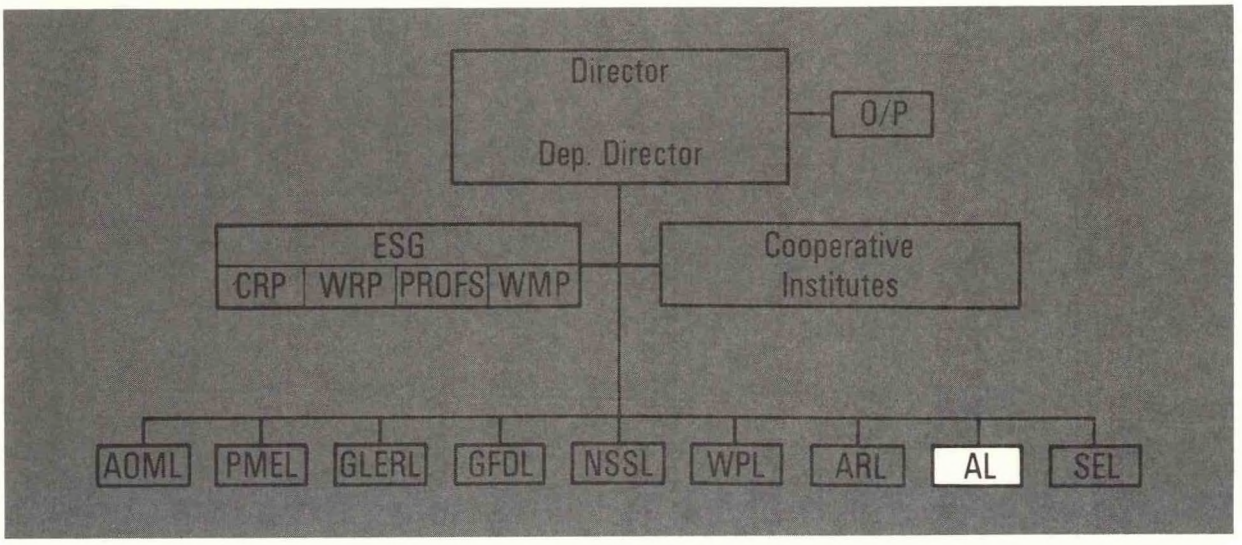
The measurement of CH_4 in flask air samples from the network by gas chromatography will continue. The results from the first year of measurements will be reported. The CH_4 analysis system will be streamlined by automating the data acquisition system, and upgraded through the purchase of a new gas chromatograph to replace an older instrument currently on loan from the Oregon Graduate Center.

The important time series of stratospheric water vapor soundings in Boulder will be continued with monthly balloon flights. In addition, as part of the satellite-borne Stratospheric Aerosol and Gas Experiment (SAGE II), water vapor and ozone will be measured at four locations from Alaska to Brazil. In order to establish the reasons for the offset between the frost-point and Lyman-alpha instruments, work will begin, to establish a laboratory methodology for comparing these as well as other instruments used in measuring stratospheric water vapor.

Continuous monitoring of the ozone content near the surface will continue at the four GMCC observatories. The resumption of regular ozonesonde flights in Hawaii will allow further evaluation of the time series of surface measurements at Mauna Loa.

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.

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 Wave and Turbulence Theory, Optical Aeronomy, and Theoretical Aeronomy.

The major focus of research is Air Quality; climate studies are also included in the Atmospheric Dynamics Program.

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 into reactive chlorine species. 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 the group have followed the approach used in these stratospheric chlorofluoromethane measurements. That is, 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 and dynamics, which include 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 alteration.

Accomplishments FY 1984

During the summer of 1984, the abundance of the sum of all of the reactive nitrogen species, NO_y, at a tropospheric site was determined for the first time. The reactive nitrogen species play important roles in tropospheric chemistry and climate, and the capability to detect their overall abundance opens up attractive prospects for determining global budgets of this key chemical family. The measurement site was located near Niwot Ridge, Colo., at an altitude of 3,000 m. NO_y was detected with a new technique developed recently in the Laboratory for that purpose. It uses the reduction of these reactive nitrogen compounds by carbon monoxide, CO, at a heated gold catalyst to yield NO, which is then detected by the Laboratory's sensitive chemiluminescence detectors. The air quality at the site varied from clean to moderately polluted, owing to transport of air from the Denver metropolitan area; thus the NO_y chemistry could be examined over a range of conditions. Correlations

involving NO_y with other species measured at the same time demonstrated the basic relations of the chemistry and transport, such as the age of the air mass and the role of the nocturnal boundary layer, in determining the production and deposition of NO_y.

In addition to the sum of the reactive nitrogen species, the summer investigation at Niwot Ridge also included separate measurements of a number of the reactive nitrogen species, many measured in concert for the first time. Knowing both the sum of the reactive nitrogen species and many of the individual components provided new insight into the partitioning among the members of this chemical family. Nitric oxide (NO), nitrogen dioxide (NO_2), and nitric acid (HNO_3), were measured by the Laboratory's instruments, and peroxyacetyl nitrate, PAN, concentrations were determined by SRI International and the National Center for Atmospheric Research. It was observed that these four species constitute a large fraction of NO_y, but not 100%, indicating that additional reactive nitrogen species are significant. PAN proved to be comparable with NO and NO_2, an important fact established here for the first time. Diurnal and seasonal behavior of the ratios showed the photochemical behavior predicted for the formation and loss of HNO_3. For example, nitric acid and NO_x ($NO + NO_2$) have been measured now at all times of day during all seasons. The ratio of HNO_3 to NO_x concentrations is observed to rise during the day and to decrease at night. For each season, this diurnal pattern can be well fit by modeling the production of HNO_3 from NO_2 by combination with hydroxyl radicals and the heterogeneous removal of HNO_3. The conclusion is that HNO_3 has a very short lifetime in the troposphere (~12 hours in summer and ~24 hours in winter) and that surface deposition is the primary removal process.

Accurate assessment of the contribution of sulfur-bearing species to acid rain in "clean" continental air requires measurement below 0.1 parts per billion by volume (ppbv) in locations where local anthropogenic contributions are usually absent and clearly recognizable. Measurements of surface tropospheric mixing ratios of sulfur dioxide, SO_2, have been carried out as part of the measurements at Niwot Ridge. The investigation was conducted using an automated portable gas chromatograph with a detection limit of about 10 parts per trillion by volume (pptv). Strong correlations of SO_2 mixing ratio with prevailing wind direction have been observed. Westerly winds frequently result in SO_2 mixing ratios below 10 pptv. Easterly "upslope" air movement bringing urban air masses from the Denver metropolitan area show SO_2 mixing ratios >1 ppbv. Positive correlation of SO_2 with gas phase HNO_3 bespeaks a common source and has implications for acid rain on the eastern slope of the Rocky Mountains. Weak correlation with particulate sulfate indicates differing sources, a slow interconversion rate, or mediating factors not always present.

Formate and acetate as well as other organic and inorganic anions have been measured in precipitation collected at Niwot Ridge (a remote site) and Boulder (an urban site). The organic anion concentration is usually at least 20% of the nitrate concentration and occasionally is equal to the nitrate. Formate is the dominant organic anion measured; concentrations as large as 9×10^{-5} molar occur in summer rain showers. Various dicarboxylic anions are observed also, but their concentrations are generally much lower than formate's. The total ion concentration is usually less at Niwot Ridge than at Boulder. However, ionic balance often leads to a somewhat lower pH at Niwot Ridge. Organic acids have been observed in precipitation previously in remote oceanic areas. The present observations show that they can be significant contributions to the acidity in urban and rural continental areas.

AL

In situ measurements of nitric oxide (NO, fall 1983 and spring 1984) and nitrogen dioxide (NO_2, spring 1984) were made during aircraft flights at altitudes ranging from 500 to 33,000 ft over the Pacific Ocean. These studies were in collaboration with the National Center for Atmospheric Research (NCAR) and were conducted with an aircraft of the National Aeronautics and Space Administration (NASA). During the fall series of flights, NO values in the marine boundary layer and the free troposphere were observed to be extremely low, with values ranging from 0 to 10 and 0 to 50 pptv, respectively. Altitude profiles within a single clean-air mass were constructed from measurements made during constant-altitude flight legs, and a positive gradient with altitude was typically observed for NO. A strong positive correlation between NO_x ($NO + NO_2$) and ozone (O_3) was observed during the spring series of flights. Typical free tropospheric NO_x values ranged from 10 to 100 pptv, with NO_2/NO ratios exceeding by an average factor of 2.5 those that would be expected during conditions of photochemical steady state. During the fall flights, elevated NO values were observed in the free troposphere during periods of subsiding stratospheric air, and evidence for the production of NO in electrically active clouds was also observed. This investigation has provided the most extensive look thus far at the budget and chemistry of NO and NO_2 in the remote global troposphere.

The Laboratory participated in the second and last of the balloon flights conducted to intercompare the results of stratospheric water vapor instruments, sponsored by NASA. These intercomparisons demonstrated that stratospheric water vapor can be measured with an accuracy of about ±25%. The most consistent results were obtained by the Lyman-alpha detector of this Laboratory and the frostpoint instrument of the Geophysical Monitoring for Climatic Change Division ARL. The difference, about 10% to 15%, was the same throughout all the flights. This consistency affords the opportunity to discover the cause of the difference, thereby allowing a homogeneous data set from these two instruments, which are the only two making regular stratospheric water vapor measurements.

The Laboratory also participated in the third and last balloon flight of the campaign sponsored by NASA. The goal was to obtain insight into how well stratospheric ozone can be measured with current instruments. Although many of the data are still being examined and compared, the initial results demonstrate that it is formidably difficult to measure ozone reliably at 40 km, where good data are critically needed to evaluate the potential alteration of the ozone layer by human activities. The Laboratory had two ultraviolet dual-beam ozone photometers on the last balloon flight and configured the pair such that tests could be made of the main sources of ozone measurement uncertainty. These data show that losses of ozone to the walls of inlet lines and to the balloon itself are major sources of error. Such information will substantially shape the strategies being formulated as to how to conduct stratospheric ozone monitoring over the coming decades.

The Laboratory's Lyman-alpha detector for water vapor was flown on board NASA's U-2 research aircraft in the spring of 1984. The goal was to examine the structure of a tropopause fold with fast-response instruments measuring stratospheric and tropospheric trace species. The data elucidate the exchange processes induced by the folding event. The negative correlations between water vapor and temperature, which are opposite to those expected in stratospheric air, suggest that these air parcels originated from near the

tropical tropopause. Since the folding event was at middle latitudes, this may be evidence of rapid long-range transport. This flight series was the first in NASA's Stratospheric Tropospheric Exchange Program, in which the Aeronomy Laboratory will be involved.

Plans FY 1985

The studies of nitrogen chemistry that were conducted at Niwot Ridge in the summer of 1984 will be conducted again in the fall or winter. This should provide considerable insight into the seasonal differences of NO_y and its components and the chemistry and transport that introduce such differences.

The tungstic acid denuder tube will be tested as a viable method for the measurement of nitric acid and ammonia. Tests will be conducted at Niwot Ridge, and comparisons will be made with the measurements of the filter-collection technique.

The NO_y technique will be added to the airborne NO and NO_2 instruments and used, in collaboration with NCAR, on a series of aircraft flights in the late summer of 1985. NASA's aircraft will carry a suite of instruments that will focus on the reactive nitrogen chemistry of the troposphere: the distributions, reactions, and instrument reliability.

A newly instrumented research van will be used to explore two aspects of the tropospheric nitrogen species. First, in California, the constituents of Pacific air masses will be examined. This measurement series will provide the opportunity to test the models of the chemistry of maritime air, a system in which a few fundamental processes are thought to be dominant. Second, the research van will make the first direct study of reactive nitrogen species emitted from the soil, which are thought to be one of the major natural sources that lead to nitrate in precipitation.

In conjunction with these nitrogen studies, a newly developed gas-chromatographic apparatus will measure the emissions of natural sulfur compounds from the soils. Two University groups will be making simultaneous studies, so that the comparison will provide insight into the reliability of such measurements. Calibration standards will have been intercompared earlier. These nitrogen and sulfur studies will be conducted in the southeastern United States, where such emissions are thought to be the largest.

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, Colo., and will use long-path (approximately 10 km) absorption techniques to examine the photochemistry of several tropospheric species. The initial measurements suggest a role of aerosols in the removal of NO_3, and these studies will be expanded.

AL

The differential absorption lidar technique will be explored as a means for measuring ozone in the free troposphere. There is currently no fully acceptable method to do such, despite the need to assess potential human alteration of this important climatic and chemical species.

The test flights will be conducted for the new instruments that will take part in the Stratospheric Tropospheric Exchange Program. The aircraft will be the ER-2, and the flights will test the Laboratory's instruments for measuring water vapor, water vapor and ice, and ozone. These species are tropospheric and stratospheric tracers. The Laboratory will later add NO_y, a stratospheric tracer, to the set. The first experiment will address small-scale exchange processes in the vicinity of jet streams. It is planned to concentrate on the lower side of the jet stream where flow of tropospheric mass into the stratosphere has been postulated to occur.

ATMOSPHERIC WAVES AND TURBULENCE THEORY

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 1984

The Atmospheric Waves and Turbulence program (1) proved that gravity waves "break" in a manner resembling the surfing of ocean waves, and that this "breaking" is the principal process by which waves cause transport in the atmosphere; (2) determined the buoyancy subrange spectrum of temperature fluctuations in atmosphere and oceans, and corrected a commonly quoted 20-year old error in the literature concerning such spectra; (3) proved that "return to isotropy"--the principal hypothesis of turbulence models--is invalid, and developed a theory to determine realistic deviations from isotropy; (4) theoretically determined how observed height variations of gravity wave amplitudes can be used to infer eddy diffusivities in the middle atmosphere; (5) predicted that gravity waves cause diffusion to be anisotropic (with horizontal diffusivities greatly exceeding vertical diffusivities); (6) explained why vertically towed grid turbulence experiments differ from horizontally towed experiments, and how each is related to atmospheric turbulence phenomena; (7) discovered a new mechanism by which gravity waves generate thin layers of turbulence as ubiquitously observed in oceans and atmospheres, namely, a dynamical instability caused by nonlinearly

steepened wave shear. This mechanism might provide the widely sought "sink" of fluctuation energy in oceans.

Plans FY 1985

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 pressure-velocity correlations under stable as well as neutral stratified conditions.

- 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 a theoretical investigation of the spectral distribution, and harmonics, of atmospheric gravity waves; an attempt to determine the "sink" of gravity wave energy in oceans and atmosphere; continuation of the modeling of diffusion and friction from 20- to 100-km altitude, the dynamical coupling of the troposphere 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. Recent new insights into the importance of gravity wave heat flux and Rayleigh friction in the middle atmosphere will be developed further. In addition, a study will be initiated of planetary wave "breakup" in the stratosphere.

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 programming techniques. This direct service function provides further coupling between this program and the more experimental side of the Laboratory.

Accomplishments FY 1984

TROPOSPHERE

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 which 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 infrared 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.

Collaboration with the Atmospheric Sampling Group has resulted in some very important advances in the understanding of the atmospheric processes that influence tropospheric ozone and acid rain. By comparing model calculated values with the ratios of HNO_3/NO_x and NO_3^-/NO_x measured at Niwot Ridge, it is concluded that the lifetimes of HNO_3 and NO_3^- are both shorter than 24 h in the planetary boundary layer. In addition, the OH concentration calculated from the model is probably a factor of 2 too high. The high sensitivity of the NO/NO_2 detector and the extensive data on NO_x and O_3 provide an opportunity to deduce the background O_3 level. Since NO_x is a precursor of O_3, the background O_3 level can be defined as the asymptotic value of O_3 when the NO_x mixing ratio is less than 0.5 ppbv. This method provides an objective way to determine the background O_3 level at a rural station by measuring O_3 and NO_x simultaneously. In addition, the seasonal variation of the O_3 mixing ratio is found to be strongly influenced by anthropogenic NO_x and hydrocarbon emissions when the measurements of O_3 are made in the afternoon. However, this is not the case for O_3 observed at night or in the morning because of low photochemical ozone production. This finding will help the analysis of ozonesonde data to evaluate the anthropogenic impact on the vertical distribution of ozone in the industrialized regions.

Nitrate deposition over remote oceanic regions and in the pre-industrial polar ice cores has been studied in order to quantify the natural background budget of NO_x, NO_3^-, and HNO_3. It is shown that the total nitrate deposition lies between 5×10^8 and 20×10^8 molec cm^{-2} s^{-1} which corresponds to 2 to 8 Tg(N) yr^{-1}.

The nitrate deposition in ice cores in the two polar regions is of particular interest. Post-industrial values in Greenland are about a factor of 2 greater than the pre-1900 values, while there has been no detectable change in Antarctica. These data can be used to evaluate the long-range transport of nitrate. Seasonal variation in the polar ice core nitrate deposition shows a clear strong summer maximum. The nitrate deposition fluxes over remote oceanic regions are not correlated with either ^{222}Rn or dust particles, indicating a non-continental NO_x source. It is concluded that the most likely source is NO produced by lightning in the upper troposphere. The total lightning source is estimated to be about 10 to 20 Tg(N)yr^{-1}. On the basis of satellite lightning frequency, the nitrate deposition flux due to lightning in North America can be estimated to be about 5% to 10% of the anthropogenic value.

AL

The transport of tropospheric ozone has been investigated by a three-dimensional global circulation model simulation in a collaborative effort with scientists at GFDL. The model assumes that ozone is transported from the stratosphere and deposited at the surface. Many of the observed spatial and temporal variations of ozone have been successfully simulated by the model, including seasonal and latitudinal variations in both absolute concentration and relative changes. There are also many disagreements between modeled results and observed values. Latitudinal distribution above 50°N indicates that

there is a major defect in the model meridional transport. Continental surface ozone in the industrialized areas is too low, suggesting the need to include photochemical production of ozone.

Development of the mesoscale air quality model has progressed as planned. A two-day mesoscale meterological model has been run for the case of July 26, 1983. There was an upslope wind during the day and the Niwot Ridge station was in full operation. The domain contains the whole western United States with 60 x 60 km resolution, and finer resolution (20 x 20 km) for Colorado. Tracer experiments have been run with a simple mass conservation scheme, with satisfactory results.

MIDDLE ATMOSPHERE

Chemical-dynamical studies of the middle atmosphere have continued, with an increased emphasis on the photochemistry and transport of ozone in both the stratosphere and mesosphere, and on the chemistry of stratospheric chlorine compounds. These studies have been performed in collaboration with the National Center for Atmospheric Research, using 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 briefly 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 can arise in photochemical modeling because often 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, and the appropriate cancellation between the two may then not be achieved. Recent dynamical studies have shown that the cancellation problem can be alleviated by using the residual Eulerian or diabatic circulations, which represent the desired net transport in the stratosphere without the need for eddy-mean flow cancellation, provided that the eddies are approximately steady and conservative.

A shortcoming of this approach, however, is the question of the role of transient, dispersive eddies in the transport of chemical constituents. Although steady conservative eddies do not appear when the dynamical equations are cast in the residual Eulerian representation, some degree of eddy transience/mixing must occur in the stratosphere. A great deal of recent work in the field has focused on the elucidation of the importance of these mixing effects. One approach to the problem is to examine the computed and observed distributions of chemical tracers such as N_2O, CH_4, $CFCl_3$, etc. N_2O and CH_4 are particularly attractive as tracers because satellite data on their global distributions have just become available. We have therefore added chlorine chemistry to our model and have compared results for the chlorofluorocarbons, N_2O, and CH_4 with available data. We find that relatively small vertical and horizontal mixing coefficients (about 3×10^9 cm^2 s^{-1} in the horizontal and 1×10^3 cm^2 s^{-1} in the vertical) provide the best calculated distributions of these diverse tracers, compared with the ensemble of observations.

In agreement with available satellite and in situ data, our model results indicate that a substantial latitude gradient in atmospheric methane occurs

near 40 km, with tropical values that are about two to three times greater than those obtained at middle latitudes. This is a result of upward transport from the methane-rich troposphere in the tropics, and downward, poleward transport at higher latitudes, by the computed mean meridional circulation. These spatial variations in methane influence the partitioning of chlorine between HCl (an inert reservoir) and ClO (a free radical that catalytically destroys ozone). Thus, the distribution of ClO depends in turn on the methane distribution (particularly near 35-40 km), with associated effects upon the chlorine-catalyzed destruction of ozone. Further, observed local variability in methane at middle latitudes is consistent with much of the observed variation in stratospheric ClO near 40 km. We have shown that spatial and short-term temporal variability in methane has potentially important consequences for the HCl and ClO distributions in the stratosphere, and their local variability, as well as for ozone densities.

A particularly fruitful application of our two-dimensional dynamical chemical model has been in the interpretation of satellite data, both from the Solar Mesosphere Explorer (SME) satellite, and from the Limb Infrared Monitor of the Stratosphere (LIMS) experiment onboard Nimbus 7. The latter experiment revealed the presence of extremely large mixing ratios of NO_x in the polar night mesosphere, and a gradual accumulation of polar mesospheric NO_x throughout the winter. We previously suggested that downward transport of thermospheric NO_x could lead to such an enhancement of NO_x at mesospheric and perhaps even stratospheric levels. If the thermospheric NO_x could reach the stratosphere, it might even influence stratospheric ozone abundances, providing a mechanism for long-range thermosphere-stratosphere coupling. The observations obtained by the LIMS experiment provide striking evidence of downward transport of thermospheric NO_x to mesospheric levels, and suggest that the upper stratosphere is also affected by downward transport poleward of about 60° in winter. We have discussed and interpreted these satellite data in detail.

Collaboration with the SME satellite team has continued. We have used the observed distribution of NO_2 to infer the N_2O_5 distribution in the stratosphere with the hope of providing theoretical information about N_2O_5 to aid experimental efforts to detect it in the stratosphere. We have also continued our study of mesospheric ozone data from SME. A particularly puzzling aspect of the SME data was the observation of pronounced seasonal oscillations near 80 km, with maxima at equinox that are about twice as large as the observed abundances at summer and winter solstice. Purely photochemical and temperature effects would tend to produce maxima at solstice, not equinox, so we were led to pursue a dynamical explanation for the observed features. Recent work has suggested that breaking small-scale gravity waves play an important role in the dynamics of the mesosphere. We have incorporated a parameterization of the propagation and dissipation of gravity waves into our dynamical-chemical model. This parameterization is used to compute both the momentum forcing and turbulent diffusion induced by the waves at mesospheric altitudes, providing the needed transport parameters for the photochemical constituents in the model. We find that the structure of the observed equinox maximum in ozone near 80 km is consistent with our theoretical results when the seasonal and latitudinal variations in turbulent diffusion induced by such waves are considered. This work suggests that observations of mesospheric ozone may have important applications in furthering our understanding of mesospheric dynamics.

AL

ATMOSPHERIC DYNAMICS AND CLIMATE

Collaborative studies with the Atmospheric Dynamics Program of the properties and variability of the tropical tropopause have continued using the existing data base of radiosonde measurements made at tropical stations over the past 30 years or more. The principal results are as follows:

- The correlation in the interannual variations of tropopause height at different stations is excellent for stations within about 10° of the Equator but falls off substantially between 10° and 20° latitude.

- There is a significant correspondence between the height of the tropopause and the phase of the quasi-biennial oscillation in the winds of the tropical lower stratosphere; the phase relationship is qualitatively consistent with the existence of the vertical motions needed to maintain geostrophic balance in the time-varying winds.

- The height of the tropopause is positively correlated with the sea-surface temperature anomalies of the eastern tropical Pacific Ocean and hence with the phase of the Southern Oscillation; in particular, tropical tropopauses tend to be high all over the world during El Niño years.

- Interannual variations in average tropical tropopause height are positively correlated with interannual variations in the total global angular momentum of the atmosphere; such a correlation could have been predicted from current theories of the general circulation of the atmosphere and angular momentum transport, but had not been observed before.

- A pronounced periodicity of about 20 days has been found in the height of the tropopause in the western Pacific at certain times of year; the same period appears to be present in the winds near the tropopause, and its relationship to the periodicities reported by others is under active investigation.

- The relationship between deep cumulus convection, tropopause height, and troposphere-stratosphere exchange is being studied; it is hoped that this will help to shed light on some basic aspects of atmospheric dynamics, and will lead to a sounder basis for estimating the response of the global atmosphere to such external influences as changes in solar radiation or changes in radiative heating brought about by changing concentrations of carbon dioxide and other trace species.

Plans FY 1985

TROPOSPHERE

Tropospheric ozone and its possible perturbation by anthropogenic activities will continue to be one of the major subjects of our research. Important problems in this area are the photochemical production and destruction of O_3, transport of O_3, the distribution of tropospheric NO_x, OH, and RO_2 radicals, and the effects of nonmethane hydrocarbons. We will continue to study these problems by working closely with the Atmospheric Sampling group

and the Atmospheric Chemical Kinetics group. 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 is a long-range goal for this group. The model will be very useful for interpreting the data at Niwot Ridge and for designing other measurement strategies. It will consist of a mesoscale meteorological model and a photochemical model. It is clear that such a model can be readily applied to study regional oxidant problems such as that of rural O_3. This model will be developed in collaboration with scientists at NCAR.

MIDDLE ATMOSPHERE

The interaction of dynamics and chemistry in the middle atmosphere represents an important element in our understanding of aeronomy. We plan to continue to pursue our studies of the natural and perturbed stratosphere and mesosphere. We hope to concentrate on the effects of future chlorine perturbations on stratospheric ozone, and to begin to include a more detailed treatment of infrared radiation in both the mesosphere and stratosphere. The latter goal should eventually lead to a coupled radiative/dynamical/chemical model, and we anticipate that such studies will lead to a more detailed understanding of the middle atmosphere and its response to perturbations.

ATMOSPHERIC DYNAMICS AND CLIMATE

The study of the tropical tropopause region using radiosonde data will continue. Emphasis will be on (1) further development of the conceptual picture of troposphere-stratosphere interaction in the tropics, (2) a thorough investigation of the 20-day periodicity in tropopause heights and winds in the western tropical Pacific, and (3) a refined and more complete study of the correlation between tropopause height and global atmospheric angular momentum, aimed at exploring the cause-and-effect relationship. The connection between tropopause properties and the wind fields of the tropical lower stratosphere and upper troposphere will be investigated.

ATMOSPHERIC DYNAMICS

AL

The objective of the Atmospheric Dynamics program area is to further our understanding of the dynamics of the atmosphere below 100 km by taking advantage of the unique experimental and analytical capabilities of the group. The principle experimental technique of the program is called the MST (mesosphere-stratosphere-troposphere) radar technique. Such radars are so sensitive that they obtain echoes from irregularities of density and humidity in the lower atmosphere, even in the absence of clouds, and from irregularities of electron density in the upper atmosphere. Radars that are sensitive enough to observe only in the lower stratosphere and the troposphere

are called ST (stratosphere-troposphere) radars. Since these radars are phase coherent, they measure the Doppler shift of the echoes, from which profiles of radial wind (including the vertical component when the antenna is pointed vertically), and profiles of certain parameters of turbulence are obtained. Because of their rapid cadence of measurement (up to one profile per minute) the MST radar technique is well suited for studying phenomena that vary rapidly in time, such as internal gravity waves and turbulence, but they are also useful for studying slowly varying phenomena, such as tides and planetary waves. Because of their great altitude range, they are particularly useful for studying the vertical transport of energy and momentum through the atmosphere in the wave fields. The program has followed several lines of experimental research to exploit the capabilities of the MST radar technique. At the present time the program has three radars in operation: the Poker Flat MST radar near Fairbanks, Alaska, the Sunset ST radar near Boulder, and the ST radar at Ponape in the Federated States of Micronesia. The Poker Flat and Ponape radars operate continuously; the Sunset radar is operated for campaigns.

Accomplishments FY 1984

AIR QUALITY

On several nights during 1983 simultaneous measurements of the turbulence structure constant C_n^2 were made by the Sunset ST radar and by an optical stellar scintillometer developed by the University of Nice, France. The profiles for two nights in November 1983 agreed very well. Since these two instruments were quite different and were independently calibrated, this agreement shows that both correctly measure C_n^2. On two nights in June, however, the scintillometer C_n^2 was much smaller over a large altitude range. If the explanation of this discrepancy turns out to be physical, rather than instrumental, then it will have important implications for atmospheric turbulence.

This group was the first to obtain data from an array of ST radars. The measurements were made by three radars in a 5-km triangle in southern France during April and May 1983 as part of the ALPEX (ALPine EXperiment) of the Global Atmospheric Research Program (GARP), in cooperation with the Laboratoire de Sondages Elcctromagnetiques de l'Environment Terrestre, Toulon, France. Cross-spectral analysis of the data has resulted in the determination of the parameters of many gravity waves, with horizontal wavelengths from 7 to 40 km and phase speeds from 5 to 20 m s^{-1}. This experiment demonstrates for the first time that arrays of ST radars can determine the properties of gravity waves in the free atmosphere, which is difficult to do by any other technique.

In 1981 we studied the generation of gravity waves by thunderstorms, using a single ST radar in Colorado. In 1983 these experiments were continued using data from three radars and 20 microbarographs in Colorado. Many of the data were provided by WPL and PROFS. Analysis continued in FY 1984 in cooperation with the Georgia Institute of Technology and the Istituto per la Fisica dell' Atmosfera, Rome, Italy.

We have continued studies of mesoscale fluctuations of wind in the atmosphere, not only in order to describe their statistical properties but also to

understand their physical nature, which is the subject of controversy. MST radar data have been analyzed to obtain the power spectra of the fluctuations as a function of frequency and vertical wavenumber. Also, in order to obtain a complete picture of the fluctuations, data collected by NASA during the Global Air Sampling Program (GASP) have been analyzed to obtain power spectra as a function of horizontal wavenumber. The resulting spectra are remarkably universal in both shape and amplitude, having a standard deviation of amplitude of only a factor of 2.5.

A study of the kinetic energy density of the atmosphere as a function of season, height, and wave period has been undertaken using the 5-year data base for Poker Flat. Preliminary results show that the atmospheric kinetic energy density for all wave periods decreases systematically with height.

In a related study, the transport of momentum in the atmosphere by gravity waves and tides has been measured using Poker Flat data. The results compare with similar measurements at lower latitudes. Both the temporal and spectral variability of this quantity with height will be immediately useful in determining how momentum is distributed throughout the atmosphere by atmospheric waves.

The mean vertical velocity plays an important role in the dynamics of atmospheric circulation, particularly in the vertical transport of energy (including latent heat) and in the initiation of precipitation. We have shown that mean vertical velocities measured by an ST radar on the Colorado Piedmont agree fairly well with mean vertical velocities inferred by analysis of radiosonde balloon data when the wind is toward the Rocky Mountains. We have also shown that during a widespread rain event the occurrence and rate of precipitation was correlated with the ST radar mean vertical velocity.

A major discrepancy has appeared between the mean vertical motions in the mesosphere observed at Poker Flat and the motions deduced from theoretical models. It is possible that this discrepancy arises from the different coordinate systems used for the radar observations (Eulerian) and current theoretical models (Lagrangian), as a result of the effect of intense gravity wave action in the region. If substantiated, this discrepancy would bear heavily on future comparisons between observations and theory.

In June 1983 we participated in the STATE (STructure and Atmospheric Turbulence Environment) program, a joint experiment using the Poker Flat MST radar and a series of experimental rockets from the Air Force Geophysical Laboratory. Preliminary analyses of the results show a very cold summer arctic mesopause and regions of intense turbulence that arise from the breakup of upward-propagating gravity waves.

AL

CLIMATE

We installed the first tropical ST radar at Ponape, Federated States of Micronesia. Vertical wind data that have been gathered continuously since early May show a number of unique characteristics of the tropical atmosphere. In particular, it appears that the radar echoes are enhanced during the typically brief but intense rainstorms. Such an effect has not been observed at these long wavelengths (6 m) in middle latitudes.

Plans FY 1985

AIR QUALITY

The generation of gravity waves by thunderstorms will be studied further by completing the analysis of the 1983 radar and microbarograph data.

Study of mesoscale fluctuations will continue by examining spectra of atmospheric parameters (including both wind and temperature) from various sources and by comparing the power spectra with models based on the theories of gravity waves and two-dimensional turbulence. Comparison of models with power spectra from MST radar data taken looking simultaneously at the vertical and at a slant will be particularly critical. Analysis of the GASP data will continue in order to determine the climatology of mesoscale spectra as a function of latitude and underlying topography.

The preliminary study of kinetic energy density profiles will be expanded by further, more detailed analyses. Initial calculations of rotary spectra will be done. The ratio of power in the clockwise to counterclockwise spectra is a measure of the ratio of downgoing to upgoing wave energy. A more detailed study of the vertical flux of horizontal wave momentum will be undertaken at Poker Flat by using antenna beam switching to make measurements symmetrically about the zenith, in addition to the present vertical/slant configuration. If fluxes measured by both configurations agree, then fluxes can be determined from the entire 5-year data base at Poker Flat. In combination with theoretical developments in the Atmospheric Waves and Turbulence program and elsewhere, these studies should lead to a greatly improved understanding of wave energy and momentum transport and deposition in the middle atmosphere.

The mean vertical velocity will continue to be studied by extensions of the methods described in Accomplishments FY 1984. However, before the capability of the MST radar technique can be fully assessed it will be essential to have a radar sited in flat terrain. For this reason we have proposed to NSF that we construct and operate a state-of-the-art ST radar near Urbana, Ill. Although this "Flatland" radar was motivated by the need to measure vertical velocities, the absence of terrain effects will make the data uniquely valuable for studying gravity waves and energy and momentum transport in the lower atmosphere. If funded, this radar will provide a major new direction for the program.

We will continue our analysis of the STATE data base, in order to understand better the relationship between neutral turbulence, echo power, and wavebreaking processes in the mesosphere-lower thermosphere. This effort will involve collaboration with a number of scientists outside the Aeronomy Laboratory.

Plans are also under way for a second series of rockets similar to STATE. This program, directed by NASA Goddard Space Flight Center, is expected to start during the winter of 1985. It will elucidate the reasons for the markedly different conditions in the summer and winter arctic mesosphere.

CLIMATE

The second major new direction of the program is the study of the tropical atmosphere using ST radars.

The Ponape radar will be improved to include a beam-swinging capability so that the horizontal wind as well as the vertical wind can be measured. These measurements should reveal the character of wind variability in the oceanic tropics.

The relation between enhanced echoes and rainfall will be studied quantitatively in order to understand the nature of the enhancements and their relation to convective cloud dynamics.

The program has been funded by NOAA's Office of Oceanic and Atmospheric Research to establish three ST radars in the equatorial Pacific for a 10-year period as part of the international Tropical Oceans, Global Atmosphere (TOGA) program. Site surveys for two of the radars have been completed and two of the radars should be installed during FY 1985. The data from the TOGA and Ponape radars will be used by Aeronomy Laboratory and other scientists to study vertical motions in large cumulonimbus clouds, the vertical transport of minor constituents, gravity waves and turbulence properties of the tropical atmosphere, and equatorial (large-scale) waves, which are thought to be important in controlling climate variability in middle latitudes.

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 still continue to receive some attention.

Accomplishments FY 1984

We measured stratospheric NO_3 over a 5-year period ending in 1983 and found its seasonal and latitudinal behavior to be in serious disagreement with that predicted by chemical models. A rapid rise in abundance at the end of March and a gradual disappearance in summer were the outstanding features of the disagreement. We have now discovered that the abundance of NO_3 is almost perfectly correlated with the previous location of stratospheric air; when the air has been at high latitude (>60°) the NO_3 content is low when the air reaches middle latitude. If the air has remained at middle latitude, then the NO_3 abundance is not anomalously low. We speculate that an unknown process, existing only at high latitude, creates in stratospheric air an unknown species capable of destroying NO_3. When the NO_3 abundance was low we formerly could obtain only upper limits; with a new diode array spectrometer we now have obtained a year's measurements, which replace the upper limits with actual measurements. The abrupt switch in stratospheric circulation at the

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end of March came as a surprise; it had not been noticed previously and in some way it must reflect the onset of heating in the upper stratosphere near the spring equinox.

We have also begun to use the diode array spectrometer to study the change in stratospheric NO_2 during the day. Previously we had been limited to measurements at sunrise and sunset and had found that unexpected anomalies existed in the morning/evening ratio of abundance; now we are beginning to obtain measurements during the entire day and night which should help to clarify these anomalies.

The full analysis of the effect of the El Chichón dust cloud upon stratospheric NO_2 is nearing completion. The very large reduction in NO_2 produced by the cloud remains unexplained; doubtless it involves heterogeneous surface reactions about which little is now known.

The first major study of stratospheric NO_2 using data from the SME satellite has been completed, and we continue to analyze more recent observations in collaboration with colleagues at the University of Colorado. We also have analysed measurements from SME in the nadir; these permit detection of NO_2 in the troposphere produced both by lightning and by human activity. For the first time such measurements can be obtained on a global basis and not just locally.

A second diode array spectrometer has been used at Fritz Peak Observatory to study NO_3 and NO_2 in the troposphere in collaboration with colleagues in the Atmospheric Sampling group. A year's measurements are under analysis and already confirm our earlier conclusion that NO_3 is strongly scavenged in the troposphere as well as in the stratosphere; once again the scavenging mechanism remains unknown as does its role in cleansing the troposphere of nitrogen oxides.

An unexpected periodic oscillation in stratospheric OH has been discovered; it remains unexplained.

An automatic instrument using twilight airglow to measure the atmospheric density at 300-400 km from the ground is now fully operational; the first measurements of thermospheric winds using molecular emissions have also been made.

Plans FY 1985

We shall continue to use and improve the long-path absorption facility to study NO_2 and NO_3 in the troposphere in an attempt to understand more about the removal of nitrogen oxides from the troposphere. We also plan to attempt measurements of other tropospheric species using this facility.

The diode array spectrometer will be used for further study of stratospheric NO_3 and NO_2, with much improved instrument sensitivity.

Analysis of the NO_2 measurements from SME will continue with emphasis on tropospheric NO_2 produced anthropogenically and by lightning.

We shall continue the long series of measurements of stratospheric OH which are unique and yielding new surprises.

ATMOSPHERIC CHEMICAL KINETICS

The primary activity of the Atmospheric Chemical Kinetics program is the experimental investigation of chemical reactions that are important in the atmosphere. Although the research is focused on the effects of man-made chemicals, a second objective is to understand the natural, unperturbed atmosphere. The information obtained in this program includes the rates and mechanisms of chemical reactions, thermochemical and spectroscopic data, and photochemical measurements.

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 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 transformed into strong acids which are deposited in remote rural locations. A hazard of these acids is 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.

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Accomplishments FY 1984

Two experiments, a laser magnetic resonance spectrometer (LMR) and a chemical-ionization flowing afterglow (CI-FA), have been used to study the mechanism by which sulfur dioxide, SO_2, is converted to sulfuric acid, H_2SO_4, in the atmosphere. This process is a major source of uncertainty in modeling acid precipitation chemistry. The central issue is whether odd hydrogen radicals, OH or HO_2, are consumed in the conversion process. If radicals are consumed, a reduction in SO_2 emissions would not necessarily produce a proportionate reduction in the amount of H_2SO_4 deposited in critical areas. This follows because the present rate of H_2SO_4 production may be limited by the number of odd hydrogen radicals produced and not by the amount of SO_2 released into the atmosphere. Recent experiments in other laboratories have provided indirect evidence that the gas phase SO_2 oxidation process may not consume radicals. Our direct LMR study confirms these experiments and shows that the OH radical that reacts with SO_2 in the primary process is regenerated as an HO_2 radical, when oxygen is present. The CI-FA experiment has directly established that the second product of the critical reaction is sulfur trioxide, SO_3. The SO_3 product is probably rapidly converted to H_2SO_4 by water vapor and on the surface of droplets and aerosols. The proposed mechanism is described by the following scheme:

$$OH + SO_2 + M \rightarrow HOSO_2 + M$$

$$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

The reaction of nitrate radicals, NO_3, with nitric oxide

$$NO_3 + NO \rightarrow 2NO_2$$

has been studied using laser-induced fluorescence detection of NO_3. This reaction is used for laboratory calibrations of NO_3 concentrations and is important in nighttime urban chemistry. The rate coefficient at room temperature was found to be about 50% larger than the accepted published value. Preliminary results at low temperatures show that it has a negative temperature dependence.

The kinetics and transport properties of gaseous sodium, Na, have been studied in a fast-flow reactor with resonant fluorescence detection of Na. Sodium is deposited in the upper atmosphere by meteors. It was recently proposed that the presence of Na in the stratosphere could modify the chemistry of chlorine species that have been shown to be effective ozone destruction catalysts. This study has shown that the reaction of Na with ozone is very rapid and that one product undergoes a second rapid reaction with ozone, which regenerates the Na. The existence of a catalytic cycle involving Na and ozone has not been previously reported. It is unlikely to be very important in the stratosphere because the concentrations of free sodium are so small in that region, but it may be of some significance at higher altitudes. The rate coefficient for the reaction of Na with chlorine, Cl_2, was found to be very large. The diffusion coefficient of Na in helium was also measured.

A study of the reaction of chlorine monoxide, ClO, with hydroxyl radicals has been completed using an LMR experiment. This reaction is important in the stratosphere because it involves two

$$ClO + OH \rightarrow HO_2 + Cl \qquad (a)$$

$$HCl + O_2 \qquad (b)$$

key chemical species. If path (b) is followed, the reaction becomes extremely important as a mechanism for converting reactive chlorine radicals (ClO) to the inert form hydrogen chloride. The results of this study indicate that the rate coefficient is about two times larger than that found in two previous, less direct studies. The yield of hydrogen chloride is small but the uncertainty limits in the present result do not place it at the insignificant level. The temperature dependence of the reaction was also measured. The kinetic data on path (a) were used to establish the thermochemistry of the hydroperoxyl radical, HO_2.

The HS radical has been detected in an LMR experiment. This development makes it possible to study the kinetics of HS which is important as a precursor to sulfuric acid. HS is known to be an intermediate in the atmospheric oxidation of H_2S and is thought to be involved in the oxidation of other sulfur compounds such as COS and CS_2.

A new experiment employing a high-resolution Fourier transform spectrometer has been developed to evaluate the products of atmospheric radical reactions. The experiment consists of discharge and hot wire radical sources, a reactor, a 1.6-m-long multipass absorption cell with a high-speed pump, and the Fourier transform interferometer. The first tests with this system have demonstrated that product molecules are detectable in the concentration range 10^9 to 10^{11} molecule cm^{-3}.

Tests were performed using hot metal wires with the objective of developing new sources of atoms and small radicals. The metals tested were platinum, iridium, tungsten, nickel, and nichrome. The species generated were atomic hydrogen, oxygen, fluorine, chlorine, and hydroxyl. All were detected by resonant fluorescence. Both hydrogen and oxygen atoms were generated in high concentrations on several different surfaces. No favorable source was found for fluorine, chlorine, or hydroxyl radicals.

Studies of collisional deactivation of vibrationally excited NO^+ were carried out in collaboration with scientists in several laboratories in Europe. This process is very important in the upper atmosphere and in perturbed atmospheres. The presence of vibrationally excited NO^+ in the atmosphere is of concern to systems that use infrared wavelengths for measurements or detection. It was found that vibrationally excited NO^+ ions are deactivated rapidly by N_2 and slowly by O_2. A theoretical model that describes the deactivation process was developed and found to be applicable to a large variety of vibrational deactivation processes involving ion species.

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Plans FY 1985

A new experiment to study gas phase reactions at atmospheric pressure will be initiated. Free radicals for these studies will be generated by pulsed laser photolysis of stable molecules. Radical detection will be achieved using resonant fluorescence, laser-induced fluorescence, or longpath absorption techniques. This experiment will be directed toward investigating reactions that are thought to exhibit a pressure dependence and are related to the formation of acid species in the troposphere.

An experiment will be developed to study the products of atmospheric photochemical processes. Although a great deal is known regarding the rates of such reactions, there is often a major uncertainty associated with the product yields. The products' identities are critically important in determining the role of a reaction in the atmosphere. The objectives of this experiment will be to identify and quantify the products of photochemical processes such as the photolysis of NO_3 and the reaction of $O(^1D)$ with N_2O. Various optical techniques and mass spectrometry will be used to measure the product yields.

Further studies will be carried out on the SO_2 oxidation mechanism. First an effort will be made to measure the efficiency of the conversion of $HOSO_2$ to HO_2 and SO_3. Then a study of SO_3 kinetics will be initiated using chemical ionization detection to see if the gas phase reaction proceeds with a significant rate.

The kinetic studies of NO_3 reactions will be continued. The temperature dependence study of the NO + NO_3 reaction will be completed first; then the reaction of NO_2 with NO_3 will be investigated as a function of temperature and pressure.

The reaction of Na with ozone will be studied further with the objective of measuring the rate coefficients associated with the catalytic ozone destruction cycle. The temperature dependence of these processes and the Na diffusion coefficient will also be studied.

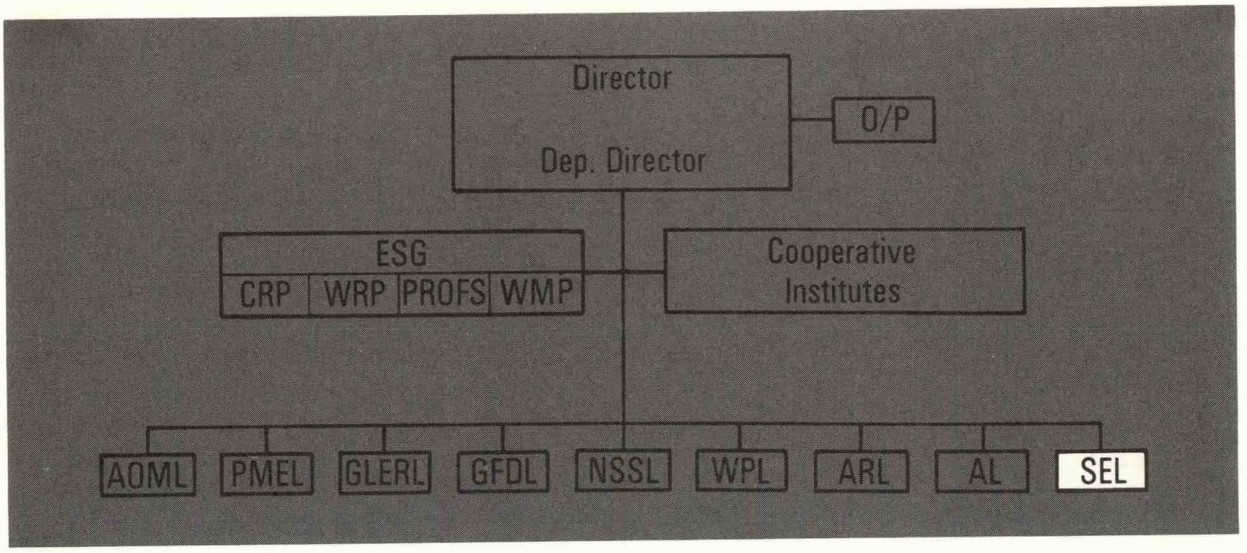
The laser magnetic resonance detection of HS radicals will be pursued with the objective of studying the reactions of HS with atmospheric gases such as O_2, O_3, and NO_2. A search for the HSO radical, which is expected to be the product of the O_3 and NO_2 reactions, will also be made.

Product detection studies will be continued with the Fourier transform spectrometer experiment. The current experiments on unstable molecules such as HOONO and $HOONO_2$ will be extended to include searches for OH and HO_2 radicals.

The collaborative studies of ion-molecule reaction kinetics will be continued. The work on the deactivation of vibrationally excited ions will be extended to cover a large range of temperatures and kinetic energies and different ion-neutral systems. Data obtained in other laboratories on the ion composition of the stratosphere and troposphere will be analyzed to gain information on the concentrations of critical trace species.

SPACE ENVIRONMENT LABORATORY
Boulder, Colorado

Harold Leinbach
Acting Director



The Space Environment Laboratory conducts research and provides services in the solar-terrestrial field. This field concerns the relationship between solar activity and geophysical effects, which can adversely affect activities including communications, transportation, energy dissemination, and national defense.

The focal point for the nation's present solar-terrestrial services is in the Space Environment Laboratory at Boulder, where, with the cooperation of the Air Weather Service, the monitoring and forecasting services are carried out to meet a wide variety of civilian, military, commercial, and Federal agency requirements. Laboratory activities include the real-time collection of solar-terrestrial data; the issuance of forecasts, alerts, and warnings of adverse solar-terrestrial conditions; the archiving and processing of solar-terrestrial data from all over the world; and the development of a better understanding of the behavior of the solar-terrestrial environment to yield significant service improvements.

SEL is composed of three Divisions: the Research Division, the Systems Support Division, and the Space Environment Services Division. The three divisions work cooperatively in providing real-time space environment services and conducting the necessary supporting research and development activities.

Highlights of the year include the installation of the new Space Environment Laboratory Data Acquisition and Display System (SELDADS II), which will replace the obsolescent SELDADS I, and the inauguration of the satellite data relay system, which distributes solar-terrestrial data to users via satellite data relay.

For the second time, Congress restored SEL's annual appropriation. However, the issue of the cut contained in the President's budget will arise again for FY 1986.

SPACE ENVIRONMENT SERVICES

The Space Environment Services Center (SESC) in Boulder is operated jointly by the National Oceanic and Atmospheric Administration (NOAA) and the Air Force Air Weather Service (AWS) and exists to provide predictions, alerts, and real-time information describing solar geophysical disturbances to users throughout the United States. In addition, it is designated the World Warning Agency (WWA) for the International Ursigram and World Days Service (IUWDS), which is operated under the International Council of Scientific Unions. SESC collects data from its own sensors, from cooperating agencies and institutions, and from other countries, both through IUWDS and through bilateral exchange agreements. The data collected include solar images and measurements of other parameters that characterize the Sun, the interplanetary medium, and the Earth's magnetosphere and ionosphere.

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 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. The Navy issues corrected satellite ephemerides based on the forecast or observed level of magnetic activity. 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 geomagnetic forecasts and warnings to minimize adverse effects on systems. Many geophysical prospecting companies using airborne magnetometers will avoid flights during the magnetically disturbed conditions that would affect measurements.

Accomplishments FY 1984

SERVICES

Forecasts, used by about one-third of SESC customers, consist primarily of daily predictions of solar and geomagnetic activity, and of other standard measures of solar variation such as the 10-cm radio flux. Most of the forecasts are for the following 3 days, although forecasts for 27 days are made for the 10-cm flux band for the global geomagnetic index, Ap. SESC maintained a full schedule of daily forecasts through FY 1984.

Alerts of solar activity and geomagnetic disturbances are issued in six major categories when disturbances exceed any of several increasing thresholds set to meet users' needs. Computers automatically search the incoming real data for variations that may indicate onset of a disturbance, but alerts are issued only after the suspected disturbances have been reviewed by trained, experienced personnel. In FY 1984, the automated alert system detected 865 events, but subsequent review showed that alerts for 29% would have been

wrong. The actual alerts issued by SESC after human correction contained an error rate of 0.5%.

Indices, summaries, and data allow users to diagnose problems in operating systems or to plan the execution of scientific experiments that must be carried out under specific environmental conditions. The indices and summaries issued by SESC in FY 1984 were based on standard 3-h and 24-h intervals.

SESC operations were carried out in FY 1984 by a staff of NOAA and Air Force forecasters and solar-technicians providing services 24 hours per day, 7 days per week. The forecase center, located in Boulder, moved into new facilities in FY 1984. The new facility is designed to provide the duty staff with ergonomically correct, easy-to-use data displays, computer terminals, and communication equipment.

REAL-TIME DATA

SESC collects data from its own sensors, from cooperating agencies and institutions, and from other countries through international exchange agreements. The result is a pool of complementary data that allows a real-time assessment of conditions in the solar-terrestrial environment from the Sun through interplanetary space and down into the Earth's environment, including the ionosphere and magnetosphere. The types of data available to SESC in FY 1984 are discussed below.

Solar Optical Observations

Solar observations with optical telescopes provide information on the state of the solar atmosphere (quiet or disturbed), such as the presence of active regions and the global distribution of solar magnetic fields. The observations are used to identify regions of high potential for solar flares, filaments with high probability of eruption, and coronal holes (sources of high-speed solar wind).

The major sources of solar optical data are the AWS global network of observatories, the Australian Dept. of Science observatories in Australia, and the U.S. National Solar Observatories at Kitt Peak and Sacramento Peak.

Solar Radio Observations

Solar radio telescope observations provide an indication of the energetic solar disturbances, acceleration of energetic electrons, and the passage shock waves through the solar atmosphere. Sources of data include the Air Weather Service global network, the Canadian solar radio measurements from Algonquin, and measurements made at Boulder, Colo.

Geomagnetic Field Observations

Geomagnetic observations provide quantitative information on the geographic extent and severity of the geomagnetic variations that occur as a result of solar wind and/or magnetospheric disturbances.

Satellite observations of the geomagnetic field at geosynchronous orbit, and ground-based data from an 18-station network (through the cooperative efforts of the Dept. of the Interior, National Science Foundation, and Universities of Alaska and New York State), are transmitted in real time to SESC to monitor the effects of solar wind disturbances on the Earth's magnetosphere.

Solar X-ray Observations

Solar X-rays produce interruptions to ionospheric communications simultaneously with the sighting of the optical solar flare. Continuous observations of solar X-ray emissions from the whole Sun are provided by the space environment monitors on the geostationary operational environmental satellites (GOES). Data are collected at Boulder by radio link directly from the satellites.

Energetic Particle Emissions

Solar emissions of high energy protons, electrons, and alpha particles may cause radiation damage to satellite systems and are potential health hazards to astronauts in space and to passengers in aircraft flying at high altitude. The same particles also cause outages on high frequency (HF) radio circuits in polar areas and are correlated with errors in very low frequency (VLF) navigation systems. The presence of upper atmosphere heating, a consequence of the magnetospheric particle precipitation and Joule heating by ionospheric currents, can be inferred by the magnitude of the total energy deposition measured by sensors on polar-orbiting satellites.

Particle observations are made on NOAA satellites--the polar-orbiting TIROS (Television and Infrared Observation Satellite) and the geosynchronous GOES.

Solar Wind Observations

Solar wind perturbations presage the occurrence of geomagnetic storms at the Earth. Preliminary solar wind data from interplanetary spacecraft are received in real-time by SESC. These data include solar wind density and velocity and the interplanetary magnetic field direction and amplitude. The primary source of these data, the NASA International Sun-Earth Explorer (ISEE-3), was dispatched from its location between the Earth and the Sun in FY 1984 and sent on a comet encounter mission under the name International Cometary Explorer (ICE). This has resulted in a decrease in its usefulness to space environment operations.

Other Geophysical Data

Other geophysical data (including cosmic ray, ionospheric, and geomagnetic) are collected in Alaska at a station jointly operated by the Air Weather Service and NOAA, from the NOAA observatory at Table Mountain near Boulder, and from various sources in an international exchange program.

DATA DISPLAY SYSTEMS

The primary data system in the service operation is the Space Environment Laboratory Data Acquisition and Display System (SELDADS) for collecting, processing, integrating, storing, and displaying solar-geophysical data from observing systems of the DOC, DOD, DOE, DOI, and the National Science Foundation, as well as international data exchange programs. Real-time data entering SELDADS are converted to engineering units, quality controlled, tested for significant solar-geophysical events, and stored for later access and archiving. Processing of the data occurs continuously, 24 hours per day, 7 days per week. The SESC forecasters are the primary users of the data base. Displays and interactive analyses of the data are used by SESC to provide its forecasts, alerts, and summary data. Data are also provided to meet the operational requirements of the Department of Defense and other national users. Summary data are transferred from SELDADS after 1 month for archiving in the National Geophysical Data Center. SELDADS was operational more than 99% of the time in FY 1984.

DISTRIBUTION OF SERVICE PRODUCTS

Service products are distributed to users in a number of ways commensurate with customer needs: Radio broadcasts on the shortwave time service WWV contain hourly announcements of space environment indices and predictions; users can call a tape-recorded message in Boulder at their own expense to obtain the same information; alerts of disturbances are distributed by telephone to users who need such information in real time; teletype messages that contain more information than can be included in verbal messages are sent on a collect basis to users who do not have access to other networks.

In its role as the World Warning Agency for the IUWDS, SESC distributes its products to regional warning centers on each of the major continents.

A major new development in FY 1984 was the initiation of a satellite broadcast service for distribution of the space environment services. The broadcast includes a standard package of forecasts, alerts, and indices that serve the widest practical user community. A standardized data format is accessible by users with microcomputers, large-scale computer systems, or standard printer systems. For example, the user may display a real-time plot of solar X-ray flux. Information can be used by commercial companies to provide further specialized services to segments of the user community.

TECHNICAL IMPROVEMENTS IN SERVICES

Geomagnetic forecasts and alerts are required by approximately two-thirds of SESC's customers. An improved format for geomagnetic forecasts was developed during FY 1984. Forecasts for 1-, 2-, and 3-day periods indicate the likelihood that the activity level will fall in each of six categories of disturbance, from very quiet to very stormy. A "climatological" data base of magnetic records is being established to provide numerical guidance for the forecaster and to give a basis of comparison for forecast verification.

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A study was begun to establish the operational needs and priorities for images and magnetograms of the Sun. It is clear that in the future images

will be transmitted from remote observatories in digital format, avoiding the cumbersome photographic processes needed to record the images and transmit facsimile pictures. The use of digital images will open the way for quantitative analysis and comparison of images. For example, these new techniques will facilitate the creation of synoptic solar maps, which even now in their hand-drawn format are a primary input to forecasting of solar activity. The requirements for a new image system, called SELSIS (Space Environment Laboratory Solar Imaging System) were formulated, and procurement of some of the components was initiated.

The measurement of magnetic shear in active regions of the Sun is being investigated as a way of improving flare forecasts. Shearing of the fields leads to storage of energy, which then may be converted into various forms of particle and electromagnetic radiation in a catastrophic process, identified as a solar flare. Advance knowledge of the total energy available would assist forecasters in estimating the maximum size flare that might occur. The rate of energy build-up may indicate when an unstable level may be reached and a flare will begin.

Plans FY 1985

SERVICES

The basic services carried out in FY 1984 will be continued in FY 1985, including real-time monitoring, data collection, and processing; the issuance of forecasts, alerts, and indices from the forecast center of SESC on a 24-hour per day, 7-day per week basis; and the distribution of service products.

Several improvements in services are planned for FY 1985:

The new geomagnetic forecast format will come on line as part of the Phase I software for SELDADS II.

A new product, to be disseminated in SESC's weekly data report, will provide a continuous plot of conditions in the space environment at synchronous satellite orbit. The new data displays will assist satellite operators in rapid diagnosis of problems with their spacecraft; problems have increased because of the satellites' electronic components, which are sensitive to disruption in the space environment.

Renovation of the forecast facility will be completed with the installation of new graphics displays that are part of the SELDADS II system. The new equipment will provide displays that tell the current status of disturbances in the solar terrestrial environment, and the operational status of the SELDADS computers and of the communication links into and out of the service center. The forecast personnel will spend much of their non-forecast duty time in establishing requirements for the content, format, and protocol for each of the display systems being constructed as part of the new SELDADS. The primary new activity will be the implementation of SELDADS II, which is described in the last section.

Other activities will be the design of a processor that will be used to collect real-time data from the NASA International Cometary Explorer (ICE). The processor will allow the solar wind data from the ICE to continue to be available in real time at least some of the time, even though the ICE is in a less desirable orbit for forecast services than was the ISEE.

TECHNICAL IMPROVEMENTS IN SERVICES

The project to improve the geomagnetic forecast format will move into forecast operations as the first phase of SELDADS II comes on line. The development work on the use of shear as a flare forecaster will continue in cooperation with the Air Force observatories. This work will also be integrated into the more advanced capabilities to be developed on the image analysis system including the capability to automate some of the current manual analysis of the synoptic type solar image data.

Present knowledge indicates that solar flares, and solar mass ejections associated with solar filaments and the steady emission from coronal holes, are capable of producing geomagnetic storms. A study will be made of why these occur for only about one-half of the observed solar events judged to be capable of producing geomagnetic activity.

RESEARCH AND DEVELOPMENT

Research and development are carried out in the Space Environment Laboratory by the Research Division and the Systems Support Division.

The Research Division carries out research in the field of solar-terrestrial relations, with the objective of improving our understanding of the effects of solar activity on human activity.

The Systems Support Division provides general support to the Space Environment Services Division and to the Research Division in planning, development, and provision of Instrument and Data systems.

Accomplishments FY 1984

OPERATIONAL SATELLITE INSTRUMENTATION

Data from operational Space Environment Monitors (SEM) which are carried on the NOAA TIROS and GOES spacecraft are essential to the operation of the National Space Environment Service. The provision of instruments of existing design to replacement spacecraft and the development of new or improved instruments for existing or new spacecraft designs is therefore a very important supporting activity. **SEL**

Instruments are normally produced by contractors (or sub-contractors) to the National Aeronautics and Space Administration, which acts in turn as a contractor to NOAA for the provision of the entire operational satellite. SEL sets the requirements for the SEM's and assists with the technical supervision

of the instrument contractor. SEL has also been asked by NASA to perform recalibration and repair as necessary on off-the-shelf instruments awaiting flight, and also recently to requalify one existing GOES High Energy Proton and Alpha Detector (HEPAD) instrument, and assemble a second from spare parts for the GOES-G and -H program. This detector provides operational information on radiation hazards caused by very high energy solar particles during very large solar flare events.

During the year, SEL delivered the first HEPAD to the GOES contractor. The second instrument is expected to be delivered in October.

The existing TIROS SEM instruments awaiting flight were supported as necessary. Two Medium Energy Proton and Electron Detector (MEPED) units were repaired and requalified.

The GOES-NEXT program was supported by finalizing the SEM requirements and revising the resulting specifications. The spacecraft Request for Proposals has been issued, and responses will be under review at the close of FY 1984.

The final report was issued on the development work carried out on the prototype of an X-ray imaging instrument for operational use on the GOES series of spacecraft. The imager is currently included in the GOES-NEXT Request for Proposals, as an example of an instrument for which an expansion capability is desired. This provision will enable the imager to be added when funding becomes available.

The framework of a new software system for the off-line processing of GOES and TIROS data was completed during 1984. The new system was rendered necessary by changes in the satellite telemetry system. Off-line processing, i.e., separate from real-time processing that provides data to SESC, provides a magnetic tape data base for use within SEL. This is used for data quality control and research and development on new service applications of the data. The tapes are also archived with NESDIS World Data Center-A for use by other scientific organizations. The new system will provide explicit routine quality control and is also being designed so that as much as possible of the system can ultimately operate within SELDADS II rather than the ERL computer system.

SELSIS—SEL SOLAR-IMAGING SYSTEM

During the year a working group was formed to study the future direction of the handling of image data in SESC. All solar image data are currently used in photographic form, and are obtained from remote observatories by wire photo systems. These systems are old and in need of replacement. The working group recommended that, rather than replace the existing systems, we move to digital image transmission, storage, and display, which is now becoming practical at reasonable cost. The recommendation was accepted and implementation is under way.

The cooperating observatories that provide the images are moving to make all data available in digital form. The benefits expected are improved image quality and, most importantly, the ability to combine image data from more than one source and to carry out quantitative image processing. The system

will bring images from Kitt Peak National Observatory, Holloman AFB, and our local H-alpha telescope into the SESC storage system and also permit the exchange of images with NASA Johnson Space Center during Shuttle Spacelab missions that require this support.

The system will be implemented in coordination with existing plans to acquire a scientific graphics workstation; a second identical workstation will be the basis for the SESC image display and processing system. All the necessary hardware is now on order.

SOLAR PHYSICS

Activity was directed toward research to improve medium- and long-range solar predictions (in the range of weeks to 10 years) and toward basic understanding of the structure and evolution of the solar corona, as a prelude to predicting the propagation of solar disturbances toward the Earth and other bodies in the solar system. Statistical studies of geomagnetic and sunspot activity resulted in advances in predicting the levels of solar-terrestrial activity as much as a decade ahead.

Solar Mapping

The goal of this activity is to replace the daily maps of the Sun, drawn by hand, with maps and charts plotted from digital files stored on computer disks. The digital data will serve to make SESC products more uniform and objective, and provide a data base for computer manipulation. An immediate improvement is realized in the accuracy of overlying images from different observing systems, taken at different times. Software developed this year permits computer production of the daily disk solar map, complete with annotation of SESC serial numbers for solar active regions. Provision is made to allow plotting of a map from data obtained one or more days earlier so that an operational map can be constructed in times when weather or equipment problems prevent receipt of solar image data.

Implementation of these mapping procedures will eliminate duplication of effort in producing the daily maps for real-time use and the production of synoptic charts used in long-range forecasting and in support of solar-terrestrial research. The conversion to a digital data base will permit coupling of solar maps with digital solar image processing as it is developed. Development of computer displays from the digital data files can proceed with current data rather than delaying this development until advent of the digital imaging. This work will facilitate application of research involving large-scale solar magnetic fields and the solar corona.

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Work continued, under contract to NASA, to provide real-time communication of daily maps of solar magnetic fields from Stanford University to SESC. The Stanford maps are plotted at the same scale and format as the maps generated from other solar images available to SESC.

A computer program was developed for using these data to compute the distribution of large-scale solar magnetic fields at the height above the solar surface where these fields are expected to couple directly to the inter-

planetary magnetic fields. This quantitative model of the solar coronal environment will be a basis for predicting the propagation of solar disturbances from the Sun.

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. These edited charts have been used to construct time series of limited latitude zones of the Sun for monitoring long-term, large-scale evolutions. The formation of strong centers of sunspots and solar flares and the occurrence of large, stable coronal holes have been tentatively associated with patterns of convergence and divergence, respectively, in the evolving large-scale patterns of magnetic fields. The maintenance of the data base on large-scale solar activity is a necessary prelude to the development of practical methods for making 27-day solar-terrestrial predictions.

Large-Scale Solar Activity

A collaborative study of solar maps combining large-scale magnetic-field patterns with filaments and coronal holes has resulted in a detailed description of the process of reversing the polarity of the poles of the Sun. The polar reversal occurs a year or two after the peak in the 11-year cycle. Study of this process may offer clues to the physics of the solar cycle and a basis for long-term solar predictions. This study found that the process was discontinuous, and occurred in organized meridional flows rather than through a diffusive process.

Long-range predictions of sources of strong X-ray flares have been resumed in support of NASA research programs directed toward solar and magnetospheric physics. The prediction technique uses time series of H-alpha synoptic charts to derive maps of velocities over the entire solar surface. Anomalies in the large-scale flows, such as excessive shear and convergence, precede the occurrence of major sunspots.

A new model for the formation and structuring of sunspot groups has been developed from study of the relationships between sunspots and the largescale magnetic fields.

Long-Term Solar-Terrestrial Activities

A study of recurrent geomagnetic activity led to a new index for separating the recurrent component from the eruptive component in geomagnetic activity. This study is being extended to use the index to make predictions of sunspot cycles several years earlier than previously possible.

Solar Flare Evaluation

Provisional mathematical models have been established for the early rise and decay of the X-ray flux from solar flares, as a step in the development of an automated means for early detection of X-ray flares and prediction of their peak intensity and rate of decay. If successful, the models will improve predictions of communication disruptions caused by solar X-ray bursts.

Solar Active Regions

A catalog is being compiled of outstanding active regions in terms of their X-ray flare production to link solar active region formation to the large-scale solar evolution. These data were used to update the correlation between sunspot class and flare activity reported at the Solar-Terrestrial Predictions Workshop sponsored by the Observatoire de Paris.

Coronal Modeling

Work continued on theoretical and empirical models of the solar corona. A study of the structure and electrical currents of the corona was completed. Modeling of solar filaments is under way to aid in predicting instabilities over neutral lines that precede solar flares and coronal transients. Algorithms have been produced for computing source surface magnetic field distributions from photospheric magnetic fields, and calculating the connection points between the Earth and the solar surface.

INTERPLANETARY PHYSICS

Approximately two-thirds of the SESC customers would benefit from improved forecasts of the occurrence of magnetic storms. The results of studies directed toward this objective are discussed below.

It is known that solar flares accompanied by Type II radio noise bursts are apt to produce shock waves in the solar wind, which travel through the interplanetary medium and produce the geomagnetic storm.

A comparison was made of the predicted times of arrival of shock waves at the Earth and the observed geomagnetic storm sudden commencement for 59 solar flare events. The predictions used the Air Force Geophysical Laboratory algorithms for shock-wave propagation based on the shock velocity at the Sun deduced from Type II bursts. The median prediction was 1.35 hours late with a standard deviation of 6.9 hours. A "Users' Guide," with instructions on reporting of these Type II shock velocities, has been distributed to all USAF solar radio observing sites.

Propagation of Solar Wind Disturbances

A time-dependent, magnetohydrodynamic (MHD) numerical model for the propagation of shock waves through the interplanetary medium was tested using data for a series of solar events in August 1979. Qualitative agreement, but with changes in phase and amplitude differences, was achieved with an approximation to a fully three-dimensional (3-D) model. Work has started on a fully 3-D, timedependent model starting with the special case of flare-generated shock waves. Both the approximate and fully 3-D models are initialized at 18 solar radii. Closer to the Sun, 2-D and the approximate 3-D model predictions of the structure of coronal disturbances have been compared with many types of coronal observations in white-light, radio, X-ray, and UV wavelengths. This work opens up the possibility, from an operational viewpoint, that real-time observations of coronal structures can be used as input for a fully 3-D model. Fundamental studies, using higher moment

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equations, were completed to demonstrate the need for incorporating thermal conduction and multi-fluid aspects into these interplanetary global circulation model programs.

Geomagnetic Activity Forecasts and Warnings

The approximate 3-D model was used with observed solar hydrogen-alpha and magnetograph data (to provide "best estimate" of solar output) to give time series of the Poynting energy parameter, and cross-tail electric field at Earth's location for a 2-week period in August 1979. This output could conceivably provide a forecaster with predictions to answer four questions: Will a disturbance occur? When will it occur? How large will it be? How long will it last?

MAGNETOSPHERIC PHYSICS

Research in the Magnetospheric Physics Area is directed toward understanding of the dynamical processes by which material and energy are transported from the solar wind into the magnetospheric system, stored, and eventually dissipated in the Earth's ionosphere. Both applications and supporting research are pursued, directed toward enhancement of the quality and utility of the Laboratory's space environment products and services.

Polar Cap Data

The first two volumes of a series of atlases of energetic particle observations by instruments aboard the NOAA/TIROS series of low-altitude, polar-orbiting satellites have been published. These data cover the period from January 1979 through May 1983, and will be continued in subsequent volumes to the present. These data permit the operational or research user to identify solar cosmic ray and other event periods of interest, establish an event chronology of importance to synoptic studies, and intercompare equivalent data from other satellites.

Omega VLF Study

A study was undertaken in support of the Omega Navigation System to investigate long-delayed (days) recoveries of the system signals following disturbances caused by Polar Cap Absorption (PCA) events. System responses during and following five large PCA events were compared with the associated particle fluxes measured on the SMS/GOES and NOAA/TIROS series of satellites. A close correlation was found between the recovery of the VLF signals and the flux of energetic protons in the range of 4-8 Mev. A simple algorithm was defined which allows the prediction of the VLF phase recovery based on the real-time observations of the proton flux. Operational tests of this algorithm have been implemented.

Data Support

A compilation of information concerning the instruments constituting the Space Environment Monitors aboard GOES satellites is being prepared. This

summary will form a basis for the use of the data both in-house and by external groups.

External Cooperative Support

Laboratory scientists provided consultation and energetic particle data from the GOES and TIROS satellites to the Defense Nuclear Agency (DNA) for use in its Long Wave Program, which studies the propagation of extremely low frequency (ELF) and very low frequency (VLF) waves at high latitudes.

Satellite data and analyses were also provided to the scientific community as a cooperative activity in the Middle Atmosphere Program (MAP), an international cooperative program under the aegis of the Scientific Committee on Solar-Terrestrial Research directed toward the study of the structure and dynamics of the high-altitude middle atmosphere through coordinated high-altitude research rockets, and by ground-based and satellite observations.

Laboratory scientists participated in NASA/Air Force working group meetings on Spacecraft-Environment Interaction in order to evaluate the environmental causes of spacecraft anomalies and failure, and to assess the operational monitoring of the near-Earth environment needed to provide useful warnings and forecasts of satellite disruptive periods. Also, there was participation in a NASA working group meeting on Spacecraft-Environment Interaction held at the U.S. Air Force Academy in October 1984.

Magnetospheric Acceleration Processes

Approximate analytic procedures have been developed to represent and characterize the magnetospheric tail acceleration process by which magnetospheric particles are energized by the cross-tail electric field. These energetic particles are precipitated into the auroral zones, and also provide a significant source of charged particles to the Earth's ring current system, which is responsible for a major portion of geomagnetic disturbance. The level of geomagnetic disturbance is the single, most important parameter in determining disturbance to communications, power transmission, and satellite systems. An extension of the original theoretical development of this important mechanism by SEL scientists has received broad acceptance by the scientific community.

Magnetospheric Boundary Phenomena

Theoretical work and model calculations continue on the dynamical processes occurring at magnetospheric boundaries. Comparison is made between model calculations and satellite observations in the context of trying to define the reconnection process by which interplanetary field lines, convected outward from the Sun by the solar wind, interact with the geomagnetic field at the magnetopause. Understanding boundary properties is crucial to understanding the processes by which solar wind energy is coupled to the magnetospheric system.

ATMOSPHERE-IONOSPHERE-MAGNETOSPHERE INTERACTIONS

The objectives of the research in the atmosphere-ionosphere-magnetosphere interactions area are to understand the transfer of energy (both in the form of electrical and mechanical energy) from the Earth's magnetosphere into the upper atmosphere and to understand and characterize the various consequences that may arise in the Earth's ionosphere and upper atmosphere because of this energy input.

The observations from instruments on board the NOAA/TIROS series of spacecraft continued to be processed and used both in research and in a growing number of operationally oriented programs. Normally, about 96% of all data gathered by these satellites is recovered and archived within 10 days of receipt. Difficulties with noisy data from the total energy detector on NOAA-7 were experienced at the end of FY 1983, and the NOAA-8 spacecraft suffered a failure in June 1984. However, the NOAA-6 spacecraft was re-activated and data are being received from that satellite. NOAA-9, scheduled for launch in late 1984, will not contain a space environment monitor, which will reduce these observations to a single spacecraft for the first time since June 1979.

Work continued on the development of the estimate of the power dissipated in the auroral atmosphere by precipitating particles, based on single passes of these satellites over the Earth's polar regions. Estimates of the total amount of power being deposited into the atmosphere may characterize the degree of geophysical activity and its consequences in a more quantitative manner than is possible with conventional magnetic indices. In the course of this study a set of statistical "maps" showing the global pattern of energy input to the atmosphere for various levels of total power input was also developed.

The statistical patterns of energy input show an isolated island of energy input located at very high latitude at about 2 p.m., which is particularly apparent at low levels of activity. Other researchers have pointed out that this particular location is also the site of a local maximum in other geophysical phenomena, notably the intensity of currents flowing between the ionosphere and a dynamo located in the magnetosphere. A study using the NOAA/TIROS data was conducted to determine the nature of the particle energy influx at this location. The energy input is exclusively in the form of electron precipitation having thin, auroral, arc-like geometries. Independent observations demonstrated the disturbance introduced into the ionosphere by this precipitation. Moreover, correlations of these TIROS data measurements with those on board high-altitude scientific satellites suggest that the fundamental cause of this precipitation is a dynamo process driven in the outer magnetosphere by a direct solar wind interaction. The comparatively simple geometry of this process may allow a theoretical analysis to be done, which in turn will shed light on the more complex nighttime magnetospheric-ionospheric-atmospheric processes.

Numerous scientific collaborations utilizing the NOAA/TIROS data were conducted during the last year. Generally, these involved the use of the data in conjunction with ground-based and satellite measurements of individual geophysical events. In addition, the statistical maps of the energy input, created from the large data base of observations that now exists, are being used by a research group at University College, London, as an input to a model

of upper atmospheric dynamics. The use of these data for such a purpose could be of great benefit to the objective of deducing the density and temperature of the upper atmosphere from the satellite observations of total energy deposition.

There were several instances of the use of the NOAA/TIROS data in support of operational programs. For the Department of Defense the historic observations were used to determine the particle environment through which large, polar-orbiting satellites (such as the Shuttle) will be required to pass. These particles, impinging upon the satellite, can produce malfunctions which, experience has shown, grow more frequent as spacecraft become larger and more complex. To this end, an analysis was done on the frequency and nature of the unusually large energy flux events that are encountered by these satellites from time to time. This analysis was forwarded to the Jet Propulsion Laboratory for evaluation.

In the same vein, these data were supplied to NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), and sometimes directly to a user, to assist in their interpretation of satellite system malfunctions that often tend to occur repeatedly within a limited period of time. One such instance centered around September 1983, and SEL was called upon to supply data from that period.

Plans FY 1985

OPERATIONAL SATELLITE INSTRUMENTATION

The Laboratory will participate in the review of contractors' proposals for GOES-NEXT. The ongoing operational satellite space environment monitoring sensor program will continue to be supported by the delivery of the HEPAD for GOES-I and by any other technical support required.

The off-line processing system will be completed, and automatic, routine, quality control will be implemented whenever possible. The system will be at least partially implemented on SELDADS II.

SELSIS—SEL SOLAR-IMAGING SYSTEM

Programming for digital communication and image storage and display will commence in early FY 1985. It is planned to have the system in limited operation by March 1985.

SOLAR PHYSICS

- Increase the opportunities for achieving, and the plans for using, a spaceborne monitor for coronal transients, solar flares, and coronal structures that influence the propagation of disturbances and material from the Sun.

- Complete operating manual for computerized, routine, solar mapping and train SESC staff so as to assure a reliable data base for both short-term and long-term solar-terrestrial predictions.

- Edit preliminary H-alpha synoptic charts for publication and for use in development of long-range solar forecasting.

- Study large-scale patterns of solar magnetic fields and their relation to the formation of centers of strong solar activity. Convert results to procedures for use in SESC 27-day (and longer) solar-terrestrial forecasts.

- Develop real-time computation of source-surface magnetic field configuration above the solar surface for use in operational evaluation of solar events. Refine communication and display of Stanford solar magnetic maps.

- Extend coronal modeling to more complex conditions at solar maximum. Add theory of fine structure in magnetic flux tube under the influence of external fields. Continue modeling of solar filaments. Attempt to tie results to efforts to model the interplanetary environment.

- Refine and continue to disseminate forecasts for the time of sunspot minimum and amplitude of Sunspot Cycle 22. Continue studies of other methods for solar cycle predictions in comparison with methods developed by laboratory scientists.

- Develop a computer technique for early recognition of an X-ray solar flare, prediction of the time of peak intensity, the magnitude of peak intensity, and the rate of decay.

- Make comprehensive study of coronal hole images at all observed wave lengths and determine utility for predictions of geomagnetic activity.

- Investigate source of the semi-diurnal X-ray detector variations between widely separated geosynchronous satellites.

- Investigate epochal nature of solar activity (4-7 month "pulses") and its relationship to the evolution of large-scale solar magnetic fields. This will include study of the phenomenon of active/inactive solar longitudes. Examine whether these studies suggest practical steps toward long-term solar-terrestrial predictions.

- Implement a verification system for one selected SESC forecast product. This would be a cooperative project with SESC. It will address those basic philosophies and principles that would be used in the future for bench marks of forecast algorithms and for decisions on directions of research efforts.

INTERPLANETARY PHYSICS

Forecast Verification

The predictive capabilities of the approximate 3-D MHD model will be tested against additional real-events to better understand the effects of different input parameters on the accuracy of the predictions.

Propagation of Solar Wind Disturbances

The approximate 3-D model will be incorporated into the new scientific work station computer. Additional graphical displays will be added, together with a complete 360-degree ecliptic plane projection of propagating disturbances. In collaboration with several contractors, a graphical capability will be developed for the 3-D model as well as an extended heliolongitudinal and heliolatitudinal capability. The model will be expanded to handle various kinds of solar disturbances such as eruptive prominences, and coronal hole streams, as well as solar flares. The solution to a two-component (electrons and protons), five-moment solar wind will be pursued together with a related study on the effect of an interplanetary electrostatic field in regions of high density, and magnetic field gradients, and electric charge separation.

MAGNETOSPHERIC PHYSICS

- Extend the Energetic Particle Atlas series to include current data.
- Continue support to external users including Long Wave Navigation Program, Spacecraft-Environment Interaction working groups, and similar activities.
- Investigate the potential of GOES magnetometer data for prediction of geomagnetic disturbance.
- Begin a study of numerical simulation techniques in magnetospheric plasma processes. Analytical work in this field has emphasized the MHD approach. It has become increasingly evident that approximations, such as charge neutrality, inherent in the MHD equations limit their application to magnetospheric processes. Plasma numerical simulations, while complex, approach the problem at a microphysics level, where such approximations can be avoided.
- Continue theoretical and model boundary work on reconnection and plasma sheet boundary phenomena.

ATMOSPHERE-IONOSPHERE-MAGNETOSPHERE INTERACTIONS

- A senior researcher from the Atmosphere-Ionosphere-Magnetosphere Interactions group will spend FY 1985 as a visiting scientist at the Stanford Space Telecommunications and Radio Laboratory and at the Lockheed Research Laboratories, Palo Alto. These research groups are very active in the field of space research, and both are vitally concerned with the impact of the near-Earth environment upon both communications and space systems. The research work performed during this period will greatly increase SEL's understanding and expertise in this important field. **SEL**
- Routine processing of NOAA/TIROS data will continue, and arrangements have been made to ensure that requests for data, particularly from operational sources, will be filled.

SELDADS II

The Space Environment Laboratory Data Acquisition and Display System (SELDADS) provides computer-assisted access to solar-geophysical data from a variety of satellites and ground-based observatories around the world in near real-time. The SELDADS II system now in development will replace the aging SELDADS I system and provide for improved access, analysis, and display of these data with increased reliability.

Accomplishments FY 1984

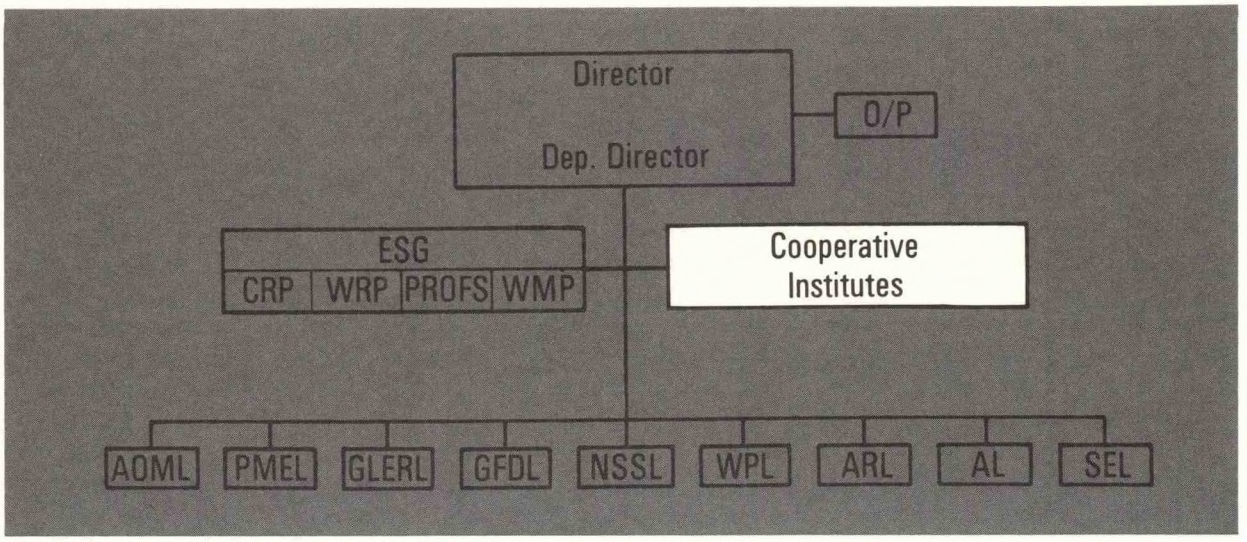
A new Data General MV10000 was installed in July in the newly prepared site near the SELDADS I, which will remain in operation until the Phase I application software of the new system is complete. Acceptance testing began in August. Software supplied will include a customized data base (software) system and a comprehensive graphics (software) system. A series of WICAT 150 computers will serve as preprocessors to operate separately on each incoming and outgoing data stream to prepare the data for introduction into the main processor, which will concentrate on data base management and analysis software. Status displays required for basic forecast center operation will be driven both by preprocessors and by the main system to provide redundancy and continuity in the new system. The preprocessors will be identical so that one that fails while handling high priority data can be replaced by another handling lower priority tasks.

A Project Management Panel to manage the development of software for the new system has been appointed, and personnel for the development effort have been identified within the Laboratory. The conceptual design for the application software has been completed and the products to be generated in the first phase of the implementation have been identified.

Plans FY 1985

The implementation will proceed in three phases. Phase I will provide a capability equal to the present SELDADS I system, and after some period of parallel operation of SELDADS I and the Phase I system, SELDADS I will be turned off. Phase II software will implement analysis capabilities that are known but have not been implemented because of the saturation of SELDADS I. Phase III software will begin the implementation of new forecast techniques such as models. Phase I software will take most of the effort in FY 1985; a beginning of Phase II will occur later in the year. Phase I is expected to be completed early in 1986 and major effort will then shift to Phases II and III.

COOPERATIVE INSTITUTES



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 research effort of NOAA and the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). The three research themes of CIMAS are Climate Variability, Ecosystem Dynamics, and Ocean-Seafloor Hydrothermal Interactions.

The CIMAS staff includes eleven Fellows who are appointed from RSMAS faculty and NOAA staff in Miami and who conduct collaborative research. Also included in FY 1984 were three Members, four Associate Scientists, six Research Associates, one Postdoctoral Associate, and three 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, which brought eleven scientists to the Miami community in FY 1984 to provide 19 lectures and 17 man-months of collaborative research.

Accomplishments FY 1984

CLIMATE VARIABILITY

Research on climate variability concerned Subtropical Atlantic Climate Studies (STACS), Equatorial Pacific Ocean Climate Studies (EPOCS), atmospheric carbon dioxide (CO_2) loading, and hurricane modeling.

Both theoretical models and field measurements indicate the Florida Straits as a critical monitoring point for determining the northward transport of mass and heat in the North Atlantic. CIMAS research efforts are directed toward understanding the effects of local forcing by the curl of the wind stress over the Gulf of Mexico and Caribbean Sea on the transport at the Florida Straits and the implications this might have on the interpretation of the routes by which heat is transported northward by the ocean.

In the previous year we discovered a strong correlation between the curl of the wind stress over the Cayman basin in the western Caribbean and the seasonal cycle in the transport at the Florida Straits suggesting that the seasonal transport is locally forced. This raised two questions: Why are there large values of the curl of the wind stress over the Caribbean? Also, if the seasonal transport is the result of local forcing, then by continuity a storage of fluid in the Caribbean is expected; why is there no indication in field measurements that such storage occurs? To answer the first question, the annual mean and annual cycle of the stress and stress curl over the Gulf of Mexico and Caribbean Sea were documented. They show that large values of the curl of the wind stress are due to the funneling effects on the trade winds by the mountains on Hispaniola and the north coast of South America. To answer the second question, a linear barotropic analytic model was developed for the Cayman basin. The results indicate that because the model is barotropic, the basin adjusts to the forcing nearly instantaneously. Very little storage of fluid occurs because the basin is open at its eastern boundary through the Windward Passage. This latter result has yet to be substantiated with field data (see below) but, if confirmed, indicates that the Windward Passage is a crucial monitoring point to understand the dynamics of the system.

Efforts have also been directed toward understanding the dynamics of the combined effects of the Caribbean Sea's island chain and the local forcing by the annual mean curl of the wind stress. To this end a series of linear equivalent barotropic models has been developed in which the island chain is modeled as a barrier. The results indicate that the system's pressure gradients adjust so as to generate a counterclockwise circulation around the barrier. These pressure gradients oppose the formation of an intense western boundary current on the North Atlantic side of the barrier. These preliminary results are intriguing because they suggest a reason why field measurements do not show an intense Antilles current on the North Atlantic side of the island chain.

Two cruises were successfully completed to the STACS experiment site at 27°N between Florida and the Bahamas this summer, one on RSMAS ORV Calanus in June and one on RSMAS ORV Cape Florida in July. During these cruises more than 100 vertical profiles of current and temperatures across the Straits of Florida were obtained. These data are now being analyzed together with results of previous cruises to accomplish one of the stated aims of the STACS experi-

ment -- to determine methods to monitor efficiently the heat and mass transport by the Florida Current on an inter-annual basis.

In support of EPOCS, a comprehensive study of the energetic mesoscale eddies (long waves) that appear annually (except during ENSO events) at the boundary between the South Equatorial Current and North Equatorial Countercurrent was completed. In addition, a large-scale surface current climatology for the Equatorial Pacific has been computed from the drifting buoy data. This will be an invaluable tool for determining surface current anomalies, both for research studies of the 1982-83 El Niño and for future real-time monitoring efforts.

A new Postdoctoral Associate began EPOCS-related research that applies empirical orthogonal function and complex demodulation techniques to the EPOCS current meter data to look at the vertical mode structures for the weekly to monthly periods.

Continued research using a time-dependent model shows that significant perturbations in the oceanic carbon cycle can occur on time scales of hundreds of years. This is significant because recently it has been shown from ice core data that fluctuations in the atmospheric CO_2 level have occurred on similar time scales. Furthermore, recent oxygen isotope data have shown that these CO_2 fluctuations led rather than lagged climate fluctuations, which implies that marine carbon cycles may be forcing climatic changes. The model results were presented at the Chapman Conference on Natural Variations in Carbon Dioxide and the Carbon Cycle in early January 1984.

Atmospheric variation in CO_2 is greatest over the Arctic's marginal ice zone (MIZ). Ocean processes research at the MIZ was conducted under the Navy-sponsored Marginal Ice Zone Experiment (MIZEX) in the Fram Strait. Final planning of this experiment was completed at Pigeon Key, Fla., at a meeting hosted by RSMAS and CIMAS. A cruise was mounted during June and July on R/V Polar Queen. Cyclesonde automatic profiling current meters (CTD's) were suspended from ice floes to document the temperature, salinity, and current structure under the ice edge. Here colder, fresher, surface water and ice from the Arctic Ocean move south along the coast of Greenland above the halocline and warmer, saltier North Atlantic water slides into the Arctic Ocean under a strong halocline. The position of the ice edge and the budgets of ice, heat, and salt are thought to play an important role in worldwide climate variability.

The development and testing of the quasi-spectral hurricane prediction model using nested grids was continued during FY 1984. Numerical experiments testing the effectiveness of spatially variable filters in controlling short-wavelength noise were carrier out. In the experiments we propagate the main signal across mesh interfaces from regions of high spatial resolution into regions of lower resolution, in order to study the effects of these filters on slow-moving (advective) signals and fast-moving (gravity wave) signals. Upon completion of these experiments, which used a one-dimensional version of the model, the two-dimensional version was restructured to utilize these filters and also to facilitate the introduction of movable meshes into the model. After the new spatial filters were introduced, a few moving-vortex experiments were carried out so that the predicted wind fields could be compared with those obtained earlier using space-independent filters. Current effort is being

directed toward producing useful graphical output of the model results in the form of three-dimensional surface plots, contour maps, and field profiles.

ECOSYSTEM DYNAMICS

Understanding the causal mechanisms of fish stock variability is the primary objective of CIMAS ecosystem dynamics research. Efforts are focused on fishes' early life-history stages and on survival and dispersion caused by physical, chemical, and biological oceanic processes. Research on the dynamics of coral reef fish also continued in FY 1984.

Comprehensive larval fish surveys have been conducted in the Gulf of Mexico since 1982. The results of the 1982 survey were compiled and published in 1984. Acquisition of data on larval distribution and abundances of the families Lutjanidae (snappers) and Serranidae (groupers) was completed. These data will be related to data on the physical environment in an effort to determine those processes important to snapper/grouper larval ecology. In addition, the research on the contribution of Gulf Stream meanders to the variability in short-term catch rates and annual production of vermilion snapper in the South Atlantic Bight was completed.

CIMAS participated in the successful atmospheric and ocean sampling for volatile organic compounds over the equatorial Pacific along 150°W longitude from 20°N to 15°S. Sea water and sea surface air samples were simultaneously collected aboard the NOAA R/V Researcher. Knowing the identities and distribution of naturally occurring volatile organic compounds in the remote equatorial Pacific, far removed from any human sources, will result in an understanding of the contribution of the marine system to global acid rain and infrared absorption. Since air and seawater samples were collected simultaneously, flux determinations will be possible. Synoptic measurements of ozone concentration and ultraviolet and infrared irradiance were also collected.

Research on the effects of protogynic hermaphroditic reproduction common to coral reef fishes, especially groupers, was nearly completed in FY 1984. A general mathematical model of this reproductive strategy was completed, and the effects of exploitation were simulated. In both static and dynamic studies it was found that protogynic hermaphroditic reproduction was a more resilient reproductive strategy then dioecious reproduction under the assumption that mating is non-random. The reverse is true under random mating patterns. These results are a first step in developing a general management strategy for important reef fish populations.

The field work for ecological studies involving microhabitat distributions of coral reef fishes within the Looe Key National Marine Sanctuary were completed in FY 1984. The distributions of 158 species were measured in 9 habitat zones within the Sanctuary. Analyses of these data will provide information on the community dynamics of reef fishes, the second step in developing a general management strategy.

The second Southeast Stock Assessment Workshop sponsored by NOAA cooperatively with CIMAS was held June 4-8, 1984. The objectives of the Workshop were to (1) provide current management advice; (2) provide a timely forum for critical review of assessment research; (3) provide direction for future re-

search; and (4) promote scientific interchange between researchers. The Workshop was attended by more than 50 scientists representing CIMAS; NOAA's Southeast, Northeast, and Southwest Fisheries Centers; state agencies of the southeast United States, Puerto Rico, and the Virgin Islands; the Gulf of Mexico, South Atlantic, and Caribbean Fishery Management Councils; and various academic institutions. Sixty stock assessment reports and documents were incorporated into the Workshop Report.

OCEAN-SEAFLOOR HYDROTHERMAL INTERACTIONS

This research theme was approved for CIMAS during FY 1984. Efforts were begun to plan the modeling of the physical dynamics of sea floor vent plumes.

Plans FY 1985

CLIMATE VARIABILITY

Research on ocean-related aspects of climate will continue in FY 1985 in support of STACS, EPOCS, CO_2 loading, and hurricane modeling. An increase in atmospheric research contributions is planned through the addition of several new Fellows. Five visiting scientists will provide 6 man-months of complementary research.

In support of STACS, efforts will be directed toward determining the influence that the Gulf of Mexico and Caribbean Sea have on the poleward transport of heat in the North Atlantic. The seasonable variability at the Windward Passage will be investigated to substantiate the FY 1984 model results.

The dynamics of the response of the eastern Caribbean to the seasonal forcing will also be investigated. The approach will be to utilize field data to test a linear equivalent barotropic model of the basin's response to the seasonal forcing. If necessary, a two-layer model will be developed. A preliminary analysis of the field data suggests that during autumn an along-channel pressure gradient develops to oppose inflow into the Caribbean at the Lesser Antilles. Confirmation of the process will be an important step toward understanding the adjustment of the North Atlantic to forcing by the trade winds. The analysis will also provide information crucial to the design of field experiments to monitor the northward heat transport through the region by the western boundary current regime.

The investigation of models of the combined effects of topography and forcing by the wind stress curl will continue. Here the focus is to determine the pressure gradients set up by the model system. This will facilitate the design of field experiments and the interpretation of the complex numerical models that are being developed for the region.

Analysis of the data collected on 15 research cruises in the Florida Straits will be completed in FY 1985. A free-falling current probe (Pegasus) section northeast of Grand Bahama Island will be established, and another cruise of the ORV Calanus is planned to determine to what extent flow in the immediate vicinity of the Bahamas contributes to Gulf Stream development. We

are especially interested in understanding increases in mass and heat transport north and east of the Bahamas.

Empirical orthogonal function and complex demodulation techniques will be applied to the EPOCS current meter data to look at the vertical mode structures for weekly and monthly periods. Also, analyses of the EPOCS drifting-buoy data sets collected before, during, and after the 1982/83 El Niño will be conducted using similar techniques.

Work on the modeling of marine chemical cycles relative to atmospheric CO_2 loading will continue with emphasis on (1) the forcing of atmospheric CO_2 fluctuation by perturbations in the ocean's nutrient cycle and hence the carbon cycle with applications to glacial-interglacial transitions, and (2) the occurrence of anoxia. Participation in MIZEX will also continue.

For hurricane modeling in FY 1985, a series of barotropic prediction calculations is planned, including a moving vortex with free pressure surface, barotropic prediction of synoptic fields, and beta effect studies. The latter studies will require the use of movable inner meshes, and this extension to the model will be implemented in the near future.

ECOSYSTEM DYNAMICS

Research on reef fish reproductive strategy and community dynamics related to exploitation will be completed in FY 1985. Modeling recruitment patterns of reef fish larvae to the reef tract of the Florida Keys will be initiated along with studies on the hydromechanics of marine fish larvae. Research on the relation between climate variability and recruitment variability will be undertaken with the addition of a new Postdoctoral Associate. Five visiting scientists are scheduled to provide 3 man-months of collaborative research.

Other biological elements of the predator-prey web involving larval fishes will be investigated through collaborative research applying innovative sampling technologies. At least three cruises are planned for 1985. The first, on the ORV Calanus, will be in the Florida Straits for the purposes of testing design modifications and additions to a plankton camera. The second two, on the ORV Cape Florida, will be for the purpose of working with an acoustic profiling system (in collaboration with its developers), as well as with the plankton camera, to examine the fine-scale vertical distribution and interactions of zooplankton populations in the Gulf Stream.

Research on volatile organic compounds in the equatorial Pacific will continue with analyses of the samples collected during FY 1984. These samples will be analyzed with a gas chromatograph/mass spectrometer.

OCEAN-SEAFLOOR HYDROTHERMAL INTERACTIONS

Research will focus on initial modeling of the physical dynamics of the convective plumes of sea floor hydrothermal vents. Planning will concentrate on a field program to make field measurements of the model's parameters and to investigate the biological processes associated with the vent field.

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 1984 CIMMS was host to researchers from China, South Africa, Japan, and France who undertook studies in mesoscale meteorological models and development of optimization analysis in Doppler radar meteorology. A CIMMS research scientist has continued his work on the Alpine Experiment and satellite-based analysis techniques. In March 1984 he traveled to China to present a paper at the International Symposium on Tibetan Plateau and Mountain Meteorology held in Beijing. Another CIMMS scientist developed a mesoscale variational temperature analysis scheme and tested this scheme using the CIMMS Mesoscale Model. This research was performed under a NASA contract, and the results were presented in April 1984 at the NASA Goddard Space Flight Center Program Review. A CIMMS scientist developed a variational optimization method to obtain two-dimensional wind field information from single-Doppler radar data. Approximately 14 students employed by CIMMS are engaged in research studies toward advanced degrees; 4 are undergraduate students. A CIMMS Research Associate worked in the NEXRAD program. Three postdoctoral Fellows on multiyear appointments work in cloud physics, mesoscale modeling, mesoscale dynamics, and convective instability.

CIMMS research results were reported in approximately 10 reports and publications during FY 1984.

Construction of new facilities for CIMMS and the School of Meteorology in the OU College of Geosciences is still an ongoing project.

In 1985 CIMMS will be host to a NEXRAD Conference in Norman on 2-4 April, and to the "International Symposium on Variational Methods in Geosciences" in September.

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 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.

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 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 28 separate research projects have been funded through CIRA, including an IPA (Intergovernmental Personnel Act) with the National Weather Service. CIRA personnel consist of 15 Fellows, 1 Post-doctoral Fellow, 5 Visiting Fellows, 9 Research Associates, 2 Visiting Scientists, and a Director. During FY 1984, 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 1984.

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.

A workshop on "Agricultural and Forest Meteorology" is planned for this fall. This workshop will facilitate interaction among participants from various departments of CSU.

In April 1985, CIRA will act as host of a workshop entitled "Cloud Top Boundary Layer" sponsored by the World Meteorological Organization. Approximately 40 scientists from throughout the world will participate.

CIRES

The Cooperative Institute for Research in Environmental Sciences (CIRES) is jointly sponsored by the University of Colorado and ERL 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 three broad areas: Environmental Chemistry, Atmospheric and Climate Dynamics, and Geodesy and Solid Earth Geophysics.

ENVIRONMENTAL CHEMISTRY

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 energy 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.

Accomplishments FY 1984

Of the many areas of active research in environmental chemistry, we highlight recent and ongoing work on the environmental effects of nuclear war. The climatic and other long-term effects of nuclear war are of immense importance to defense planning of our country. It is expected that in the near future NOAA will play a lead role in further evaluating the consequences of nuclear war, especially the effects on the atmosphere and climate. CIRES work in such evaluation illustrates the type of interdisciplinary research that is made possible through cooperative institutes where scientists from a broad range of disciplines can work together on problems that cannot be approached from any single research perspective.

The discovery of the long-overlooked climatic effect now know as "nuclear winter" was made in a collaborative research effort by a CIRES Fellow and the Director of the Max Planck Institute for Chemistry in Mainz, West Germany, and first published in a Swedish environmental journal in June 1982. The original work has since been expanded by the authors as well as by numerous scientists in both university and government laboratories. Briefly, the large quantities of smoke aerosol produced by thousands of fires in forests, industry, and urban areas would be sufficient to absorb most of the solar radiation incident on the Earth's atmosphere throughout most of the Northern Hemisphere. The blockage of sunlight from reaching the surface would result in cooling of midcontinent temperatures by as much as a few tens of degrees centigrade. Because of the large heat capacity of the mixed layer, ocean temperatures would be little changed, and the relatively warm ocean air would partially ameliorate the temperature effect near coastlines. The highly perturbed atmosphere would be characterized by a strong temperature inversion, and the normal separation between troposphere and stratosphere would no longer be well defined; the residence time of the smoke aerosol in such an atmosphere might be considerably enhanced. In any case, it is expected that the low temperatures resulting from a nuclear winter would persist for at least a few weeks and possibly several months. Recent work by investigators at the National Center for Atmospheric Research (NCAR) has shown that a homogeneous black cloud would not be necessary to produce these effects; a black patch of continent size passing over a land area for only 2 days could result in a "quick freeze" with comparable biological consequences.

Plans FY 1985

Continuing research is aimed at reducing the very large uncertainties associated with these effects. To name a few, these uncertainties include the amounts and size distribution of smoke aerosol produced in the various types of fires, the optical properties of the aerosol, the scavenging of aerosol by precipitation events, and the response of the Earth-atmosphere system to such a large perturbation in its heat balance. Other work is aimed at evaluating the effects on the postwar environment of the large numbers of different pyrotoxins produced in the nuclear war fires.

ATMOSPHERIC AND CLIMATE DYNAMICS

Research focuses on elucidating and describing various aspects of the fundamental processes of the atmosphere, oceans, and cryosphere as interactive media. The effort at CIRES is an interplay between theoretical and observational studies. Reflecting the wide range of topics involved, the research done by this group is quite diversified and falls into three broad categories: studies of long-time-scale climate variability as affected by continental configurations and ice sheet dynamics; studies of secular time-scale variability, for which historical and contemporary climate records offer an observational data base; and studies of processes that are relevant to understanding both climate variability and its real-time component, weather.

Major segments of the CIRES work relating to Climate Analysis and Climate Modeling are performed as part of ERL's Climate Research Program. Other components of the Atmospheric & Climate Dynamics program, supported independently, are described below.

Accomplishments FY 1984

ATMOSPHERE-OCEAN INTERACTION

The coupling of the atmosphere and ocean at the sea surface and its role in weather and climate is one of the most important and least understood problems of atmospheric and climate dynamics. CIRES research includes investigations into boundary layer adjustment processes, in both media, singly and interactively, and climatological aspects of the coupling on large scales.

Modeling and analysis of the mechanics of the stratocumulus-topped marine boundary layer using data gathered under the auspices of NOAA's Equatorial Pacific Ocean Climate Studies program has placed emphasis on the transition from solid stratocumulus to broken trade cumulus and its climatological implications. Although the mechanics can be interpreted consistently using relatively simple modeling techniques, processes traditionally thought to be unimportant (such as the diurnal cycle) are in fact sometimes dominant. Marine stratocumulus occurs not only in the subtropics east of the major continents, associated with coastal upwelling, but also, as a result of cold, continental air outbreaks, over the western oceans. A climatological study of cold air outbreaks and resulting marine cyclogenesis off the east coast of Asia suggests

that north-south sea-surface temperature gradients are a critical aspect of air-sea interaction and that the interannual variability of the frequency of this cyclogenesis is influenced significantly by large-scale variability associated with the El Niño/Southern Oscillation (ENSO) phenomenon. A study of the climatology of the Ekman convergence in the subtropical Pacific Ocean has shown that the poleward heat fluxes due to these processes contribute significantly to the total flux and are probably of major importance to the ENSO problem.

CRYOSPHERE-CLIMATE INTERACTION

Interactions between polar sea ice, snow cover, and climate have been the main focus of recent work. Satellite and synoptic data are being used to analyze relationships between cloud cover and Arctic ice. A classification of daily 700-mb circulation patterns has been prepared, and the distribution of cloud within high-latitude synoptic systems is being determined for comparison with outputs from the Goddard Institute of Space Sciences (GISS) general circulation model. A project to map the seasonal progression of surface melt in the Arctic from high-resolution DMSP imagery has begun. Sea-ice data provided by the NASA Scanning Multifrequency Microwave Radiometer (SMMR) sensor have been assessed. A Department of Energy project is continuing to assess the variability of lake freeze-up/break data from Canada and Finland in relation to climatic factors, as a guide to possible CO_2-induced warming effects.

CIRES also operates the World Data Center-A (WDC-A) for Glaciology (Snow and Ice) and the associated National Snow and Ice Data Center. Base funding is provided by NOAA's National Environmental Satellite, Data, and Information Service; DOE, NASA, NOAA, and the Office of Naval Research 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 has large collections of global Defense Meteorological Satellite Program imagery, glacier photographs, and glaciological literature. Data management services are being provided for the Marginal Ice Zone Experiment (MIZEX) project.

PALEOCLIMATOLOGY-PALEOCEANOGRAPHY

Work continues on understanding how past global climate has changed, and in particular to investigate hydrological interactions with the ocean circulation, 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 IN COMPLEX GEOMETRY

Work is concentrated on atmospheric wave motions and turbulence. Experimental work with clear-air Doppler radars aids in our understanding of atmospheric flows and transport over complex terrain and computer-aided analysis of viscous flows and/or transport problems in engineering science. The two are intimately connected since the atmospheric flow models are nonhydrostatic.

One continuing 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.

A second activity is seeking to develop improved algorithms for numerical simulation of incompressible flow in computer-aided design. These are being applied to the study of physical instabilities, free and/or moving surface problems that arise in many industrial applications, and flow of stratified fluids in complex geometries.

Work is also in progress on flow and stability problems related to manufacturing in space, in cooperation with scientists at NASA Lewis Laboratory and scientists in Lyon, France, in preparation for Shuttle experiments.

WAVE DYNAMICS

A quasi-linear time-dependent model has been developed in collaboration with scientists at NOAA and NCAR. This model incorporates interactions among the mean atmospheric circulation, planetary waves, chemistry, and radiation. The model will be used to study various dynamical and transport problems in the stratosphere and mesosphere.

Another modeling effort is addressing the problem of tidal variability. Simulation studies of meteor echo returns have been performed to determine whether the observed tidal variability is due to noise or geophysical events. The results indicate that a portion of the variance of tidal amplitudes and phases can be attributed to incoherent noises. However, this variance generates random amplitude and phase changes whereas the observed variability shows progressive systematic changes.

In another project, we are examining clear-air Doppler radar data for gravity wave and tidal momentum fluxes. These fluxes are important for determining the frictional drag in the atmosphere. A method for determining the spectral content of the momentum flux was developed.

Plans FY 1985

ATMOSPHERE-OCEAN INTERACTION

- Initiation of a major field research program with partial funding from NOAA/ERL, to investigate the causes of variability of stratocumulus clouds over the Pacific off the coast of California. This will be highly relevant to the interagency First International Satellite Cloud Climatology Regional Experiment.

- Development of a mixed-layer upper boundary condition for isentropic models of the large-scale ocean circulation systems and use of the resulting coupled model to study the dynamics of the subtropical convergence.

- Modeling studies, in collaboration with NCAR scientists, of the role that a parameterization of stratus and stratocumulus clouds would play in a general circulation model's climate.

- Planning for future exchange visitors to pursue the studies of the connection between ENSO and Asian climate and for execution of the field phase of the Frontal Air-Sea Interaction Experiment in early FY 1986.

CRYOSPHERE-CLIMATE INTERACTION

- Analysis of cloudiness computed by the GISS GCM for a control experiment will be analyzed and compared with observed summer conditions.

- The NSIDC/WDC-A for glaciology will install a VAX-750 and prepare to implement software developed at JPL to process microwave data on sea ice conditions (NASA funding). A DoD-funded image display and analysis system will also be installed.

WAVE DYNAMICS

Results from the coupled dynamical-chemical model will be analyzed. Particular emphasis will be placed on the planetary wave transport of nitric oxide and its relationship to the sporadic winter anomaly. The question of tidal variability will be further addressed. We intend to develop a simple model to test gravity wave and tidal interaction, and determine the tidal structure from wind data.

Analysis of spectral information of the momentum flux will continue, especially focusing on the tropospheric generation of energy and the deposition of momentum due to the breakdown of gravity waves and tides. A field experiment will be conducted at Jicamarca, Peru, to study breaking tides in the equatorial region.

SOLID-EARTH GEOPHYSICS

Solid-earth geophysics continues to be one of the principal themes of CIRES research, although most support program support is obtained from sources other than 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 geodesy, observational and theoretical seismology, geodynamics (crustal deformation using modern geodetic techniques), engineering seismology, and laboratory studies of rock failure and rock properties under high stresses.

Accomplishments FY 1984

The location of a magnitude 5.8 earthquake near Adak Island, Alaska, was predicted months in advance of the event on the basis of data provided by the CIRES Adak Seismic Network and prediction concepts and approaches developed by CIRES researchers. Although no basis for fixing the time has been developed, the identification of the locations with high precision gives convincing evidence of progress in understanding the seismotectonics of subduction zone earthquakes. A specific forecast of a large earthquake in the region of Adak Canyon before October 1985 has been made public, as a test of the hypothesis of precursory quiescence.

CIRES has pioneered in research on seismic quiescence as a precursor to large earthquakes. Detailed studies during the past year of seismicity patterns in southern California and Hawaii have produced additional results on the diagnostic value of such studies, as well as new insights into the problems using routinely compiled data catalogs for this purpose. Studies of changes in inelastic attenuation of seismic waves prior to earthquakes have been carried out for both the Aleutian Islands and Hawaii seismic zones.

The theoretical seismology program has continued to be concentrated on problems of nuclear test monitoring. The power of the quasi-harmonic deconvolution technique developed in CIRES has been demonstrated with additional cases, and important steps toward solving the remaining technical problems confronting a comprehensive nuclear test ban treaty have been taken.

The analysis of sea-level data throughout Greece and the Greek islands has been completed in the search for evidence of vertical crustal movements. The results show that some islands are rising, some are subsiding, but on the whole the region is more stable than had been thought. This research is part of a NASA-supported crustal dynamics project.

Studies of seismic velocity anisotropy, a new initiative in CIRES during the past few years, have resulted in a new mineralogical model of the upper mantle, in new results for the structure and properties of the crust and upper mantle under southeastern China, and acquisition of data on upper mantle seismic anisotropy under Tonga and Fiji. The Tonga-Fiji seismic network is supported by NSF.

The geodynamics program has developed a variety of modern techniques to investigate local and regional deformation of 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 facility 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.

CIRES is the focus of a major geodesy research program involving state-of-the-art space technology. The University NAVSTAR Consortium, with the University of Colorado, Columbia, Harvard, MIT, Princeton, CalTech, and the University of Texas participating, will assemble, test, maintain, and use terminals

for highly accurate relative positioning of satellites. The terminals will receive signals from the NAVSTAR/Global Positioning System satellites to attain 1-cm accuracy in three dimensions over baselines up to 100 km for a 3-h observation. Global tectonic and earthquake problems will be addressed with this revolutionary surveying technique. Other work in geodynamics includes studies of tectonic processes by monitoring random and magnetotelluric signals.

Research in engineering seismology has progressed in three different directions. Hybrid numerical techniques have been developed to calculate the ground motion amplifications due to local geology and topography. These techniques have been used to study surface motion amplifications due to subsurface cavities at different depths and of various shapes. The results have engineering applications also in ultrasonic nondistructive evaluation. A multiple scattering approach and averaging techniques have been used to study wave propagation in media with microstructures. Calculated effective wave speeds show important variations with porosity and distribution of microcracks. The third area of study is the seismic response of long underground structures like pipelines and tunnels. Our careful analysis of the interaction between the structures and the surrounding ground has led to the identification of most important parameters governing the response.

Research in rock mechanics has led to reliable techniques for locating incipient fault planes. Surface deformation measurements using optical holography reveal an elongated bulge on the sample prior to failure. The fracture occurs along the long axis of the bulge. For constant strain rate ($\sim 10^{-7} s^{-1}$) experiments, in which a sample is axially compressed under confining pressure, the bulge first appears at approximately 60% of the failure stress. During creep experiments the bulge becomes visible during the secondary creep stage. Although surface deformation measurements clearly show the location of the eventual fault plane, other techniques have been unable to indicate the location of the incipient fracture. Neither changes in elastic wave velocity and attenuation nor crack statistics obtained from scanning electon microscopy on dilatant samples are sensitive enough to reveal the incipient failure zone.

The development of a failure zone was studied by observing the time- and environment-dependent growth of single cracks in glass and of crack systems in rocks. In contrast to previous theory, present experimental data, derived from optical holography, microscopy, elastic wave velocity and attenuation measurements and the location of acoustic emissions, show the failure zone to be very narrow and extending beyond the visible macrocrack tip.

Through the development of a new acoustic transducer with a flat frequency response between 10 kHz and 6 MHz and a small (<100μm) sensing area, it is now possible to study acoustic emissions from rock samples in the same manner that earthquakes are studied by seismology. Starting, propagating, and stopping phases of single cracks have so far been recorded.

Plans FY 1985

CIRES

Earthquake prediction research will continue along the same general lines, with special attention to observations related to the accurately predicted earthquake near Adak Island. Further work on attenuation changes in Hawaii will be completed. The multi-investigator, multi-national studies in Greece will continue.

Laboratory, theoretical, and field studies of seismic anisotropy will continue. Work on anisotropy under the Pacific basin will be done by a visiting scientist from Japan. A Fulbright Fellow from Egypt is working on a seismotectonic map for the National Geophysical Data Center, NESDIS.

It is expected that the GPS program will expand considerably in the future. There is a vast field of opportunity for GPS measurements. NSF is projecting to fund the consortium with approximately $5 million between now and 1990.

Work on wave propagation in media with microstructures will be focused on the effect of the properties of the interfaces between the micro-inclusions and the surrounding matrix on attenuation. Also anisotropy caused by oriented inclusions will be studied. The hybrid numerical technique will be extended to analyze wave scattering from near-surface cavities and cracks. This extended technique will be used to study also the three-dimensional response of structure embedded close to the surface.

The new capability in microseismology will be used to study the elastic wave radiation from dynamic fractures in simple and complex materials. The aim is to characterize both the nature of the dynamic failure and the medium through which the elastic waves propagate.

Whole rock deformation and "single crack" propagation experiments will be continued with a view toward a better understanding of the failure process. Variables such as moisture content, rate of deformation, minerology, and grain size will be considered and their effects isolated.

A new project was initiated to determine the stresses in the mantle that are responsible for plate tectonics. The attenuation of seismic waves in the mantle is thought to be due to interaction of waves with dislocations in crystals. The equilibrium density of dislocations is a function of the applied stress and temperature. By measuring the attenuation of acoustic waves at seismic frequencies as a function of dislocation density and temperature in single crystals of olivine we expect to infer the stresses that exist in the mantle.

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 1984

CLIMATE RESEARCH

Use of satellite observations for minitoring the trade winds is being investigated. The eastern Pacific trade wind indices derived from low-level

satellite winds proved excellent monitors of the record-breaking 1982-83 Southern Oscillation. The negative phase began in early 1982, similar in timing to previous strong oscillations, and in early 1983 reached maximum negative values more than three times larger than those recorded during the 1976-77 Southern Oscillation. However, this was not preceded by a strong positive phase as in previous oscillations. Although the equatorial easterlies returned to above normal by mid-1983, the area index of the southeast trades remained below normal throughout 1983. The strength of the trade winds off the Peruvian coast has trended downward for the past six years and remained at record low values throughout 1983.

Surface winds obtained from satellite observations have been reduced to the surface level on semimonthly and monthly time scales by use of a scheme based on monthly climatological shears between the long-term means of ship winds and Geophysical Operational Environmental Satellite (GOES) low-level winds. These satellite winds are merged with ship winds and other conventional data to produce the monthly mean surface wind field over the tropical Pacific Ocean in support of climate research.

Evaluation of a historical marine data set compiled from merchant ship weather observations is continuing, to determine its usefulness for identifying secular changes in sea-air heat flux. These observations incorporate a variety of measurement errors and differing methods of observation. Changes in tropical sea-air heat flux over the past 125 years may not stand out above the general noise level, except possibly on heavily traveled routes with many ship observations.

Composite analysis has been completed of the vertical structure of the near-equatorial convergence zone (CZ) for the Special Observing Periods 1 and 2 of the First GARP Global Experiment (FGGE). Satellite photographs were used to locate the CZ and classify the intensity of convection within the CZ. Omega dropwindsondes provided the data for the vertical structure. Marked variations in the vertical structure between the central and eastern Pacific regions were observed. A deep cool/dry band located between 130°W and 160°W, which penetrated from the surface to the upper troposphere, separated these different regions. The cool/dry band appeared to be associated with persistent interactions between the tropical and middle-latitude circulation in the region.

Studies of interactions between tropical and middle latitudes used the FGGE Omega dropwindsonde data set to investigate cirrus surges and the structure of the nearby equatorial convergence zone. A weakening, and sometimes a complete breakdown, of the CZ was found east of cirrus surges associated with these interactions. In addition, it was found that in many instances the cirrus surges were not cumulonimbo-genetic, but instead appeared to be the result of broadscale ascent of tropical air east of a penetrating subtropical trough. The CZ at the "root" of the cirrus surge was notably lacking in cumulonimbi. A model for Southern Hemisphere interactions appeared useful for understanding the mechanisms present during these interactions.

EQUATORIAL OCEANOGRAPHY

JIMAR

Preliminary descriptive analysis and processing of the Line Islands profiling data have been the main activities under the Pacific Equatorial

Ocean Dynamics (PEQUOD) Program. One interesting qualitative result is that the so-called "deep jets", the stack of alternately eastward and westward currents that are characteristic of the deep water near the Equator, have no perceptible vertical propagation over the period of observation of more than 1 year. Their amplitude changes irregularly on a variety of time scales, but some of the jets persist throughout the record. This appears to rule out the hypothesis that the jets are vertically propagating, linear, equatorially trapped waves of annual or interannual period.

Analysis of the North Pacific Experiment (NORPAX) data has continued. A major effort has gone into the study of sampling and aliasing in the ship station data. General techniques were developed for determining the errors in harmonic analysis of irregularly sampled data. It was found that the internal error estimates from harmonic analysis using multiple linear regression techniques are generally underestimated by as much as a factor of 2. In the NORPAX Tahiti Shuttle experiment, for most variables we found that no significant difference can be distinguished between the two extreme longitudes of the ship track, 150°W and 158°W. To study the annual cycle, it is generally better to analyze all sections together, without regard for longitude.

Sea level response in the equatorial Pacific during the 1982-83 El Niño was analyzed. Evidence of equatorially trapped Kelvin waves of first and second baroclinic mode was found in calculated cross correlation functions. These waves were apparently forced in the western Pacific by energetic westerly wind events. Complex empirical orthogonal function (EOF) analysis of sea level was begun.

Meteorological data from the Line Island Profiling Program of PEQUOD were analyzed to understand the linear warming trend in sea surface temperature (SST) at Jarvis Island during most of 1982. It was found that anomalous net heating of the sea surface could not explain the SST anomaly. Timing of central Pacific SST, sea level, wind, and surface current changes suggests a nonlocal cause for SST warming early in the 1982-83 El Niño. EOF decomposition of time-latitude fields shows that simple advective balance held during the early phase of the event. The conclusion is that pulse-like Kelvin waves detected in earlier work were responsible.

Theoretical studies of equatorial waves have continued. A study has been completed of the propagation of wind-driven Kelvin waves into the deep equatorial ocean in the presence of realistic background stratification. There is a significant energy flux from the surface layer into the deep water in these calculations. As of the end of FY 1984 there is no consensus among equatorial modelers on this point, and further study and discussion are in order.

TSUNAMI RESEARCH

The solid-state tsunami gage program, under National Science Foundation sponsorship, was completed through the lab test and field-deployable versions with the final development of a 6-in-diameter lab test system and a 4-in field test prototype. Both units performed successfully in the fast-sample mode needed for tank tests. Recommendations for a final version were made.

The call-out procedure and tsunami observers' list for all islands was updated. Trial time-lapse films were made by the new observers at sites on

East Kauai and West Hawaii. Official permission was obtained from the National Park Service for a permanent camera installation at Kawaihae.

The Hawaii tsunami of 29 November 1975 was modeled, assuming a landslide for the source. Three-dimensional calculations for solving the incompressible Navier-Stokes equations were performed on the Los Alamos CRAY computer. The observed tsunami wave profile, which showed that near the source the second wave was larger than the first wave, was found to be inconsistent with a landslide source model for the tsunami.

The Los Alamos shallow-water-wave computer program called SWAN was adapted for use on the University of Hawaii Harris computer. The program code was used to study tsunami waves interacting with circular islands, triangular islands of dimensions characteristic of the island of Hawaii, and Hilo Bay. The formation of tsunami waves from initial surface depressions or uplifts was studied for a circular island and a triangular island for the May 1983 earthquake in the Sea of Japan. The program was also used to study the wave interaction in Waianae harbor (Oahu) to help local authorities improve the entrance wave interactions. The program code is being used by a University of Hawaii graduate student to study the effect of tides on the Musi river in Indonesia.

Plans FY 1985

CLIMATE RESEARCH

- Evaluation of the marine data deck will continue, and it has been proposed to expand surface wind monitoring to cover the global tropics. This is part of the TOGA (Tropical Oceans and Global Atmosphere) program.

- Study of middle-latitude tropical interactions and their influence on tropical circulations and on El Niño/Southern Oscillation (ENSO) events will continue. These investigations will include an analysis of extreme ENSO events through use of satellite imagery and studies of tropical and middle-latitude interactions, a comparison between equatorial easterly and westerly winds and their attendant precipitation, and a characterization of the South Pacific Convergence Zone (SPCZ). Recent studies of the Australian summer monsoons suggest a linkage among the monsoon, SPCZ, and Southern Hemisphere extratropics.

- Two TOGA data centers, one for sea level and the other for wind data, will be located at JIMAR.

- The sea level data center will produce monthly sea level anomaly maps for the tropical Pacific in near real time (1 month delay). A similar product for the tropical Indian Ocean will be produced when an adequate network is in place.

EQUATORIAL OCEANOGRAPHY

JIMAR

- Pegasus data will be analyzed from PEQUOD.

- Shuttle data from 4°S to 10°N will be analyzed with emphasis on the mean and seasonal cycle.

- A 5-year study of seasonal and interannual variability of synoptic oscillations in the central equatorial Pacific will be undertaken.

- A numerical model will be developed to study the effect of coastal geometries on equatorial waves. There will also be work on an equatorial model forced by a meandering intertropical convergence zone (ITCZ) and interactions of equatorial waves with mean flows.

TSUNAMI RESEARCH

- Research will continue on numerical studies of tsunami generation, propagation, and run-up.

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 1984

Climate

JISAO has contributed to the Equatorial Pacific Ocean Climate Studies (EPOCS) and Tropical Oceans and Global Atmosphere (TOGA) research programs involving both observational and theoretical climate studies. An atlas consisting of a series of time-lagged, seasonal correlation and regression charts and time series for El Niño events during the period 1950-80 has been prepared; it is based on the comprehensive set of marine surface observations produced by the staff of CIRES. The same data set has also been analyzed with a view toward apparent interdecadal trends in sea-surface temperature induced by changes in measurement techniques.

There is continuing analysis of hydrographic and current meter data from the Hawaii-Tahiti Shuttle Experiment with the goal of documenting finestructure variability in the upper equatorial Pacific Ocean. One component of the study has been to develop a theory for the Equatorial Subsurface Countercurrents which are strong, subsurface eastward flows below the thermocline in the Atlantic and Pacific. This work is the first comprehensive theoretical treatment of these recently discovered currents in which their dynamics and relationship to the Equatorial Undercurrent are explored.

Another component of the theoretical studies involves examining wave/mean-flow interactions in an equatorial ocean model with emphasis initially on how stable, low-frequency equatorial Kelvin and long Rossby waves are modified by realistic mean flows like the Equatorial Undercurrent.

JISAO Senior Fellows have participated actively in the planning for the TOGA program at both the national and international level. In the area of planetary wave/mean flow interaction, one Postdoctoral Fellow has been engaged in studying various aspects of translating Rossby wave critical layers to assess the effects of mean flow change on the dynamics of critical layers.

ENVIRONMENTAL CHEMISTRY

JISAO is supporting postdoctoral research in trace element removal both in laboratory and in natural systems, and has played an active role during the Past two years in organizing the Environmental Chemistry activities at the University of Washington. Environmental chemists are distributed among departments all over the university campus; this organization improves communication and helps focus their mutual research activities.

Plans FY 1985

- JISAO has recently been designated an Experimental Climate Forecast Center in the United States National Climate Program. The research of the Center will involve the following themes in support of the development of a long-range forecasting capability: observational studies designed to complement the modeling activity; use of the Community Climate Model for sensitivity and predictability studies with emphasis on tropical sea-surface temperature anomalies; cooperation with NCAR and GFDL in aspects of model development such as the treatment of mountains; and diagnostics of dynamically based intermediate and long-range operational forecasts and extended runs of a global-circulation model.

- A high priority during FY 1985 will be to secure funding for the continuation of the core program in Environmental Chemistry and to revive the core program in estuaries, which has been dormant since 1981. In addition, the Institute will explore the possibility of expanding activities in fisheries and marine biology, with emphasis on year-to-year variability in recruitment.

APPENDIX: Acronyms and Abbreviations

ACE	Arctic Cyclone Experiment
ADC	area of deeper convection
AFE	average forecast errors
AFOS	Automation of Field Operations and Services (NWS)
AGASP	Arctic Gas and Aerosol Sampling Program
AIMCS	Airborne Investigations of Mesoscale Convective Systems
AL	Aeronomy Laboratory (ERL)
ALPEX	ALPine EXperiment
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
APEX	Arctic Polynya EXperiment
ARL	Air Resources Laboratory (ERL)
ARTCC	Air Route Traffic Control Center
ASCOT	Atmospheric Studies in COmplex Terrain (DOE)
ASV	anodic stripping voltammetry
ATDD	Atmospheric Turbulence and Diffusion Division (ARL)
ATOLL	Analysis of the Tropical Ocean Lower Layer
AWIPS-90	Advanced Weather Interactive Processing System for the 1990's
AWS	Air Weather Service (USAF)
BAO	Boulder Atmospheric Observatory (ERL)
CAC	Climate Analysis Center (NMC)
CAMS	control and monitoring system
CAPTEX	Cross-APpalachian Tracer EXperiment
CBI	computer-based instruction
CESD	Computer and Engineering Support and Development
CG	cloud to ground
CHILL	CHicago ILLinois
CI-FA	chemical ionization-flowing afterglow
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
COADS	Comprehensive Ocean-Atmosphere Data Set
CODAR	Coastal Ocean Dynamics Applications Radar
CONDORS	CONvective Dispersion Observed by Remote Sensors
CRP	Climate Research Project (ERL/ESG)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSU	Colorado State University
CTD	conductivity, temperature, depth
CWP	Central Weather Processor
CWSU	Center Weather Service Unit
DIAL	differential absorption lidar
DLM	deep-layer mean
DMS	dimethyl sulfide
DNA	Defense Nuclear Agency
DOC	dissolved organic carbon
DOD	Department of Defense
DOE	Department of Energy
DOPLIGHT	DOPpler-LIGHTning

DRASER	Doppler Radar And Storm Electricity Research (NSSL)
DSET	Desert Sunshine Exposure Test
ECMWF	European Center for Medium-range Weather Forecasting
ELF	extremely low frequency
ENAMAP	Eastern North American Model of 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
FACE	Florida Area Cumulus Experiment
FDP	fluorescent dye particles
FGGE	First GARP Global Experiment
FM-CW	frequency modulation-continuous wave
FOCI	Fisheries Oceanography Cooperative Investigations (NOAA)
FOX	Fisheries Oceanography Experiment
GARP	Global Atmospheric Research Program
GASP	Global Air Sampling Program
GCM	general circulation model
GEP	good éngineering practice
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
GRAMA	Green River Ambient Model Assessment
GTS	Global Telecommunication System
HEPAD	High Energy Proton and Alpha Detector
HF	high frequency
HOT	Hydrometeorological Operational Tool
HRC	highly reflective clouds
ICE	International Cometary Explorer
IMETS	Interactive Meteorological Educational and Training System (PROFS)
I/O	input/output
IPC	International Pyrheliometer Comparison
IRIS	International Research Investigations of the Subarctic
ISEE	International Sun-Earth Explorer
ITCZ	intertropical convergence zone
JAWS	Joint Airport Weather Studies
JIC	Joint Ice Center
JIMAR	Joint Institute for Marine and Atmospheric Research
JISAO	Joint Institute for Study of the Atmosphere and Ocean
JSPO	Joint System Program Office (NEXRAD)
KSC	Kennedy Space Center

LFM	limited fine mesh
LIMS	Limb Infrared Monitor of the Stratosphere
LMR	laser magnetic resonance
MAG	Mesoscale Applications Group (ESG/WRP)
MAP	Middle Atmosphere Program (SEL)
MAPS	Mesoscale Analysis and Prediction System (PROFS)
MATS	Mesoscale Atmospheric Transport Studies
MCC	mesoscale convective complex
MCS	mesoscale convective system
MEPED	Medium Energy Proton and Electron Detector
MERIT	Minimum Energy Routes using Interactive Techniques (NASA)
METREX	MEtropolitan TRacer EXperiment
MFM	movable fine-mesh [hurricane model]
MHD	magnetohydrodynamic
MIZEX	Marginal Ice Zone EXperiment
MRG	Mesoscale Research Group (ESG/WRP)
MSI	multi-spectral imagery
MSG	Mesoscale Studies Group (ERL/ESG)
MST	mesosphere-stratosphere-troposphere
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDBC	NOAA Data Buoy Center
NEPRF	Naval Environmental Prediction Research Facility
NEROS	NorthEast Regional Oxidation Study
NESDIS	National Environmental Satellite, Data, and Information Service (NOAA)
NEXRAD	NEXt-generation weather RADar
NHC	National Hurricane Center (NWS)
NICG	National Interagency Coordinating Group
NMC	National Meteorological Center (NWS)
NOAA	National Oceanic and Atmospheric Administration
NOMAD	Navy Oceanographic Meteorological Automatic Device
NORPAX	NORth PAcific Experiment
NOS	National Ocean Service (NOAA)
NOVA	NOAA Operational VAS Assessment
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory (ERL)
NWP	numerical weather prediction
NWS	National Weather Service
OAD	Ocean Assessment Division (NOS)
OAO	Office of Aircraft Operations (NOAA)
ODW	Omega dropwindsonde
OHER	Office of Health and Environmental Research
O-K PRE-STORM	Oklahoma-Kansas PRE-STORM
ORNL	Oak Ridge National Laboratory
OSC	Ocean Service Center
PACE	Precipitation Augmentation for Crops Experiment
PAH	polycyclic aromatic hydrocarbon
PBL	planetary boundary layer

PBM	Photochemical Box Model
PCA	polar cap absorption
PEM	Pollution Episodic Model
PEPE	Prolonged Episode Pollution Experiment
PEQUOD	Pacific EQUatorial Ocean Dynamics
PIXE	Proton-Induced X-ray Emission
PMEL	Pacific Marine Environmental Laboratory (ERL)
PPI	plan position indicator
P-PRIME	Pollutant-Particle Relationships In the Marine Environment
PRE-STORM	Preliminary Regional Experiment for STORM-Central
PROFS	Program for Regional Observing and Forecasting Services (ERL/ESG)
PROVAS	PROfiler-VAS
QSTING	quasi-spectral time integration on nested grids
RADAP	RAdar DAta Processor
RADRES	RADar REsolution Study (PROFS)
RAMM	Regional And Mesoscale Meteorology (NESDIS)
RAPS	Regional Air Pollution Study
RITS	Radiatively Important Trace Species
ROM	Regional Oxidant Model
RSMAS	Rosenstiel School of Marine and Atmospheric Science (U. of Miami)
SAGA	Soviet-American Gases and Aerosol
SAGE	Stratospheric Aerosol and Gas Experiment
SANBAR	SANder's BARotropic [model]
SAO	semiannual oscillation
SAP	spline analysis package
SBC	stationary band complex
SBUV	solar backscatter ultraviolet
SEADEX	Shoreline Environmental Atmospheric Diffusion Experiment
SEFC	SouthEast Fisheries Center (NMFS)
SEL	Space Environment Laboratory (ERL)
SELDADS	SEL Data Acquisition and Display System
SELSIS	SEL Solar Imaging System
SEM	Space Environment Monitor
SESC	Space Environment Services Center (SEL)
SFMR	stepped-frequency microwave radiometer
SIO	Scripps Institution of Oceanography
SLAR	side-looking airborne radar
SLEUTH	System for Locating Eruptive Underwater Turbidity and Hydrography
SLP	sea level pressure
SME	Solar Mesosphere Explorer
SPCZ	South Pacific convergence zone
SPM	suspended particulate matter
SST	sea surface temperature
ST	stratosphere-troposphere
STACS	SubTropical Atlantic Climate Studies
STATE	STructure and Atmosphere Turbulence Environment
STORM	STormscale Operational and Research Meteorology

TAG	Trans-Atlantic Geotraverse
TAP	Transformation and Assimilation of Pollutants [by Natural Processes]
THRUST	Tsunami Hazard Reduction Using System Technology
TIROS	Television and InfraRed Observation Satellite
TOGA	Tropical Oceans and Global Atmosphere
TOPEX	[Ocean] TOPography EXperiment
TOPS	Total Ocean Profiling System
TOTO	TOtable Tornado Observatory
TOVS	TIROS Operational Vertical Sounder
TRIP	Thunderstorm Research International Program
USAF	U.S. Air Force
USGS	U.S. Geological Survey
UV	ultraviolet
VAD	velocity-azimuth display
VAS	VISSR Atmospheric Sounder
VENTEX	VENTing EXperiment
VHF	very high frequency
VISSR	Visible Infrared Spin Scan Radiometer
VLF	very low frequency
VVP	volume velocity processing
WATOX	Western ATlantic Ocean Experiment
WDC-A	World Data Center-A
WINDSAT	WIND-measuring SATellite
WMO	World Meteorological Organization
WMP	Weather Modification Program (ERL/ESG)
WOCE	World Ocean Circulation Experiment
WPL	Wave Propagation Laboratory (ERL)
WRP	Weather Research Program (ERL/ESG)
WRR	World Radiometer Reference
WSFO	Weather Service Forecast Office
WWA	World Warning Agency
WWCE	westerly wind/convection episode
XBT	expendable bathythermograph

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